Point-by-point response to anonymous reviewer 1 comments

After our preliminary response that addressed the main critics of anonymous reviewer 1, we here provide the point-by-point reply, which, regarding the general comments is largely a repetition of our earlier post. Any changes in sentences of the manuscript are highlighted in red in this reply. In general, we are rather disappointed with the general comments that do provide only few information (e.g. references that show that benthic foraminifer stratigraphy in the Arctic Ocean is useless) on which the opinion of the reviewer is based.

General Comments

The manuscript demonstrates the difficulties of benthic foraminiferal biostratigraphy in the Central Arctic Ocean using multiple bioevents. However, the manuscript does not seem to propose a novel way forward nor does it make a strong assertion that researchers currently using the bioevents should stop applying these methods.

(from previous post) The reviewer is correct in saying that the applied methods are not novel but previous research has shown that this bioevent approach is useful for stratigraphic interpretations in the Pleistocene. Since there is little evolutionary turnover in Pleistocene benthic foraminifers (see below) an alternative approach has been developed to provide biostratigraphic information for sediment cores from northern subpolar to polar latitudes. In deep-sea sediment cores from the Norwegian Sea, Streeter et al. (Streeter et al., 1982) observed that the calcareous benthic foraminifer *Pullenia bulloides* shows a distinct maximum in relative abundance at the transition of marine isotope stage 4 to 5. Subsequent studies by Haake and Pflaumann (Haake and Pflaumann, 1989) and Haake et al. (Haake et al., 1990) revealed consistent *P. bulloides* absolute abundance maxima (specimens per ccm) in the deep Norwegian-Greenland Sea in MIS 5a. Thereafter, Fronval and Jansen (Fronval and Jansen, 1996), Knies et al. (Knies et al., 1998), Wollenburg et al. (Wollenburg et al., 2001), and many others used *P. bulloides* absolute abundance maxima as stratigraphic tool to constrain MIS 5a. Similarily, the agglutinated benthic foraminifer *Siphotextularia rolshauseni* depicts a consistent maximum in absolute abundance in cores from the Norwegian-Greenland Sea in early MIS 2 that may be used for correlation of sediment cores (e.g., Nees and Struck, (Nees and Struck, 1994), Bauch et al., (Bauch et al., 2001); Wollenburg et al., (Wollenburg et al., 2001). Like the bioevents described in our manuscript, these events were attributed to periods of more intense Atlantic water advection. These studies show that certain benthic foraminifers show distinct coeval distribution patterns/abundance maxima that can be calibrated to specific marine isotope stages in defined oceanic areas. Therefore, we do not agree that this established stratigraphic approach in Pleistocene benthic foraminifer work should not be applied in the Arctic Ocean.

Since an Arctic Ocean chronostratigraphy cannot be established with a single method and in particular traditional planktic microfossil and stable oxygen isotope stratigraphy is only useful for specific time intervals, we reviewed published benthic foraminifer data to evaluate the potential of abundance patterns for stratigraphic correlation. In the central Arctic Ocean, distinct stratigraphic occurrences and abundance maxima of benthic foraminifer species have been recognized for quite some time (e.g. Herman (Herman, 1974); O´Neill (O'neill, 1981); Ishman et al. (Ishman et al., 1996); Cronin et al. (Cronin et al., 2014), e.g. a distinct abundance maximum of *Bulimina aculeata* is restricted to a narrow stratigraphic interval in the Pleistocene e.g.(Jakobsson et al., 2001; Polyak et al., 2004). *Bolivina arctica* that occurs in low abundances in upper Pleistocene sediments from the central Arctic Ocean, shows a basin-wide pronounced highest common occurrence terminated by a distinct decrease at a distinct stratigraphic level e.g. (Herman, 1974; Scott et al., 1989). Therefore, Backman et al. (Backman et al., 2004) and Polyak et al. (2004) used relative abundance maxima and range bottoms of certain taxa for correlating sediment cores across the Arctic Ocean.

In our manuscript the comparison of absolute abundances (specimens/g) with relative abundances (% of a species in an assemblage) revealed that absolute abundances are confined to narrower stratigraphic intervals than relative abundances, because bioturbation in these low sedimentation settings (Löwemark and Singh, 2024) may cause misleading occurrences of species in glacial intervals with low benthic foraminifer contents. Dislocation will result in high relative abundances but low absolute abundances of taxa in these glacial sediments. This point is clearly addressed in Figure 2 of the manuscript which compares relative and absolute abundances of *Stetsonia horvathi* and demonstrates this advantage of absolute abundances over relative abundances. As a high absolute abundance of a species in interglacial sediments increases the likelihood of dislocation by bioturbation into glacial sediments, relative abundance maxima of e.g. *B. arctica* are therefore shifted into underlying glacial sediments that reflect adverse environmental conditions (Fig. 3).

The introduction implies that benthic forams are underutilized in biostratigraphy (starting line 89) and leads the reader to think benthic forams will be shown to be useful by the study, but this outcome does not occur. Thus, I am not clear what the authors intend to contribute with this manuscript other than to say others have said that benthic forams do not work well for biostratigraphy in the Central Arctic and when they looked at three cores to evaluate some potential biomarkers, they found that those others were correct. Since there was no real methodological advance or significant new source of data applied to challenge the prior assertion that benthic foraminifera are not useful for Arctic biostratigraphy, I don’t believe the findings are significant enough to warrant publication.

See comments above. We will make it more clear in the manuscript that our analyses demonstrates that *B. arctica, O. umbonatus* and, limited to water depths <2000 m, *B. aculeata* bioevents are valid stratigraphic markers if applied in specimen-rich samples as absolute abundance maxima. But benthic foraminifera are not biomarkers. Moreover, previous work already have demostrated the potential of benthic foraminifers for Arctic Ocean stratigraphy (Backman et al., 2004; Polyak et al., 2004). So we do not understand what “to say others have said that benthic forams do not work well for biostratigraphy in the Central Arctic” mean. References for this statement are missing.

I also have methodological concerns in the application of the bioevents. Many of the bioevents used in the manuscript rely on common occurrences as biomarkers rather than first and last appearances typically viewed as necessary in biostratigraphy.

(from previous post) In an evolutionary sense within the time interval we are looking at, there are no first or last appearances of deep-sea benthic foraminifera species in the Arctic

Ocean (except for the disappearance of *Haplophragmoides obscurus*). Studies suggest a drastic change in North Pacific to Arctic water mass structure, ice cover, and phytoplankton composition during the Mid-Brunhes Transition (MBT)~ 430–350 ka (Kender et al., 2019). With the increase in the amplitude of glacial cycles expressed after the MBT, an expansion of sea-ice extent and thickness and an intense Atlantic Water advection is presumed (Polyak et al., 2013). The phytoplankton is affected as well (see Fig. 5), thus, different phytodetritus for the benthic community became available. Very obviously the extinction of *H. obscurus* is linked to these environmental change, and *B. arctica* which has been recorded for at least the last 1.5 Mio. yrs diminished after the MBT. To us it is also logical that the *B. aculeata* and *O. umbonatus* bioevents are a reflection of the intensified Atlantic Water advection in one of those interglacials after the MBT, when the modern Arctic deep-water benthic foraminiferal community hadn't stabilized yet. Thus, in our cores from 1073 m (PS2185-6), 2351 m (PS72/340-5) and 2732 m (PS72/396-5) (Figure 1, Table 1), and the cited literature we observe a basin-wide coincident acme of *Bulimina aculeata* (at water depths <2000 m), the lowest common occurrence (LCO) of *Oridorsalis umbonatus,* and the highest common occurrence (HCO) of *Bolivina arctica* that we assign to respective bioevents routed in fundamental paleoecological changes. This manuscript focuses on the application of bioevents as a stratigraphic basis. More comprehensive paleoecological statements would require a detailed evaluation of all species present and statistical analyses that include modern fauna e.g. (Wollenburg et al., 2001; Wollenburg et al., 2004).

Apart from these facts, the applied terminology is well-established in microfossil biostratigraphy (e.g. Berggren et al., 1995; Wade et al., De Schepper and Head, 2008), and the recent review of Piller (2026) includes the terminology used in our work.

Common occurrence bioevents are prone to spatial differences in environment and preservation and are generally not seen as reliable.

This is what we were testing in this manuscript with our own cores and published data, and we demonstrate that defined by absolute abundance maxima in specimen-rich samples, the bioevents *B. aculeata, B. arctica* and *O. umbonatus* are recorded across the Arctic Ocean. In contrast *P. bulloides* and *E. exigua* maxima are rather local phenomenon in the Arctic Ocean Pleistocene record. Unfortunately, the reviewer list no references to support his notion that "common occurrence bioevents… are generally not seen as reliable."

Given unique spatial distribution patterns for foraminifera are acknowledged even in the first line of the abstract and other places in the manuscript, I'm not clear how common occurrence bioevents are valid in this setting.

We observe spatial distribution patterns triggered e.g. by differences in food supply in deep-sea foraminiferal faunas as in the modern central Arctic Ocean. However, the bioevents followed glacial intervals and were enabled by advective recolonization events in a changing paleoenvironment. *B. aculeata* just lived during that bioevent in the central Arctic Ocean, *B. arctica* diminished to insignificant abundances after the bioevent, *H. obscurus* disappeared fully after the event and only *O. umbonatus*, that had its first occurrence in the respective bioevent in our cores became a common species at those sites.

Further, the authors highlight that they use “absolute abundance” for defining bioevents, and figures report # of individuals per gram of sediment, which are heavily affected by changes in sedimentation rates and hiatuses.

We would like to disagree here, because while the only foraminifera in a sample has a relative frequency of 100%, with mean sample weights of around 100 g, it would have an absolute abundance of 0.001 nos/g.dry weight. Despite all the problems we encounter in Arctic sediment cores with low sedimentation rates and hiatuses, the positive aspect is that bioevents are strictly linked to brown layers and thus interglacial/interstadial conditions. The highly variable sedimentation rates of glacial gray or pink sediments are irrelevant to this study, except to show that in such sediments, the very low foraminiferal abundances can indeed lead to relative abundance peaks.

These features of the Arctic record are frequently highlighted in the manuscript (ex. line 487) as hindering biostratigraphic correlation, but the impact of changing sedimentation on the abundances being used to recognize bioevents is not addressed.

We agree with the reviewer and apologize having not added any information on sedimentation rates in our work. We used three sediment cores with different sediment rates in the Brunhes Chron, ranging from ca. 1.5 mm/ka (PS72/396-5), over ca. 5 mm/ka (PS2185-6) to ca. 10 mm/ka (PS72/340-5). Unfortunately, we did not describe these variability in average sedimentation rates in the manuscript but we will add this information to the revised version. Despite this range over about one order of magnitude, we do not see any effect of variable sedimentation rates on the presence/absence of bioevents.

However, we have to emphazise that, as absolute ages cannot be assigned to each depth in the sediment cores, it is impossible to calculate reliable sedimentation rates. Few radiometric ages are available, and radiocarbon ages are limited to the uppermost sediment column but authigenic overgrowth has an impact on the measurements. We know that the top 20 cm of a box core from the site of PS2185 (PS2185-6) were deposited over roughly 30 ^{14}C ka (Wollenburg et al., 2023) which would result, ignoring likely different sedimentation rates between glacial and Holocene sediments, in a mean sedimentation rate of ~6 mm/^{14}C ka for this core section. In the box corer taken at site PS72/396 radiocarbon ages of 18.6 ^{14}C ka at 6.5 cm sediment depth indicate a mean sedimentation of ~3 mm/^{14}C ka for MIS2-Holocene. In both cores below these depths calcareous shells were significantly affected by authigenic overgrowth (Wollenburg et al., 2023) resulting in unreliable ^{14}C -ages.

Without a robust age model and reliable sedimentation rates, no one should calculate accumulation rates. Therefore, we are just working with the intervals of specimen-rich samples when identifying the respective bioevents in our cores (e.g. the HCO of *B. arctica* in samples with a mean of 92774 benthic foraminifera per sample for core PS2185-6). All respective tables can be downloaded from Pangaea once the manuscript is published.

The bioevents are assigned to interglacial stages with high foraminiferal numbers, here the characterizing species show high specimen numbers (e.g. *B. arctica* absolute abundances in the bioevent vary between 300 and 1500 spec.g dry weight in samples with 124120-243568 benthic foraminifera specimens (PS2185-6). It obviously was a problem to make the respective tables just available upon request before the manuscript is finalized.

Given how bioevents are being recognized and defined in the manuscript, they do not seem an appropriate method for assessing chronology in the region from first principles and I’m not clear why the exercise was done.

We are confident that the previous comments explain that our approach is useful for stratigraphic analyses in the Arctic Ocean.

Further, the manuscript concedes that proposed correlations are preliminary and numerical ages are “too imprecise” (in abstract) and states that there is no robust independent chronostratigraphy available (Line 571). With the lack of robust chronological data, the exercise of evaluating the usefulness of bioevents seems futile given there is no reliable chronology to compare to. The outcome of the manuscript seems to just solidify existing uncertainty albeit with methods that may be not be expected to alleviate that uncertainty.

From previous response. We have to accept that the Arctic Ocean chronostratigraphy still has a lower temporal resolution than the Pleistocene chronostratigraphy in most other oceans (e.g. O´Regan et al., 2026). Due to the high freshwater input (e.g. Morris, 1988; Nørgaard-Pedersen et al., 1998) and diagenetic alterations (Wollenburg et al., 2023), stable isotope curves in the Arctic Ocean do not correspond to those in the global ocean (Lisiecki and Raymo, 2005) and comprise considerable gaps due to absence of calcareous foraminifers. Therefore, a stable oxygen isotope stratigraphy cannot be established and different methods must be applied to define stratigraphic tie points for Pleistocene sediments. In the time interval studied, AMS ^{14}C ages (e.g., Wollenburg et al., 2023 and references therein), ^{231}Pa and ^{230}Thxs extinction ages (Hillaire-Marcel et al., 2017; Song et al., 2023) and calcareous nannofossil bioevents (Razmjooei et al., 2023) form the basis to calibrate benthic foraminifer bioevents to independent chronostratigraphic data. This allows to relate bioevents to certain time intervals that are represented by marine isotope stages, and not to exact numerical ages. That is why we stated that the correlation to marine isotope stages is provisional and the bioevents and the assigned ages should be tested in future studies. To be honest this is the only way to prove or disprove the validity of these bioevents and their age assignments. But based on our new data and the extensive literature data we are quite confident that our suggestions are not too far way off from reality.

The discussion then provides extensive review of ecological and environmental reasons for the abundance changes in different taxa that are often speculative and not well-rooted in the results provided in the study or connected to the biostratigraphic questions, particularly given the emphasis in other parts of the manuscript that the Arctic has complex spatial differences in environment.

This statement is not specific, and the reviewer does not explain why he/she/them believes that our extensive review is often speculative and not well-rooted in the results. Thus, it is impossible to comment on this opinion.

The conclusions state that “a standardized methodology is applied to define robust bioevents” but it does not appear that any of the bioevents investigated are indeed robust, particularly given the conceded lack of radiometric ages and the strong impacts of ecologic and taphonomic processes.

We think that we have shown in the manuscript that some benthic foraminifer are useful stratigraphic indicators. Moreover our own study and the comparison with published data shows that, based on an assignment to marine isotope stages, we have coeval events of *O. umbonatus*, *Bolivina arctica* and at depths <2000 m also *Bulimina aculeata* in the central Arctic Ocean.

Conclusions further make recommendations on how to best do biostratigraphy as if the study demonstrated their methods were successfully, but I have difficulty seeing that success.

See comments above.

Some assertions in the conclusions are not tested by the study. For example, the relative success of relative abundances and absolute abundances in identifying events is not systematically evaluated.

From previous reply. In all figures depicting the stratigraphic distribution of species both absolute and relative abundances are shown. We did not further expand on this issue because we have included as an example Figure 2 with a comparison of relative and absolute abundances. But, if requested we may address this issue with each bioevent discussion (e.g. above for *B. arctica*) in the revised version of the manuscript. Generally, using absolute abundance data makes stratigraphic work in the Arctic Ocean easy because taxomomic knowledge of only stratigraphically important taxa is needed. In contrast, for a correct counting of relative abundances all species and specimens must be identified and a comparison between different labs does require similar taxonomic concepts for all species.

Different to many central Arctic Ocean foraminiferal studies we worked on the size fraction >63 µm, as Polyak et al. (2004) already showed that species such as *Bolivina arctica* are too small to be adequately recorded in the size fraction >150 µm. In our manuscript we define bioevents using absolute abundances (specimens per gram dry sediment) of the grain size fraction >63 µm from large sample volumes (76->100 g per sample) and samples that contain large specimen numbers. Such a strict definition of the data used to describe Arctic bioevents is at present not applied in routine stratigraphic work. Often only the larger grain-size spectrum >125 µm or >100 µm is considered in foraminifera analyses and interpretations are based on relative abundances or the presence of species at a specific stratigraphic level. Information on sample size, specimen numbers per sample, actual specimen counts, relative (%) and absolute (nos./g dry sediment) abundances of calcareous and agglutinated species of all species mentioned in the manuscript and of all cores are deposited in Pangaea and will be available for download after acceptance of the manuscript.

Although much of the discussion reviewed ecological drivers of species patterns, those are not mentioned in the conclusions except to say they could account for the formation of the bioevents.

We had the focus of the manuscript on stratigraphy but will include this information in the conclusion of the revised version.

Some of my confusion may be due to the organization of the manuscript and below I point out some aspects of organization that made understanding and following of the arguments within difficult.

We appreciate any suggestions which will help to improve the manuscript.

Although I did not look at the appendixes in detail, they are well illustrated and taxa are thoroughly described. A publication presenting that effort would be very valuable to others working in the region.

We are grateful for this comment.

Specific Comments

Line 45: Does no water mass exchange happen on the Pacific side of the Arctic? It does not seem that interaction between the subpolar latitudes and the Arctic is only occurring through the Fram Strait based on most maps of high latitude currents.

We are grateful for this comment, we simply forgot to add information on the water depth to the first part of the sentence and added the Barents Sea because it is important for intermediate water depth exchange. The sentence was changed to 'Since an unrestricted exchange of intermediate to deep-water masses with subpolar latitudes is only facilitated through Fram Strait and the Barents Sea, these intermediate to deep-water species had to be transported as juvenile specimens (propagules) by Atlantic Water to CAO sites during time periods favourable for their propagation.'

Line 47: propagules of foraminifera are known to be viable for (at least) decades, so using "vital transport" to imply that transport must occur rapidly while the individuals are alive seems misleading.

We would be grateful for a respective citation that foraminifera propagules survive for decades. Foraminifera propagules are juvenile foraminifera, not resting stages, being able to survive for up to 2 years before continuing to grow (Alve and Goldstein, 2014; Alve and Goldstein, 2010). However, our statement was not about speed but about the maximum distance that can be achieved as in the central Arctic Ocean each transported propagule will have to be transported over deep basins to reach a suitable ridge. The mean transit time of modern Atlantic Water circulation in the Arctic Ocean is 15-55 years for a full circle (Wefing et al, 2021, doi.org/10.5194/os-17-111-2021). We have changed the respective passage to ~~`The possible time span of a vital transport, and thus the maximum reachable location for settlement within the Arctic Ocean, depends on the species, the vitality of a respective specimen, the local environmental conditions, and the strength of Atlantic water advection´.~~

` The maximum reachable location for settlement within the Arctic Ocean, depends on the species, the local environmental conditions, and the strength of Atlantic water advection.' In the discussion (4.4. Recolonization) we have added information and the respective modified passage now reads `Based on studies on shallow-water foraminifera and occasional net catches, it is assumed that also the dispersal and recolonization of foraminifera in the deep realm occurs via propagules, juvenile individuals smaller than 32 µm (Alve and Goldstein, 2010; Alve and Goldstein, 2003; Murray, 2006; Gooday and Jorissen, 2012). The possible time span of a viable transport of propagules is different for different species and up to two years (Alve and Goldstein, 2014; Alve and Goldstein, 2010). As Fram Strait is the only deep-water connection of the Arctic (sill depth ~2500 m) to the world's ocean, any recolonization has to occur through Fram Strait. Propagules are advected by inflow of waters from subpolar latitudes, then circulating anticlockwise as Atlantic Water (~200-600 to 850 m) and Upper Polar Deep Water (Rudels and Carmack, 2022; Timmermans and Marshall, 2020). That Atlantic Water advection is a main factor controlling the distribution of certain foraminiferal species in the Arctic Ocean has been previously suggested based on the restricted distribution of certain taxa in areas close to the Atlantic water inflow (Wollenburg and Kuhnt, 2000). Combined sediment and water DNA analyzes around western and northern Svalbard now support these observations and indicate effective foraminiferal propagule dispersal by Atlantic Water (Nguyen, 2022; Nguyen et al., 2025). From entrance to exit the mean transit time of modern Atlantic Water circulation in the Arctic Ocean is 15-55 years for a full circle (Wefing et al., 2021). In the past the maximum reachable location for a settlement of Atlantic-derived foraminifera species within the Arctic Ocean, depended on the species, the local environmental conditions, and the strength of Atlantic water advection during that time. In particular the availability of food, played then a major role for the successful colonization at a particular site, not only for the invading species but also the species endemic to the CAO (*H. obscurus, B. arctica*).'

Line 126-line 130: This discusses that bioevents were defined for 1500-1700 m, but focuses on two cores that are more than 2300 m water depth. It is not well explained why this is a "test of whether species are restricted to certain water depths," or why the depth ranges of these taxa are not known. Is the test more about whether the bioevents can be recognized in deeper waters? The depth of the "reference core PS2185-6" is not given here.

We agree that this part of the introduction does not clearly state for what reason core PS2185-6 has been included.

The position of all cores are shown in Fig. 1 and the respective geogr. coordinates and water depths in Table 1. For core PS2185-6 water depth is 1073 m.

From previous response. Since previous benthic foraminifera research has mainly focused on benthic foraminifers from sediment cores located in relatively shallow water depths (500-<1900 m), we used the relatively well-studied core PS2185-6 from the shallow Lomonosov Ridge (1073 m water depth) as the reference core for previously studied shallow water sites. The Lomonosov Ridge represents a barrier to deep water exchange >1870 m between the Eurasian Basin and Amerasian Basin (Björk et al., 2007), which is why deep-water sediment cores must be considered for a reconstruction of paleo-deep water circulation/change within the Arctic Basins. Therefore, it was important to us to gather for the first time respective information on bioevents from two deep-water cores (2351 and 2723 m) from the Amerasian Basin. These new data confirmed that *Bulimina aculeata* is a stratigraphic marker at sites located above 2000 m water depth (e.g. Backman et al., 2004), whereas *Bolivina arctica* and *Oridorsalis umbonatus* can be used at water depths ranging from ~3000 to 560 m.

We have rewritten the respective passage to `We focus on the interval with normal magnetic polarity in the upper to middle Pleistocene. Since previous benthic foraminifera research has mainly focused on sediment cores retrieved from relatively shallow water depths (500-<1900 m) (e.g., O'Neill, 1981; Scott et al., 1989; Jakobsson et al., 2001; Backman et al., 2004; Polyak et al., 2004; Cronin et al., 2008; Cronin et al., 2013; Cronin et al., 2014; Lazar and Polyak, 2016), we used the relatively well-studied core PS2185-6 from the Lomonosov Ridge (1073 m water depth) as reference core for such sites (Fig. 1, Table 1). However, the Lomonosov Ridge represents a barrier to deep water exchange >1870 m between the Eurasian Basin and Amerasian Basin (Björk et al., 2007), which is why deep-water sediment cores must be considered for a reconstruction of paleo-deep water circulation/change within the Arctic Basins. Therefore, we included core PS72/396-5 and PS72/340-5 retrieved from ~2300 m and ~2700 m water depth, respectively, on the southern Mendeleev Ridge (Fig. 1). ´

Line 130: citations for “published data” are not given. Perhaps direct the reader to the table of sources?

We are grateful for this comment. Table 1 should have included the respective citations but accidentially we submitted an older version without any reference.

Line 221: Here the assertion is made that absolute abundances are not affected by other taxa in a sample like relative abundance are. However, in discrete samples where a particular number of specimens is counted to, the absolute abundance is very much affected by the other taxa. If I pick 300 specimens (as recommended on line 992) and there are no other species, I would get 300 of one species and thus a higher abundance than I would if many other taxa were present. Similarly if the constraint is to pick 1 gram of sediment.

The number of species correlates logarithmically with the number of individuals counted, and once 300 individuals have been counted, the estimated number of species remains virtually unchanged (Imbrie and Kipp, 1971; Murray, 1991; Schmiedl, 1995). Therefore, a sample size of 300 individuals (from a split sample) is considered ideal for a reliable interpretation of regional and temporal changes in fauna based on raw data (Imbrie and Kipp, 1971; Murray, 1991; Schmiedl, 1995) and also used in our study. We would like to illustrate why the reviewer’s reasoning is mathematically incorrect using the following example. If only e.g. *B. arctica* specimens would be found in one full (no split) sample of core PS2185-6 (mean sample weight ~100 g), these 300 specimens would have a relative abundance of 100%, while their absolute abundance would be only 3 nos/g.dry weight (300 specimen divided by 100 g sediment). This is not comparable with an absolute abundance of ~300-1500 nos/g. dry weight that this species may reach in the respective bioevent in our cores. Again, the abundance of other taxa in a sample is irrelevant if you calculate absolute abundances.

Line 223: If comparison of relative abundance data is “difficult” because agglutinated taxa are sometimes not included, why can’t the relative abundances simply be recalculated excluding the agglutinated taxa? By restricting the calculation to only calcareous taxa, this issue would be avoided.

This is correct (we would have to exclude also most of our calcareous taxa) but it should be usually attemped to count all foraminifer taxa in a sample to give an account on the assemblage being as complete as possible. You have to agree on a set of species that you include and a set of species that you exclude if you want to compare relative abundances between different labs. You also would always have to verify if these selected species still cover the vast majority of the actual fauna, which again would require to share actual counts. We changed the respective sentences in lines 219-223 to `Moreover, relative abundances, generally used in arctic studies (Adler et al., 2009; Polyak et al., 2013; Lazar et al., 2016; Chauhan et al., 2014; Chauhan et al., 2015; Hanslik et al., 2013), are first of all influenced by variable abundances of the other taxa in an assemblage´.

Line 265: Pronounced lithological variability is mentioned, which could profoundly affect the density of foraminifera in ways that are uninformative to biostratigraphy or to ecological analyses. Line 355 reemphasizes this by point out that some lithologies do no have forams at all. Again on line 487 talks about variable accumulation and stratigraphic breaks, which will affect the densities for foraminifera obtained, and thus, create patterns in “absolute abundance.”

Working on Arctic Ocean sediments means that you have to deal with discontinuous microfossil records. The occurrence of microfossils is here related to brown biogenic carbonate-rich intervals (figs. 3-5) which reflect interglacial/interstadial conditions. Therefore, we can only use these intervals for biostratigraphic purposes and paleoecological analyses. Of course, barren intervals are useless for such analyses. When looking at the stratigraphic occurrence of *B. arctica* in the three cores, it can be easily recognized that brown layer in the uppermost part of the cores have much lower absolute abundances than below pink-white layer PW 2. Despite average sedimentation rates ranging in the three cores between 1.5 to about 10 mm/ka this pronounced pattern of *B.arctica* remains visible in all cores.

Section 3.2. Figures are referred to qualitatively and with subjective terms when quantitative, objective, comparisons would be more useful. Ex. “Bolivina arctica are rarely abundant to dominant” however, it is not clear the meaning of “rarely,” “abundant,” or “dominant.” Or “Benthic foraminifer assemblages are generally dominated by Stetsonia horvathi” does not appear to be true from the figures (perhaps this is because each panel has different y-axes, which makes comparison difficult) and without quantification, the sentence is hard to rely on. The generalization of patterns in calcareous taxa across the cores is also difficult because some of the statements seem to be true for one core and not others.

We have used these rather descriptive terms to keep the chapter 3.2 as short as possible, because all details are easily visible in figures 3 to 11 including the absolute abundances, marked in red, that is the only useful quantification for biostratigraphic analyses in the Arctic Ocean. Since reviewer 2 did not comment on this issue, we are not sure how to proceed, and we would appreciate very much comments by the editor. We could add definitions for e.g. rare, common, abundant and dominant in the methods section but these terms will also include arbitrary ranges of relative and absolute abundances meaning also that we will have one terminology for relative and another for absolute abundances.

Line 519: In the discussion the term "foraminifer maximum" is introduced for the first time and it is unclear what this is referring to.

We are sorry for not explaining this term and have now added 'planktic' and the depth interval of the planktic foraminifer maximum, referring to fig. 5, and the respective citation (Spielhagen et al., 1997). The sentence is now` Although the extinction age at the base of the upper planktic foraminifer maximum at 170 cm (Spielhagen et al., 1997) has large uncertainties with respect to stratigraphic interval and age (Song et al., 2023), the core section with the three foraminifer maxima between 160 and 240 cm is older than MIS 6 (Fig. 5).'

Section 4.2.1 of the discussion relies on the change between agglutinated-dominated foram assemblages and calcareous-dominated assemblages for correlation, but in the results the authors note that the distribution of agglutinated foraminifera is different in each core examined in the manuscript. The change over is only obvious in Figure 5, but it is claimed for two of the cores (line 592) even though only Figure 5 is the only stratigraphic figure referenced in the section.

The paragraph from line 589 to 595 refers, as stated at the beginning of the paragraph, to shipboard data of core PS87/030-1 that has been correlated to PS2185-6. The shipboard data are published in the expedition report (Stein, 2015) which can be download as a pdf document. So, we do only refer to one of our cores (PS2185-6) and published data of core PS87/030-1 that we did not analyse.

The majority of the section is simply reviewing past work that seems unaffected by the new data even though the claim (Line 580) is made that the new data have an effect. The support for the argument is not clear.

The reviewer is correct in saying that simply past work is reviewed. This was already stated in the abstract that our intention was to include as much previous work as possible to evaluate whether individual bioevents are useful or not. For the eastern Arctic Ocean, we conclude (line 608) that this changeover was probably synchronous.

The claim in line 580 refers to the previous sentence in lines 578-580, where a tentative age of this turnover is given, that cannot be supported by the age tie-points and the new benthic foraminifer data of core PS2185-6, and an evaluation of previously published benthic foraminifer records and the age models of the respective cores. We suggest rephrasing this part slightly to make this argument more clear.

‘Cronin et al. (2008) suggest that this turnover may have occurred in MIS 7 to 9, but they note that the age control is based only on sites from the central Lomonosov Ridge. However, the ~~new stratigraphic data~~ age tie-points used for the new benthic foraminifer record of PS 2185-6 rather suggest an older age, and the evaluation of previous published data of cores from the Amerasian Basin suggest a time-transgressive change in the benthic foraminifer assemblages across the CAO.’

Line 928: Assertions about switch from r to k strategists in the Arctic are tenuous and not well supported by data. It appears to rely on only one taxon in one core and a different taxon in another core.

In this chapter we describe a fundamental change in benthic foraminifer assemblages from calcarous to purely agglutinated taxa in middle Pleistocene sediments in the CAO (Cronin et al., 2008; this study). We then discuss that this the fundamental change could be coincident with the mid-Pleistocene transition environmetal change in mid latitudinal benthic foraminiferal faunas, where this fundamental changes are regarded as change from predominantly k strategists to r strategists, with the respective references. We then cite Hottinger (1983) who considered larger agglutinated species as k strategists and Linke (1982, we could also cite his paper from 1989) who has carried out feeding experiments with *Cribrostomoides subglobosum* and *Pyrgo rotalaria* in which these species behaved as k strategists. *P. rotalaria* likely substitutes the agglutinated taxon *H. obscurus* at shallower sites (e.g. site PS2185) in deeper waters at 2700 m (PS72/396-5). Experimental studies on selected deep-sea taxa are extremely rare and for the Nordic Seas to Arctic Ocean largely restricted to the work of Linke and the high-pressure culturing experiments of the first author of this study. We consider the reference of Linke (1992) who has analysed the cell processes of these species in detail as profound and sufficient. If further published work should be cited, we will add a new reference Faizieva et al (Scientific Reports accepted), were the first author of this study has investigated the colonization of freshly settled phytodetritus by benthic foraminifera – with no reproduction of these two species.

Some data that is used as supporting evidence of some claims is cited as unpublished ideas by one of the authors and relying on unpublished information does not give confidence in the interpretations. For example, in section 3.2, unpublished data (line 366) is mentioned and attributed to one of the authors rather than being presented in the current manuscript as results, but this data on the abundance of a planktonic could easily be provided.

This sentence states that planktic foraminifera assemblages in cores PS72/340-5 and PS/396-5 mainly consist of *Neogloboquadrina pachyderma*. This is common to all Arctic Ocean sediment cores and has no consequences for this study. If requested the respective data can be added to the files uploaded in Pangaea, but those data are irrelevant for this study on benthic foraminifera.

Later in the discussion (line 940) unpublished information about the ecology of a purported k-strategist (Pyrgo) is given as unpublished observations by one of the authors. This same taxon is further supported as being a k-strategist based on the lack of reports of food-triggered reproduction, but no citation is given so it is not clear it anyone even tested the relationship and lack of knowledge should not be used a supporting evidence.

See our response to the critics made in line 928. In the sentences before line 940 we have cited the work of Linke (1992), Linke and Lutze (1993), Hottinger (1983) and Evans (1995) to support this k-strategist assumptions. E.g. Linke (1992) provided ATP and metabolic investigations on *Cribrostomoides subglobosum* (a large agglutinated taxon like *H. obscurus*) and *P. rotalaria* and e.g. showed that both taxa consumed their own cytoplasm during times of low food availability, and concluded that they are k-strategists. The sentence starting in line 940. `It is a long-living species (Wollenburg unpublished observation) without spontaneous reproduction in response to export events,´ refers to four decades of Rose Bengal and 10 years high-pressure culturing of Arctic deep-sea sediments with benthic foraminifera (in subsequent years isolated specimen). These experiments showed that reproduction of both species was not triggered by food. However, we will simply delete this sentence and may in the revised manuscript cite the first authors observations on the colonization of benthic foraminifera in freshly settled fluff, with no reproduction of both species, in the just accepted Scientific Reports manuscript by Faizieva et al. `Benthic foraminiferal colonisation of phytodetritus during spring bloom within the marginal sea ice zone off northern Svalbard continental margin´.

Technical Comments

On organization

The abstract is very long and should be shortened by about half. Synthesizing the results rather than listing each in turn would also help the reader understand the main thesis of the manuscript, which is not currently evident.

Although only reviewer 1 recommends to shorten the abstract whereas reviewer 2 does not below you will find a new version focussing only on the “positive” results (definition of three bioevents and their implications) rather than describing the results of the complete evaluation of all previously used bioevents. The deleted text is crossed out in this new version.

`Benthic foraminifers show distinct temporal and spatial distribution patterns in the Central Arctic Ocean (CAO) demonstrating their potential to provide robust age constraints and to address paleoceanographic change in the Pleistocene. Several benthic foraminifer bioevents have been previously reported from the upper and middle Pleistocene that are here critically evaluated by studying three sediment cores from the Mendeleev and Lomonosov ridges and analysing published data sets. Based on this data bioevents are defined by using absolute abundances of species in the >63 µm grain size fraction, whereas relative abundances are considered not reliable because taphonomic processes such as disintegration and/or dissolution overprint the original assemblage composition. Bioevents are ~~calibrated~~ correlated to lithological horizons and then linked to Quaternary subseries and marine isotope stages based on available independent stratigraphic data.

Three calcareous bioevents can be defined in the Brunhes Chron (Middle Pleistocene): (1) the highest common occurrence of *Bolivina arctica* (~MIS 9) ~~at the top of lithological unit L in brown bed B 7~~, (2) the lowest common occurrence of *Oridorsalis umbonatus* ~~at the base of~~

~~brown bed ?B 4~~ (~MIS 7), and (3) the acme of *Bulimina aculeata* (~MIS 7) ~~in brown bed ?B 4~~ in water depths of less than ~2000 m. The lowest common occurrence of *Oridorsalis umbonatus* is coeval with the base of the acme of *Bulimina aculeata* at shallow sites (<2000 m). The proposed correlation to marine isotope stages should be considered provisional and subject to modifications as additional age tie-points become available. So far numerical ages for these bioevents are too imprecise due to the limited number of biostratigraphic and radiometric ages.

Further benthic foraminifer bioevents may be useful for stratigraphic correlation on a regional to supra-regional scale but require evaluation of previous taxonomic identifications and additional sediment core studies. The extinct agglutinated species *Haplophragmoides obscurus* disappeared on Lomonosov Ridge in the Middle Pleistocene but the complex taxonomy and the few data on the occurrence in arctic sediment cores currently prohibits the application as biostratigraphic marker. The assemblage turnover from agglutinated to calcareous benthic foraminifera occurred close to the first downcore change of normal to reverse magnetic polarity and might be a synchronous event in the eastern Arctic Ocean in middle Pleistocene sediments older than MIS 11 indicating a possible relation to the mid-Brunhes event. This fundamental change in assemblage composition is time-transgressive because it probably occurred in the Amerasian Basin in the Early Pleistocene. ~~However, there is sedimentological evidence for a significant gap in the sedimentary sequences on Lomonosov Ridge at the stratigraphic level of the assemblage turnover. Since stratigraphic tie-points are not available for the sequences below this event, it remains speculative if the ages are closer to each other in both basins.~~

~~In the Late Pleistocene the identification of bioevents is hampered by sporadic occurrences of benthic foraminifera, and the disputable chronostratigraphy due to possible hiati and/or condensed sections in MIS 2 to MIS 5 sediments. The identification of MIS 5 is a controversial issue, and it might be missing in some cores from Lomonosov Ridge, possibly due to extensive carbonate dissolution, while certain brown layers in the Amerasian Basin are potential candidates for this interglacial. The acme of *Siphotextularia rolshauseni* that was previously described as stratigraphic marker for MIS 2 sediments in the Norwegian-Greenland Sea can only be used in the Fram Strait area and at the upper continental slope of the northern Barents Sea. *Pullenia bulloides*, frequently used to identify MIS 5a in polar to subpolar sediments, is only sporadically present in Pleistocene sediments from the CAO and is not confined to a specific stratigraphic interval. Since this species shows variable abundances in cores from water depths less than 2000 m in the Fram Strait area and at the northern Barents Sea continental margin in the Pleistocene, it is not anticipated that it is a stratigraphically useful species.~~

The bioevents in the CAO are caused by a complex interplay of various biological processes. Apart from *B. arctica* and *H. obscurus* that likely evolved in the Arctic Ocean, the species characterizing these bioevents such as *B. aculeata* and *O. umbonatus* must have invaded the Arctic Ocean as propagules from subpolar latitudes. Likely by Atlantic Water advection through Fram Strait the maximum reachable location for settlement within the Arctic Ocean, depended on the species, the local environmental conditions, and the current speed. These sites must have faced a high (*H. obscurus*, *B. arctica*, *O. umbonatus*), or significantly higher particulate organic carbon export to the sea floor than today (*B. aculeata*) to explain the respective species dominance. Such environmental conditions must have prevailed basin-wide to trigger coincident changes in assemblage compositions. The onset of a massive discharge of detrital dolomite-rich ice-rafted debris might have caused the abrupt collapse of a *Bolivina arctica* dominated fauna and almost disappearance of *Haplophragmoides obscurus*. The most conspicuous change in the environment is expressed in the turnover from predominance of agglutinated to calcareous foraminifer which ~~was probably~~ might have been caused by a fundamental change in food supply and its quality, and/or dissolution. However, the formation of bioevents cannot be attributed alone to biological processes. Due to selective dissolution of thin-shelled epifaunal taxa, assemblages are enriched in robust epifaunal and/or infaunal calcareous species, or may consist only of an agglutinated taphocoenosis.´

Organization of the manuscript is at times confusing and some paragraphs are not logically linked to each other or structured with clear topical themes. For example, section 3.2 starts with the calcareous assemblage, then reports on agglutinated assemblage and then shifts back to calcareous taxa on line 397 and back to agglutinated on line 445. The paragraphs from line 393-448 are all about single taxon with no connections between the paragraphs or a clear narrative. It then switches back to assemblage-level results. Subheadings and topic sentences are needed in order to follow the ideas.

We propose to divide the section into two subchapters:

3.21 Stratigraphic occurrence of calcareous and agglutinated foraminifera

Line 355 to line 392

3.22 Stratigraphic occurrence of individual species

Line 393 to line 489

The current organization of the manuscript also puts information in unexpected places. For example: Section 3.1 in the Results appears to be a review of prior work rather than presenting any new results. This should be moved above results into methods or a background section about the study site.

We are grateful for this suggestion and move this section as subchapter into the ~~introduction~~ methods.

JENS: ABER DANN ALS SUBCHAPTER?

Section 3.2 is in the Results, but is primarily discussion and review, making it very difficult to focus on the new information.

Here we disagree, because this section describes the new results of the three cores, **and** the evaluation of previous data sets with respect to our approach using absolute abundances instead of relative abundances. This is done here for the first time, and therefore needs to be described.

Section 4.1 of the discussion does not seem to be connected to any results and instead is background on the chronology of the cores, which would be more appropriate before the results in a section on site background.

This section is included in the discussion to shortly describe the most recent developments in Arctic Ocean chronostratigraphy, based on few landmark papers (Hillaire-Marcel et al., 2018; Razmjooei et al., 2023; Song et al., 2023; Wollenburg et al., 2023) which are still not considered in subsequent studies (e.g. Zehnich et al., 2025). We are not sure whether a reader will recognize this chapter if it is placed under results but we appreciate suggestions of the editor who is more familiar with the community reading CP.

Section 4.3 also does not seem connected to any results and is background on the ecology of foraminifera and what controls their distribution in the Arctic. The only potential connection provided is to the shift from agglutinated to calcareous taxa.

We think it is important that the reader understands that we are looking at residual faunas in sediment cores and that calcite dissolution and/or the disintegration of agglutinated foraminifera alters the assemblages we find in the sediments. But we will keep this critics in mind and will cut-off information that is not essential like e.g. the infaunal activity of foraminiferal species not relevant for the manuscript. As the second reviewer didn't rise respective critics however, we still kept most of the information that we find relevant to understand the ecological background for the paleoecological changes that allowed the formation of the respective bioevents. The changed part so far reads 'Since evolutionary turnover does not play a role in the stratigraphic occurrence of most benthic foraminifer species in the Pleistocene of the Arctic Ocean, the composition of assemblages is determined by the complex interaction of ecologic requirements and taphonomic processes (Table B1). Thus, the formation of bioevents is controlled by a set of factors rather than a single environmental variable (Martin, 2003; Loubere et al., 1993; Loubere and Rayray, 2016). The spatial distribution of living benthic foraminifera and their preference for specific bathyal water depths is essentially controlled by their food and oxygen requirements (Jorissen, 2003; Jorissen et al., 1995). To a lesser extent competition, grain size of sediments, current activity, and ~~bottom water pH determine the bathyal faunal composition (Gooday and Jorissen, 2012). Species like Lobatula wuellerstorfi (= Cibicides wuellerstorfi) further require a minimum hydrostatic pressure for reproduction (Wollenburg et al., 2015).~~ bottom water pH, and hydrostatic pressure determine the bathyal faunal composition (Gooday and Jorissen, 2012; Wollenburg et al., 2015).

However, foraminifera do not exclusively live at the sediment surface but can also survive at significant sediment depths if labile organic matter and oxygen is still available (Jorissen, 2003). Mean modern carbon export in the permanently ice-covered CAO is considered amongst the lowest in the world's oceans (Honjo et al., 2008; Nowicki et al., 2022) resulting in particulate organic carbon (POC) fluxes of 0.17–1 g C $m^{-2}yr^{-1}$ at depths >1000 m (Harada, 2015; Roca-Martí et al., 2016). The low amount of POC reaching the seafloor in the CAO is usually immediately consumed at the sediment surface and not buried to sustain living foraminifera, below the surface centimeter under a permanent ice cover (Wollenburg and Mackensen, 1998b). Moderate to deep-infaunal living taxa like *Melonis zaandami* and *Nonionellina labradorica* ~~or various Elphidiids~~ are only sustained where food flux is seasonally high, at the seasonally ice-free areas. Species with an even higher food-demand like *Bulimina aculeata* (Jorissen et al., 1995) are absent from the modern Arctic Ocean (Wollenburg and Mackensen, 1998a, b; Wollenburg and Kuhnt, 2000).

Benthic foraminifera have been used to reconstruct past sea ice conditions (Cronin et al., 2008b; Polyak et al., 2013; Seidenkrantz, 2013). However, benthic foraminifera are only indirectly linked to sea-ice conditions because primary production and sedimentation of organic matter is related to light-penetration through sea ice, upwelling processes at the ice margin and release of ballast material from melting sea ice (Anderson et al., 2003; Mar, 2014; Swoboda et al., 2024). The ice-covered bathyal Arctic Ocean is characterized by opportunistic shallow-infaunal and epilithic/-phytic foraminiferal taxa adapted to low to very moderate carbon flux (Wollenburg and Kuhn, 2000). In seasonally ice-free areas the surplus of labile organic matter provided by export from algae blooms (Swoboda et al., 2024) at the ice edge cause an increase in the number of species that dwell on the sea floor in the accumulated phytodetritus (Faiezieva et al., in press).’

Figure 1 needs a legend for the bathymetrical color scale.

We are grateful for this comment and will add the the missing information.

Table 1 provides water depths, but some are negative and some are positive. Needs standardization.

We are grateful for this comment and will correct the table accordingly.

Having all the time series for the cores plotted in different figures (Figures 3-5) on different pages also makes it hard to compare among the cores and see any common patterns necessary for evaluation biostratigraphy utility of the bioevents.

The reviewer may have not realized that we provide two different sets of figures. First of all figures 3 to 5 include the data of the new cores, and then figures 6 to 11 shows the stratigraphic distribution of individual species both in the new cores and other cores whose data have been published previously. In these figures the lithological marker beds PW 1 and PW 2 are depicted to show how the stratigraphic occurrence is related to these layers. We think these figures demonstrate how well our approach works for individual species.

Line 424: “NP26 record” is confusing. There are two cores with this designation in Table 1 and the abbreviation is the same as used for nannoplankton biozones.

Unfortunately, the composite of these two cores NP26-5 and NP26-32 (NP stands for North Pole) has been described as “NP 26 cores” by Polyak et al. (2004). We will use instead of “composite NP26 record” composite record of cores NP26-5 and NP26-32.

Figure 12. I am not clear on how this illustrates preservation potential. Where does the orange triangle come from? How is enrichment of robust taxa being illustrated? There are clearly samples where less robust taxa are present and robust taxa are not.

The orange triangle is a qualitative judgement based on data show in Appendix B: Ecology, shell characteristics, and preservation of main calcareous taxa. It is based on shell thickness, chamber arrangement and habitat depth. It is a figure that shows the distribution of 4 species downcore. That dissolution affected samples differently, is shown in exemplified images of fig. 13.

We have changed the legend of fig. 12 to `Influence of the preservation potential (qualitative assessment based on Appendix B: Ecology, shell characteristics, and preservation of main calcareous taxa) of *Epistominella arctica*, *E. exigua*, *Bolivina arctica* and *Bulimina aculeata* on the formation of absolute abundance maxima in core PS2185-6. The more robust species are successively enriched with increasing selective dissolution´ in the revised version.

Main text with reference to this fig. `As dissolution affects the thin-shelled epifaunal shells first, abundant to dominant robust infaunal species such as *Bolivina arctica, Oridorsalis umbonatus*, and especially *Bulimina aculeata* reflect a significant taphonomic loss in associated thin-shelled epi- and shallow-infaunal species (Figs. 12-13). Such relict assemblages are often preserved in the brown layers. At the termination of warmer climatic conditions or an extended perennial ice cover the taphonomic loss was even higher. Here the whitish and edged shells of thick-shelled calcareous infaunal taxa are accompanied only by shell fragments of a diminishing number of thin-shelled *Stetsonia horvathi* and *Epistominella arctica* in the small size fraction (Fig. 12)´.

All figures with abundance data and relative abundance data are plotted on different scales making it very hard to compare across species in a single figure or across the figures. Axes should be standardized.

If we adjust the scales to a common standard, then it will be difficult to see the stratigraphic patterns of species that have low absolute abundances. A standard depth scale would either lead to a very compressed figure 3 with curves almost impossible to read, or figures 4 and 5 being enlarged to a size that does not fit on a page or being during editing reduced to page size that makes it difficult to read details. We kindly ask the editor how to procced with this issue.

There are numerous typographical and formatting errors that need careful proof reading.

The final version will be checked by our secretary/foreign language assistant before submission.

References

Alve, E. and Goldstein, S.: The Propagule Method as an Experimental Tool in Foraminiferal Ecology, in, 1-12, 10.1007/978-4-431-54388-6_1, 2014.

Alve, E. and Goldstein, S. T.: Dispersal, survival and delayed growth of benthic foraminiferal propagules, Journal of Sea Research, 63, 36-51, https://doi.org/10.1016/j.seares.2009.09.003, 2010.

Backman, J., Jakobsson, M., Lovlie, R., Polyak, L., and Febo, L. A.: Is the central Arctic Ocean a sediment starved basin?, Quaternary Science Reviews, 23, 1435-1454, https://doi.org/10.1016/j.quascirev.2003.12.005, 2004.

Bauch, H., Erlenkeuser, H., Spielhagen, R., Struck, U., Thiede, J., and Heinemeier, J.: A multiproxy reconstruction of the evolution of deep and surface waters in the subarctic Nordic seas over the last 30,000 yr, Quaternary Science Reviews, 20, 659–678, 10.1016/S0277-3791(00)00098-6, 2001.

Cronin, T. M., DeNinno, L. H., Polyak, L., Caverly, E. K., Poore, R. Z., Brenner, A., Rodriguez-Lazaro, J., and Marzen, R. E.: Quaternary ostracode and foraminiferal biostratigraphy and paleoceanography in the western Arctic Ocean, Marine Micropaleontology, 111, 118-133, http://doi.org/10.1016/j.marmicro.2014.05.001, 2014.

Fronval, T. and Jansen, E.: Rapid changes in ocean circulation and heat flux in the Nordic seas during the last interglacial period, Nature, 383, 806-810, 1996.

Haake, F.-W. and Pflaumann, U.: Late Pleistocene foraminiferal stratigraphy on the Vøring Plateau, Norwegian Sea, Boreas, 18, 343-356, 1989.

Haake, F.-W., Erlenkeuser, H., and Pflaumann, U.: *Pullenia bulloides* (Orbigny) in sediments of the Norwegian/Greenland Sea and the northeastern Atlantic Ocean: paleo-oceanographic evidence, BENTHOS ´90, Sendai, 235-244,

Herman, Y.: Arctic Ocean Sediments, Microfauna, and the Climatic Record in Late Cenozoic Time, Berlin, Heidelberg, 283-348, https://doi.org/10.1007/978-3-642-87411-6,

Imbrie, J. and Kipp, N. G.: A new micropaleontological method for quantitative paleoclimatology: Application to a late Pleistocene Caribbean core, in: The Late Cenozoic Glacial Ages., edited by: Turekian, K., Yale University Press, New Haven, 71-181, 1971.

Ishman, S. E., Polyak, L. V., and Poore, R. Z.: Expanded record of Quaternary oceanographic change: Amerasian Arctic Ocean, Geology, 24, 139-142, https://doi.org/10.1130/0091-7613(1996)024<0139:EROQOC>2.3.CO;2, 1996.

Jakobsson, M., Løvlie, R., Arnold, E. M., Backman, J., Polyak, L., Knutsen, J.-O., and Musatov, E.: Pleistocene stratigraphy and paleoenvironmental variation from Lomonosov Ridge sediments, central Arctic Ocean, Global and Planetary Change, 31, 1-22, https://doi.org/10.1016/S0921-8181(01)00110-2, 2001.

Kender, S., Aturamu, A., Zalasiewicz, J., Kaminski, M. A., and Williams, M.: Benthic foraminifera indicate Glacial North Pacific Intermediate Water and reduced primary productivity over Bowers Ridge, Bering Sea, since the Mid-Brunhes Transition, J. Micropalaeontol., 38, 177-187, 10.5194/jm-38-177-2019, 2019.

Knies, J., Vogt, C., and Stein, R.: Late Quaternary growth and decay of the Svalbard/Barents Sea ice sheet and paleoceanographic evolution in the adjacent Arctic Ocean, Geo-Marine Letters, 18, 195-202, https://doi.org.10.1007/s003670050068, 1998.

Löwemark, L. and Singh, A.: Influence of deep-reaching bioturbation on Arctic Ocean radiocarbon chronology, Communications Earth & Environment, 5, 293, 10.1038/s43247-024-01461-0, 2024.

Murray, J. W.: Ecology and palaeoecology of benthic Foraminifera, Journal of the Marine Biological Association of the United Kingdom, 71, 402, 10.1017/S0025315400053650, 1991.

Nees, S. and Struck, U.: The biostratigraphic and paleoceanographic significance of Siphotextularia rolshauseni Phleger and Parker in Norwegian-Greenland Sea sediments, Journal of Foraminiferal Research, 24, 233-240, https://doi.org/10.2113/gsjfr.24.4.233, 1994.

Nguyen, N.-L.: Metabarcoding reveals high diversity of benthic foraminifera linked to water masses circulation at coastal Svalbard, Geobiology, 00, 1–18, 10.1111/gbi.12530, 2022.

Nguyen, N.-L., Pawłowska, J., Szymańska, N., Zajączkowski, M., Weiner, A., De Schepper, S., and Pawlowski, J.: Assessing the passive dispersal of benthic foraminifera through environmental DNA, Limnology and Oceanography, 71, n/a-n/a, 10.1002/lno.70294, 2025.

O'Neill, B. J.: Pliocene and Pleistocene benthic foraminifera from the central Arctic Ocean, Journal of Paleontology, 55, 1141-1170, 1981.

Polyak, L., Best, K. M., Crawford, K. A., Council, E. A., and St-Onge, G.: Quaternary history of sea ice in the western Arctic Ocean based on foraminifera, Quaternary Science Reviews, 79, 145-156, https://doi.org/10.1016/j.quascirev.2012.12.018, 2013.

Polyak, L., Curry, W. B., Darby, D. A., Bischof, J., and Cronin, T. M.: Contrasting glacial/interglacial regimes in the western Arctic Ocean as exemplified by a sedimentary record from the Mendeleev Ridge, Palaeogeography, Palaeoclimatology, Palaeoecology, 203, 73-93, https://doi.org/10.1016/S0031-0182(03)00661-8Nørga, 2004.

Schmiedl, G.: Rekonstruktion der spätquartären Tiefenwasserzirkulation und Produktivität im östlichen Südatlantik anhand von benthischen Foraminiferenvergesellschaftungen = Late Quaternary benthic foraminiferal assemblages from the eastern South Atlantic Ocean : Reconstruction of deep water circulation and productivity changes, University Bremen, Bremen, 160 pp., 1995.

Scott, D. B., Mudie, P. J., Baki, V., MacKinnon, K. E., and Cole, F. E.: Biostratigraphy and late Cenozoic paleoceanography of the Arctic Ocean: Foraminiferal, lithostratigraphic, and isotopic evidence, Geological Society of America Bulletin, 101, 260-277, https://doi.org/10.1130/0016-7606(1989)101<0260:BALCPO>2.3.CO;2, 1989.

Spielhagen, R. F., Bonani, G., Eisenhauer, A., Frank, M., Frederichs, T., Kassens, H., Kubik, P. W., Mangini, A., Nørgaard-Pedersen, N., Nowaczyk, N. R., Schäper, S., Stein, R., Thiede, J., Tiedemann, R., and Wahsner, M.: Arctic Ocean evidence for late Quaternary initiation of northern Eurasian ice sheets, Geology, 25, 783-786, https://doi.org/10.1130/0091-7613(1997)025<0783:AOEFLQ>2.3.CO;2, 1997.

Streeter, S. S., Belanger, P. E., Kellogg, T. B., and Duplessy, J. C.: Late Pleistocene paleo-oceanography of the Norwegian-Greenland Sea: Benthic foraminiferal evidence, Quaternary Research, 18, 72-90, http://dx.doi.org/10.1016/0033-5894(82)90022-9, 1982.

Wefing, A. M., Casacuberta, N., Christl, M., Gruber, N., and Smith, J. N.: Circulation timescales of Atlantic Water in the Arctic Ocean determined from anthropogenic radionuclides, Ocean Sci., 17, 111-129, 10.5194/os-17-111-2021, 2021.

Wollenburg, J. E. and Kuhnt, W.: The response of benthic foraminifers to carbon flux and primary production in the Arctic Ocean, Marine Micropaleontology, 40, 189-231, https://doi.org/10.1016/S0377-8398(00)00039-6, 2000.

Wollenburg, J. E., Knies, J., and Mackensen, A.: High-resolution paleoproductivity fluctuations during the past 24 kyr as indicated by benthic foraminifera in the marginal Arctic Ocean, Palaeogeography, Palaeoclimatology, Palaeoecology, 204, 209-238, https://doi.org/10.1016/S0031-0182(03)00726-0, 2004.

Wollenburg, J. E., Kuhnt, W., and Mackensen, A.: Changes in Arctic Ocean paleoproductivity and hydrography during the last 145 kyr: the benthic foraminiferal record, Paleoceanography, 16, 65-77, https://doi.org/10.1029/1999PA000454, 2001.