Author’s response to Dr. G. Cortese

We are grateful to your comments and useful suggestions that improved our manuscript greatly. As described below, we have revised our manuscript. Please note that the expression in blue colored letters are the ones provided by you whereas those in black are our replies.

Specific comments:

Page 16647, line 12-15
This means it was not dominant only during the full sea ice season. Probably this is also the reason why the environmental conditions you associate this species with are very confusing/not clear...

According to your comment and comment 5-23 of reviewer 2, we revised the text as follows:
“*Amphimelissa setosa* was dominant during the open water and the beginning and the end of ice cover seasons with well-grown ice algae, ice fauna and with alternation of stable water masses and deep vertical mixing.”
was changed to
“*Amphimelissa setosa* was dominant during the season with open water as well as at the beginning and at the end of the seasons with sea ice cover. Cold and well mixed water mass based on summer ice edge were essential for high reproduction and growth of *A. setosa*.”

Page 16647, line 17-19
It is not clear at all how this relates to productivity/species diversity in radiolarians...

We revised the text as follows:
“greater, which might be associated with the seasonal increase of solar radiation that induce the growth of algae on the ice and the other phytoplankton species under the sea-ice.”
was changed to
“greater. This might be associated with the seasonal increase of solar radiation stimulating the growth of algae on the ice and other phytoplankton species under the sea-ice, upon which the actinommids can feed on.”

Page 16647, line 19-21
This is a very general statement, as it does not explain in detail how sea-ice impacts radiolarians (if you think that the discussion on A. setosa vs. Actinommidae is that explanation, well, you do not need last period then)... and in a way one would expect it to be so, as the presence and extent of sea ice have a very strong impact on various environmental variables and processes that will, eventually, have an impact on any plankton group.

“These indicated that the dynamics of sea-ice was a major factor affecting the productivity, distribution, and composition of radiolarian fauna.”
was changed to

“This evidence suggests that the dynamics of sea-ice are a major factor affecting the general biological productivity, distribution, and composition as demonstrated in the radiolarian fauna.”

Page 16648, line 2
Specify which water mass or, at the very least, replace this with "North Pacific".

We accepted your suggestion and replaced “pacific” with “North Pacific”.

Page 16648, line 6-7
Why? How?
Possibilities: enhance (with melting injecting nutrients in the surface ocean, thus promoting blooms/export) and reduce (as the lack of ice cover favours outgassing)
And: whatever Nishino's argument is on the circulation itself (see next comment)...
It would probably be better to split this part in a few sentences, otherwise it becomes too long and complex.

Thanks for your comment.
We explained in the next comment.

Page 16648, line 13-14
You however do not explain why....
Is this exclusively by the fact that the circulation pattern generates downwelling of surface waters within the gyre?

We revised the text as follows:
“The efficiency of the biological pump is reduced within the Beaufort Gyre, and conversely, it is enhanced outside the Beaufort Gyre (Nishino et al., 2011).”
was changed to
“Melting of sea ice reduce the efficiency of the biological pump within the Beaufort Gyre because of deepening of the nutricline caused by freshwater accumulation within the gyre (Nishino et al., 2011). Conversely, the efficiency of the biological pump is enhanced outside the gyre because of nutrient supply from shelves and improved light penetration (Nishino et al., 2011).”

Page 16649, line 2
What do you mean by this word?

We replaced “regime” with “conditions”

Page 16649, line 28-29
mentioned already, remove.
Replace with: "...Ocean, and discuss..."

According to your comment, we replaced “Ocean based on plankton tow samples and sediment trap material, respectively. We discuss.” with “Ocean, and discuss”.

Page 16650, line 10
I am not quite sure "psu" is used anymore, I think salinity is now dimensionless, but please check with a physical oceanographer

Thanks for your comment. We removed “psu” throughout the text.

Page 16650, line 26
We replaced “Atlantic Water (AW), Canada Basin Deep Water (CBDW)” with “Atlantic Water (AW) and Canada Basin Deep Water (CBDW)”.

Page 16651, line 1
either "which are" (if this refers to the surface waters), or "and is" if it refers to the deeper water mass.

We here refer to the deeper water and as you suggested, we replaced “which is” with “and is”.

Page 16651, line 14
You are already saying "simultaneously", so what you mean is obvious.

According to your suggestion, we replaced “from a CTD observation with the plankton sampling” with “from a CTD cast”

Page 16654, line 17
We replaced “$H = -P_i \log_2 P_i$” with “$H = -\Sigma P_i \log_2 P_i$”.

Page 16654, line 18
What do you mean by this?

We meant the contribution of species as relative abundance in total radiolarian.

Page 16654, line 18
Add a sentence explaining why the traps were lowered, example:
"This was done in order to...."

The traps were lowered for some reason unintentionally.
We revised the text as follows:
“Moored trap depth for the upper trap was lowered by about 80 m during the second year (about 260 m depth) than during the first year (about 180 m depth). Especially, during July-August in 2012, the moored trap depth was lowered to about 300 m (Fig. S1).”
was changed to
“Moored trap depth for the upper trap was lowered by about 80 m during the second year (about 260 m depth) than during the first year (about 180 m depth), caused by entanglement of the mooring ropes. During July-August in 2012, the moored trap depth was lowered to about 300 m, because of intensified water currents (Fig. S1).”

Page 16655, line 1
This is a bit too detailed, and could go to the legend of some of your tables.
I suspect the renaming suggestion does not have a taxonomic value, as you do not re-describe it anyway here.

We disagree in this judgement as this species is repeatedly being referred to as a species with a sagittal ring belonging to the family Spyridae. There is no sagittal ring and therefore this is not a Spyridae. The problem is in which nassellarian family to put this species? We have concluded to assign this species to the family Plagiacanthidae, and that it should be referred to as *Tripodiscium gephyristes*. As the species is not redescribed and therefore does not have a taxonomic value is correct, but never the less it do show that it is no Spyridae. We do not claim any authorship for this renaming, just making the point that it is no Spyridae.

We consider this taxonomic note important and it should be exposed in our text, not hidden as a subtitle in table legend.

Page 16655, line 8
We added the following text to the end of the text on line 8:
"until a proper taxonomic analysis has been undertaken".

Page 16655, line 14
either "Radiolaria" or "radiolarians"

We use "radiolarians".

Page 16656, line 8
We replaced "are juvenile forms of" with "are mostly two-shelled juvenile forms of".

Page 16656, line 14
We replaced "Adult" with "adult".

Page 16656, line 25
I am not quite sure you can call that common.... maybe use "present"/"rare".
I did not fix it earlier on in this page because your statements were about several species, and some of them had abundances around 6%, so while that is not really common, it sort of makes sense.

Thank you for your comment.
We replaced "Station 32 (0.4%) but common at Station 56 (1.4%)" with "Station 32 (0.4%) but with a slight increase at Station 56 (1.4%)".

Page 16659, line 3
As this paper is about a lot of things: when? Or are you citing a general issue/observation (in which case you may want to rephrase to something like: "While it is generally assumed that...") ?
On a separate note: this is all good, but (due to their generally higher abundances/fluxes) it applies a lot more to diatoms than radiolarians.
Thanks for your comment.
We revised the text as follows:

"Biogenic particle flux into the deep sea in the Canada Basin was low"
was changed to
"Biogenic particle flux into the deep sea in the Canada Basin was generally assumed to be low"

Page 16659, line 9-13
As mentioned above, it would be good to actually say how does the diatom flux compared to radiolarians, just to get an idea of their relative importance in this environment.

"The biogenic opal collected in this study mainly consisted of radiolarians and diatoms, therefore siliceous skeletons of radiolarians and diatoms might play important role to export biogenic silica to the deep Arctic. Relatively high flux of radiolarians in arctic microplankton might contribute to substantial part of the POC flux."

was changed to

"The biogenic opal collected in this study mainly consisted of radiolarians and diatoms based on our microscopic observations. Other siliceous skeletons (silicoflagellate skeletons, siliceous endoskeleton of dinoflagellate genus *Actiniscus*, chrysophyte cysts, ebridian flagellate, and palmales) are minor components in the same trap samples (Onodera et al., 2014), therefore siliceous skeletons of radiolarians and diatoms might play an important role to export biogenic silica to the deep Arctic. Onodera et al. (2014) also estimated the diatom contribution to POC flux at station NAP, but more than half of the contribution to total POC has not been explained yet. Relatively high flux of radiolarians in arctic microplankton might contribute to a substantial part of the POC flux."

We added the following reference:

"Onodera, J., Watanabe, E., Harada, N., and Honda, M. C.: Diatom flux reflects water-mass conditions on the southern Northwind Abyssal Plain, Arctic Ocean, Biogeosciences Discuss., 11, 15215-15250, doi:10.5194/bgd-11-15215-2014, 2014."

Page 16659, line 16-18

If you put it this way, one always thinks about the question: "When?".
How about: "The radiolarian fauna observed in this study of the western Arctic Ocean was found to have a close affinity..."

According to your suggestion, we changed the text as follows:

"Radiolarian fauna in the western Arctic Ocean had"

was changed to

"The radiolarian fauna observed in this study was"

Page 16660, line 8

Or: ".... suggested the possibility of endemism for..."

We accepted your suggestion, and revised lines 7-13 as follows:

"Kruglikova et al. (2009) described two new species *Actinomma georgii* and *A. turidae*, and suggested the possibility of endemism for these two species. They also indicated a fifth group *Actinomma* indet. (their fig. 5, p. 32) which probably consists of still several undescribed species. Their argument was that the endemism arose as radiolarians had been rapidly evolving under the stressful conditions in the Arctic Ocean, and that speciation or morphogenesis within the family Actinommidae might be ongoing in the central Arctic Basin. Our results support this hypothesis, and suggest that local speciation or morphogenesis took place not only in the central Arctic basin, but also in the western Arctic Ocean."

Page 16660, line 13

I am not quite sure this is proof of that, given the paucity of recent work in the Arctic Ocean. It essentially is a measure of Bjorklund's and Kruglikova's taxonomic interest... and it refers to VERY few new species.

We replaced "This is demonstrated by the occurrence of a" with "This is demonstrated by the occurrence of what we interpret as".

Page 16660, line 14

We replaced "Actinomma" with "*Actinomma*".

Page 16661, line 6-7

A mention of the Bjorklund et al., 1998 MarMicro paper would also be good for your argument, as A. setosa was found with similar percentages (in surface sediments) on the Voering Plateau (NE of Iceland, within Arctic surface water).

We added the following text to the end of the text on line 7:
"Bjørklund et al. (1998) reported its distribution in the western part of the GIN Seas, being dominant (up to 76%) at the Iceland Plateau and common (>20%) just north of the Iceland–Faeroe Ridge. In the eastern part of the Barents Sea, west of Novaja Zemlya, Bjørklund and Kruglikova (2003) reported *Amphimelissa setosa* as the dominant (77%) species."

Page 16661, line 18

That's a very thin logical link. In the absence of information specifically on these species (or at the very least the genus), I would delete this as too hypothetical.

According to your comment and comment 5-14 of reviewer 2, we added vertical profiles of chlorophyll *a* at station 32 and 56 to figure 2.
"Small spumellarians might be herbivorous (Anderson 1983) so Actinommidae spp. juvenile forms and *A. l. leptodermum* might therefore be bound to the euphotic zone where phytoplankton prevails."
was changed to
"Our results show that Actinommidae spp. juvenile forms and *A. l. leptodermum* are most abundant in the upper water layers where phytoplankton also prevails (Fig. 2). It is most likely that the juvenile actinommids and *A. l. leptodermum* may be bound to the euphotic zone, and so can be herbivorous."

Page 16661, line 24

You cannot use "also" if you just said that it is a surface dweller...

Thank you for your comment.
We deleted "also".

Page 16663, line 1-3

That's very slim evidence... that would translate to ca. 0.5 degree over last century or so. Do you really think that half a degree affects the distribution of a species that much? I would tend to rather believe that the studies from the 50s/60s simply did not pick it up, so there is more a sampling bias than a "warming trend" observation.

Thanks for your comment.
According to your comment and comments 5-16 and 5-19 of reviewer 2, we replaced Page 16662, line 21-22 as follows:
"This species has not been observed in the Canada Basin during the 1950s and 1960s (Hülseman 1963, Tibbs 1967)."
was changed to
"Itaki et al. (2003) first noticed that *Ceratospyris histricosus* had not been observed in the Canada Basin during the 1950s and 1960s and he pointed out that the common occurrence of this species in the Chukchi and Beaufort seas in 2000 might be an effect of the recent warming of the AIW."

We added the following text to the end of the text on line 3 in page 16663:

“It is not so much the effect of the temperature itself that is causing the expanding distribution of *C. histricosus*, but the general temperature increase indicates that larger volumes of warmer AW is entering the Arctic Ocean. The increasing volumes of inflowing AW will therefore increase the chances for more exotic radiolarians to reach further and further into the Arctic Ocean and the Chukchi Sea.”

Page 16663, line 5-6

This is the other aspect that plays a big role in these findings: mesoscale dynamics (i.e., warm-core eddies). If a certain water mass/sediment trap study is "lucky" to happen to sample waters at exactly a location/time affected by the passage of a few of them, then suddenly a lot of these warm water species are picked up and reported.

While it is a viable mechanism (and probably a right interpretation in terms of a warming Arctic... in terms of higher frequency of warm-core eddies being shedded northwards and making it into the Arctic), it still contains a big sampling bias.

In this case surface sediments would help a lot to assess the long-term trends (and the significance and relative abundance of such faunas), as even the topmost cm or so would integrate decades/centuries.

If anything, they may risk to integrate too long a time period, sort of "diluting" the recent signal/trends (if any).

Any place in the Arctic with a sediment drift allowing sub-centennial resolution in the topmost few centimeters? Probably such a sedimentary archive does not exist...

The pulsating inflow of warm water is important, and as you mentioned above, these events also happened in the past is difficult to prove as there is no sediment cores that can pick up these signals that only have a very limited distribution in time. Areas with such high sedimentation rate probably do not exist!

We regard this as a discussion between you and us and should not be commented on in our text.

Page 16664, line 10

distribution? abundances?

Thanks for your comment.

We added “distribution”.

Page 16664, line 11

Is the Iceland Sea a marginal sea?!?!?!

The Iceland Sea is according to my understanding partly covered with winter ice and the East Greenland Current (water from the Arctic Ocean) is passing on its western side. We regard this sea as a marginal sea to the Arctic Ocean. We still want to say YES, it is a marginal sea.

Page 16666, line 2

Do you really mean "under" here or "lower"?

Thanks for your comment. We really mean “lower”.

Page 16667, line 1

You do not elaborate much at all about the biological pump, so why mention it at different places in the text?!?!?!
I can see how it belongs in the next section, when you start talking about Watanabe's mesoscale-resolving ocean modelling, but till this point in the text, its association to radiolarians is very vague...

Thanks for your comment. We mention the biological pump in the next chapter.
We replaced "biological pump system" with "ecological conditions".

Page 16667, line 18
disturbance? passage?

Thanks for your comment.
We added "passage" to the text.

Page 16668, line 10
availability of?
This is a rather vague statement, without other data/discussion to back it up.

Thanks for your comment.
We replace "reflect the food supply" with "reflect the availability of food supply".

Page 16668, line 10-11
You just mentioned this exact group of species as spread between "wide vertical distribution" and "intermediate to deep", and all of a sudden they become "deep"
We revised the text as follows:

"Flux of deep water dwellers (*Pseudodictyophimus g. gracilipes*, *P. plathycephalus*, Plagiacanthidae gen. et sp. indet., *Cycladophora davisiana*)"
was changed to
"The flux of *Pseudodictyophimus g. gracilipes*, *P. plathycephalus*, Plagiacanthidae gen. et sp. in det. and *Cycladophora davisiana*"

Page 16668, line 13-15
I will mention this here, but similar examples occur at other spots in the text (essentially ALL your conclusions/hypotheses trying to link radiolarian abundances/flux and feeding habits):
I do realise that you use mitigating words as "maybe", "probably", "suggest", etc, but these hypotheses are not based on anything factual, not a shred of data, and remain highly controversial.
Just because a few deep-living radiolarian species increase in abundance, it does not necessarily mean that organic matter export to depth increases (and so on, and so on). It's just a conjecture, maybe not even an hypothesis.
If you had measurements of organic matter at various levels in the water column, and through time, and you would see some correlation to species abundance, you might have been able to formulate such an hypothesis.
Even then, as you surely know, correlation is not causality, and such a coincidence between organic matter and species data would not prove the hypothesis.

Thanks for your comments.
We revised the text as follows:

“This probably indicates that decomposing material from the primary production during the sea-ice free season was transported to great depths, giving nutrition to the deep water radiolarian fauna.”

was changed to

“This probably indicates that decomposing material from the primary production during the sea-ice free season was transported to great depths and might also act as a substrate for bacterial growth, providing the deep water radiolarians with sufficient food elements. We have no data to support this but in the Chukchi Sea, moderately high rates of bacterial production at the end of the growing season (July-August) have been found (Cota et al., 1996; Wheeler et al., 1996; Rich et al., 1997).”

and added three references as follows:

Cota, G. F., Pomeroy, L. R., Harrison, W. G., Jones, E. P., Peters, F., Sheldon Jr, W. M., and Weingartner, T. R.: Nutrients, primary production and microbial heterotrophy in the southeastern Chukchi Sea: Arctic summer nutrient depletion and heterotrophy, Mar. Ecol. Prog. Ser., 135, 247-258, 1996.

Rich, J., Gosselin, M., Sherr, E., Sherr, B., & Kirchman, D. L.: High bacterial production, uptake and concentrations of dissolved organic matter in the Central Arctic Ocean, Deep-Sea Res. Pt. II, 44, 1645-1663, 1997.

Wheeler, P. A., Gosselin, M., Sherr, E., Thibault, D., Kirchman, D. L., Benner, R., Whitledge T. E.: Active cycling of organic carbon in the central Arctic Ocean, Nature, 380, 697-699, 1996.

Page 16668, line 18-19

I don't understand what you mean here

We revised the text as follows:

“In addition, the flux peak during March in 2011 was made up of more than 80% of *A. setosa*, which were surface water species although the peaks around the same period were not found in the upper trap. Therefore, the flux peaks during March in 2011 would be derived from some lateral advection at a depth lower than 180 m or a re-suspension of shelf bottom materials into the upper water column.”

was changed to

“In addition, in the lower trap the flux peak during March in 2011 was made up of more than 80% of *A. setosa*, a definite surface water species. However, during this period a similar peak was not found in the upper trap. Therefore, the flux peaks during March 2011 could be derived from some lateral advection at a depth lower than 180m or a re-suspension of shelf sediments.”

Page 16669, line 3

We inserted the text below.

We similarly thankful to G. Cortese for his detailed comments and correcting our English, this greatly improved our manuscript.

Page 16691, Figure 8

Maybe include references (and location) for each of the other studies?
Example: AB (xxxx Sea, Xxxx et al., 2012), SA (xxxx Sea, Xxxx et al., 2013), etc

We revised the text as follows:
"Fig. 8. Box plot of total radiolarian fluxes at Station NAP and previous studied areas in the North Pacific Ocean."
was changed to
"Fig. 8. Box plot of total radiolarian fluxes at Station NAP and previous studied areas in the North Pacific Ocean (Okazaki et al., 2003, 2005; Ikenoue et al., 2010, 2012a). Summary information of previous sediment trap studies in the North Pacific Ocean is shown in table S5."

Page 16681, Table 3
We replaced "*Tripodiscium gephyristes*, Hülsemann (1963)" with "*Tripodiscium (Tholospyris) gephyristes*, Hülsemann (1963)". It will be of great help for the reader.

Technical corrections:

Thanks for your suggestions.
We accepted all technical corrections from you.

Author's response to reviewer #2
We are grateful to your comments and useful suggestions that improved our manuscript greatly. As described below, we have revised our manuscript. Please note that the expression in blue colored letters are the ones provided by you whereas those in black are our replies.

Summary of reviewer's comment
This paper is the key paper to understand the marine siliceous-test bearing Rhizaria in the Arctic Ocean. The result is so interesting that potential readers to Biogeoscience will recognized the value of this manuscript. However, it is unfortunate that this manuscripts have many problems: (i) this manuscript has forgotten citing many important references in the Arctic polycystines; (ii) some terminologies are not precise more or less; (iii) discussion includes many unscientific opinions; and (iv) some points leave scope for misunderstanding as an act of injustice. Although I am positive to be published, these four points must be revised for acceptance. I will make comments and suggestions to help the authors accept this manuscript.

Summary of the comments
(i) Insufficient citation of the previous publications
Although the papers regarding on the Arctic polycystines are a few, several important papers are massing. Bernstein (1931, 1932, 1934) and Meunier (1910) are very informative for your study. Dolan et al. (2014) is of particular importance. Dolan et al. (2014) studied the surface water plankton samples from summer 2011 and 2012 in the Chukchi Sea and this paper noted the abundance of radiolarians (*Amphimelissa setosa*) is quite low in 2012, compared with 2011. **You must refer this paper and discuss something in your manuscript because the studied period is overlapped each other.**
Kosobokova et al. (2002) is also much related with your manuscript.

Bernstein 1931 is listing from the Kara Sea: Two Acantharia species, *Amphimelissa setosa, Dictyophimus clevei, Dictyophimus* sp. *Plectacantha oikiskos*? and *Sticholonche* sp. This does not give us very much information. No quantitative data.

Bernstein 1932 is listing is making comments on: *Amphimelissa setosa*, *Plectacantha oikiskos, Dictyophimus gracilipes (clevei* is rejected herin), *Dictyophimus tetracanthus* (but not identified properly), *Doralapsis heteropora* (Acantharia), *Sticholonche zanglea.* This does not give us very much information. No quantitative data.

Bernstein 1934 is listing two Ancantharia species, *Plectacantha oikiskos, Phormacantha hystrix, Dictyophimus gracilipes, Dictyophimus multispinus, Amphimelissa setosa, Actinomma leptodermum, Sticholonche zanglea.* Still no quantitative data, and not very much information.

Bernstein's three papers does not report on anything important rather than abundant Acantharia and Taxopodia (*Sticholonche zanglea*).

We refer to Bjørklund and Kruglikova (2003) and they refer to Bernstein (1931, 1932, 1934) so we perfectly well know about this literature. However, Bernstain is not a radiolarian specialist and with all the stations and material she has studied, and only listing a handful (VERY FEW) of species and in most cases only finding VERY FEW individuals, it is obvious that her species list, is not optimal, nor is her material. The only significant information is her 1932 discussion of *D. gracilipes* and her new *D. multispinus* (in 1934). This is also a fact we are reporting on in Bjørklund and Kruglikova (2003) and Bjørklund et al. (2013), as well as in our present MS with many morphological variations of *Dictyophimus*. We do not yet know what this variation means.

Meunier (1910) does not give us any significant information except a short note on two new species: *Amphimelissa stenostoma* and *Sticholonche ventricosa*. No quantitative data and not very much information to use.

The three Bernstein papers and the one by Meunier have been added to our text, but no information of any significance can be extracted from these papers. We have not used the *A. stenostoma* concept as there are transitional forms in addition to the forms with round versus reticulate pores as discussed by Bjørklund and Swanberg 1987. Meunier mention that his *A.* (*Bortyostrobus*) *setosa* is approximately similar to Jørgensen fig 83 on plate XVI. There is not at all any similarity as the species Meunier refer to is *Lithomelissa setosa*. *Amphimelissa setosa* is on the other hand illustrated on pl XVIII fig 109 a-b. So this Meunier paper is not very helpful or informative for our study. However, they have now been included. Thanks for reviewer.

We inserted the following text in page 16649 between lines 21 and 22:
"Bernstein (1931, 1932, 1934) reported on six Polycystina, two Acantharia and two Taxopodia species, but did not give any information on abundance in the Barents Sea and Kara Sea for the Polycystina, but for the Acantharia and Taxopodia she reported them to be abundant, with a maximum occurrence in the deeper and warmer Atlantic water. Meunier (1910) also reported on Acantharia,Taxopodia and Nassellaria in the Kara Sea and the Arctic Ocean, but he stated (page 196) that his material was not rich in radiolarians."

Dolan et al. (2014).
Thanks for your good recommendation.
Please see our response to your comment 5-10, 5-12, 5-23, 5-27.

Kosobokova et al. (2002)
Please see our response to your comment 1-2.

(ii) Some terminologies are not precise more or less
(ii)-a "Radiolaria
As the authors said, the term "Radiolaria" is problematic. The author used the term "radiolaria" which includes Phaeodaria (p. 16652, Lines 1- 3: To avoid complications…", but this treatment has no scientific reason. Rather than, this still makes confusions to readers.
"Radiolaria" include not only polycystines but also Acantharia and Taxopodia. Furthermore, the term "Radiolaria" traditionally include the cercozoan Phaeodaria, or had been simply equal to Phaeodaria or Collodaria, in regardless of taxonomic long distance from polycystine. The different concept of Radiolaria for plankton studies has lead serious confusion among them, but polycystine, Acantharia, Taxopodia, and Phaeodaria MUST BE CLEARLY separated each since they have quite different ecology. **This clarification is important to your manuscript.** Bernstein (1931) reported abundant taxopods from 200–355 m water depths at Station 28 (75º24'30"N, 63 º59'E) and abundant acantharians from almost all the stations examined by Bernstein. As early as 1900's, Meunier (1910) also reported Acantharia and Taxopodia in the Kara and Barents Sea.

Thus, I strongly recommend to you that you MUST use **"radiolarian polycystines and phaeodarians", "Polycystina and Phaeodaria", or "marine siliceous Rhizaria"** See Suzuki & Aita (2011).

What the reviewer is suggesting does not look very good in our eyes:
1) "radiolarian polycystines and phaeodarians" If anything: polycystine radiolarians and phaeodarians
2) "Polycystina and Phaeodaria" Suzuki & Aita (2011) reject Polycystina as a taxon name.
3) "marine siliceous Rhizaria" Can be used like this: marine siliceous Rhizaria (Spumellaria, Nassellaria and Phaeodaraia)

Thanks for your comment.
According to your comment, we refer to Suzuki and Aita (2011) and inserted the following text in page 16649 between lines 4 and 5 (1 Introduction):

"In our study we have analyzed only the siliceous forms of class Rhizaria and herein we have used the definition of Radiolaria as defined by Suzuki and Aita (2011). In their taxonomic scheme they include the following orders: Collodaria, Nassellaria, Spumellaria, Acantharia and Taxopodia. In addition we do include order Entactinaria which Suzuki and Aita (2011) reported getting extinct during the Permian, but Bjørklund et al. (2008) demonstrated its presence also in recent plankton and sediment samples. In this study we have excluded order Acantharia as they have a skeleton of $SrSO_4$ and Collodaria, a group that normally do not possess a skeleton or only with loose spines. Therefore, our study only includes forms with a solid skeleton of SiO_2. In this paper we have chosen to include data also on order Phaeodaria which have not been assigned to Radiolaria but to Cercozoa in recent studies using molecular biology (Cavalier-Smith and Chao, 2003; Nikolaev et al., 2004; Adl et al., 2005; Yuasa et al., 2005). To make the text read well we therefore use Radiolaria, or radiolarians when appropriate, to also include Phaeodaria, this to make it possible for us to compare already published data from the north Pacific region (Okazaki et al., 2003, 2005; Ikenoue et al., 2010, 2012a)."

With this change, we revised table 3 as follows:
We added "Rhizaria, Cavalier-Smith (2002)", "Cercozoa, Cavalier-Smith (1998); emend. Adl et al. (2005)" , and the column of taxonomic rank to table 3.

(ii)-b living radiolarians and dead radiolarians
This manuscript regarded the cells stained with Rose-Bengal as "living radiolarians", but it is not precise. As Rose Bengal simply stains the cytoplasm of cells, the dead cell which still keeps unconsumed cytoplasm can be dyed red as well. In particular, the cytoplasm of dead cells may not dissolve in water columns because of very cool Artic sea waters. Thus, you need to separate "living cells" from "dead cells with cytoplasm." **However, it is practically difficult to do such things**, you need to add some careful implications throughout the text. In an opposite manner, some living cells cannot be stained with Rose Bengal. What did you treat these cases in your manu? **For added explanations, please refer to p. 262 of Okazaki et al. (2004). He carefully wrote as "stained specimens were counted as ''Live'', and empty skeletons were counted as ''Dead''. We determined that specimens were ''Live'' if their protoplasm stained clearly, to avoid false staining by other organisms." Please do not copy and paste this sentence.**

Thanks for your comment.
The siliceous shells can easily be colored red by the bacteria, but then it is the bacteria that have been colored, not the siliceous shells.
According to your comment, we changed the sentence in page 16652, line 4-5 as follows:

"We determined that specimens were "living", if their protoplasm was stained clearly, this to avoid false staining by other organisms such as bacterial growth)."
was changed to
"Plankton tow samples were stained with Rose-Bengal to discriminate between living and dead specimens. Specimens that clearly stained bright red were interpreted as living cells, while cells that did not stain red, or just barely indicated a red shine, were interpreted as dead because of the lacking protoplasm. This is also in accordance to Okazaki et al. (2004)."

(ii)-c adult and juvenile
You applied these terms for *Amphimelissa setosa* and Actinommidae for example. What kind of morphotypes was called as "adult" and "juvenile"? **You should define it anywhere in the manuscript.**
According to your comment, we inserted the following text in page 16656, lines between 6 and 7:
"We defined the 2-shelled forms of Actinommidae as juvenile. Then the 3 and 4 shelled forms will be adult. For the *Amphimelissa setosa* we defined those with cephalis only as juveniles. Those with a well developed cephalis and with a barely or well developed thorax are defined as adult."

(ii)-d comparative terms
The authors repeatedly used "warmer", "colder" and other comparative terms. But, the authors should concerns what kind of images will bring such comparative terms by Biogenscience readers. For example, you wrote "a warm Atlantic species" in the abstract, but this species live in the seawater of **0.5 to 4 ºC** according to previous studies. Although this is apparently warmer in the Arctic, but it will be very difficult to figure out without knowledge to the potential authors.

Thanks for your comment.
According to previous studies *C. histricosus* in the Norwegian fjords do live in much higher temperatures. We do not have data here but we will be surprised if this species is not living in the upper water layers of Sognefjorden in temperatures up to 7 ºC and probably higher. But this we cannot confirm now.

This is a comment we do not agree in. The warm water species you refer to is *C. histricosus* and this is normally a "warm water species" compared to other species living in the Arctic Ocean. However, the only real "cold water" species we have is *A. setosa*, all the other Arctic Ocean species (except *A. turidae* and *A. georgii* and some other forms) are also basically found in the Norwegian Sea and should therefore also be "warm water" species. Therefore, somewhere in our text we could state something like: As also reported by Itaki et al. (2003) we support the idea that *C. histricosus* is a new intruder in the PWW- water in the Chukchi Sea area.
Please also see our response to your comment 0-2, 5-11, 5-13, 5-19.

(iii) Discussion includes many unscientific opinions

When I carefully read the manuscript, I found may the intentions with ambiguous evidences, inappropriate reasons, and mistakes with insufficient review of the already published papers throughout the manuscript. Although I welcome attractive hypothesis and presumptions, I cannot connive the logically unsupported intentions.

(iii)-a the fear of artificial high diversity and endemism in the Arctic Ocean **As much is known to biologists and taxonomists, the diversity is significantly and artificially controlled by different taxonomic concepts. The artificial endemism is also created depended on the published years of new taxa.** Although you intention about the high diversity and strong endemism in the Arctic Ocean might be true, I have nothing to say that you manuscript is inevitably affected with your discussion. First of all, all the specialists with the exception of your group identified the adult Actinomma as only two species (Actinomma boreale group and Actinomma leptodermum group, rarely Actinomma leptodermum longispinum). They generally add the word "group" so that their identification gets together variable morphotypes of Actinomma. On the other hand, you group separated these 2 species into 7 taxa (Act. boreale, Act. geogeri, Act. l. leptodermum, Act. l. longispinum, Act. trudidae, Actinomma sp. morphotype A, and Actinomma sp. morphotype B). Published years of new taxa is apparently effected to your discussion. Act. geogeri and Act. turgidae were described in Kruglikova et al. (2009), and the new genus Joergensenium was described in Bjørklund et al. (2008). As the authors also well recognize, **there are many un-illustrated undescribed species to Actinomma and Joergensenium in the North Pacific.** Under such circumstances, nobody say whether your opinion in the higher diversity and endemism is correct or not. At least, the absence of Joergensenium in the North Pacific is apparently wrong. **You should add the comment as "Our opinion is, however, needed to be tested with re-examination of Actinomma-specimens in the North Pacific and is also awaited to describe Joergensenium species in other regions."**

Dear reviewer, we hope you are aware that Dr. Kruglikova has been working with radiolarians in the North Pacific since the 1960's. Can we then assume that she more or less do know the radiolarian fauna in this area? Can we assume that she has enough material from several stations in the North Pacific? When she published on *A. georgii* and *A. turidae* (to mention only these two) she stated in the description that these two species had not been observed outside the Arctic Ocean. They are not so far observed in the Norwegian Sea proper, but *A. turidae* is found in the Cleve plankton material but in tows from ca 2600-0m, probably in the deep part, as it was not found in Cleve's shallow hauls. Nowhere in the World Ocean do we have a concentration of Actinommidae as high as in the deep polar basins, 70-90%. Nowhere do we have such a high variability in the skeletal shapes and forms as in the Arctic Ocean. This has been stated in Bjørklund and Kruglikova (2003) paper and is further expressed herein. The forms *Actinomma* sp. morphotype A, and *Actinomma* sp. morphotype B are both found in the Chukchi Sea material only, not in the material the lead author worked up from the North Pacific and the southern Bering Sea. In other words they are by us, in the material we have available, only found in the Arctic Ocean proper, and that is why we define them as endemic to the Arctic Ocean.

The reviewer say: At least, the absence of Joergensenium in the North Pacific is apparently wrong.

As far as we can understand we have in our MS never stated that Joergensenium does not exist in the North Pacific, but we state that *Joergensenium* sp A and *Joergensenium* sp. B (not described yet but in progress) is only found in the Arctic Ocean. The lead author has **not** observed this species in his sediment trap material from the North Pacific and southern Bering Sea. Also we see some other *rare* (very few) forms of *Joergensenium* in our material, also supportive to our statement that there is a big variability among the actinommids, and similarly also among the entactinarians, in the Arctic Ocean.

(iii)-b the origin of the Arctic polycystine species
It is interesting because the people who studied the North Atlantic tends to say the origin from the North Atlantic (Petrushevskaya, 1979; Kruglikova, 1999) while those who studied the North Pacific said the North Pacific origin to the Arctic species (Motoyama, 1997, Mar Micropal, 30, p. 45–63 ; Matul & Abelmann, 2005). However, you only cited the papers in the North Atlantic origin. You discarded the North Pacific origin hypothesis by the absence of *Stylochlamydium venustum* (in Atlas of Boltovskoy et al 2010, this species is listed at 3 stations with 1-3% in plankton above 150m. We regard this a shallow.) and *Ceratocyrtis borealis* (in Atlas of Boltovskoy et al 2010, this species is listed at 5 stations with 5-10% in plankton above 150m, we regard this a shallow.) in the Arctic, but this is not a good reason because these two species are deep-water species (they are not) which cannot pass through the shallow Bering Strait. The origin of the Arctic species should be discussed with the shallow-water species which potentially can pass through the Bering Strait. In addition, each species can be derived from the North Atlantic or the North Pacific, or the both. **As your paper does not focus on the origin of the Arctic species, unconcluded opinions are better not to be used in your manuscript as much as possible.**

We are saying that the present day Arctic Ocean radiolarian fauna was introduced after the last Glaciation, or very early in the Holocene (Kruglikova et al 2009). We are of the opinion that very few radiolarian elements are at present being introduced to the Arctic Ocean from the Pacific. To our knowledge we have no Pacific radiolarian species in the Chukchi Sea fauna that has established a local population.
If you as a reviewer tell us that the two above species are "deep water dwellers", then we have different opinions on what deep water really is. To us plankton collected at depth shallower than 150 m represent shallow water. When one species occur with >10% above 150m, then we tend to believe that this is good enough evidence for a very limited RECENT transport of Pacific polycystins into the Arctic Ocean via the Bering Strait. Your reference to Matul and Abelman (2005) (*Amphimelisa setosa*) is definitely a shallow water species, but its migration is not a recent event.

(iii)-c Presumptions about food preferences to each taxa
The authors tried to determine food preferences of your concerned polycystine taxa. I can agree about "ice-algae" and other ice-organisms in ice as a source of food to the polycystines, but the author should take care on the point that it does not directly imply phytoplankton feeder or the abundance of the polycystines is controlled by the abundance of phytoplankton. The ice-organisms in ice are the importance source of organic matter in principal. If you want to insist on your herbivorous hypothesis, two kinds of data are essential: (i) The seasonal change of chlorophyll a and (ii) the sediment trap data where your concerned polycystines increase and decrease. Without these data, imprudent imagine should not be said, avoiding from unscientific confusion.

According to your comment, we revised our manuscript.
Please see our response to your comment 5-12, 5-14, 5-15, 5-23, 5-25.

(iv) Some points leave scope for misunderstanding as an act of injustice
(iv)-a Title

I believe you did it by accident, the title of your manuscript is very similar to that of Dolan et al. (2014). Dolan et al. (2014) published the Arctic radiolarians and tintinnids entitled "Microzooplankton in a warm Arctic: a comparison of tintinnids and radiolarians from summer 2011 and 2012 in the Chukuchi Sea" (Acta Protozoologica, 53: 101 – 113). In consideration with Dolan (2014), **the word "microzooplankton" in your title is too general than your objects. Thus, the term "microzooplankton" must be deleted from the title at least.**
One of substitute titles is "Flux variations and vertical distributions of **Polycystina and Phaeodaria (marine siliceous Rhizaria)** in the western Arctic Ocean: environmental indices in a warming Arctic." Please consider it.

According to your comment, we changed the title as follows:
Our current title: Flux variations and vertical distributions of microzooplankton (Radiolaria) in the western Arctic Ocean: environmental indices in a warming Arctic
was changed to
New title: "Flux variations and vertical distributions of siliceous Rhizaria (Radiolaria and Phaeodaria) in the western Arctic Ocean: indices of environmental changes"

Please also see our response to your summary comment (ii)-a Radiolaria.
.

(iv)-b Insufficient citation
I was also much surprised but the nearly identical important sentence and interpretations have been already clearly written in previous paper (Itaki et al., 2003). Itaki et al. (2003, p. 1519, Right column, Lines 23 – 25) wrote "No information on C. historicosa was reported from many plankton samples **from the Canadian Basin in the 1950s and 1960s (Hülsemann, 1963; Tibbs, 1967)**". On the other hand, you wrote on p.1662, Lines 21–22 as "This species has not been observed in **the Canadian Basin during the 1950s and 1960s (Hülsemann, 1963; Tibbs, 1967)**". **So, the priority of this notice has Itaki et al (2003) but not you.** This is unallowable because this mention brought the distinguishing discussion in your manuscript. **It is better for the authors to check such mistakes throughout the manuscript.**

Thanks for your comment.
This can be fixed by adding a reference after our statement. We had no intention to take this as our observation as that was Itaki. Please see our response to comment 5-16.

Reviewer's suggestion

Detailed comments
0. Title and abstract
Comment 0-1. Title
Avoiding from unexpected doubt, I suggest a substitute tile such as **"Flux variations and vertical distributions of Polycystina and Phaeodaria (marine siliceous Rhizaria) in the western Arctic Ocean: environmental indices in a warming Arctic"**

Thanks for your suggestion.
Please see our response to your summary comment (iv)-a Title above.

Comment 0-2. Abstract

The sentences about *Ceratocyrtis histricosus* will bring a misunderstanding to readers. The authors said "**a warm Atlantic water species**", but this mention is wrong. First of all, this species favors on the seawater of **0.5ºC to 4ºC** (Itaki et al., 2003). Can you say "a warm" species, cannot you? The second point is "Atlantic water species."

Thanks for your comment.
We deleted the text about *Ceratocyrtis histricosus* in Abstract but we discussed this species in section 5.3.3 Upper AW association.
Please see our comment below and also see our response to your comment 5-16, 5-17, 5-18, 5-19, 5-20.

The reviewer must know that the intention with our text is to say that this species is originating from the Norwegian Sea and has been transported by the "warm Atlantic water". Therefore its presence in the Chukchi Sea (0.5ºC to 4ºC) is not the temperature, which this species favors, but it has adapted to this temperature in the Chukchi Sea. In the Norwegian coastal water where the temperature at summer is significantly warmer and in the fjords, where it is even warmer, this species is present in low numbers at temperatures up to at least 7ºC (Swanberg and Bjørklund 1987), and may be even higher.

According to Takahashi & Honjo (1981), these species was trapped in the 988 and 3755 m water depths in **the equatorial Atlantic Ocean**.

Please look on his plate. This is not the real *C. histricosus*. as defined by Jørgensen.

Thus, this species is **NOT a warm species**.
1st. This is not *C. histricosus*.
2nd.You refer to traps at 988 and 3755 m. What does a trap do? We thought it collected material from the depth above each sampling depth (from 988m to 0m and from 3755m to 0m). By this technique you have no information from where the bugs in the traps do originate from. They may all come from the photic zone or greater depths, we do not know from which depth the collected material lived at.

This species is a **cosmopolitan species,** including the southern oceans. Please see the distribution map of occurrence data shown below. Thus, this is **NOT an Atlantic species.**

Yes the reviewer is correct, this is probably a cosmopolitan species. What we really mean when we say an "Atlatic water species" is that this species is being introduced to the Arctic Ocean through the Fram Strait, and that it is a member of the Norwegian Sea *C. histricosus* population that has been transported northwards by the Atlantic warm water (Gulf Current). We should try to restructure our statements on this.
It is correct as the reviewer #2 state that *C. histricosus* is not only an Atlantic species, but it is still a question for the Arctic Ocean *C. cistricosus* population, from where did they come?

I briefly listed the occurrence points of this species as well.
I made an occurrence list of this species as below.
[North Pacific]
plankton from Vityaz' St. 3518 (27° 12' 3" N - 138° 17' 8" E) by Petrushevskaya (1971a).
surface sediments from China Station (30º30'N, 123ºE, the year of 1959) by Tan & Tchang (1976)

Based on the line drawings this is similar to the *C. histricosus* as defined by Jørgensen but we are not 100% sure.

sediments from Stations VS-R-115a, -116b, and -60a by Benson (1983)

Our co-author worked with Benson when he entered his data into Radiolaria.org. They settled on *C. histricosus* but it was different from the original form, but concluded to use this name.

surface sediments from Sample NPNT 17-1 (33° 45' 0" N - 138° 0' 0" E), by Nishimura & Yamauchi (1984a)

This time Nishimura is as far away from *C. histricosus* as it is possible to come (if you refer to her pl. 24 fig 9). This is not even close to the real form and has nothing to do with *Helotholus histricosus* Jørgensen.

[equatorial Pacific]
plankton from RIS St. 52 (14° 1' 0" S - 131° 26' 0" W) by Petrushevskaya (1971a)

Petrushevskaya do know the Norwegian Sea fauna and her identification is probably correct.

Core RC12-66 (2° 37' 0" N - 148° 13' 0" W) by Nigrini & Lombari (1984)
[Okhotsk]

Specimen on Pl 15 fig 6 does look like *C. histricosus* but it is broken and very doubtful. We are not at all convinced on this identification.

surface sediments from Vityaz' St. 6691 by Kruglikova (1975)
[Indian Ocean]

DSDP 27-262-3 (10° 52' 11.4" S - 123° 50' 46.8" E) by Kling (1977)

On Kling's plate 1, fig 6 another not complete and well preserved specimen is illustrated. Cephalis and upper part of thorax should be furnished with needle shaped spines, none can be seen. This specimen has only the outline of *C. histricosa*, not the characteristic spines. We would not take this identification for granted.

[equatorial Atlantic]
sediment trap at the PARFLUX Mark II, Station E (13° 32' 12" N - 54° 6' 0" W), by Takahashi & Honjo (1981).

What is shown in their plate 7 figs 5-7 is not *Helotholus histricosus* as defned by Jørgensen. What is illustrated here is not even close to the real Norwegian Sea and fjord forms, which we know very well. See Dolven et al 2013 where the Jørgensen type collection is discussed and the real *C. histricosus* specimens are illustrated.

1. Introduction

Comment 1-1. p. 16648. Line 15: Particle flux play important roles in the carbon export.
As your manuscript treated not only polycystines but also phaeodarians, **Lampitt et al. (2009) may be cited** if you have no objections and no doubt. If you want to put emphasis on polycystines, this paper is inappropriate for this purpose.

Thanks for your suggestion.
We also treate phaeodarians, but not put emphasis on them, so we don't cite the reference in this study.

Comment 1-2. p. 16648, Line 26-27 Microzooplankton.. a key component of pelagic food webs.
Not only Calbert and Landry (2004). **Kosobokova et al. (2002) is better to be cited** because this paper shows quantitative data of "food" from the gut of a mesopelagic copepods, Spinocalanus antacticus above the Lomosonov Ridge, the Arctic Ocean. This is the practical evidence about your mention.

Thanks for your good recommendation. We added this reference.

Comment 1-3. p. 16649, Lines 18-25.
Should refer **Bernstein (1931, 1932, 1934)**. This paper is of particular important to know the vertical distribution of marine protists before the World War II.
Meunier (1910) may be cited either, because a new taxopod species is described in the Arctic.

Thanks for your suggestions.
We added these four papers as the references.

These papers do not tell us very much as they are all from the eastern part of the Arctic Ocean (Barents and Kara Seas). We do not talk about Taxopodia and also this one is from the eastern part of the Arctic Ocean. What is more important in Meunier (1910) is that Meunier described a new *Amphimelissa* species. However, we have not separated between these two as it is only possible to separate the two in well-developed specimens. *A. setosa* has a lateral flatten cylindrical skeleton, Meunier's new species is inward curved at the terminal end. All the in-between forms cannot be identified properly. We have not used Meunier's species and all forms have been identified as *A. setosa*.

Please see also our response to your summary comment (i).

2. Oceanographic setting

Excellent!

3. Materials and methods

3.1 Plankton tow samples

Comment 3-1. p. 16651, Line 14 CTD
a CTD observation ---> a CTD **(Conductivity Temperature Depth profiler)** observation I know CTD, but readers may not know it.

We agreed with your comment. We changed the text as follows:
"a CTD observation"
was changed to
"a CTD (Conductivity Temperature Depth profiler) cast"

Comment 3-2. p. 16652, Lines 1 – 3. To avoid complications…
The "to avoid complications" is no scientific reason. If you want get them together, you can select "**marine siliceous-test Rhizaria**" In addition, **this manuscript must note that**

"Acantharia and Taxopodia did not examined in this study" anywhere else, because they apparently belong to Radiolaria. If you use the term "marine siliceous Rhizaria", you only note about Taxopodia.

Thanks for your comment.
We deleted the following text:
Phaeodaria have not been recognized as Radiolaria but as Cercozoa in recent studies using molecular biology (Cavalier-Smith and Chao, 2003; Nikolaev et al., 2004; Adl et al., 2005; Yuasa et al., 2005). To avoid complications we dealt with the phaeodarians as one of the radiolarian groups according to the classical taxonomy (Anderson et al., 2002; Takahashi and Anderson, 2002).

And we inserted a revised explanation in page 16649 between lines 4 and 5 (1 Intoroduction):
Please also see our response to your summary comment (ii)-a Radiolaria.

3.4. Taxonomic notes

Comment 3-3. Tripodiscium gephyristes

It is like to use the genus Archibursa (Type species: Archibursa tripodiscus Haeckel, 1887, subsequently designated by Campbell, 1954) rather than Tripodiscium. Just suggestion. **This does not constitute the essential point for acceptance.**

Thanks for your suggestion. However, we retain "Tripodiscium gephyristes" as it is.

4. Results

4.1. Radiolarians collected by plankton tows.

Comment 4-1. No collodarians

MUST comment "No Collodaria have been found" or "We did not concern about skeletonless Collodaria" here. This information also should be added on Section 4.2 "Radiolaria collected by sediment trap" The presence or absence of visible Collodaria has been **a critical issue in the Arctic** since the probable Collodaria were detected in an environmental molecular sequence data in the Arctic (See Lovejoy et al., 2006; Lovejoy & Potvin, 2011). Lovejoy et al. (2006) wrongly cited Collodaria as Spumellarida. Please take care about it. Collodaria always harbor algal symbiont so far as known (Suzuki and Aita, 2011), thus the implication of Collodaria will be focused in near future.

According to your comment, we inserted the following text:

Page 16655 between lines 12 and 13 (section 4-1)
"We have observed taxopodians, but they have not been identified according to the two species as defined by Meunier (1910), nor have they been quantified. Furthermore, we have not been able to observe any collodarian individuals although we cannot exclude their presence in the Arctic Ocean (Lovejoy et al., 2006; Lovejoy & Potvin, 2011)."

Page 16657 between lines 15 and 16 (section4-2)
"We have observed taxopodians, but they have not been identified nor quantified. Furthermore, we have not been able to observe any collodarian individuals."

4.1.1 Standing stock and diversity of radiolaria

Good.

4.1.2 Vertical distribution of radiolarian species and environment

Comment 4–2. p. 16656, Lines 11-12.

You must **show criterion for selected 14 species for Biogeoscience readers**, although I can easily understand your criteria by my experience.

According to your suggestion, we added a following sentence:
"The selected taxa were radiolarian taxa with 1% or higher relative abundance through the upper 1000 m of the water column at either of the two stations and with high relative abundance in each water depth."

4.2.1. Radiolarian flux and diversity in the upper trap

Comment 4-3. p. 16657, Lines 21-22.

Prior to document the numerical total radiolarian flux, the author should explain the **strong distinctive seasonality in the total radiolarian flux at the first**.

According to your comment, we changed the text as follows:
"Total radiolarian flux in the upper trap varied from 114 to 14,677 specimens m^{-2} day^{-1} with an annual mean of 2,823 specimens m^{-2} day^{-1} (Fig. 5). The highest fluxes were observed during the beginning of sea-ice cover season (November in 2010 and 2011, >10,000 specimens m^{-2} day^{-1}). The fluxes were higher during the open water season (August–October in 2011, >5,000 specimens m^{-2} day^{-1}) and around the end of sea-ice cover season (July–August in 2011, >4,000 specimens m^{-2} day^{-1}) than those during the sea-ice cover season (December–June, mostly <800 specimens m^{-2} day^{-1}) ."

was changed to

"The highest total radiolarian fluxes in the upper trap were observed during the beginning of sea-ice cover season (November in 2010 and 2011, >10,000 specimens m^{-2} day^{-1}) (Fig. 5). The fluxes were higher during the open water season (August–October in 2011, >5,000 specimens m^{-2} day^{-1}) and around the end of sea-ice cover season (July–August in 2011, >4,000 specimens m^{-2} day^{-1}) than during the sea-ice cover season (December–June, mostly <800 specimens m^{-2} day^{-1}). The fluxes varied from 114 to 14,677 specimens m^{-2} day^{-1} with an annual mean of 2,823 specimens m^{-2} day^{-1}. "

Comment 4-4 p. 16657 Lines 25 – p. 16658 Line 1.

Should **show the average** of the total radiolarian flux in the intervals of **August-October in 2011 and December-June in 2012,** because you show the annual mean though your sampling intervals on Line 23, page 16657.

According to your comment, we showed the average of the total radiolarian flux as follows:
"(August–October in 2011, > 5000 specimens m^{-2} day^{-1})"

was changed to

"(August–October in 2011, average, 5,710 specimens m^{-2} day^{-1})"

"(December–June, mostly< 800 specimens m^{-2} day^{-1})"

was changed to

"(December–June, average in 2011, 944 specimens m^{-2} day^{-1}; average in 2012, 723 specimens m^{-2} day^{-1})"

4.2.2 Radiolarian flux and diversity in the lower trap

Comment 4-5 p. 16658 Lines 18-19

Should estimate the average of the total radiolarian flux in the intervals of May-September in 2012.

According to your comment, we showed the average of the total radiolarian flux as follows: “(0–80 specimens m^{-2} day^{-1}) during May–September in 2012.”

was changed to

“(average, 21 specimens m^{-2} day^{-1}) during May-September in 2012.”

5. Discussion

5.1 Comparison between Arctic and North Pacific Oceans

Comment 5-1 p. 16659, Line 4. shell-bearing microplankton

Not precise. Lorica-bearing tintinnids show very high diversity and abundance in the Arctic Ocean (see Meunier, 1919, for example). Organic-walled dinoflagellates are also detected from the Artic a well (Lovejoy and Potvin, 2011). **Should write “mineralized skeletal-bearing microplankton.”** How about planktic foraminifers? Some comment will be needed about it for readers, although the abundance of planktic forams has been reported few in many previous papers.

According to your comment, the following text:

”due to the low productivity of shell-bearing microplankton”

was changed to

” due to the low productivity of siliceous and calcareous microplankton”

Comment 5-2 p. 16659 Line 7–9. annual means and Fig. 8

I understand that the annual means are generally shown in these studies, but you need to explain what kind of scientific implication can be shown with the annual means in YOUR DATA. **Although I don’t say to delete the annual means, you must add more reasonable quantitative data, as commented below.** You data show apparent two abundant seasons and two sparse seasons in a year. As long as you discuss the contribution of biogenic particle flux in the section 5.1 of this manuscript, are the sparse seasons needed to be averaged with abundant seasons? How long does the biogenetic opal flux make contributions to the carbon export in water columns or sea-floor? Six months? A week? **You should carefully consider the efficient duration of your concerned opal biogenetic fluxes.**

I strongly recommend you that you must regards only the flux of the direct efficient duration, calculating becomes more complex:

Procedures as follows:

(i) The abundant seasons in your concerned locations are decided. By using parametric statistics, the low values out of 2σ (for example) are regarded as “less contributing duration”.

(ii) The intervals of contributing season (duration) are specified by the procedure (i).

(iii) You calculate the mean in this limited interval. The unit “week” may be better, because the organic carbon of a given opal flux will completely consume with a week.

I imagine this will reveal a significantly large contributions of polycystines and diatoms in the Arctic than any other North Pacific Ocean.

According to your comment, we revised the text as follows:

“The biogenic opal collected in this study mainly consisted of radiolarians and diatoms, therefore siliceous skeletons of radiolarians and diatoms might play important role to export biogenic silica to the deep Arctic. Relatively high flux of radiolarians in arctic microplankton might contribute to substantial part of the POC flux.”

was changed to

“However the radiolarian fluxes in the upper trap showed an apparent abundant season (July-November) and a sparse season (December-June) in a year, and that the lower trap also showed an extremely low flux during May-September 2012. Therefore we regarded the period when radiolarian fluxes were higher than 1σ (3,489: upper trap; 5,675: lower trap) as a contributing period. As a result, the mean of radiolarian fluxes during the contributing period in the western Arctic Ocean showed a higher value (7,344: upper trap; 11,871: lower trap) than at any other stations in the North Pacific Ocean (Table S5). The biogenic opal collected in this study mainly consisted of radiolarians and diatoms based on our microscopic observations. Other siliceous skeletons (silicoflagellate skeletons, siliceous endoskeleton of dinoflagellate genus *Actiniscus*, chrysophyte cysts, ebridian flagellate, and palmales) are minor components in the same trap samples (Onodera et al., 2014), therefore siliceous skeletons of radiolarians and diatoms might play an important role to export biogenic silica to the deep Arctic. Onodera et al. (2014) also estimated the diatom contribution to POC flux at station NAP, but more than half of the contribution to total POC has not been explained yet. Relatively high flux of radiolarians in arctic microplankton might contribute to a substantial part of the POC flux."

5.2 Characteristic and ongoing speciation…

Comment 5-3 p. 16659 Lines 17 – 19 close affinity to the Atlantic fauna

You need data. Must make a compiled species list to the Bering Sea, Arctic Ocean, Norwegian Sea & Denmark Strait, and Baffin Bay & Davis Strait. And then, the number of overlapped species in the Arctic Ocean with the Pacific and North Atlantic oceans will be documented in the manuscript. **The references MUST BE SELECTED from the papers with ILLUSTRATIONS. Please ignore the papers with wrongly identified taxonomic names.**

The papers on the Arctic oceans are also complied for this purpose, because you may find extinct species in the Arctic Ocean, although you must take care wrongly identified specimens as well.

We can see many papers talking about the radiolarian fauna in the Bering Sea (Blueford, 1983 sediment) and in the two trap stations (one in the Bering Sea one in the North Pacific; Ikenoue et al., 2012a):, and most lately the Kruglikova et al. (2013) and Sirenko (2013) with a detailed list also in the North Pacific and Bering Sea. Those lists are quite different from the species lists from the Norwegian, Greenland and Iceland Seas. This list is well known, and maybe we can just refer here to Bjørklund and Kruglikova (2003) and we also think Itaki et al. (2013) refer to the arctic radiolarian fauna to be of an Atlantic affinity.

Blueford, J. R.: Distribution of Quaternary radiolaria in the Navarin Basin geologic province, Bering Sea. *Deep Sea Research Part A. Oceanographic Research Papers*, *30*, 763-781, 1983.

Kruglikova S. B.: Radiolaria-Polycystina from the bottom sediments of the World Ocean as bioindicators of environmental fluctuations. Moscow, GEOS, 2013. ‐ 231 p.

Sirenko, B. I.: Check-list of species of free living invertebrates of the Russian Far Eastern Seas, Zoological Institute RAS, St. Petersburg, 75, 83, 2013.

We have never found any extinct polycystine species in the surface sediments of the Arctic Ocean. However, in the Barents Sea some rare individuals can be found. However, we do not know about any papers reporting on reworked or extinct species or specimens in the Arctic Ocean. How can you find extinct radiolarian species in the Arctic Ocean? If you refer to *A. seosa* this is a species that is still living, and one of the dominant species in the Arctic Ocean. Do you have any examples of extinct radiolarian species in the Arctic Ocean?

It is enough here to refer to other peoples conclusions.
We changed the text as follows
"The radiolarian fauna observed in this study of the western Arctic Ocean was found to have a close affinity to the Atlantic fauna, and the family Cannobotryidae and Actinommidae were dominant in the western Arctic Ocean."
was changed to
"The radiolarian fauna observed in this study was characterized by high dominance of two families, the Cannobotryoidae and the Actinommidae (Fig. 3). *Amphimelissa setosa* is the dominant species, while the actinommids make a species association with a close affinity to the Norwegian Sea fauna. *Amphimelissa setosa* first appeared in the North Pacific and migrated into the North Atlantic through the Arctic Ocean during the Pleistocene interglacial optima (Matul and Abelmann, 2005). This species became extinct in the North Pacific close to the MIS 4/5 boundary (Kruglikova, 1999; Matul et al., 2002; Ikenoue et al., 2011), and has not been observed in recent materials in the North Pacific (Ikenoue et al., 2012a)."

Comment 5-4 p. 16669, Lines 18 – 22. Petrushevskaya (1979).. Bjorklund and Kruglikova (2003)…
This is NOT based on your data. **You must add the discussion BASED ON YOUR DATA.**

No, it is enough here to refer to other peoples conclusions, however we did add a line and refer to our species list in Table 3.
We inserted the following text in page 16659 lines between 22 and 23:
"This is also supported by the species listed in Table 3, they all occur in the Norwegian Sea, except for the taxa that we at present classify as endemic to the Arctic Ocean."

Comment 5-5 p. 16659, Lines 22 – 25. Inflow… from … Pacific… negligible…Stylochlamydium venustum, and Ceratospyris borealis are absent in the western Arctic Ocean.

MUST DELTE THIS SENTENCE AND CHANGE EVIDENCES. This verification is ridiculous. As the deepest point in the Bering Strait is 42 m water depths at the present. Even if the sea level raised in warmer periods than the present such as MIS 5 77-110 ka), MIS 9 (300 – 330 ka), MIS 11 (375-420 ka), and MIS 19, the deeper-water species are primarily unable to intrude into the Arctic Ocean. Stylochlamydium venustum and Ceratospyris borealis lives in the 50–100 m and 100–300 m water depths (Okazaki et al., 2005, p. 2252). Okazaki et al (2005) studied the south of the eastern Aleutian Islands, the most adjacent region to the Bering Sea **but not the Okhotsk**, suggesting that these two species live in similar water depths in the Bering Sea. **Thus, these species have never used to prove the no effect of the North Pacific Waters to the Arctic Ocean, unless you have data these two species live in shallower than 42 m water depths in the BERING SEA!**

We changed the text as follows:
"Inflow of radiolarians with waters from the northern part of the Pacific Ocean is probably negligible since the most abundant and typical radiolarian species in the North Pacific such as *Stylochlamydium venustum*, and *Ceratospyris borealis* are absent in the western Arctic Ocean."
was changed to
"Inflow of radiolarians with waters from the northern part of the Bering Sea is probably negligible since the most abundant and typical radiolarian species in the recent Bering Sea such as *Stylochlamydium venustum*, and *Ceratospyris borealis* are absent in the western

Arctic Ocean. These two species are surface dwellers in the North Pacific (Tanaka and Takahashi, 2008) and are major species in the recent Bering Sea (Ikenoue et al., 2012a)."

Dear reviewer, you are right in one thing, we do not have to state anything about the inflow of radiolarians with water from the northern Pacific. What we are trying to say is that the fauna in the Chuchi Sea and the Pacific part (western part) of the Arctic Ocean is MAINLY recruited by fauna elements originating from the Norwegian Sea in the Early Holocene and now being brought around in the Arctic Ocean by the Gulf Stream, or with other words, Atlantic warm water. There are no RECENT typical Pacific/Bering Sea polycystine species that has established a planktonic population in the Chukchi Sea. You refer to Okazaki et al (2005) Table 6 at p. 2252. Do you really believe that the species listed in the Surface dweller column only live in the 50-0 m zone? Do you similarly exclude the species in the second column (100-50m zone) not to live in the 50-0 m zone? According to your reference to Table 6 *Spongotrochus glacialis* should only live in the 50-0m zone. Is this the case? Hülsemann reportd this species to be common/abundant at great depth in her material from the Arctic Ocean! As you know, we still lack the evidence that Pacific polycystines have established populations in the Chukchi Sea or elsewhere in the Arctic Ocean. All the species we are listing in Table 3 all occure in the Norwegian Sea, except for two, *Cornutella strylophaena* and *Cornutella longiseta*. However, we know that the Norwegian Current entering the Arctic Ocean through the Fram Strait is rather rich in polycystine species. We do not think there is any doubt that the Arctic Ocean polycystines mainly are being recruited from the Norwegian Sea during early Holocene time. The Norwegian Sea fauna is again is being recruited from the North Atlantic.

If you want to say as such, you must show the evidence from the species which live in shallower than 42 m water depths.

We do not know about any paper reporting on living polycystines in the shallow (northeastern) part of the Bering Sea. Also the sediments are barren or at best low in biogenic opal in this part of the Bering Sea. Of the 0.8 Sv of Pacific water flowing into the Arctic Ocean we do not know about any papers reporting on a definitive Pacific polycystine establishment.

Why do you ignore Matul and Abelmann (2005)? This paper said that Amphimelissa setosa appeared in the Sea of Okhotsk, and **crossed the Bering Strait at MIS 5e.**

This means that *A. setosa* cannot be transported today, and it is the present day transport we are discussing.
If you read Matul and Abelman (2005), you will see that they refer to "Bjørklund personal communication" that *A. setosa* was observed in DSDP site at MIS 10 time (40-60% *A. setosa*). At MIS 5e *A. setosa* was already established in the North Atlantic. We still miss data on its first occurrence in the North Atlantic though. So far the Pacific has the oldest recorded occurrence.

This means that Amphimelissa setosa at least is originated from the North Pacific, differing from Petrushevskaya (1979). **This contradiction MUST BE EXPLAINED in your manuscript if you need to say about the origin of the species in your manusript.**

How was the radiolarian fauna in the Arctic Ocean during the last glaciation? No data tell us that the Arctic Ocean was holding a radiolarian population. All cores from the Arctic Ocean show barren of opal, the same is in the Norwegian Sea glacial period. After *A. setosa* had been introduced to the Arctic Ocean from the Pacific, this species was then established on the Atlantic side of the Arctic Ocean. On the onset of Holocene the North Atlantic Radiolarian fauna was first observed in the Norwegian Sea at about 12000 14C yrs BP, *A. setosa* was the dominant species in Norwegian Sea Younger Dryas sediments. At the Glacial/Holocene boundary the fauna changed significantly, drop in *A, setosa* and a jump in new species introduced with the Holocene establishment of the warm trans-Atlantic Current, the Gulf Stream. The first major Fauna shift has been estimated to reach the Fram Strait in early Holocene 9800 14C yrs BP. Many of the species living in the Norwegian Sea and that once in a while is accompanied with fauna following the strong pulses of intruding Atlantic water, does not make it all the way to the most remote places of the Arctic Ocean. Therefore, only a handful of species can adapt to the harsh arctic environments. Those species reaching the Chukchi Sea are essentially all in the Norwegian Sea. The Arctic Ocean radiolarian fauna is today very young in geological terms, and the fauna has adapted accordingly. Actinomma has evolved in a special way and new forms have developed. Not necessary to repeat our endemic species, but as far as we can judge, based on the material we have available from the Arctic Ocean, Nordic Sea, Barents Sea and the North Pacific, Sea of Okhotsk and the Bering Sea, we have not observed our endemic species elsewhere than in the Arctic Ocean.

But you are right we do not need to talk about the origin of the species. At least two of the radiolarian workers on this MS feel it is a way to interpret our data.

Comment 5-6 p. 16659, Lines 25 – p. 16660, Line 11.

The authors insisted that Actinomma morphogroup sp. A, Actinomma morphogroup B, Joergensenium sp. A have not been reported in other areas in the Arctic Ocean, nor in the North Pacific and in the North Atlantic." but this is nonsense. (i) **The genus Joergensenium was described in the year of 2008 (Bjørklund et al., 2008). As far as I know, NO PAPERS regarding on the Arctic radiolarians, except for Dolan et al. (2014), have been published AFTER to 2008.**

Bjørklund et al 2013 published on about 145 species of which ca 95 had a warmer water origin, the rest of a local boreal-arctic origin, of an Atlantic affinity.

We have not seen these forms in our sediment trap materials from the North Pacific and Bering Sea (Ikenoue et al., 2012a).

How to note the existence of this genus and this species in the previously published references?

Dear reviewer, we do NOT talk about analyzing previous papers! We talk about results from analyzing the material that we ourselves have available from the Arctic Ocean, Nordic Seas, Barents Sea, and the North Pacific, Sea of Okhotsk and the Bering Sea, Again, we do not discuss the genus *Joergensenium* but we discuss two very specific forms, *Joergensenium* sp. A and *Joergensenium* sp. B. These two forms HAVE NOT SO FAR, in our material, been observed outside the Chukchi Sea.

It could have been identified as Entactinaria gen. and sp. indet.

In my personal experience, I often saw Joergensenium-specimens in the North Pacific.

Again dear reviewer, what you will call Entactinaria today you earlier probably would classify as one or another kind of Actinommidae. But if you often have seen Jorgensenium-species (Entactinaria) then you have seen something that Suzuki and Aita (2011) got extinct in the Permian(?). So why have you not call these forms for Entactinaria if you have often seen them? As you know, the central part of Actinommida (*Actinomma*) is quite different from Entactinaria (*Joergensenium*).
(ii) The second point is that you must not use taxonomically confused groups for this purpose. Except for the papers with Kjell Bjørklund and his colleagues, almost all the papers use the taxonomic names *Actinomma boreale* group and *Actinomma leptodermum* groups in the North Pacific, and they have never tried to distinguish your Actinomma morphogroup sp. A, Actinomma morphogroup sp. B, Actinomma georgi, and Actinomma turidae. The high diversity of actinommids and Joergensnium has still be owned by the difference on the taxonomic concepts unless someone try to look for them from the North Pacific and North Atlantic actinommids, although your interpretation is presumed to be true.

If so the "*Actinomma boreale* group" is a garbage can and cannot be used for any ecological interpretations, as we do not know the ecology of the different species that is included in this "group". The same for "*Actinomma leptodermum* group" There is almost no morphological criteria that you can point on saying that this specimen is this species or that specimen is that species. The only way of a safe separation is via lots of hard work analyzing pictures and making statistical measurements on a whole set of specimens in a sample. All the species in the "*Actinomma boreale* group" and the "*Actinomma leptodermum* group" will make bad paleoecological reconstructions. What about *Actinomma boreale/leptodermum* group in the Norwegian Sea? What kind of ecological resolution do you get by grouping like this? When splitting in Adult A. boreale and *A. leptodermum leptodermum* you will see that in the Norwegian Sea the latter has its main population in colder water than the *A. boreale* population. What is included in the north Pacific "*Actinomma boreale* group" and the "*Actinomma leptodermum* group" is not known, but probably they are different from the real forms in the Nordic Sea, the home area from where they were described.

In the North Pacific you will never be able to find these four *Actinomma* species as they are, in our opinion, endemic to the Arctic Ocean. We have looked in relevant material and have not found them.

We changed the title of section 5.2 as follows:
"*5.2. Characteristic and ongoing speciation of radiolarians in the western Arctic Ocean"*
was changed to
"*5.2. Characteristic and ongoing morphogenesis and speciation of radiolarians in the western Arctic Ocean"*
We changed the text as follows:
"In our results the radiolarian fauna in the western Arctic Ocean were characterized by a wide diversity of the family Actinommidae and high standing stock of *Joergensenium* sp. A in the PWW (Table S6). *Actinomma* morphogroup A (58 specimens), *Actinomma* morphogroup B (57 specimens), *Joergensenium* sp. A (1401 specimens) observed in the western Arctic Ocean in our study have not been reported in other areas in the Arctic Ocean, nor in the North Pacific and in the North Atlantic. Although we could not conclude yet, *Actinomma* morphogroup A and B and *Joergensenium* sp. A might be new species endemic for the western Arctic. Kruglikova et al. (2009) described two new species *Actinomma georgii* and *A. turidae*, and suggested the endemism hypotheses for these two species as a result that radiolarians had been rapidly evolving under the stressful conditions in the Arctic Ocean and

that the central Arctic Basin might be the center of an ongoing speciation within the family Actinommidae."
was changed to
"Our results suggest that the radiolarian fauna in the western Arctic Ocean was characterized by a wide morphologic variability in the skeletons within the family Actinommidae and high standing stock of *Joergensenium* sp. A in the PWW (Table S6). *Actinomma* morphogroup A (58 specimens), *Actinomma* morphogroup B (57 specimens), *Joergensenium* sp. A (1,401 specimens), has so far only been observed in the western Arctic Ocean in our study. We have not seen this species outside the Arctic Ocean, neither in the North Pacific or in the North Atlantic. *Actinomma* morphogroup A and B and *Joergensenium* sp. A might be new species endemic for the western Arctic. Kruglikova et al. (2009) described two new species *Actinomma georgii* and *A. turidae*, and suggested the possibility of endemism for these two species. They also indicated a fifth group *Actinomma* indet. (their fig. 5, p. 32) which probably consists of still several undescribed species. Their argument was that the endemism arose as radiolarians had been rapidly evolving under the stressful conditions in the Arctic Ocean, and that speciation or morphogenesis within the family Actinommidae might be ongoing in the central Arctic Basin."

Comment 5-7 p. 16660, Lines 11 – 13. Our result might support this hypothesis…
Why? How? You need explanation, in consideration with my comment shown above.

This was no problem for reviewer #1, and obvious not for us either. The many morphological forms and shapes in *Actinomma* and may be in *Joergensenium* too, in the Arctic Ocean, is a result of the stressed ecological conditions. This is not explained but discussed in Kruglikova et al. (2009).
In our present paper we write, and we do not think we can say very much more at present: "The reason for radiolarian species speciation in this area is still not understood but we can only speculate that this can be controlled by the harsh environmental stress (Allen and Gilooly, 2006; Kruglikova et al., 2009), particularly the extremely cold water masses under the sea-ice (−1.7°C) and the always-changing quality of the water masses, affected by the inflowing Pacific water."

Comment 5-8 p. 16660, Lines 15 – 16. Joergensenium .. undescribed species…
What do you want to say?

That in the Arctic Ocean we still have some difficult and undescribed species both in genus *Actinomma* and *Joergensenium*.

As I repeatedly say, this genus was first described in 2008, and nobody tried to check the species belonging to this genus so far. Joergensenium apollo describe by Kamikuri (2010) is the only species after the first description of this paper. However, the existence of this genus has been known in many radiolarian specialists but no body illustrated in the publications.

We do not think this is known by many radiolarian specialists. Most 3 and 4 shelled specimens with more than 6 radial spines are dumped into the mysterious *Actinomma*-group, under different and incorrect names. So, what do you want to say? We cannot see anything wrong in our story and statement, nor could reviewer #1. When not present in the North Pacific and the Bering Sea we simply refer to Ikenoue et al (2012a) paper where they discuss the radiolarian fauna in sediment traps. The lead author knows the fauna and when he worked up the Chukchi Sea material and found the new forms, cited by us herein, he had not observed these forms in the trap material from the Bring Sea north the North Pacific. Therefore we claim that these forms are endemic to the Arctic Ocean as they are not found in the Nordic Seas either. Based on the pictures in Kamikuri (2010) our Arctic forms are different.

Comment 5-9 p. 16660, Lines 16 – 17. The reason for … speciation.. is still not understood…
One of reasons is apparently caused by THE different taxonomic concept and insufficient knowledge on un-illustrated Joergensenium-species in the North Pacific.
In conclusion, no supported your own evidences and reliable fact have been shown in the section 5.2, the reviewer strongly recommend the authors that this section MUST BE DLETED or thoroughly changed with caution.

Why so? What is the problem? We do not discuss the North Pacific *Joergensenium* forms, nor the different *Actinomma* forms! If reviewer #2 is of the opinion that we cannot discuss these two genera in the Arctic Ocean before we know their occurrence in the North Pacific, how then can the study of radiolaria progress? Is the North Pacific the key area only? No, for the time being we will stick to our story and future work will justify if we are wrong or right. In our previous and present papers we are trying to open up the understanding that *Actinomma* is and has been a trash-can of problematic species. We have shown that from this trash-can you can extract *Joergnsenium*.as these forms used to be classified as *Actinomma* spp., in other words, a real trash-can. In the Arctic Ocean we have a majority of actinommids in terms of % values in the radiolarian skeletons in the surface sediments and with a high variability of shapes. This is the main argument to state that there is an active and ongoing speciation, or call it morphogenesis if you want, of actinommids in the Arctic Ocean. Our documentation of new forms and shapes are evidence that something special is going on in this area, this special thing we call "morphogenesis" or "speciation". You do not like our expression "speciation", we have now also added the term "morphogenesis", but you cannot reject us to propose that this is how we interpret our data, namely that "morphogenesis" is a result of ecological changes, which again leads some of these forms to succeed being new species through "speciation".

5.3 Vertical distribution

5.3.1 PSW and PWW association

Comment 5-10 p. 16660, Line 24 – 1661 Line 7. Amphimelissa setosa:
The review about the ecology of Amphimelissa setosa is insufficient in your manuscript. Bernstein (1931) noted that this species live in the **–1.68ºC to –1.29ºC and 34.11 to 34.78 "permils"** in the Arctic Ocean, for example. I think this data is in concordant to the opinion in Matul and Abelmann (2005) (cold and saline) (p. 1661, Line 7). Dolan et al. (2014) also documented that Amphimelissa setosa occupies the radiolarian fauna in the Arctic and provides no clear indications of possible differences in microzooplankton prey abundances or compositions. You should make discussion with these previous studies. The important thing is these two papers regard the Arctic Ocean.

Thanks for your comment.
We inserted the following text page 16661 lines between 5 and 6 as follows:
"…..(Itaki et al., 2003). Bernstein (1931) noted that this species live in the cold (-1.68ºC to -1.29ºC) and saline (34.11 to 34.78) waters in the Arctic Ocean. Matul and Abelmann (2005) also suggested…"
As for Dolan et al. (2014), we refer to it later. Please see our response to your comment 5-12, 5-23, 5-27.

As the taxonomic scheme to Amphimelissa setosa is different by authors, you first make sure whether the same morphotype is called as the same species name. Amphimelissa setosa in Dolan et al (2014) is identical to that in Bernstein (1931).

Bernstein (1931) refer to Menuir (1910) where another *Amphimelissa* species is described. We do not have this available, but if Menuir is operating with two *Amphimelissa* species, then Bernstein is either disregarding Menuir's new species or is not able to separate the two. So how can you state that *A. setosa* by Doland et al (2014) is identical to Bernstein (1931)?
We guess we all know how to recognize *A. setosa*, but in this study we have not differentiated between the one with round pores and the one with reticulated pores, as defined by Bjørklund and Swanberg.

Comment 5-11 Comparative terms
The explanation of this manuscript is ambiguous. What degrees were "**warmer temperature** than Station 56", "**cold but moderate warm**"? (See p. 16660, Line 27). 30 ºC? 0.1 ºC? **Readers cannot image it as you wish.**

Thanks for your comment.
We revised the text as follows:
"At Station 32, these two water masses exhibited warmer temperature than Station 56; indicating that cold but moderate warm, and well mixed water mass were more favorable for this species than the perennial cold water mass such as PWW (100–250 m)."
was changed to
"At Station 32, these two water masses exhibited warmer temperature (about one degree higher at the temperature peak) than Station 56; indicating that cold to moderately warm (-1.2 to 1.6 ºC), and well mixed water mass were more favorable for this species than perennial cold water masses such as PWW (100-250 m)."

Comment 5-12 p. 16661, Line 1
"**More favorable" (p. 16661, Line 1) needs more deep discussion** because Dolan et al. (2014) found the abundance of this species is quite different between 2011 and 2012 (Fig. 3 of Dolan et al., 2014). Your interpretation about the ecology of Amphimelissa setosa can explain this paradox or not? You should mention something based on your data**.**

According to your comment.
We inserted the following text in **page 16661 lines between 1 and 2**:
"According to Dolan et al. (2014), *A. setosa* showed significantly lower abundances with higher chlorophyll *a* concentrations of 2012, the low sea ice year, compared to the year of 2011 with higher sea ice and lower chlorophyll *a* concentrations. Thus, the abundance of phytoplankton protoplasm with the remains of chlorophyll *a* is not related with the abundance of *A. setosa*. This is harmonious with our result that chlorophyll *a* was a little higher at Station 56 but the abundance of *A. setosa* at Station 56 was fairly lower than that at Station 32 in contrast to Actinommidae spp. juvenile forms, *Actinomma l. leptodermum*. Therefore the favorable condition for *A. setosa* is related to cold and well mixed water mass and any other organisms except for those from phytoplankton near the summer sea-ice edge."

Comment 5-13 Actinommids and Spongotrochus glacialis (p. 16661, Lines 8 – 26)
colder (p. 16661, Line 16), "cold but water" (p. 16661, Line17). **See the comment 5-11.**
Thanks for your comment. We changed the text as follows:

"At Station 56, SML and PSW water masses were colder and more homogeneous than at Station 32; indicating that Actinommidae spp. juvenile forms and *A. l. leptodermum* preferred cold but warmer water than PWW."

was changed to

"At Station 56, SML and PSW water masses were colder (-1.2 to 0.6 ºC) and more homogeneous than at Station 32; indicating that Actinommidae spp. juvenile forms and *A. l. leptodermum* preferred slightly warmer water than PWW (-1.6 ºC)."

Comment 5-14 p. 16661, Line 17 – 18: Small spumellarians might be herbivorous (Anderson, 1983).

What are you thinking? **See the summary of comments (iii)-c.** The knowledge of Roger Anderson is mostly based on the tropical collodarians and a few spumellarians. Please let me know if you know the papers which Roger regarded the cold water regions. The second, Roger has never studied Actinommidae in your sense. I **strongly comment to you that you properly read Anderson (1983) and his many papers.** At all, can herbivorous polycystines survive the long polar night when marine algae in the vegetative stage may not be present? If you insist that Actinommidae spp. juvenile forms and A. leptodermum are herbivorous euphotic taxa, it is better to write the sentence that their abundance increases in association with increasing in phytoplanktons.

According to your comment. We added vertical profiles of chlorophyll *a* at station 32 and 56 to figure 2.

We revised the text as follows:

"Small spumellarians might be herbivorous (Anderson 1983) so Actinommidae spp. juvenile forms and *A. l. leptodermum* might therefore be bound to the euphotic zone where phytoplankton prevails."

was changed to

"Our results show that Actinommidae spp. juvenile forms and *A. l. leptodermum* are most abundant in the upper water layers where phytoplankton also prevails (Fig. 2). It is most likely that the juvenile actinommids and *A. l. leptodermum* may be bound to the euphotic zone, and so can be herbivorous."

With this change, we revised the following text:

Page 16651, lines 12 and 13

"Hydrographical data (temperature, salinity)"

was changed to

"Hydrographical data (temperature, salinity, dissolved oxygen, and chlorophyll *a*)"

Page 16652, line 9

"Profiles of temperature, salinity, and dissolved oxygen"

was changed to

"Profiles of temperature, salinity, dissolved oxygen, and chlorophyll *a*"

Page 16652, lines 23 and 24

"Temperature, salinity, and dissolved oxygen show"

was changed to

"Temperature, salinity, dissolved oxygen, and chlorophyll *a* show"

Caption of figure 2

"Figure 2. The depth distributions of total dead and living radiolarians at stations 32 (a), and 56 (b) in comparison to vertical profiles of temperature, salinity, dissolved oxygen (Nishino, 2013), and living radiolarian diversity index (Shannon and Weaver, 1949). Also the different water masses are identified Surface Mixed Layer (SML), Pacific Summer Water (PSW), Pacific Winter Water (PWW), Atlantic Water (AW), and Canada Basin Deep Water (CBDW)."
was changed to
"Figure 2. Depth distributions of total dead and living radiolarians at stations 32 (a), and 56 (b) in comparison to vertical profiles of temperature, salinity, dissolved oxygen, and chlorophyll *a* (Nishino, 2013), and living radiolarian diversity index (Shannon and Weaver, 1949). The different water masses are identified as: Surface Mixed Layer (SML), Pacific Summer Water (PSW), Pacific Winter Water (PWW), Atlantic Water (AW), and Canada Basin Deep Water (CBDW)."

We inserted the following text in **page 16652 lines between 23 and 24**:
"Chlorophyll *a* higher than 0.1 mg m^{-3} was observed in 0-80 m depth."

We added the following text after **page 16652, line 27**:
In 0-80 m depth, chlorophyll *a* was a little higher at Station 56 than at Station 32.

Guess you can ask the same question for any animal group in the Arctic Ocean. What do you think happens with the crustaceans, many of them feeding on phytoplankton exclusively? From where do the tintinnids get their winter food? Our traps indicate that radiolarians are present all through the year. This means that they do survive the winter! The same traps also indicate that phytoplankton is also present throughout the year (Onodera et al., 2014).
We do not insist, we carefully suggest that this is a possibility.

Comment 5-15 p. 16661, Lines 24 – 26 S. glacialis
Okazaki et al. (2005) is also cited to show the water depths of S. glacialis because the study are is closer than the Okhotsk Sea of Okazaki et al. (2004). "Spongotrochus glacialis is associated with the phytoplankton production, but this does not simply mean herbivorous species. **Casey et al. (1979) clearly wrote Spongotrochus glacialis is heterotrophic bacteria feeder (Fig. 5 of Casey et al., 1979). In conclusion, this paragraph should be revised in consideration with these comments.**

May be not phytoplankton feeders, but never the less it would be very convenient to eat what is around you at any time. May be we should ask Casey what he base his statement on. Casey, as we do herein, simply suggests *S. glacialis* to be a "heterotrophic bacteria feeder". He did not conduct any experiments to settle this. If you know to which experiment Casey used to make such a conclusion, please let me know.
The examples you refer us to are at least as weak as ours. Another taxonomic point: how many of us "radiolarian experts" do really understand the taxonomy of *S. glacialis*? I think this species also is a garbage-can where our colleagues put forms that are big, flat, spongy with spiny rim, with and without a pylome etc. etc. and do not pay attention to smaller differences and details. At present we do not know what is the real *S. glacialis* and the different forms that has been incorporated in this species are many. However, what we call S. glacialis fit Hülsamnn's description and as her and our material is from almost the same area we still accept her species concept. This at least to be consistent within our own papers.

5.3.3 Upper AW association

Comment 5-16 p. 16662, Lines 21 – 22. "… the 1950s and 1960s.

Itaki et al. (2003, p. 1519, Right column, Lines 23 – 25) wrote "No information on C. historicosa was reported from many plankton samples **from the Canadian Basin in the 1950s and 1960s (Hülsemann, 1963; Tibbs, 1967)**". On the other hand, you wrote "This species has not been observed in **the Canadian Basin during the 1950s and 1960s (Hülsemann, 1963; Tibbs, 1967)". So, the priority of this notice has Itaki et al (2003) but NOT YOU!**
Thanks for your comment.
We had no intention to take this as our observation as that was Itaki. We use your suggestion in your comment 5-19.

Comment 5-17 p. 16662, Lines 26 – p. 16663, Line 1.
It may be hard for the potential readers to differentiate your new discovery from the results of Itaki et al. (2003), although you precisely wrote this point. You noted that "according to McLaughlin et al. (2011), the mean temperature of the PWW within the Canada Basin increased slightly (~ 0.05ºC) from 2003 to 2007.." However, Itaki et al. (2003) has already showed a similar thing (though quite different), "According to Swift et al. (1997), the temperature of the AIW in 1994 at the Chukchi-Mendeleyev boundary is higher by at least 0.2ºC than in the 1950s and 1960s." In regardless of quite different, this makes an impression to say the exactly same things. I will propose a suggested solution later.

Thank you for your suggestion. We used your suggestion in your comment 5-19.

Comment 5-18 p. 16663, Lines 1 – 3. the recent warming of the PWW and AW might induce the expansion of the habitat of C. histricosa into the PWW.
Itaki et al. (2003) commented that "Interestingly, this water temperature corresponds to the lower limit for survival of this species" (p. 1520, in the Conclusion). Thus, if you consider the warming phenomena in the PWW led inversion by C. histricosa into this water, **you should show that the sea water temperature of the PWW exceeds the lower limit for survival of C. histricosa.**

We guess that you are perfectly well aware of that nobody knows the lower limit for survival of this species, not even the upper limit. We have added the following sentence as we do not think that the temperature itself is the reason for the areal expansion of *C. histricosus*:
"... expansion of the habitat of *C. histricosus* into the PWW. It is not so much the effect of the temperature itself that is causing the expanding distribution of *C. histricosus*, but the general temperature increase indicates that larger volumes of warmer AW is entering the Arctic Ocean. The increasing volumes of inflowing AW will therefore increase the chances for more exotic radiolarians to reach further and further into the Arctic Ocean and the Chukchi Sea."

Comment 5-19 A suggested discussion for your 5.3.3
"Ceratocyrtis histricosus occurred commonly in the upper AW (250 – 500 m) and rarely in the PPW. Ceratocyrtis histricosus is a species interpreted as being introduced from the Norwegian Sea, most likely during the early Holocene by the warm Atlantic water drifting through the Arctic Ocean (Kruglikova, 1999). Itaki et al. (2003) first noticed that Ceratospyris histricosus has not been observed in the Canada Basin during the 1950s and 1960s and he pointed out that the common occurrence of this species in the Chukchi and Beaufort seas in 2000 may be the effect of the recent warming of the AIW. Itaki et al. (2003) also introduce that the temperature of the AIW in 1994 at the Chukchi-Mendeleyev boundary was higher by at least 0.2ºC than in the 1950s and 1960s, from Swift et al (1997). Differing from Itaki et al. (2003), we first found this species in

the PWW. According to McLaughlin et al. (2011), the mean temperature of the PWW within the Canada Basin increased slightly (~0.05ºC) from 2003 to 2007 and then remained constant until 2010. According to Itaki et al. (2003), C. histricosus can survive in the temperature range of 0.5–4ºC. Although our data on the temperature of the PWW is apparently lower than the lower limit for survival of this species (Fig. 2), the rare existence of this species in the PWW may be caused by unobserved warming in the PWW or by appearance of other optimistic conditions for C. histricosus. However, the warming in the AIW has already been recognized in 1994 (Swift et al., 1997) and that in the PPW is also reported by McLaughlin et al. (2011), suggesting that the recent warming of the PWW and AW might induce the expansion of the habitat of C. histricosus into the PWW."

Thanks to the reviewer 2. This made a good point. We use your suggestion and add a few sentences in response to your comment 5-18 to show that we simply do not think that these small temperature changes are that critical, but that the expansion is done due to increased volume of Atlantic water.

We revised the text as follows:
"*Ceratocyrtis histricosus* occurred commonly in the upper AW (250-500 m) and rarely in the PWW. This species is a species interpreted as being introduced from the Norwegian Sea, most likely during the early Holocene, by the warm Atlantic water drifting through the Arctic Ocean (Kruglikova, 1999). Itaki et al. (2003) first noticed that *Ceratospyris histricosus* had not been observed in the Canada Basin during the 1950s and 1960s and he pointed out that the common occurrence of this species in the Chukchi and Beaufort seas in 2000 might be an effect of the recent warming of the AIW. Itaki et al. (2003) also introduced that the temperature of the AIW in 1994 at the Chukchi-Mendeleyev boundary was higher by at least 0.2ºC than in the 1950s and 1960s, from Swift et al (1997). Differing from Itaki et al. (2003), we first found this species in the PWW. According to McLaughlin et al. (2011), the mean temperature of the PWW within the Canada Basin increased slightly (~0.05ºC) from 2003 to 2007 and then remained constant until 2010. According to Itaki et al. (2003), *C. histricosus* can survive in the temperature range of 0.5–4ºC. Although our data on the temperature of the PWW is apparently lower than the lower limit for survival of this species (Fig. 2), the rare existence of this species in the PWW may be caused by unobserved warming in the PWW or by appearance of other optimistic conditions for *C. histricosus*. However, the warming in the AIW has already been recognized in 1994 (Swift et al., 1997) and a warming in the PWW is also reported by McLaughlin et al. (2011), suggesting that the recent warming of the PWW and AW might induce the expansion of the habitat of *C. histricosus* into the PWW. It is not so much the effect of the temperature itself that is causing the expanding distribution of *C. histricosus*, but the general temperature increase indicates that larger volumes of warmer AW is entering the Arctic Ocean. The increasing volumes of inflowing AW will therefore increase the chances for more exotic radiolarians to reach further and further into the Arctic Ocean and the Chukchi Sea."

Comment 5-20 p. 16663, Lines 4 – 10

Yes, the pulse of the tropical-subtropical radiolarian taxa into the Arctic Ocean is known, but **you need to cite Brady (1878) and Itaki & Khim (2007).** Brady (1878) wrote the presence of tropical-subtropical polycystine species but has never illustrated these species. Itaki & Khim (2007) examined the samples of Brady (1878) and they first proved the existence of such tropical-subtropical species in the Arctic Ocean.

It is correct that they identified the species on Brady's slides but in their discussion and their abstract they clearly conclude that these samples studied by Brady and identified by Haeckel should best be regarded as "sample contamination or misidentification of samples. These samples should according to Itaki be interpreted as "uncertain and should be regarded with suspicion".
Because the pulse of the tropical-subtropical radiolarian taxa into the Arctic Ocean has already been known in the late 19th century.

This is also how we interpret Itaki's data, but Itaki is of the impression that this is not the case but that samples has been misidentified or mixed and should not be used or used with care.

In addition, **Bjørklund et al. (2012) clearly declared that the reported pulses may not be a consequence of global warming** (See the abstract of Bjørklund et al (2012)). This point is the important point in Bjørklund et al. (2012), you **MUST NOT WRITE BEING MISUNDERSTOOD AS A RESULT OF GLOBAL WARMING!**

Thanks for your comment.
We go through the MS and, make sure that we are not understood as we state that *C. histriosus* can be interpreted by the reader as a result of global warming. We rewrote the text about *C. histriosus.* Please see our response to your comment 5-18.

5.3.4 Lower AW association

No problem.

5.4 Seasonal and annual radiolarian flux

5.4.1 Radiolarian fauna and seasonal sea-ice concentration

Comment 5-21 the necessity of a family name
The family name "Cannobotryidae" is unnecessary to show in this section because only a single species constitutes this family.

According to your comment.
We deleted Cannobotrydae or replaced it with *Amphimelissa setosa*.

Comment 5-22 p. 16664, Lines 9 – 10.
See the comment shown above.

We agreed with your comment.

Comment 5-23 p. 16664, Lines 17 – 21. Swanberg and Eide (1992) … correlated with chlorophyll a.
Dolan et al. (2014) found the opposite fact in the Arctic. Swanberg and Eide (1992) regarded the Norwegian Sea. According to Dolan et al. (2014), Amphimelissa setosa was significantly lower abundances with higher chlorophyll concentrations of 2012, the low sea ice year, compared to the year of 2011 with significant sea ice and lower chlorophyll concentrations (p. 109 – 110, Dolan et al. 2014). **Thus, the abundance of phytoplankton protoplasm with the remains of chlorophyll a is not entirely related with the abundance of Amphimelissa setosa.** On the other hand, although Dolan et al. (2014) did not note, the summer ice edge is likely related with the abundance of Amphimelissa setosa. This will support your opinion in p. 16664, Lines 20-21. **Thus, it is better for the authors to change the discussion about the importance of phytoplankton, in consideration with Dolan et al. (2014).**

Thanks for your good recommendation. We revised the text as follows:
"Thus A. setosa prefer water masses near the summer ice edge for reproduction and growth."
was changed to
"Dolan et al. (2014), however, reported that the abundance of *A. setosa* was not entirely related to high Chlorophyll *a* with low sea-ice concentration as we have said in section 5.3.1. Therefore we interpreted that cold and well mixed water mass based on summer ice edge and maybe other ice fauna were essential for high reproduction and growth of *A. setosa*."

and with this change, we also revised page 16647, lines 12-15.
"*Amphimelissa setosa* was dominant during the open water and the beginning and the end of ice cover seasons with well-grown ice algae, ice fauna and with alternation of stable water masses and deep vertical mixing."
was changed to
"*Amphimelissa setosa* was dominant during the season with open water as well as at the beginning and at the end of the seasons with sea ice cover. Cold and well mixed water mass based on summer ice edge were essential for high reproduction and growth of *A. setosa*. Our data indicate that *A. setosa* might have a three months life cycle."

and further more, we inserted the following text in page 16664, lines between 14 and 15.
"Zasko et al. (2014) also reported that *A. setosa* was essentially absent in the plankton samples in the central polar basins."

Comment 5-24 p. 16664, Line 28; p. 16665, Line 1. "Actinommidae"
"Actinommidae" ---> "the actinommids", because **the Actinommidae regarded in your paper is very limited species. Please check your "Actinommidae" throughout the text.**

According to your comment.
We replaced "Actinommidae" with "the actinommids".

Comment 5-25 p. 16665, Lines 6 – 8. feeds on algae
See the general comment. It may be wrong.

We changed the text as follows:
This might indicate that Actinommidae spp. juvenile form can feed on algae growing on the ice or other phytoplankton under the sea-ice. Therefore, *A. setosa* and the actinommids might have different nutritional niches.

Please also see our response to your comment 5-26.

Comment 5-26 p. 16665, Lines 9 – 20.
I can agree with your opinion about "Therefore, Amphimelissa setosa and Actinommidae have different nutritional niches.", but I cannot completely understand your logic. First of all, why is the example of the Okhotsk Sea (Okazaki et al., 2003) needed to prove your opinion? Can you defense your opinion against the following possibility? The different nutritional niches between Amphimelissa setosa and the adult actinommids are easily presumed from the cell size. The skeletal diameter of the adult actinommids is 120–300 μm in diameter (only for *A. georgii* and *A. turidae* and some undescribed forms of similar size, but majority are *A. boreale* and *A. lept. leptodermum* about 80 μm), whereas the length and width of Amphimelissa setosa are 65 μm and 50 μm,

respectively. The cell volume of the former ranges from 9.05×105 mm3 to 1.41×107 mm3 while that of the latter is 2.16×105 mm3. Thus, the cell volume of the adult actinommids is 4 to 65 times larger than that of Amphimelissa setosa. If the metabolism is the same each other, the required volume of feed at a given time is quite different. So, if they have the same food preference, Amphimelissa setosa has an advantage over the adult actinommids in starving conditions. However, if food is sufficiently supplied enough to reach to the sea-floor, they did not under starving conditions because these two polycystines are plankton. Thus, if you insist "different nutritional niches", you probably need to show the data about the independent changes in the standing stocks or fluxes between these two taxa. Differences of reproduction rates between Amphimelissa setosa and the actinommids cannot be used for proving your opinion because we have no data on the number of survival daughter cells from a single (a couple of?) polycystine species. **In conclusion, the paragraph between Lines 9 – 20 on Page 16665 should be deleted unless you can show more scientific evidences.**

Thanks for your comment.
Because there is winter sea ice, comparable situation as in the Chukchi Sea.
Page 16665, lines 9-20 is not right as the reason for different nutritional niches between *Amphimelissa setosa* and Actinommidae but is right as the reason that the diversity indices were negative correlated with the total radiolarian fluxes in the Arctic Ocean on the contrary to that in the Okhotsk Sea.
Thus we deleted the text as follows:
"This study showed that the productivity of radiolarian was low but diversity was high under the sea-ice (Figs. 5 and 6). In contrast, radiolarian fauna in the sediment trap set in the Okhotsk Sea showed low diversity during the winter to spring when seasonal sea-ice covered the surface (Okazaki et al., 2003). The maximum total radiolarian flux during the summer season around the sea-ice edge and the open water is characterized by high dominance of A. setosa (> 90 %) in our area. Such high dominance of single species does not occur and major nine taxa contributed more than 60% to the radiolarian assemblage in the Okhotsk Sea (Okazaki et al., 2003). *Amphimelissa setosa*, which have small and delicate siliceous skeleton, might respond to primary production more directly and rapidly and develop earlier than Actinommidae, which have more robust skeleton. Therefore, *Amphimelissa setosa* and Actinommidae have different nutritional niches."
was changed to
"This study showed that the productivity of radiolarians was high, but diversity was low, during summer season with low sea-ice concentration in the western Arctic Ocean (Fig. 5 and 6). In contrast, radiolarian fauna in the sediment trap set in the Okhotsk Sea showed high diversity during summer season (Okazaki et al., 2003). The maximum total radiolarian flux during the summer season around the sea-ice edge and the open water is characterized by high dominance of *A. setosa* (>90%) in our area. Such high dominance of a single species does not occur in the Okhotsk Sea, where the main nine taxa contributed with more than 60 % of the radiolarian assemblage (Okazaki et al., 2003). *Amphimelissa setosa*, which has a small and delicate siliceous skeleton, might respond to water mass conditions near summer ice edge both more directly and more rapidly. The contrast of seasonal diversity between these two areas was due to the difference of species composition and their response to water mass changes with low sea-ice."

and we added the folowing text after p. 16665, Lines 6 – 8 as follows: "…under the sea-ice. Therefore, *A. setosa* and the juvenile actinommids might have different nutritional niches"

5.4.2 year difference

Comment 5-27 p. 16667, Lines 4 – 20.

Must discuss the result of Dolan et al. (2014). In similar to your results, the abundance of Amphimelissa setosa is significantly lower in 2012 than 2011. You said that "Amphimelissa setosa… not changed before and after the cold eddy passage." You need to consider your discussion when you see Dolan et al (2014).

According to your comment, we revised the text as follows:
"*Amphimelissa setosa* was the most dominant (> 90 %) during this period and the radiolarian species composition was not changed before and after the cold eddy passage. Therefore the cold eddy in addition to seasonal water mass variations with sea ice formation would enhance the high radiolarian flux, but not diversity, in 2010."
was changed to
"*Amphimelissa setosa* was the most dominant species (>90%) and showed the highest flux (13,840 specimens m^{-2} day^{-1}) during November 2010 in the upper trap. The flux of this species was about 3,500 specimens m^{-2} day^{-1} higher and kept the highest value half a month longer than that in 2011. The cold eddy passage would transport a cold and well mixed water mass, conditions favorable for *A. setosa*. Therefore the cold eddy passage in addition to seasonal water mass variations with sea ice formation would enhance the high radiolarian flux."

Taxonomy

Comment 6-1 Spongotrochus glacialis ---->Spongotrochus aff. glacialis

I don't make sure whether the illustrated specimen was properly identified as this species, because I cannot recognize the presence of central empty sphere and the empty space between the circumferential ring and the central sphere. The most referable illustrations for Spg. glacialis are shown on pl. 60, fig. 5, and pl. 31, figs. 1, 2a and 3a of Nakaseko and Nishimura (1982).

We replaced *Spongotrochus glacialis* with *Spongotrochus* aff. *glacialis* only in plate 3, fig.9.

The specimens we have seen in the Arctic Ocean seem to follow Hülsemann's description fairly well. She did not show any photographs but her discussion of the species seems logical and safe. We also confer with Petrushevskaya 1968 on this species. We think we have used the *Spongotrochus glacialis* correctly, but the *Spongotrochus* aff. *glacialis* we do not know what to name rather than say it is close to the real one *Spongotrochus glacialis.* Therefore we continue to use "*Spongotrochus glacialis*".

Errata

We found several mistakes and corrected as follows.

Page 16658, line 17
"October-November"
was changed to
"November-December"

Page 16658, lines 24-26
"During July–September 2011, juvenile and adult forms of A. setosa were dominant during June–July and August–September, respectively." was deleted.

Page 16661, line 4
80% was changed to 86%.

References
We added the following papers to the references in our manuscript.

Bernstein, T.: Protist plankton of the North-west part of the Kara Sea, Transactions of the Arctic Institute, 3, 1–23, 1931 (in Russian with English summary).

Bernstein, T.: Über einige arktische Radiolarien, Arch. Protistenkunde, 76, 217–227, 1932.

Bjørklund, K. R., Dumitrica, P, Dolven, J. K., Swanberg, N. R.: Joergensenium rotatile n. gen., n. sp. (Entactinaria, Radiolaria): its distribution in west Norwegian fjords, Micropaleontology, 53, 457–468, 2008.

Cavalier-Smith, T.: A revised six-kingdom system of life, Biol. Rev., 73, 203-266, 1998.

Cavalier-Smith, T.: The phagotrophic origin of eukaryotes and phylogenetic classification of Protozoa, Int. J. Syst. Evol. Micr., 52, 297-354, 2002.

Dolan, J. R., Yang, E. J., Kim, T. W. and Kang, S.-H.: Microzooplankton in a warming Arctic: A comparison of tintinnids and radiolarians from summer 2011 and 2012 in the Chukchi Sea, Acta Protozool., 53, 101–113, 2014.

Ikenoue, T., Takahashi, K., Sakamoto, T., Sakai, S., and Iijima, K.: Occurrences of radiolarian biostratigraphic markers *Lychnocanoma nipponica sakaii* and *Amphimelissa setosa* in Core YK07-12 PC3B from the Okhotsk Sea, Memoirs of the Faculty of Science, Kyushu University. Series D, Earth and Planetary Sciences, 32, 1-10, 2011.

Kosobokova, K. N., Hirche, H. -J. and Scherzinger, T.: Feeding ecology of Spinocalanus antarcticus, a mesopelagic copepod with a looped gut, Mar. Biol., 141, 503–511, 2002.

Lovejoy, C., Massana, R., and Pedrós-Alió, C.: Diversity and distribution of marine microbial eukaryotes in the Arctic Ocean and adjacent seas, Appl. Environ. Microb., 72, 3085–3095, doi:10.1128/AEM.72.5.3085-3095.2006, 2006.

Lovejoy, C. and Potvin, M.: Microbial eukaryotic distribution in a dynamic Beaufort Sea and the Arctic Ocean, J. Plankton Res., 33, 431–444, 2011.

Matul, A., Abelmann, A., Tiedemann, R., Kaiser, A., and Nürnberg, D.: Late Quaternary polycystine radiolarian datum events in the Sea of Okhotsk, Geo-mar. lett., 22, 25-32, 2002.

Meunier, A.: Microplankton des Mers de Barents et de Kara, Duc d'Orléans, Campagne arctique de 1907, 255 pp., 1907.

Onodera, J., Watanabe, E., Harada, N., and Honda, M. C.: Diatom flux reflects water-mass conditions on the southern Northwind Abyssal Plain, Arctic Ocean, Biogeosciences Discuss., 11, 15215-15250, doi:10.5194/bgd-11-15215-2014, 2014.

Petrushevskaya, M. G.: The history of the microplankton of the Norwegian Sea (on the Deep Sea Drilling materials). Academy of Sciences, USSR, Zoological Institute, Nauka, Leningrad, 77-183, 1979 (in Russian).

Suzuki N. and Aita Y.: Achievement and unsolved issues on radiolarian studies: Taxonomy and cytology, Plank. Benth. Res., 6, 69–91, 2011.

Swift, J. H., Jones, E. P., Aagaard, K., Carmack, E. C., Hingston, M., Macdonald, R. W., McLaughlin, F. A., Perkin, R. G.: Waters of the Makarov and Canada basins, Deep-Sea Res. Pt. II, *44*, 1503–1529, 1997.

Tanaka, S. and Takahashi, K.: Detailed vertical distribution of radiolarian assemblage (0-3000 m, fifteen layers) in the central subarctic Pacific, June 2006, Mem. Fac. Sci., Kyushu Univ., Ser. D, Earth and Planet. Sci., 32, 49-72, 2008.

Acknowledgements

We inserted following two text.

In page 16669 lines between 3 and 4.

We are thankful to one anonymous reviewer who had some good and helpful comments and suggestions.

In page 16669 lines between 6 and 7.

This work was partly carried out when TI was visiting the Natural History Museum, University of Oslo in 2013.

Flux variations and vertical distributions of siliceous Rhizaria (Radiolaria and Phaeodaria) in the western Arctic Ocean: indices of environmental changes

Takahito Ikenoue [a, b, c, *], Kjell R. Bjørklund [b], Svetlana B. Kruglikova [d], Jonaotaro Onodera [c], Katsunori Kimoto [c], Naomi Harada [c]

a: Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan

b: Natural History Museum, Department of Geology, University of Oslo, P.O. Box 1172 Blindern, 0318 Oslo, Norway

c: Research and Development Center for Global Change, JAMSTEC, Natsushima-cho 2-15, Yokosuka, 237-0061, Japan.

d: P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovsky Prospect 36, 117883 Moscow, Russia

*Corresponding author; Present address: Central Laboratory, Marine Ecology Research Institute, 300 Iwawada, Onjuku-machi, Isumi-gun, Chiba 299-5105 Japan; E-mail: ikenoue@kaiseiken.or.jp

Abstract

The vertical distribution of radiolarians was investigated using a vertical multiple plankton sampler (100−0, 250−100, 500−250 and 1,000−500 m water depths, 62 µm mesh size) at the Northwind Abyssal Plain and southwestern Canada Basin in September 2013. To investigate seasonal variations in the flux of radiolarians in relation to sea-ice and water masses, a time series sediment trap system was moored at Station NAP (75°00'N, 162°00'W, bottom depth 1,975 m) in the western Arctic Ocean during October 2010–September 2012. We monitored species abundance changes in the fourteen most abundant radiolarian taxa, and how they related to the vertical hydrographic structure in the western Arctic Ocean. The radiolarian flux was comparable to that in the North Pacific Ocean. *Amphimelissa setosa* was dominant during the season with open water as well as at the beginning and at the end of the seasons with sea ice cover. Cold and well mixed water mass based on summer ice edge were essential for high reproduction and growth of *A. setosa*. Our data indicate that *A. setosa* might have a three months life cycle. During the sea-ice cover season, however, oligotrophic and cold-water tolerant actinommids were dominant, productivity of radiolaria was lower, and species diversity was greater. This might be associated with the seasonal increase of solar radiation stimulating the growth of algae on the ice and other phytoplankton species under the sea-ice, upon which the actinommids can feed on. This evidence suggests that the dynamics of sea-ice are a major factor affecting the general biological productivity, distribution, and composition as demonstrated in the radiolarian fauna.

Keywords: Radiolarians, Western Arctic Ocean, Sea-ice, Beaufort Gyre, Sediment trap

1. Introduction

In recent years, summer sea-ice extent in the Arctic Ocean has decreased rapidly due to global climate change (Stroeve et al., 2007, 2012). The sea-ice in the Arctic Ocean reached its minimum extent in September 2012 since the beginning of satellite observation (NSIDC, 2012). The most remarkable sea-ice decrease was observed in the western Arctic Ocean, on the Pacific side (Shimada et al., 2006; Comiso et al., 2008; Markus et al., 2009). In the western Arctic Ocean, the advection of warm North Pacific water through the Bering Strait contributes to both sea-ice melt in summer and an inhibition of sea-ice formation during winter (Shimada et al., 2006; Itoh et al., 2013).

Biological CO$_2$ absorption is an important carbon sink in the ice-free regions of the Arctic Ocean (Bates et al., 2006; Bates and Mathis, 2009). Melting of sea-ice can both enhance and reduce the efficiency of the biological pump in the Arctic Ocean, depending on ocean circulation (Nishino et al., 2011). The Beaufort High, a high-pressure system over the Canada Basin in the Arctic Ocean, drives the sea-ice and the water masses anticyclonically, as the Beaufort Gyre (Fig. 1). In the Canada Basin, the Beaufort Gyre governs the upper ocean circulation (Proshutinsky et al., 2002), and it has strengthened recently due to the decreasing sea-ice (Shimada et al. 2006; Yang 2009). Melting of sea ice reduce the efficiency of the biological pump within the Beaufort Gyre because of deepening of the nutricline caused by freshwater accumulation within the gyre (Nishino et al., 2011). Conversely, the efficiency of the biological pump is enhanced outside the gyre because of nutrient supply from shelves and improved light penetration (Nishino et al., 2011).

Particle flux plays an important role in the carbon export (Francois et al., 2002). Based on sediment trap samples from the Canada Basin and Chukchi Rise, Honjo et al. (2010) found that the annual average of sinking particle flux was three orders of magnitude smaller than that in epipelagic areas where the particle flux was the main mechanism for carbon export to greater depths. However, Arrigo et al. (2012) observed a massive algal biomass beneath fully consolidated pack ice far from the ice edge in the Chukchi Sea during the summer, and suggested that a thinning ice cover increased light transmission under the ice and allowed blooming of algae. Boetius et al. (2013) also reported that the algal biomass released from the melting ice in the Arctic Ocean was widely deposited at the sea floor in the summer of 2012. Therefore, it is inferred that biomass of zooplankton also changed seasonally under the sea-ice in the Arctic Ocean, as a result of the variable sea-ice conditions. Microzooplankton are recognized as a key component of pelagic food webs (e.g., Kosobokova et al., 2002; Calbet and Landry, 2004), but the seasonal and interannual changes in their communities within sea ice regions are still poorly understood.

To understand the effect of sea ice reduction on marine ecosystems in the Arctic Ocean, we studied productivity, distribution, composition, and biological conditions of living radiolarians in both plankton tow samples and sediment trap samples.

In our study we have analyzed only the siliceous forms of class Rhizaria and herein we have used the definition of Radiolaria as defined by Suzuki and Aita (2011). In their taxonomic scheme they include the following orders: Collodaria, Nassellaria, Spumellaria, Acantharia and Taxopodia. In addition we do include order Entactinaria which Suzuki and Aita (2011) reported getting extinct during the Permian, but Bjørklund et al. (2008) demonstrated its presence also in recent plankton and sediment samples. In this study we have excluded order Acantharia as they have a skeleton of $SrSO_4$ and Collodaria, a group that normally do not possess a skeleton or only with loose spines. Therefore, our study only includes forms with a solid skeleton of SiO_2. In this paper we have chosen to include data also on order Phaeodaria which have not been assigned to Radiolaria but to Cercozoa in recent studies using molecular biology (Cavalier-Smith and Chao, 2003; Nikolaev et al., 2004; Adl et al., 2005; Yuasa et al., 2005). To make the text read well we therefore use Radiolaria, or radiolarians when appropriate, to also include Phaeodaria, this to make it possible for us to compare already published data from the north Pacific region (Okazaki et al., 2003, 2005; Ikenoue et al., 2010, 2012a).

Radiolaria are one of the most common microzooplankton groups, they secrete siliceous skeletons, and their abundance in a region is related to temperature, salinity, productivity and nutrient availability (Anderson, 1983; Bjørklund et al., 1998; Cortese and Bjørklund, 1997; Cortese et al., 2003). Their genus and family levels taxa also respond to various oceanographic conditions by altering their distribution patterns and compositions (Kruglikova et al., 2010, 2011). In recent studies, Ikenoue et al. (2012a, b) found a close relationship between water mass exchanges and radiolarian abundances based on a fifteen-year long time-series observation on radiolarian fluxes in the central subarctic Pacific. Radiolarian assemblages are also related to the vertical hydrographic structure (e.g., Kling, 1979; Ishitani and Takahashi, 2007; Boltovskoy et al., 2010), therefore variations in their abundance and proportion might be useful environmental proxies for water mass exchanges at each depth interval, especially as some of them occur in response to recent climate change (e.g., ocean circulation, expansion and decline of sea-ice, influx of water mass from other regions).

The radiolarian assemblages in the western Arctic Ocean has been studied mainly based on the samples collected by plankton tow at ice-floe stations (Hülsemann, 1963, Tibbs, 1967), and in the Beaufort Sea in summer of 2000 (Itaki et al., 2003) or in surface sediment samples, mainly over the Atlantic side of the Arctic Ocean (Bjørklund and Kruglikova (2003). Bernstein (1931, 1932, 1934) reported on six Polycystina, two Acantharia and two Taxopodia species, but did not give any information on abundance in the Barents Sea and Kara Sea for the Polycystina, but for the Acantharia and Taxopodia she reported them to be abundant, with a maximum occurrence in the deeper and warmer Atlantic water. Meunier (1910) also reported on Acantharia, Taxopodia and Nassellaria in the Kara Sea and the Arctic Ocean, but he stated (page 196) that his material was not rich in radiolarians. However, the knowledge of the geographical and the depth distribution of living radiolarians is still limited, and their seasonal and annual changes have not been studied in the western Arctic Ocean because of seasonal sea-ice coverage.

This is the first extensive study of the seasonal and interannual flux changes of radiolarians in the western Arctic Ocean. We present radiolarian depth distributions and flux variations in the western Arctic Ocean, and discuss their seasonality and species associations in relation to the environmental conditions (temperature, salinity, depth, sea-ice concentration, and downward shortwave radiation).

2. Oceanographic setting

The hydrography in the western Arctic Ocean has been discussed in several studies (e.g., Aagaard et al., 1985; McLaughlin et al., 2011) and the upper 1,000 m of the water column can be divided into five distinct water masses. The surface water is characterized by low temperature and low salinity water (Aagaard et al., 1981) and can be subdivided into three layers, i.e. Surface Mixed Layer (SML), Pacific Summer Water (PSW), Pacific Winter Water (PWW). The SML (0-25 m) is formed in summer by sea-ice melt and river runoff and is characterized by very low salinities (less than 28). The PSW (25-100 m) and PWW (100-250 m) are cold halocline layers originating from the Pacific Ocean via the Bering Sea. The PSW flows along the Alaskan coast and enters the Canada Basin through the Bering Strait and Barrow Canyon (Coachman and Barnes, 1961) (Fig. 1). The PSW is relatively warmer and less saline (30-32 in the 1990s, 28-32 in the 2000s, according to Jackson et al., 2011) than the PWW. The PSW is further classified into warmer and less saline Alaskan coastal water and cooler and more saline Bering Sea water (Coachman et al., 1975), which originate from Pacific water that is modified in the Chukchi and Bering Seas during summer. The Alaskan coastal water is carried by a current along the Alaskan coast, and spread northwards along the Northwind Ridge by the Beaufort gyre depending on the rates of ice cover and decay (Shimada et al., 2001). The PWW is characterized by a temperature minimum (of about −1.7°C) and originates from Pacific water that is modified in the Chukchi and Bering Seas during winter (Coachman and Barnes, 1961). The PWW is also characterized by a nutrient maximum and its source is regenerated nutrients from the shelf sediments (Jones and Anderson, 1986).

The deep water is divided into Atlantic Water (AW) and Canada Basin Deep Water (CBDW). AW (250-900 m) is warmer (near or below 1°C) and saltier (near 35) intermediate water than the surface waters, and is originating from the North Atlantic Ocean, via the Norwegian Sea. The CBDW (below 900 m) is a cold (lower than 0°C) water mass located beneath the AW and has the same salinity as the AW. The CBDW is formed by the brine formation on the shelves, which makes cold and saline water mass sink over the continental margin into the deep basins (Aagaard et al., 1985).

3. Materials and methods

3.1. Plankton tow samples

Plankton tow samples were collected by vertical multiple plankton sampler (VMPS). The instrument (mesh size: 62 µm, open mouth area: 0.25 m^2) was towed from 4 layers (100-0, 250-100, 500-250, and 1,000-500 m) at 2 stations (Station 32 in Northwind Abyssal Plain, 74°32'N, 161°54'W; Station 56 in southwestern Canada Basin, 73°48'N, 159°59'W) (Fig. 1 and Table 1) in September 2013. Hydrographical data (temperature, salinity, dissolved oxygen, and chlorophyll *a*) down to 1,000 m water depth were simultaneously obtained from a CTD (Conductivity Temperature Depth profiler) cast. The volume of seawater filtered through the net was estimated using a flow meter mounted in the mouth ring of the plankton net.

The samples collected by VMPS were split with a Motoda box splitter and a rotary splitter (McLane™WSD-10). The split samples were fixed with 99.5% ethanol for radiolarian studies. Plankton samples were stained with Rose-Bengal to discriminate between living and dead specimens. The split samples were sieved through a stainless screen with 45 µm mesh size. Remains on the screen were filtered through Gelman® membrane filters with a nominal pore size of 0.45 µm. The filtered samples were desalted with distilled water. The edges of each filtered sample were cut according to slide size in wet condition and mounted on glass slides on a slide warmer. Xylene was added to the dried filters and samples, which were then permanently mounted with Canada balsam. Radiolarian taxa were identified and counted with a compound light microscope at 200 x or 400 x magnification. Plankton tow samples were stained with Rose-Bengal to discriminate between living and dead specimens. Specimens that clearly stained bright red were interpreted as living cells, while cells that did not stain red, or just barely indicated a red shine, were interpreted as dead because of the lacking protoplasm. This is also in accordance to Okazaki et al. (2004). All specimens on a slide were identified and counted, and their individual numbers were converted to standing stocks (No. specimens m^{-3}).

3.2. Hydrographic profiles

Profiles of temperature, salinity, dissolved oxygen, and chlorophyll *a* down to 1,000 m depth at stations 32 (Northwind Abyssal Plain) and 56 (southwestern Canada Basin) in September 2013 are from Nishino (2013) and shown in Fig. 2a and b, respectively. At Station 32, temperature showed sharp decrease from the surface and down to about 25 m depth with a sharp increase at the base of SML. The PSW is generally cold (about −1°C) with a maximum value (1.6°C) at about 50 m and shows a rapid decrease with increasing depth. The PWW is the coldest water (minimum value −1.6°C) at about 200 m. Highest temperatures are found in the AW (near or below 1°C) at about 400 m with a gradual decrease below 500 m. Salinity showed low values (25-28) in the SML, increasing rapidly with depth from 28-32 in the PSW. In the PWW there is a gradual increase of salinity from 32 to 35, while there is a slight decrease below the PWW/AW boundary. Dissolved oxygen showed maximum value (405 µmol/kg) at the boundary between SML and PWW, rapid decrease with increasing depth in the PSW and PWW, minimum value (270 µmol/kg) around the boundary between PWW and AW, and slight increase below that. Chlorophyll *a* higher than 0.1 mg m^{-3} was observed in 0-80 m depth. Temperature, salinity, dissolved oxygen, and chlorophyll *a* show almost similar values at both Station 32 and Station 56 except for SML and PSW. In the SML, salinity at Station 32 was slightly lower than at Station 56. In the PSW, a temperature peak at Station 32 was about one degree higher, and a little deeper, compared to Station 56. In 0-80 m depth, chlorophyll *a* was a little higher at Station 56 than at Station 32.

3.3. Sediment trap samples

Particle flux samples were collected by a sediment trap (SMD26 S-6000, open mouth area 0.5 m^2, Nichiyu Giken Kogyo, Co. Ltd.) rotated at 10–15-day intervals moored at 184 m (4th October 2010–28th September 2011)-260 m (4th October 2011–18th September 2012) and 1,300 m (4th October 2010–28th September 2011)-1,360 m (4th October 2011–18th September 2012) at Station NAP (Northwind Abyssal Plain, 75°00'N, 162°00'W, bottom depth 1,975 m) (Fig. 1; Table 2). The mooring system was designed to set the collecting instrument at approximately 600 m above the sea floor. This depth of the moored sediment traps was chosen in order to avoid possible inclusion of particles from the nepheloid layer, reaching about 400 m above the seafloor (Ewing and Connary, 1970). Recoveries and redeployments of the traps were carried out on the Canadian Coast Guard Ship I/B (ice breaker) “Sir Wilfrid

Laurier" and R/V "Mirai" of Japan Agency for Marine-Earth Science and Technology. The sample cups were filled with 5% buffered formalin seawater before the sediment trap was deployed. This seawater was collected from 1,000 m water depth in the southern Canada Basin, and was membrane filtered (0.45 mm pore size). The seawater in the sample cups was mixed with sodium borate as a buffer (pH 7.6–7.8) and 5% formalin was added as a preservative.

The samples were first sieved through 1 mm mesh to remove larger particles, which are not relevant for the present study. The samples were split with a rotary splitter (McLane^{TM}WSD-10). At first, we used 1/100 aliquot size of the samples to make microslides for microscope work (species identification). We made additional slides in case of low radiolarian specimen numbers. In order to remove organic matter and protoplasm, 20 ml of 10% hydrogen peroxide solution are added to the samples in a 100 ml pyrex beaker, and heated (not boiling) on a hot plate for one hour. After this reaction was completed, Calgon® (hexametaphosphate, surfactant) solution was added to disaggregate the sample. The treated samples were then sieved through a screen (45 μm mesh size). Both the coarse (>45 μm) and fine (<45μm) fractions were filtered through Gelman membrane filters with a nominal pore size of 0.45μm and desalted with distilled water. The edges of each filtered sample were cut according to slide size in wet condition and mounted on glass slides on a slide warmer. Xylene was added to the dried filters and samples, which were then permanently mounted with Canada balsam.

We made slides of both the coarse (>45 μm) and the fine (<45 μm) fraction of each sample. For the enumeration of radiolarian taxa in this study, we counted all specimens of radiolarian skeletons larger than 45 μm encountered on a slide. Each sample was examined under an Olympus compound light microscope at 200 x or 400 x magnification for species identification and counting. The radiolarian flux (No. specimens m^{-2} day^{-1}) was calculated from our count data using the following formula:

$$\mathrm{Flux} = N*V/S/D \qquad (1)$$

where N is the counted number of radiolarians, V the aliquot size, S the aperture area of the sediment trap (0.5 m^2), and D the sampling interval (day). Diversity indices using the Shannon-Weaver log-base 2 formula (Shannon and Weaver, 1949) were calculated for total radiolarians

$$H = -\sum P_i \log_2 P_i \qquad (2)$$

where H is the diversity index, P is the contribution of species (relative abundance in total radiolaria) and i is the order of species.

As supplemental environmental data, the moored sediment trap depth and the water temperature (accuracy of + 0.28°C) were monitored every hour (sensor type: ST-26S-T). Moored trap depth for the upper trap was lowered by about 80 m during the second year (about 260 m depth) than during the first year (about 180 m depth), caused by entanglement of the mooring ropes. During July-August in 2012, the moored trap depth was lowered to about 300 m, because of intensified water currents (Fig. S1). Time-series data of sea-ice concentration around Station NAP during the mooring period were calculated from the sea-ice concentration data set (http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_Smith OIv2/, cf. Reynolds et al., 2002).

3.4. Taxonomic note

The species described by Hülsemann (1963) under the name of *Tholospyris gephyristes* is not a Spyridae. This species has been accepted as a Spyridae by most workers, but this species lacks the sagittal ring that is typical for the Spyridae. We have therefore assigned this species to the family Plagiacanthidae. We suggest this species be renamed to *Tripodiscium gephyristes* until a proper taxonomic analysis has been undertaken.

4. Results

4.1. Radiolarians collected by plankton tows

A total of 43 radiolarian taxa (12 Spumellaria, 3 Entactinaria, 26 Nassellaria, and 2 Phaeodaria) were identified in the plankton tow samples (Table 3). We have observed taxopodians, but they have not been identified according to the two species as defined by Meunier (1910), nor have they been quantified. Furthermore, we have not been able to observe any collodarian individuals although we cannot exclude their presence in the Arctic Ocean (Lovejoy et al., 2006; Lovejoy & Potvin, 2011). The numbers of individuals for each radiolarian taxon are in Tables S1 (Station 32) and S2 (Station 56).

4.1.1. Standing stocks and diversities of radiolarians

The abundance of living radiolarians at Station 32 was about two times higher than at Station 56 at each depth interval in the upper 500 m, the depth level at which the abundance of living radiolarians decreased with increasing water depth at both stations (Fig. 2a and b). The abundance of dead radiolarians also decreased with water depth at both stations except for 100–250 m depth at Station 32 (Fig. 2a and b). The abundance of dead radiolarians was generally higher than living radiolarians at both stations except for in the 0–100 m depth at Station 32. The living radiolarian diversity index was low in the 0-100 m depth interval, increased with depth, reached a maximum at about 400 m, and then slightly decreased below 500 m depth at both stations.

At Station 32, *Amphimelissa setosa* (58%) and *Amphimelissa setosa* juvenile (22%) were dominant, and *Joergensenium* sp. A (6%), *Pseudodictyophimus clevei* (4%), Actinommidae spp. juvenile forms (3%), and *Actinomma leptodermum leptodermum* (1%) were common (Fig 3a). At Station 56 the Actinommidae spp. juvenile forms (38%) and *Amphimelissa setosa* (29%) were dominant, and *Actinomma leptodermum leptodermum* (6%), *Amphimelissa setosa* juvenile (6%), *Pseudodictyophimus clevei* (5%), and *Joergensenium* sp. A (4%) were common (Fig 3b). We defined the 2-shelled forms of Actinommidae as juvenile. Then the 3 and 4 shelled forms will be adult. For the *Amphimelissa setosa* we defined those with cephalis only as juveniles. Those with a well developed cephalis and with a barely or well developed thorax are defined as adult. Actinommidae spp. juvenile forms are mostly two-shelled juvenile forms of *Actinomma leptodermum leptodermum* and *Actinomma boreale*, making it impossible to separate between the two.

4.1.2. Environmental significance of the vertical distribution of radiolarian species

We selected fourteen abundant radiolarian taxa to show their relation to the vertical hydrographic structure in the western Arctic Ocean (Fig. 4). The selected taxa were radiolarian taxa with 1% or higher relative abundance through the upper 1,000 m of the water column at either of the two stations and with high relative abundance in each water depth.

Adult and juvenile forms of *Amphimelissa setosa* were mainly distributed in the 0–250 m depth at both stations. In the 0-100 m depth, adult and juvenile stages were dominant (70% and 28%, respectively) at Station 32, and at Station 56 (23% and 7%, respectively) following the juvenile *Actinomma* spp. (56%). In the 100–250 m depth, *A. setosa* was the dominant species at both stations. At Station 32, the abundance of *A. setosa* in the 100–250 m depth interval was lower than in the 0–100 m depth, whereas at

Station 56, the abundance in the 100-250 m depth was almost the same as in the 0–100 m depth.

Actinommidae spp. juvenile forms and *Actinomma l. leptodermum* were absent in 0–100 m depth at Station 32, but both, especially Actinommidae spp. juvenile forms (56%), were abundant at Station 56. Both were common in the 100-250 m depth at both stations (8% and 4%, respectively at Station 32; 14% and 7%, respectively at Station 56), and decreased in abundance in the 250–500 m depth. *Spongotrochus glacialis* was rare in the 0-100 m depth at Station 32 (0.4%) but with a slight increase at Station 56 (1.4%). In deeper layers *S. glacialis* was rare.

Joergensenium sp. A, *Pseudodictyophimus clevei,* and *Actinomma boreale* were abundant in the 100–250 m depth at both stations. *Joergensenium* sp. A was absent in the 0–100 m depth but abundant in the 100–250 m depth and rare in deeper depths. *Pseudodictyophimus clevei* was found throughout from the surface to 1,000 m depth, but was rare at Station 32 except for in 100-250 m. *Actinomma boreale* was rare and mainly found in the 100–250 m depth at both stations.

Ceratocyrtis histricosus was mainly found in the 250–500 m depth, and occurred also in the 100–250 m depth at both stations. *Tripodiscium gephyristes* was widely distributed below 100 m depth at Station 56, while at Station 32 this species was scarce at all depth layers. *Pseudodictyophimus g. gracilipes* occurred in very low numbers at both stations through the upper 1,000 m. *Pseudodictyophimus plathycephalus*, Plagiacanthidae gen. et sp. indet., and *Cycladophora davisiana* were most abundant below 500 m depth at both stations.

4.2. Radiolaria collected by sediment trap

A total of 51 radiolarian taxa (15 Spumellaria, 3 Entactinaria, 31 Nassellaria, and 2 Phaeodaria) were identified in the upper and lower sediment trap samples at Station NAP during 4th October 2010–18th September 2012 (Table 3). We have observed taxopodians, but they have not been identified nor quantified. Furthermore, we have not been able to observe any collodarian individuals. The number of radiolarians counted in each sample ranged from 8 to 1,100 specimens in the upper trap, and from 0 to 2,672 specimens in the lower trap (Tables S3 and S4). There were 15 samples with fewer than 100 specimens (2 samples in upper trap, 13 samples in lower trap). Most of the species recognized in our sample materials are shown in Plates 1-9.

4.2.1. Radiolarian flux and diversity in the upper trap

The highest total radiolarian fluxes in the upper trap were observed during the beginning of sea-ice cover season (November in 2010 and 2011, >10,000 specimens m^{-2} day^{-1}) (Fig. 5). The fluxes were higher during the open water season (August–October in 2011, average, 5,710 specimens m^{-2} day^{-1}) and around the end of sea-ice cover season (July–August in 2011, >4,000 specimens m^{-2} day^{-1}) than during the sea-ice cover season (December–June, average in 2011, 944 specimens m^{-2} day^{-1}; average in 2012, 723 specimens m^{-2} day^{-1}). The fluxes varied from 114 to 14,677 specimens m^{-2} day^{-1} with an annual mean of 2,823 specimens m^{-2} day^{-1}. The diversity of radiolarians, however, was higher during the sea-ice cover season (>3) than during the open water season (<2) (Fig. 5). The diversity indices were negatively correlated with the total radiolarian fluxes ($r = -0.91$) (Fig. 6).

Species composition varied seasonally. Adult and juvenile *Amphimelissa setosa* were most dominant (90%) during the sea-ice free season, and the beginning and the end of sea-ice cover season. The juvenile and adult forms were abundant in earlier and later seasons, respectively (Fig. 7). During the sea-ice cover season, however, Actinommidae spp. juvenile forms (range, 0–51%; average, 18%), *Actinomma leptodermum leptodermum* (range, 0–14.6%; average, 4%), *Actinomma boreale* (range, 0–33%; average, 4%) were dominant. Relatively high percentages of *Pseudodictyophimus clevei*, *Pseudodictyophimus gracilipes*, *Tripodiscium gephyristes* were also observed during the sea-ice cover season.

4.2.2. Radiolarian flux and diversity in the lower trap

Total radiolarian flux in the lower trap varied from 0 to 22,733 specimens m^{-2} day^{-1} with an annual mean of 4,828 specimens m^{-2} day^{-1} (Fig. 5). The fluxes were high during November–December both in 2010 and 2011 and during March in 2011 (>10,000 specimens m^{-2} day^{-1}), while extremely low (average, 21 specimens m^{-2} day^{-1}) during May-September in 2012. Diversity did not change greatly, and increased slightly during May-July 2011, and in April 2012 when the radiolarian fluxes were low. The diversity indices were weakly negatively correlated with the radiolarian fluxes ($r = -0.52$) (Fig. 6).

Adult and juvenile stages of *Amphimelissa setosa* were dominant throughout the sampling periods (range, 66–92%; average, 82%). The relative abundance of *A. setosa* juvenile was slightly increased in 2012 in comparison to 2010 and 2011.

5. Discussion

5.1. Comparison between Arctic and North Pacific Oceans

Biogenic particle flux into the deep sea in the Canada Basin was generally assumed to be low due to the low productivity of siliceous and calcareous microplankton, which plays an important role in the biological pump process (Honjo et al., 2010). However, we observed high radiolarian fluxes (14,677: upper trap, 22,733: lower trap) at Station NAP during the open water season and around the beginning and the end of sea-ice cover season in 2011-2012. The annual means (2,823: upper trap, 4,823: lower trap) were comparable to those observed in several areas of the North Pacific Ocean (Fig. 8, Table S5). However the radiolarian fluxes in the upper trap showed an apparent abundant season (July-November) and a sparse season (December-June) in a year, and that the lower trap also showed an extremely low flux during May-September 2012. Therefore we regarded the period when radiolarian fluxes were higher than 1σ (3,489: upper trap; 5,675: lower trap) as a contributing period. As a result, the mean of radiolarian fluxes during the contributing period in the western Arctic Ocean showed a higher value (7,344: upper trap; 11,871: lower trap) than at any other stations in the North Pacific Ocean (Table S5). The biogenic opal collected in this study mainly consisted of radiolarians and diatoms based on our microscopic observations. Other siliceous skeletons (silicoflagellate skeletons, siliceous endoskeleton of dinoflagellate genus *Actiniscus*, chrysophyte cysts, ebridian flagellate, and palmales) are minor components in the same trap samples (Onodera et al., 2014), therefore siliceous skeletons of radiolarians and diatoms might play an important role to export biogenic silica to the deep Arctic. Onodera et al. (2014) also estimated the diatom contribution to POC flux at station NAP, but more than half of the contribution to total POC has not been explained yet. Relatively high flux of radiolarians in arctic microplankton might contribute to a substantial part of the POC flux.

5.2. Characteristic and ongoing morphogenesis and speciation of radiolarians in the western Arctic Ocean

The radiolarian fauna observed in this study was characterized by high dominance of two families, the Cannobotryoidae and the Actinommidae (Fig. 3). *Amphimelissa setosa* is the dominant species, while the actinommids make a species association with a close affinity to the Norwegian Sea fauna. *Amphimelissa setosa* first appeared in the North Pacific and migrated into the North Atlantic through the Arctic Ocean during the Pleistocene interglacial optima (Matul and Abelmann, 2005). This species became extinct in the North Pacific close to the MIS 4/5 boundary (Kruglikova, 1999; Matul et al., 2002; Ikenoue et al., 2011), and has not been observed in recent materials in the North Pacific (Ikenoue et al., 2012a). Petrushevskaya (1979) pointed out that the arctic-boreal radiolarian species known from the Arctic Ocean basins had been originated from the early Postglacial Norwegian Sea polycystine radiolarian fauna. Bjørklund and Kruglikova (2003) also concluded that the modern radiolarian fauna in the Arctic Ocean had a close affinity to the Norwegian Sea radiolarian fauna. This is also supported by the species listed in Table 3, they all occur in the Norwegian Sea, except for the taxa that we at present classify as endemic to the Arctic Ocean. Inflow of radiolarians with waters from the northern part of the Bering Sea is probably negligible since the most abundant and typical radiolarian species in the recent Bering Sea such as *Stylochlamydium venustum*, and *Ceratospyris borealis* are absent in the western Arctic Ocean. These two species are surface dwellers in the North Pacific (Tanaka and Takahashi, 2008) and are major species in the recent Bering Sea (Ikenoue et al., 2012a). Our results suggest that the radiolarian fauna in the western Arctic Ocean was characterized by a wide morphologic variability in the skeletons within the family Actinommidae and high standing stock of *Joergensenium* sp. A in the PWW (Table S6). *Actinomma* morphogroup A (58 specimens), *Actinomma* morphogroup B (57 specimens), *Joergensenium* sp. A (1,401 specimens), has so far only been observed in the western Arctic Ocean in our study. We have not seen this species outside the Arctic Ocean, neither in the North Pacific or in the North Atlantic. *Actinomma* morphogroup A and B and *Joergensenium* sp. A might be new species endemic for the western Arctic. Kruglikova et al. (2009) described two new species *Actinomma georgii* and *A. turidae*, and suggested the possibility of endemism for these two species. They also indicated a fifth group *Actinomma* indet. (their fig. 5, p. 32) which probably consists of still several undescribed species. Their argument was that the endemism arose as radiolarians had been rapidly evolving under the stressful conditions in the Arctic Ocean, and that speciation or morphogenesis within the family Actinommidae might be ongoing in the central Arctic Basin. Our results support this hypothesis, and suggest that local speciation or morphogenesis took place not only in the central Arctic basin, but also in the western Arctic Ocean. This is demonstrated by the occurrence of what we interpret as new and still undescribed *Actinomma* species. These new forms are very similar to *A. boreale*, but with a different structure of the medullary shells. Also within the radiolarian group Entactinaria, in the genus *Joergensenium*, one or two undescribed species are found. The reason for radiolarian species speciation in this area is still not understood but we can only speculate that this can be controlled by the harsh environmental stress (Allen and Gilooly, 2006; Kruglikova et al., 2009), particularly the extremely cold water masses under the sea-ice (−1.7°C) and the always-changing quality of the water masses, affected by the inflowing Pacific water.

5.3. Vertical distribution of species and hydrographic structure

5.3.1. PSW and PWW association

Amphimelissa setosa and its juvenile stages were found in shallow cold-water in both stations 32 and 56. Specifically, they were more abundant in the SML and PSW (0-100 m) at Station 32 than Station 56. At Station 32, these two water masses exhibited warmer temperature (about one degree higher at the temperature peak) than Station 56; indicating that cold to moderately warm (-1.2 to 1.6 ºC), and well mixed water mass were more favorable for this species than perennial cold water masses such as PWW (100-250 m). According to Dolan et al. (2014), *A. setosa* showed significantly lower abundances with higher chlorophyll *a* concentrations of 2012, the low sea ice year, compared to the year of 2011 with higher sea ice and lower chlorophyll *a* concentrations. Thus, the abundance of phytoplankton protoplasm with the remains of chlorophyll *a* is not related with the abundance of *A. setosa*. This is harmonious with our result that chlorophyll *a* was a little higher at Station 56 but the abundance of *A. setosa* at Station 56 was fairly lower than that at Station 32 in contrast to Actinommidae spp. juvenile forms, *Actinomma l. leptodermum*. Therefore the favorable condition for *A. setosa* is related to cold and well mixed water mass and any other organisms except for those from phytoplankton near the summer sea-ice edge. The vertical and geographic distribution of *A. setosa* has been described in several previous studies. This species dominated (60-86%) the radiolarian assemblage through the upper 500 m of the water column in the Chukchi Sea and the Beaufort Sea and so can be an indicator of cold

Arctic surface water (Itaki et al., 2003). Bernstein (1931) noted that this species live in the cold (-1.68ºC to -1.29ºC) and saline (34.11 to 34.78) waters in the Arctic Ocean. Matul and Abelmann (2005) also suggested that *A. setosa* prefers well-mixed, cold and saline surface/subsurface waters. Bjørklund et al. (1998) reported its distribution in the western part of the GIN Seas, being dominant (up to 76%) at the Iceland Plateau and common (>20%) just north of the Iceland–Faeroe Ridge. In the eastern part of the Barents Sea, west of Novaja Zemlya, Bjørklund and Kruglikova (2003) reported *Amphimelissa setosa* as the dominant (77%) species.

Actinommidae spp. juvenile forms, *Actinomma l. leptodermum*, *Spongotrochus glacialis* were mainly distributed in the PSW and PWW and preferred different water masses from *Amphimelissa setosa*. *Actinomma l. leptodermum* and *Actinomma boreale* had been reported as a group (e.g., Samtleben et al., 1995), due to identification problems, particularly of the juvenile stages, but the adult stages can be separated into two species following Cortese and Bjørklund (1998). *Actinomma l. leptodermum* were absent in the water masses of SML and PSW at Station 32, but they were abundant in these water masses at Station 56. At Station 56, SML and PSW water masses were colder (-1.2 to 0.6 ºC) and more homogeneous than at Station 32; indicating that Actinommidae spp. juvenile forms and *A. l. leptodermum* preferred slightly warmer water than PWW (-1.6 ºC). Our results show that Actinommidae spp. juvenile forms and *A. l. leptodermum* are most abundant in the upper water layers where phytoplankton also prevails (Fig. 2). It is most likely that the juvenile actinommids and *A. l. leptodermum* may be bound to the euphotic zone, and so can be herbivorous. *Spongotrochus glacialis*, showing a similar vertical distribution as Actinommidae spp. juvenile forms and *Actinomma l. leptodermum*, also preferred warmer water than PWW. This species inhabited surface water in the Okhotsk Sea, and is well adapted to low temperatures and low salinities (Nimmergut and Abelmann 2002). Okazaki et al. (2004) reported *S. glacialis* as a subsurface dweller with abundance maximum in the 50–100 m interval in the Okhotsk Sea, associated with the phytoplankton production.

5.3.2. PWW association

Joergensenium sp. A, *Pseudodictyophimus clevei*, and *Actinomma boreale,* were mainly distributed in the PWW. *Joergensenium* sp. A and *P. clevei* might prefer cold water (-1.7°C) with low turbulence. The depth distribution of *Joergensenium* sp. A was restricted to the PWW (100-250 m) and the upper AW (250-500 m), but *P. clevei* was more widely distributed. *Joergensenium* sp. A has not yet been described from recent radiolarian assemblages, so it can be suggested that this species might occur only on the Pacific side of the Arctic Ocean and might serve as an indicator for the PWW layer. Standing stocks of *A. boreale* were lower than Actinommidae spp. juvenile forms and *A. l. leptodermum* at both stations, and mainly occurred in the PWW. In the surface sediments of the Greenland, Iceland and Norwegian Seas, *A. boreale* is associated with warm (Atlantic) water, whereas *A. l. leptodermum* seems to have broader environmental tolerance, as it is associated with both the cold East Greenland Current and the warm Norwegian Current water (Bjørklund et al., 1998). Other environmental factors such as salinity, food availability, or seasonal differences of their growth stages due to the sampling period might influence the standing stocks of *A. boreale*.

5.3.3. Upper AW association

Ceratocyrtis histricosus occurred commonly in the upper AW (250-500 m) and rarely in the PWW. This species is a species interpreted as being introduced from the Norwegian Sea, most likely during the early Holocene, by the warm Atlantic water drifting through the Arctic Ocean (Kruglikova, 1999). Itaki et al. (2003) first noticed that *Ceratospyris histricosus* had not been observed in the Canada Basin during the 1950s and 1960s and he pointed out that the common occurrence of this species in the Chukchi and Beaufort seas in 2000 might be an effect of the recent warming of the AIW. Itaki et al. (2003) also introduced that the temperature of the AIW in 1994 at the Chukchi-Mendeleyev boundary was higher by at least 0.2ºC than in the 1950s and 1960s, from Swift et al (1997). Differing from Itaki et al. (2003), we first found this species in the PWW. According to McLaughlin et al. (2011), the mean temperature of the PWW within the Canada Basin increased slightly (~0.05ºC) from 2003 to 2007 and then remained constant until 2010. According to Itaki et al. (2003), *C. histricosus* can survive in the temperature range of 0.5–4ºC. Although our data on the temperature of the PWW is apparently lower than the lower limit for survival of this species (Fig. 2), the rare existence of this species in the PWW may be caused by unobserved warming in the PWW or by appearance of other optimistic conditions for *C. histricosus*. However, the warming in the AIW has already been recognized in 1994 (Swift et al., 1997) and a warming in the PWW is also reported by McLaughlin et al. (2011), suggesting that the recent warming of the PWW and AW might induce the expansion of the habitat of *C. histricosus* into the PWW. It is not so much the effect of the temperature itself that is causing the expanding distribution of *C. histricosus*, but the general temperature increase indicates that larger volumes of warmer AW is entering the Arctic Ocean. The increasing volumes of inflowing AW will therefore increase the chances for more exotic radiolarians to reach further and further into the Arctic Ocean and the Chukchi Sea.

Bjørklund et al. (2012) reported 98 tropical-subtropical radiolarian taxa in the area north of Svalbard in the eastern Arctic Ocean. They stated that there are always pulses of warm Atlantic water that do reach the Arctic Ocean, transporting warmer water fauna. We did not observe any tropical and subtropical radiolarian taxa in the western Arctic Ocean. However, future, continuous monitoring of the annual changes in the radiolarian fauna, including *C. histricosus*, in the western Arctic Ocean might be able to pick up this type of signal.

5.3.4. Lower AW association

Pseudodictyophimus plathycephalus, Plagiacanthidae gen. et sp. indet. (Pl. 8, Figs. 11-18), and *Cycladophora davisiana* were abundant in the cold and oxygenated lower AW at both stations. However, their distribution patterns in PWW and upper AW water masses were slightly different between Station 32 and Station 56 whereas temperature, salinity, and dissolved oxygen have similar values at both stations. Their standing stocks might therefore reflect the influence of other variables than hydrographic conditions alone. *Pseudodictyophimus g. gracilipes* is widely distributed in the World Ocean, and known to inhabit the surface layer at high latitudes, while living at greater depth at low latitudes (Ishitani and Takahashi, 2007; Ishitani et al., 2008). Itaki et al. (2003) reported that the maximum depth *P. g. gracilipes* occurred at 0-50 m in the Chukchi Sea and 25-50 m in the Beaufort Sea. However, in our results, *P. g. gracilipes* did not show any specific vertical distribution, and its standing stocks were low.

5.4. Seasonal and annual radiolarian flux

5.4.1. Radiolarian fauna and seasonal sea-ice concentration

Seasonal radiolarian fluxes at Station NAP were characterized by the high dominance of a few species and the changes of their ratios in the upper trap with the seasonal changes in sea-ice concentration. *Amphimelissa setosa* adult and its juvenile forms were dominant during the open-water season and around the beginning and the end of ice-cover seasons, while the actinommids (Actinommidae spp. juvenile forms, *Actinomma l. leptodermum*, *Actinomma boreale*) were dominant during the ice-cover season (Fig. 5). These observations might explain the regional difference in the radiolarian species distribution in the Arctic Ocean. *Amphimelissa setosa* were dominant in Arctic marginal sea sediments (Iceland, Barents, and Chukchi Seas) where sea-ice disappeared in the summer but Actinommidae were dominant in the central Arctic Ocean (Nansen, Amundsen, and Makarov Basins) where the sea surface was covered by sea-ice throughout the year (Bjørklund and Kruglikova, 2003). Zasko et al. (2014) also reported that *A. setosa* was essentially absent in the plankton samples in the central polar basins. The summer ice edge hosts well-grown ice algae and ice fauna (Horner et al., 1992; Michel et al., 2002; Assmy et al., 2013) and its presence causes an alternation between stable water masses and deep vertical mixing where the nutrients are brought to the surface (Harrison and Cota, 1991), with both conditions being favorable for primary productivity. Swanberg and Eide (1992) found that abundance of *A. setosa* and its juveniles was correlated well with Chlorophyll *a* and phaeopigments along the ice edge in summer in the Greenland Sea. Dolan et al. (2014), however, reported that the abundance of *A. setosa* was not entirely related to high Chlorophyll *a* with low sea-ice concentration as we have said in section 5.3.1. Therefore we interpreted that cold and well mixed water mass based on summer ice edge and maybe also other ice fauna elements were essential for high reproduction and growth of *A. setosa*.

From the upper trap, a flux peak of *A. setosa* juvenile occurred at the end of the sea-ice season, and that the flux peak of adult *A. setosa* occurred at the beginning of the sea-ice season (Fig. 7). The time interval between these peaks might indicate that *A. setosa* has a three months life cycle. *Pseudodictyophimus clevei* also shows flux peaks during the beginning of the sea-ice season (November-December) (Fig. 7). These two species seem to prefer to live under a cold water mass with sea-ice formation. On the contrary, juvenile stages of actinommids were dominant during the ice-cover season (Fig. 5). Therefore, we interpreted the actinommids to be tolerant of oligotrophic and stratified cold water masses. Itaki and Bjørklund (2007) reported that reproduction could occur even at the juvenile stage in at least some actinommids since they frequently found conjoined juvenile Actinommidae skeletons in the Japan Sea sediments. Furthermore, the flux of Actinommidae spp. juvenile forms increased towards the end of the sea-ice cover season, accompanied by an increase in downward shortwave radiation (Fig. 5 and 7). This might indicate that Actinommidae spp. juvenile form can feed on algae growing on the ice or other phytoplankton under the sea-ice. Therefore, *A. setosa* and the juvenile actinommids might have different nutritional niches.

This study showed that the productivity of radiolarians was high, but diversity was low, during summer season with low sea-ice concentration in the western Arctic Ocean (Fig. 5 and 6). In contrast, radiolarian fauna in the sediment trap set in the Okhotsk Sea showed high diversity during summer season (Okazaki et al., 2003). The maximum total radiolarian flux during the summer season around the sea-ice edge and the open water is characterized by high dominance of *A. setosa* (>90%) in our area. Such high dominance of a single species does not occur in the Okhotsk Sea, where the main nine taxa contributed with more than 60 % of the radiolarian assemblage (Okazaki et al., 2003). *Amphimelissa setosa*, which has a small and delicate siliceous skeleton, might respond to water mass conditions near summer ice edge both more directly and more rapidly. The contrast of seasonal diversity between these two areas was due to the difference of species composition and their response to water mass changes with low sea-ice.

Actinomma boreale, *Spongotrochus glacialis*, *Joergensenium* sp. A were probably related to food supply to the PWW during the sea-ice free season. Relatively higher fluxes of these three species in the upper trap in summer 2012 compared to summer 2011 might be due to an effect of the deeper mooring depth of the trap after October 2011 (Fig. 7 and S1). This might be caused by their vertical distribution patterns, as they are more abundant at depths lower than the first upper trap depth (about 180 m) (Fig. 3a). On the other hand, *Ceratocyrtis histricosus* and *Tripodiscium gephyristes* in the upper trap showed increase in their fluxes from May to September in summer 2012. The water temperature at the upper trap depth also increased during the same period (Fig. 7 and S1), we therefore interpreted their increase to be related to the mixing of nutrient and warm upper AW and lower PWW, rather than a decrease in sea ice concentrations due to their preference for the warm, upper AW.

5.4.2. Radiolarian fauna and interannual difference in ocean circulation

Intensification of geostrophic currents on the periphery of Beaufort Gyre (Fig. 1) has been reported in recent years (Nishino et al., 2011; McPhee, 2013). This intensification is caused by increasing volume of water from sea-ice melt associated with the reduction of arctic summer sea-ice and the river runoff to the basins (Proshutinsky et al., 2009; Yamamoto-Kawai et al., 2008). The total radiolarian flux showed lower production during summer (July-September) in 2012 than in 2011 in both the upper and, especially, lower traps (Fig. 5). Most radiolarian taxa also showed lower flux during summer of 2012 (Fig. 7). On the other hand, fluxes of the actinommids (Actinommidae spp. juvenile forms, *Actinomma l. leptodermum*, *Actinomma boreale*), possibly adapted to cold and oligotrophic water, showed higher values during December 2011-September 2012 than during December 2010-September 2011. Actinommidae spp. juvenile forms and *A. l. leptodermum* were most abundant in the depth interval of 0-100 m at Station 56 in the southwestern Canada Basin. Therefore, we interpreted these data to mean that cold and oligotrophic water in the Canada Basin began to spread to Station NAP in the Northwind Abyssal Plain from December 2011 and continued to affect the radiolarian fluxes at least until September 2012. McLaughlin et al. (2011) reported that the position of the center of the Beaufort Gyre shifted westwards and that the area under the influence of the gyre spread northwards and westwards in recent years. Moreover, high-resolution pan-Arctic Ocean model results also showed that the Beaufort Gyre expanded by shifting its center from the Canada Basin interior to the Chukchi Borderland in 2012 compared with 2011, and the ocean current direction in the surface 100 m layer switched northwestward to southwestward in December 2011 (E. Watanabe, personal communication, 2014). Thus, recent intensification of Beaufort Gyre currents associated with sea-ice reduction, would have affected the surface water mass conditions and as well as the ecological conditions in the western Arctic Ocean.

5.4.3. Vertical and lateral transport

Flux peaks of total radiolarians in the lower trap are delayed by about two weeks in comparison to the upper trap (Fig. 5). Therefore, the sinking speed of the aggregated radiolarian particle flux between these depths were averaged to 74 m day^{-1} during November-December 2010, 86 m day^{-1} during July-August 2011, and 73 m day^{-1} during November 2011. Watanabe et al. (2014) simulated movement of cold and warm eddies using a high-resolution pan-Arctic Ocean model, and suggested that the high total mass flux during October-December 2010 at Station NAP, as we determined using sediment samples, was mainly due to the enhancement of the marine biological pump by an anti-cyclonic cold eddy. Shelf-break eddies induce the lateral transport of resuspended bottom sediments composed of old carbon, and enhance the biological pump (O'Brien et al., 2013; Watanabe et al., 2014). Actually, the passage of a cold eddy was observed as a cooling and a deepening of the moored trap depth in the corresponding period (Fig. S1). *Amphimelissa setosa* was the most dominant species (>90%) and showed the highest flux (13,840 specimens m^{-2} day^{-1}) during November 2010 in the upper trap. The flux of this species was about 3,500 specimens m^{-2} day^{-1} higher and kept the highest value half a month longer than that in 2011. The cold eddy passage would transport a cold and well mixed water mass, conditions favorable for *A. setosa*. Therefore the cold eddy passage in addition to seasonal water mass variations with sea ice formation would enhance the high radiolarian flux.

Radiolarian fluxes in the lower trap were generally higher than in the upper trap except for May-September 2012 (Fig. 5). The extremely low fluxes in the lower trap during this interval might be due to a decrease of aggregate formation. The latter process, which helps rapid sinking of biogenic particles, would be suppressed by influx of oligotrophic surface water originating from the Beaufort Gyre in the Canada Basin. In the southwestern Canada Basin (Station 56), high standing stock of dead radiolarian specimens (Fig. 2) might indicate an inefficient biological pump in this area. In addition, fluxes of Actinommidae spp. juvenile forms were lower in the lower trap, in spite of their high abundance in the upper trap since December 2011. We speculate that the disappearance of fluxes of Actinommidae spp. juvenile forms in the lower trap might be due to lack of aggregate formation.

Higher abundance in the lower trap of species having a wider vertical distribution (*Pseudodictyophimus g. gracilipes*, *P. plathycephalus*) or intermediate to deep water distribution (*Ceratocyrtis histricosus, Tripodiscium gephyristes*, Plagiacanthidae gen. et sp. indet., and *Cycladophora davisiana*) might be attributed to the reproduction of these species at a depth level situated between the upper and lower traps. The seasonal changes in the fluxes of intermediate and deep dwellers to the lower trap would reflect the availability of food supply. The flux of *Pseudodictyophimus g. gracilipes*, *P. plathycephalus*, Plagiacanthidae gen. et sp. in det. and *Cycladophora davisiana* in the lower trap was high during July-August 2011. This probably indicates that decomposing material from the primary production during the sea-ice free season was transported to great depths and might also act as a substrate for bacterial growth, providing the deep water radiolarians with sufficient food elements. We have no data to support this but in the Chukchi Sea, moderately high rates of bacterial production at the end of the growing season (July-August) have been found (Cota et al., 1996; Wheeler et al., 1996; Rich et al., 1997). Most of the radiolarian species in the lower trap also peak during March 2011, a period of heavy ice cover and low downward shortwave radiation. In addition, in the lower trap the flux peak during March in 2011 was made up of more than 80% of *A. setosa*, a definite surface water species. However, during this period a similar peak was not found in the upper trap. Therefore, the flux peaks during March 2011 could be derived from some lateral advection at a depth lower than 180m or a re-suspension of shelf sediments.

Acknowledgements

We are grateful to the captain, officers and crews of the CCGS Sir Wilfrid Laurier, R.V. Mirai (JAMSTEC), operated by GODI, R/V, Dr. Humfrey Melling (IOS, Canada), Dr. Shigeto Nishino for their help in the mooring operation and sampling collection. We are thankful to Dr. A. Matul (P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow) for critically reading and commenting on our manuscript. We similarly thankful to G. Cortese for his detailed comments and correcting our English, this greatly improved our manuscript. We are thankful to one anonymous reviewer who had some good and helpful comments and suggestions. This work was supported by JSPS KAKENHI Grant Number 22221003 to NH and JSPS KAKENHI Grant Number 24•4155 and 26740006 to TI. TI received partial fund from Tatsuro Matsumoto Scholarship Fund of the Kyushu University. This work was partly carried out when TI was visiting the Natural History Museum, University of Oslo in 2013.

References

Aagaard, K., Coachman, L. K., and Carmack, E.: On the halocline of the Arctic Ocean, Deep-Sea Res. Pt. I, 28, 529–545, 1981.

Aagaard, K., Swift, J. H., and Carmack, E. C.: Thermohaline circulation in the Arctic Mediterranean seas, J. Geophys. Res., 90, 4833–4846, 1985.

Adl, S. M., Simpson, G. B., Farmer, M. A., Andersen, R. A., Anderson, O. R., Barta, J.

R., Bowser, S. S., Brugerolle, G., Fensome, R. A., Fredericq, S., James, T. Y., Karpov, S., Kugrens, P., Krug, J., Lane, C. E., Lewis, L. A., Lodge, J., Lynn, D. H., Mann, D. G., Mccourt, R. M., Mendoza, L., Moestrup, Ø., Mozley-Standridge, S. E., Nerad, T. A., Shearer, C. A., Smirnov, A. V., Spiegel, F. W., and Taylor, M. F. J. R.: The new higher level classification of Eukaryotes with emphasis on the taxonomy of protists, J. Eukaryot. Microbiol. 52, 399–451, 2005.

Allen, A. P. and Gilooly, J. F.: Assessing latitudinal gradients in speciation rates and biodiversity at the global scale, Ecol. Lett., 9, 947–954, 2006.

Anderson, O. R.: Radiolaria, Springer, New York, 365 pp., 1983.

Arrigo, K. R., Perovich, D. K., Pickart, R. S., Brown, Z. W., van Dijken, G. L., Lowry, K. E., Mills, M. M., Palmer, M. A., Balch, W. M., Bahr, F., Bates, N. R., Benitez-Nelson, C., Bowler, B., Brownlee, E., Ehn, J. K., Frey, K. E., Garley, R., Laney, S. R., Lubelczyk, L., Mathis, J., Matsuoka, A., Mitchell, B. G., Moore, G. W. K., Ortega-Retuerta, E., Pal, S., Polashenski, C. M., Reynolds, R. A., Scheiber, B., Sosik, H. M., Stephens, M., and Swift, J. H.: Massive phytoplankton blooms under Arctic sea ice, Science, 336, 1408, doi:10.1126/science.1215065, 2012.

Assmy, P., Ehn, J. K., Fernández-Méndez, M., Hop, H., Katlein, C., Sundfjord, A., Bluhm, K., Daase, M., Engel, A., Fransson, A., Granskog, M. A., Hudson, S. R., Kristiansen, S., Nicolaus, 5 M., Peeken, I., Renner, A. H. H., Spreen, G., Tatarek, A., and Wiktor, J.: Floating ice–algal aggregates below melting Arctic Sea ice, PLoS ONE, 8, e76599, doi:10.1371/journal.pone.0076599, 2013.

Bailey, J. W.: Notice of microscopic forms found in the soundings of the Sea of Kamtschatka, Am. J. Sci. Arts, 22, 1–6, 1856.

Bates, N. R. and Mathis, J. T.: The Arctic Ocean marine carbon cycle: evaluation of air-sea CO2 exchanges, ocean acidification impacts and potential feedbacks, Biogeosciences, 6, 2433–2459, doi:10.5194/bg-6-2433-2009, 2009.

Bates, N. R., Moran, S. B., Hansell, D. A., and Mathis, J. T.: An increasing CO2 sink in the Arctic Ocean due to sea-ice loss, Geophys. Res. Lett., 33, L23609, doi:10.1029/2006GL027028, 2006.

Bernstein, T.: Protist plankton of the North-west part of the Kara Sea, Transactions of the Arctic Institute, 3, 1–23, 1931 (in Russian with English summary).

Bernstein, T.: Über einige arktische Radiolarien, Arch. Protistenkunde, 76, 217–227, 1932.

Bernstein, T.: Zooplankton des Nordlischen teiles des Karischen Meeres, Transactions of the Arctic Institute, 9, 3–58, 1934 (in Russian with German summary).

Bjørklund, K. R. and Kruglikova, S. B.: Polycystine radiolarians in surface sediments in the Arctic Ocean basins and marginal seas, Mar. Micropaleontol., 49, 231–273, 2003.

Bjørklund, K. R., Cortese, G., Swanberg, N., and Schrader, H. J.: Radiolarian faunal provinces in surface sediments of the Greenland, Iceland and Norwegian (GIN) seas, Mar. Micropaleontol., 35, 105–140, 1998.

Bjørklund, K. R., Dumitrica, P, Dolven, J. K., and Swanberg, N. R.: Joergensenium rotatile n. gen., n. sp. (Entactinaria, Radiolaria): its distribution in west Norwegian fjords, Micropaleontology, 53, 457–468, 2008.

Bjørklund, K. R., Kruglikova, S. B., and Anderson, O. R.: Modern incursions of tropical Radiolaria into the Arctic Ocean, J. Micropalaeontol., 31, 139–158, doi:10.1144/0262-821X11-030, 2012.

Bjørklund, K. R., Itaki, T., and Dolven, J. K.: Per Theodor Cleve: a short résumé and his radiolarian results from the Swedish Expedition to Spitsbergen in 1898, J. Micropalaeontol., 33, 59–93, 2014.

Boetius, A., Albrecht, S., Bakker, K. B., Bienhold, C., Felden, J., Fernández-Méndez, M., Hendricks, S., Katlein, C., Lalande, C., Krumpen, T., Nicolaus, M., Peeken, I., Rabe, B., Rogacheva, A., Rybakova, E., Somavilla, R., and Wenzhöfer, F.: Export of algal biomass from the melting arctic sea ice, Science, 339, 1430–1432, doi:10.1126/science.1231346, 2013.

Boltovskoy, D., Kling, S. A., Takahashi, K., and Bjørklund, K. R.: World atlas of distribution of recent polycystina (Radiolaria), Palaeontol. Electron., 13, 1–230, available at: http: //palaeo-electronica.org/2010_3/215/index.html (last access: 29 November 2014), 2010.

Burridge, A. K., Bjørklund, K. R., Kruglikova, S. B., and Hammer, Ø.: Inter- and intraspecific morphological variation of four-shelled *Actinomma* taxa (Radiolaria) in polar and subpolar regions, Mar. Micropaleontol., 110, 50–71, 2013.

Calbet, A. and Landry, M. R.: Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems, Limnol. Oceanogr., 49, 51–57, 2004.

Cavalier-Smith, T.: A revised six-kingdom system of life, Biol. Rev., 73, 203-266, 1998.

Cavalier-Smith, T.: The phagotrophic origin of eukaryotes and phylogenetic classification of Protozoa, Int. J. Syst. Evol. Micr., 52, 297-354, 2002.

Cavalier-Smith, T. and Chao, E. E. Y.: Phylogeny and classification of phylum Cercozoa (Protozoa), Protist, 154, 341–358, 2003.

Cleve, P. T.: Plankton collected by the Swedish Expedition to Spitzbergen in 1898, Kgl. Svenska Vetensk. Akad. Hand., 32, 1–51, 1899.

Coachman, L. and Barnes, C. A.: The contribution of Bering Sea water to the Arctic Ocean, Arctic, 14, 147–161, 1961.

Coachman, L. K., Aagaard, K., and Tripp, R. B.: Bering Strait: the regional physical oceanography, University of Washington Press, Seattle, 172 pp., 1975.

Comiso, J. C., Parkinson, C. L., Gersten, R., and Stock, L.: Accelerated decline in the Arctic sea ice cover, Geophys. Res. Lett., 35, L01703, doi:10.1029/2007GL031972, 2008.

Cortese, G. and Bjørklund, K. R.: The morphometric variation of *Actinomma boreale* (Radiolaria) in Atlantic boreal waters, Mar. Micropaleontol., 29, 271–282, 1997.

Cortese, G. and Bjørklund, K. R.: The taxonomy of boreal Atlantic Ocean. Actinommida (Radiolaria), Micropaleontology, 44, 149–160, 1998.

Cortese, G., Bjørklund, K. R., and Dolven, J. K.: Polycystine radiolarians in the Greenland–Iceland–Norwegian seas: species and assemblage distribution, Sarsia: North Atlantic Marine Science, 88, 65–88, 2003.

Cota, G. F., Pomeroy, L. R., Harrison, W. G., Jones, E. P., Peters, F., Sheldon Jr, W. M., and Weingartner, T. R.: Nutrients, primary production and microbial heterotrophy in the southeastern Chukchi Sea: Arctic summer nutrient depletion and heterotrophy, Mar. Ecol. Prog. Ser., 135, 247-258, 1996.

Dolan, J. R., Yang, E. J., Kim, T. W. and Kang, S.-H.: Microzooplankton in a warming Arctic: A comparison of tintinnids and radiolarians from summer 2011 and 2012 in the Chukchi Sea, Acta Protozool., 53, 101–113, 2014.

Dolven, J. K., Bjørklund, K. R., and Itaki, T.: Jørgensen's polycystine radiolarian slide collection and new species, J. Micropalaeontol., 33, 21–58, 2014.

Dumitrica, P.: Cleveiplegma n. gen., a new generic name for the radiolarian species Rhizoplegma boreale (Cleve, 1899), Revue de Micropaléontologie, 56, 21–25, 2013.

Ehrenberg, C. G.: Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen, Abhandlungen, Jahre 1838, K. Preuss. Akad. Wiss., Berlin, 59–147, 1838.

Ehrenberg, C. G.: Über das organischen Leben des Meeresgrundes in bis 10 800 und 12 000 Fuss Tiefe, Bericht, Jahre 1854, K. Preuss. Akad. Wiss., Berlin, 54–75, 1854.

Ehrenberg, C. G.: Über die Tiefgrund-Verhältnisse des Oceans am Eingange der Davisstrasse und bei Island, Monatsberichte. Jahre 1861, K. Preuss. Akad. Wiss., Berlin, 275–315, 1862.

Ehrenberg, C. G.: Mikrogeologischen Studien über das kleinste Leben der Meeres-Tiefgrunde aller Zonen und dessen geologischen Einfluss, Abhandlungen, Jahre 1873, K. Preuss. Akad. Wiss., Berlin, 131–399, 1873.

Ehrenberg, C. G.: Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht der mikroskopischen Palaontologie gleichartig analysirter Gebirgsarten der Erde, mit specieller Rucksicht auf den Polycystinen-Mergel von Barbados, Abhandlungen, Jahre 1875, K. Preuss. Akad. Wiss., Berlin, 1–225, 1875.

Ewing, M. and Connary, S.: Nepheloid layer in the North Pacific, in: Geological Investigations of the North Pacific, edited by: Hays, J. D., Geol. Soc. Am. Mem., 126, 41–82, 1970.

Francois, R., Honjo, S., Krishfield, R., and Manganini, S.: Factors controlling the flux of organic carbon to the bathypelagic zone of the ocean, Global Biogeochem. Cy., 16, 1087, doi:10.1029/2001GB001722, 2002.

Haeckel, E.: Die Radiolarien (Rhizopoda Radiaria) – Eine Monographie, Reimer, Berlin, 572 pp., 1862.

Haeckel, E.: Über die Phaeodarien, eine neue Gruppe kieselschaliger mariner Rhizopoden, Jenaische Zeitschrift für Naturwissenschaft, 14, 151–157, 1879.

Haeckel, E.: Prodromus Systematis Radiolarium, Entwurf eines Radiolarien-Systems auf Grund von Studien der Challenger-Radiolarien, Jenaische Zeitschrift für Naturwissenschaft,15, 418–472, 1881.

Haeckel, E.: Report on the Radiolaria collected by the H.M.S. *Challenger* during the Years 1873–1876, Report on the Scientific Results of the Voyage of the H.M.S. *Challenger*, Zoology, 18, 1–1803, 1887.

Harrison, W. G. and Cota, G. F.: Primary production in polar waters: relation to nutrient availability, Polar Res., 10, 87–104, 1991.

Hertwig, R.: Der Organismus der Radiolarien, Jenaische Denkshr., 2, 129–277, 1879.

Honjo, S., Krishfield, R. A., Eglinton, T. I., Manganini, S. J., Kemp, J. N., Doherty, K., Hwang, J., Mckee, T. K., and Takizawa, T.: Biological pump processes in the cryopelagic and hemipelagic Arctic Ocean: Canada Basin and Chukchi Rise, Prog. Oceanogr., 85, 137–170, 2010.

Horner, R. A., Ackley, S. F., Dieckmann, G. S., Gulliksen, B., Hoshiai, T., Legendre, L., Melnikov, I. A., Reeburgh, W. S., Spindler, M., and Sullivan, C. W.: Ecology of sea ice biota. 1. Habitat, terminology, and methodology, Polar Biol., 12, 417–427, 1992.

Hülseman, K.: Radiolaria in plankton from the Arctic drifting station T-3, including the description of three new species, Arc. Inst. North Am. Tech. Pap., 13, 1–52, 1963.

Ikenoue, T., Ishitani, Y., Takahashi, K., and Tanaka, S.: Seasonal flux changes of radiolarians at Station K2 in the Western Subarctic Gyre, Umi no Kenkyu (Oceanography in Japan), 19, 165–185, 2010 (in Japanese, with English abstract).

Ikenoue, T., Takahashi, K., Sakamoto, T., Sakai, S., and Iijima, K.: Occurrences of radiolarian biostratigraphic markers *Lychnocanoma nipponica sakaii* and *Amphimelissa setosa* in Core YK07-12 PC3B from the Okhotsk Sea, Memoirs of the Faculty of Science, Kyushu University. Series D, Earth and Planetary Sciences, 32, 1-10, 2011.

Ikenoue, T., Takahashi, K., and Tanaka, S.: Fifteen year time-series of radiolarian fluxes and environmental conditions in the Bering Sea and the central subarctic Pacific, 1990–2005, Deep-Sea Res. Pt. II, 61–64, 17–49, 2012a.

Ikenoue, T., Ueno, H., and Takahashi, K.: Rhizoplegma boreale (Radiolaria): a tracer for mesoscale eddies from coastal areas, J. Geophys. Res., 117, C04001, doi:10.1029/2011JC007728, 2012b.

Ishitani, Y. and Takahashi, K.: The vertical distribution of Radiolaria in the waters surrounding Japan, Mar. Micropaleontol., 65, 113–136, 2007.

Ishitani, Y., Takahashi, K., Okazaki, Y., and Tanaka, S.: Vertical and geographic distribution of selected radiolarian species in the North Pacific, Micropaleontology, 54, 27–39, 2008.

Itaki, T. and Bjørklund, K. R.: Conjoined radiolarian skeletons (Actinommidae) from the Japan Sea sediments, Micropaleontology, 53, 371–389, 2007.

Itaki, T., Ito, M., Narita, H., Ahagon, M., and Sakai, I.: Depth distribution of radiolarians from the Chukchi and Beaufort Seas, western Arctic, Deep-Sea Res. Pt. I, 50, 1507–1522, 2003.

Itoh, M., Nishino, S., Kawaguchi, Y., and Kikuchi, T.: Barrow Canyon fluxes of volume, heat and freshwater revealed by mooring observations, J. Geophys. Res., 118, 4363–4379, 2013.

Jackson, J. M., Allen, S. E., McLaughlin, F. A., Woodgate, R. A., and Carmack, E. C.: Changes to the near surface waters in the Canada Basin, Arctic Ocean from 1993–2009: a basin in transition, J. Geophys. Res., 116, C10008, doi:10.1029/2011JC007069, 2011.

Jones, E. P. and Anderson, L. G.: On the origin of the chemical properties of the Arctic Ocean halocline, J. Geophys. Res., 91, 10759–10767, 1986.

Jørgensen, E.: Protophyten und Protozöen im Plankton aus der norwegischen Westküste, Bergens Museumus Aarbog 1899, 6, 51–112, 1900.

Jørgensen, E.: The Protist plankton and the diatoms in bottom samples, Plates VIII–XVIII, Bergens Museuns Skrifter, 1, 49–151, 1905.

Kling, S. A.: Vertical distribution of polycystine radiolarians in the central North Pacific, Mar. Micropaleontol., 4, 295–318, 1979.

Kosobokova, K. N., Hirche, H. -J. and Scherzinger, T.: Feeding ecology of Spinocalanus antarcticus, a mesopelagic copepod with a looped gut, Mar. Biol., 141, 503–511, 2002.

Kozur, H. and Möstler, H.: *Entactinaria subordo* Nov., a new radiolarian suborder, Geologisch Paläontologische Mitteilungen, Innsbruck, 11, 399–414, 1982.

Kruglikova, S. B.: Distribution of Polycystine radiolarians from recent and Pleistocene sediments of the Arctic-boreal zone, Berichte zur Polarforschung (Reports on Polar Research), 306, 120–133, 1999.

Kruglikova, S. B., Bjørklund, K. R., Hammer, Ø., and Anderson, O. R.: Endemism and speciation in the polycystine radiolarian genus *Actinomma* in the Arctic Ocean: description of two new species *Actinomma georgii* n. sp., and *A. turidae* n. sp., Mar. Micropaleontol., 72, 26–48, 2009.

Kruglikova, S. B., Bjørklund, K. R., Dolven, J. K., Hammer, Ø., and Cortese, G.: High-rank polycystine radiolarian taxa as temperature proxies in the Nordic Seas, Stratigraphy, 7, 265–281, 2010.

Kruglikova, S. B., Bjørklund, K. R., and Hammer, O.: High rank taxa of Polycystina (Radiolaria) as environmental bioindicators, Micropaleontology, 57, 483–489, 2011.

Lovejoy, C. and Potvin, M.: Microbial eukaryotic distribution in a dynamic Beaufort Sea and the Arctic Ocean, J. Plankton Res., 33, 431–444, 2011.

Lovejoy, C., Massana, R., and Pedrós-Alió, C.: Diversity and distribution of marine microbial eukaryotes in the Arctic Ocean and adjacent seas, Appl. Environ. Microb., 72, 3085–3095, doi:10.1128/AEM.72.5.3085-3095.2006, 2006.

Markus, T., Stroeve, J. C., and Miller, J.: Recent changes in Arctic sea ice melt onset, freezeup, and melt season length, J. Geophys. Res., 114, C12024, doi:10.1029/2009JC005436, 2009.

Matul, A., Abelmann, A., Tiedemann, R., Kaiser, A., and Nürnberg, D.: Late Quaternary polycystine radiolarian datum events in the Sea of Okhotsk, Geo-mar. lett., 22, 25-32, 2002.

Matul, A. and Abelmann, A.: Pleistocene and Holocene distribution of the radiolarian *Amphimelissa setosa* Cleve in the North Pacific and North Atlantic: evidence for water mass movement, Deep-Sea Res. Pt. II, 52, 2351–2364, 2005.

McLaughlin, F. A., Carmack, E., Proshutinsky, A., Krishfield, R. A., Guay, C. K., Yamamoto-Kawai, M., Jackson, J. M., and Williams, W. J.: The rapid response of the Canada Basin to climate forcing: From bellwether to alarm bells, Oceanography, 24, 146–159, doi:10.5670/oceanog.2011.66, 2011.

McPhee, M.: Intensification of geostrophic currents in the Canada Basin, Arctic Ocean, J. Climate,26, 3130, doi:10.1175/JCLI-D-12-00289.1, 2013.

Meunier, A.: Microplankton des Mers de Barents et de Kara, Duc d'Orléans, Campagne arctique de 1907, 255 pp., 1907.

Michel, C., Nielsen, T. C., Nozais, C., and Gosselin, M.: Significance of sedimentation and grazing by ice micro- and meiofauna for carbon cycling in annual sea ice (northern Baffin Bay), Aquat. Microb. Ecol., 30, 57–68, 2002.

Murray, J.: The Radiolaria. Narrative of the cruise of the H.M.S. "*Challenger*" with a general account of the scientific results of the expedition, in: Report from the Voyage of the H.M.S. *Challenger*, edited by: Tizard, T. H., Moseley, H. N., Buchanan, J. Y., and Murray, J., Narrative, 1, 219–227, 1885.

Müller, J.: Über die Thalassicollen, Polycystinen und Acanthometren des Mittelmeeres, Abhandlungen, Jahre 1858, K. Preuss. Akad. Wiss., Berlin, 1–62, 1858.

Nikolaev, S. I., Berney, C., Fahrni, J., Bolivar, I., Polet, S., Mylnikov, A. P., Aleshin, V. V., Petrov, N. B., and Pawlowski, J.: The twilight of Heliozoa and rise of Rhizaria, an emerging supergroup of amoeboid eukaryotes, P. Natl. Acad. Sci. USA, 101, 8066–8071, 2004.

Nimmergut, A. and Abelmann, A.: Spatial and seasonal changes of radiolarian standing stocks in the Sea of Okhotsk, Deep-Sea Res. Pt. I, 49, 463–493, 2002.

Nishino, S., Kikuchi, T., Yamamoto-Kawai, M., Kawaguchi, Y., Hirawake, T., and Itoh, M.: Enhancement/reduction of biological pump depends on ocean circulation in the sea-ice reduction regions of the Arctic Ocean, J. Oceanogr., 67, 305–314, doi:10.1007/s10872-011-0030-7, 2011.

Nishino, S.: R/V *Mirai* cruise report MR13-06, 226 pp., available at: www.godac.jamstec.go.jp/darwin/datatree/e (last access: 29 November 2014), JAMSTEC, Yokosuka, Japan, 2013.

NSIDC (National Snow and Ice Data Center): Arctic sea ice extent settles at record seasonal minimum, available at: http://nsidc.org/arcticseaicenews/2012/09/ (last access: 29 November 2014), 2012.

O'Brien, M. C., Melling, H., Pedersen, T. F., and Macdonald, R.W.: The role of eddies on particle flux in the Canada Basin of the Arctic Ocean, Deep-Sea Res. Pt. I, 71, 1–20, 2013.

Okazaki, Y., Takahashi, K., Yoshitani, H., Nakatsuka, T., Ikehara, M., and Wakatsuchi, M.: Radiolarians under the seasonally sea-ice covered conditions in the Okhotsk Sea: flux and their implications for paleoceanography, Mar. Micropaleontol., 49, 195–230, 2003.

Okazaki, Y., Takahashi, K., Itaki, T., and Kawasaki, Y.: Comparison of radiolarian vertical distributions in the Okhotsk Sea near the Kuril Islands and in the northwestern North Pacific off Hokkaido Island, Mar. Micropaleontol., 51, 257–284, 2004.

Okazaki, Y., Takahashi, K., Onodera, J., and Honda, M. C.: Temporal and spatial flux changes of radiolarians in the northwestern Pacific Ocean during 1997–2000, Deep-Sea Res. Pt. II, 52, 2240–2274, 2005.

Onodera, J., Watanabe, E., Harada, N., and Honda, M. C.: Diatom flux reflects water-mass conditions on the southern Northwind Abyssal Plain, Arctic Ocean, Biogeosciences Discuss., 11, 15215-15250, doi:10.5194/bgd-11-15215-2014, 2014.

Petrushevskaya, M. G.: The history of the microplankton of the Norwegian Sea (on the Deep Sea Drilling materials). Academy of Sciences, USSR, Zoological Institute, Nauka, Leningrad, 77-183, 1979 (in Russian).

Petrushevskaya, M. G.: Radiolarians of orders Spumellaria and Nassellaria of the

Antarctic region (from material of the Soviet Antarctic Expedition), in: Studies of Marine Fauna IV(XII): Biological Reports of the Soviet Antarctic Expedition (1955–1958), edited by: Andriyashev, A. P. and Ushakov, P. V., Academy of Sciences of the USSR, Zoological Institute, Leningrad, 3, 2–186, 1967 (translated from Russian and published by Israel Program for Scientific Translations, 1968).

Petrushevskaya, M. G.: Radiolyarii Nassellaria v planktone Mirovogo Okeana, Issledovaniya Fauny Morei, 9, 1–294, 1971 (+ App., 374–397), Nauka, Leningrad, in Russian.

Popofsky, A.: Die Radiolarien der Antarktis (mit Ausnahme der Tripyleen), in: Deutsche Südpolar-Expedition 1901–1903. X, Zoologie, 2, part 3, edited by: Drygalski, E., Georg Reimer, Berlin, 184–305, 1908.

Proshutinsky, A., Bourke, R. H., and McLaughlin, F. A.: The role of the Beaufort Gyre in Arctic climate variability: seasonal to decadal climate scales, Geophys. Res. Lett., 29, 2100, doi:10.1029/2002GL015847, 2002.

Proshutinsky, A., Krishfield, R., Timmermans, M. L., Toole, J., Carmack, E., McLaughlin, F., Williams, W. J., Zimmermann, S., Itoh, M., and Shimada, K.: Beaufort Gyre freshwater reservoir: state and variability from observations, J. Geophys. Res., 114, C00A10, doi:10.1029/2008JC005104, 2009.

Reynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C., and Wang, W.: An improved in situ and satellite SST analysis for climate, J. Climate, 15, 1609–1625, 2002.

Rich, J., Gosselin, M., Sherr, E., Sherr, B., & Kirchman, D. L.: High bacterial production, uptake and concentrations of dissolved organic matter in the Central Arctic Ocean, Deep-Sea Res. Pt. II, 44, 1645-1663, 1997.

Riedel, W. R.: Subclass radiolaria, in: The Fossil Record, edited by: Harland, W. B. et al., Geol. Soc. London, London, UK, 291–298, 1967.

Saha, S., Moorthi, S., Pan, H. L., Wu, X. R., Wang, J. D., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D., Liu, H. X., Stokes, D., Grumbine, R., Gayno, G., Wang, J., Hou, Y. T., Chuang, H. Y., Juang, H. M. H., Sela, J., Iredell, M., Treadon, R., Kleist, D., Van Delst, P., Keyser, D., Derber, J., Ek, M., Meng, J., Wei, H. L., Yang, R. Q., Lord, S., Van den Dool, H., Kumar, A., Wang, W. Q., Long, C., Chelliah, M., Xue, Y., Huang, B. Y., Schemm, J. K., Ebisuzaki, W., Lin, R., Xie, P. P., Chen, M. Y., Zhou, S. T., Higgins, W., Zou, C. Z., Liu, Q. H., Chen, Y., Han, Y., Cucurull, L., Reynolds, R. W., Rutledge, G., and Goldberg, M.: The NCEP climate forecast system reanalysis, B. Am. Meteorol. Soc., 91, 1015–1057, 2010.

Samtleben, C., Schäfer, P., Andruleit, H., Baumann, A., Baumann, K. H., Kohly, A., Matthiessen, J., and Schröder-Ritzrau, A.: Plankton in the Norwegian–Greenland Sea: from living communities to sediment assemblages – an actualistic approach, Geol. Rundsch., 84, 108–136, 1995.

Shannon, C. E. and Weaver, W.: The Mathematical Theory of Communication, University of Illinois Press, Urbana, 125 pp., 1949.

Shimada, K., Carmack, E. C., Hatakeyama, K., and Takizawa, T.: Varieties of shallow temperature maximum waters in the western Canadian Basin of the Arctic Ocean, Geophys. Res. Lett., 28, 3441–3444, 2001.

Shimada, K., Kamoshida, T., Itoh, M., Nishino, S., Carmack, E., McLaughlin, F., Zimmermann, S., and Proshutinsky, A.: Pacific Ocean inflow: influence on catastrophic reduction of sea ice cover in the Arctic Ocean, Geophys. Res. Lett., 33, L08605, doi:10.1029/2005GL025624, 2006.

Stroeve, J., Holland, M. M., Meier, W., Scambos, T., and Serreze, M.: Arctic sea ice decline: faster than forecast, Geophys. Res. Lett., 34, L09501, doi:10.1029/2007GL029703, 2007.

Stroeve, J. C., Serreze, M. C., Holland, M. M., Kay, J. E., Malanik, J., and Barrett, A. P.: The Arctic's rapidly shrinking sea ice cover: a research synthesis, Climatic Change, 110, 1005–1027, doi:10.1007/s10584-011-0101-1, 2012.

Suzuki N. and Aita Y.: Achievement and unsolved issues on radiolarian studies: Taxonomy and cytology, Plank. Benth. Res., 6, 69–91, 2011.

Swanberg, N. R. and Eide, L. K.: The radiolarian fauna at the ice edge in the Greenland Sea during summer, 1988, J. Mar. Res., 50, 297–320, 1992.

Swift, J. H., Jones, E. P., Aagaard, K., Carmack, E. C., Hingston, M., Macdonald, R. W., McLaughlin, F. A., Perkin, R. G.: Waters of the Makarov and Canada basins, Deep-Sea Res. Pt. II, *44*, 1503–1529, 1997.

Takahashi, K.: Radiolaria: flux, ecology, and taxonomy in the Pacific and Atlantic, in:, Ocean Biocoenosis, Ser. 3, edited by: Honjo, S., Woods Hole Oceanographic Institution Press, Woods Hole, MA, 303 pp., 1991.

Takahashi, K. and Honjo, S.: Vertical flux of Radiolaria: a taxon-quantitative sediment trap study from the western tropical Atlantic, Micropaleontology, 27, 140–190, 1981.

Tanaka, S. and Takahashi, K.: Detailed vertical distribution of radiolarian assemblage (0-3000 m, fifteen layers) in the central subarctic Pacific, June 2006, Mem. Fac. Sci., Kyushu Univ., Ser. D, Earth and Planet. Sci., 32, 49-72, 2008.

Tibbs, J. F.: On some planktonic Protozoa taken from the track of Drift Station Arlis I, 1960–1961, J. Arct. Inst. N. Am., 20, 247–254, 1967.

Watanabe, E., Onodera, J., Harada, N., Honda, M. C., Kimoto, K., Kikuchi, T., Nishino, S., Matsuno, K., Yamaguchi, A., Ishida, A., and Kishi, M. J.: Enhanced role of eddies in the Arctic marine biological pump, Nat. Commun., 5, 3950, doi:10.1038/ncomms4950, 2014.

Welling, L. A.: Environmental control of radiolarian abundance in the central equatorial Pacific and implications for paleoceanographic reconstructions, Ph.D. thesis, Oregon State Univ., Corvallis, 314 pp., 1996.

Wheeler, P. A., Gosselin, M., Sherr, E., Thibault, D., Kirchman, D. L., Benner, R., Whitledge T. E.: Active cycling of organic carbon in the central Arctic Ocean, Nature, 380, 697-699, 1996.

Yamamoto-Kawai, M., McLaughlin, F. A., Carmack, E. C., Nishino, S., and Shimada, K.: Freshwater budget of the Canada Basin, Arctic Ocean, from salinity, _18O, and nutrients, J. Geophys. Res., 113, C01007, doi:10.1029/2006JC003858, 2008.

Yang, J.: Seasonal and interannual variability of downwelling in the Beaufort Sea, J. Geophys. Res., 114, C00A14, doi:10.1029/2008JC005084, 2009.

Yuasa, T., Takahashi, O., Honda, D., and Mayama, S.: Phylogenetic analyses of the polycystine Radiolaria based on the 18s rDNA sequences of the Spumellarida and the Nassellarida, Eur. J. Protistol., 41, 287–298, 2005.

Table captions

Table 1. Logistic and sample information for the vertical plankton tows for radiolarian standing stock (S. S.) at two stations during R/V *Mirai* Cruise MR13-06

Table 2. Locations, mooring depths, standard sampling interval, and sampled duration of sediment trap station in the western Arctic Ocean. *Details of the exact durations for each sample are shown in tables S3 and S4.

Table 3. List of 51 radiolarian taxa encountered in the plankton tow and sediment trap

samples. All taxa are found in the trap, and * refer to taxa found in trap only.

Supplement table captions

Table S1. Radiolarian counts of living and dead specimens (45μm-1 mm) in plankton tows at Station 32

Table S2. Radiolarian counts of living and dead specimens (45μm-1 mm) in plankton tows at Station 56

Table S3. Radiolarian counts (45μm-1 mm) in upper trap at Station NAP

Table S4. Radiolarian counts (45μm-1 mm) in lower trap at Station NAP

Table S5. Summary information of previous sediment trap studies in the North Pacific Ocean

Table S6. Polycystine radiolarian species by family in the Arctic Ocean modified after Bjørklund and Kruglikova, 2003

Figure captions

Fig. 1. Map of the Chukchi and Beaufort Seas showing the locations of sediment trap (solid triangle) and plankton tows (solid circles). Gray arrows indicate the cyclonic circulation of the Beaufort Gyre and the inflow of Pacific water through the Bering Strait, respectively.

Fig. 2. Depth distributions of total dead and living radiolarians at stations 32 (a), and 56 (b) in comparison to vertical profiles of temperature, salinity, dissolved oxygen, and chlorophyll *a* (Nishino, 2013), and living radiolarian diversity index (Shannon and Weaver, 1949). The different water masses are identified as: Surface Mixed Layer (SML), Pacific Summer Water (PSW), Pacific Winter Water (PWW), Atlantic Water (AW), and Canada Basin Deep Water (CBDW).

Fig. 3. Compositions of living radiolarian assemblages in plankton samples through the upper 1000 m of the water columns at stations 32 (Northwind Abyssal Plain) (a) and 56 (southwestern Canada basin) (b).

Fig. 4. Depth distributions of fourteen living radiolarians in plankton samples at stations 32 (a) and 56 (b).

Fig. 5. (a) Total radiolarian fluxes, diversity index and sea-ice concentration in upper trap at Station NAP. 2 samples with fewer than 100 specimens are marked with asterisk. Sea-ice concentration data are from Reynolds et al. (2002)

(http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/). (b) Radiolarian faunal compositions in upper trap at Station NAP. (c) Downward short wave radiation at the surface of sea-ice and ocean (after sea-ice opening) around Station NAP from National Centers for Environmental Prediction-Climate Forecast System Reanalysis (NCEP-CFSR) (Saha et al., 2010). (d) Total radiolarian fluxes and Shannon-Weaver diversity index in the lower trap at Station NAP. 13 samples with fewer than 100 specimens are marked with asterisk. (e) Radiolarian faunal compositions in lower trap at Station NAP. Barren area: no samples due to trap failure.

Fig. 6. Scatter plots of diversity indices and total radiolarian fluxes at upper (a) and lower trap (b). In these plots, samples with fewer than 100 specimens were excluded.

Fig. 7. Two-year fluxes of major radiolarian taxa at Station NAP during the sampling period.

Fig. 8. Box plot of total radiolarian fluxes at Station NAP and previous studied areas in the North Pacific Ocean (Okazaki et al., 2003, 2005; Ikenoue et al., 2010, 2012a). Summary information of previous sediment trap studies in the North Pacific Ocean is shown in table S5.

Supplement figure caption

Fig. S1. Moored trap depth and the water temperature in the upper trap.

Plate lists

Plate 1. 1–4. *Actinomma boreale* (Cleve, 1899). 1, 2. *Actinomma boreale,* same specimen. NAP10t Shallow #23. 3, 4. *Actinomma boreale,* same specimen. NAP10t Shallow #24. 5–10. *Actinomma leptodermum leptodermum* (Jørgensen, 1900). 5, 6. *Actinomma leptodermum leptodermum,* same specimen. NAP10t Deep #12. 7, 8. *Actinomma leptodermum leptodermum,* same specimen. NAP10t Deep #12. 9, 10. *Actinomma leptodermum leptodermum,* same specimen. NAP10t Deep #12. 11–14. *Actinomma* morphogroup A. 11, 12. *Actinomma* morphogroup A, same specimen. NAP10t Deep #4. 13, 14. *Actinomma* morphogroup A, same specimen. NAP10t Deep #4. 15–18. *Actinomma leptodermum* (Jørgensen, 1900) *longispinum* (Cortese and Bjørklund, 1998). 15, 16. *Actinomma leptodermum longispinum,* same specimen. NAP10t Deep #12. 17, 18. *Actinomma leptodermum longispinum* juvenile, same specimen. NAP10t Deep #12. 19–24. Actinommidae spp. juvenile forms. 19, 20.

Actinomma sp. indet., same specimen. NAP10t Deep #12. 21, 22. *Actinomma* sp. indet., same specimen. NAP10t Deep #12. 23, 24. *Actinomma* sp. indet., same specimen. NAP10t Deep #12. 25–26. *Actinomma turidae* (Kruglikova and Bjørklund, 2009), same specimen. NAP10t Deep #22.

Scale bar= 100 µm for all figures.

Plate 2. 1–4. *Actinomma* morphogroup B. 1, 2. *Actinomma* morphogroup B, same specimen. NAP10t Deep #4. 3, 4. *Actinomma* morphogroup B juvenile, same specimen. NAP10t Deep #15. 5, 6. *Drymyomma elegans* (Jørgensen, 1900), same specimen. NAP10t Deep #14. 7–9. *Actinomma friedrichdreyeri* (Burridge, Bjørklund and Kruglikova, 2013), same specimen. NAP11t Deep #4. 10–11. *Cleveiplegma boreale* (Cleve, 1899), same specimen. NAP11t Deep #12.

Scale bar= 100 µm for all figures.

Plate 3. 1–4. *Arachnosphaera dichotoma* (Jørgensen, 1900). 1, 2. *Arachnosphaera dichotoma,* same specimen. NAP11t Deep #5. 3, 4. *Arachnosphaera dichotoma,* same specimen. NAP11t Deep #4. 5–8. *Streblacantha circumtexta*? (Jørgensen, 1905). 5, 6. *Streblacantha circumtexta*? juvenile form, same specimen NAP10t Deep #12. 7, 8. *Streblacantha circumtexta*? Juvenile form, same specimen. NAP10t Shallow #23. 9–11. *Spongotrochus glacialis* (Popofsky, 1908). 9. *Spongotrochus* aff. *glacialis*. NAP10t Shallow #24. 10, 11. *Spongotrochus glacialis,* same specimen. NAP10t Shallow #22. 12. *Stylodictya* sp. NAP10t Shallow #16.

Scale bar= 100 µm for all figures.

Plate 4. 1–7. *Joergensenium* spp. 1, 2, 3. *Joergensenium* sp. A, same specimen. NAP10t Deep #12. 4, 5. *Joergensenium* sp. A, juvenile forms of 1–3, same specimen. NAP11t Deep #4. 6, 7. *Joergensenium* sp. B, same specimen. NAP11t Deep #9. 8–9. *Enneaphormis rotula* (Haeckel, 1881), same specimen. NAP11t Deep #4. 10–11. *Enneaphormis enneastrum* (Haeckel, 1887), same specimen. NAP10t Deep #12. 12–16. *Protoscenium simplex* (Cleve, 1899). 12, 13, 14. *Protoscenium simplex,* same specimen. NAP10t Deep #12. 15, 16. *Protoscenium simplex,* same specimen. NAP10t Deep #12.

Scale bar= 100 µm for all figures.

Plate 5. 1–6. *Ceratocyrtis histricosus* (Jørgensen, 1905). 1, 2, 3. *Ceratocyrtis histricosus,* same specimen. NAP10t Deep #12. 4, 5, 6. *Ceratocyrtis histricosus,* same specimen. NAP10t Deep #12. 7–10. *Ceratocyrtis galeus* (Cleve, 1899). 7, 8. *Ceratocyrtis galeus,* same specimen. NAP10t Deep #6. 9, 10. *Ceratocyrtis galeus*, same specimen. NAP10t Deep #4. 11–12. *Arachnocorys umbellifera* (Haeckel, 1862), same specimen apical view. NAP10t Deep #4. 13–16. *Cladoscenium tricolpium* (Haeckel, 1887). 13, 14. *Cladoscenium tricolpium*, same specimen. NAP10t Deep #6. 15, 16. *Cladoscenium tricolpium*?, same specimen. NAP10t Deep #14. 17–18. *Lophophaena clevei* (Petrushevskaya, 1971), same specimen. NAP10t Shallow #14. 19–27. *Phormacantha hystrix* (Jørgensen, 1900). 19, 20. *Phormacantha hystrix*, same specimen. NAP10t Deep #12. 21, 22. *Phormacantha hystrix*, same specimen. NAP10t Deep #12. 23, 24, 25. *Phormacantha hystrix*, same specimen. NAP10t Deep #12. 26, 27. *Phormacantha hystrix*, same specimen. NAP10t Deep #12.

Scale bar= 100 µm for all figures.

Plate 6. 1–4. *Peridium longispinum*? (Jørgensen, 1900). 1, 2. *Peridium longispinum*?, same specimen. NAP11t Deep #4. 3, 4. *Peridium longispinum*?, same specimen. NAP11t Deep #4. 5–6. *Plectacantha oikiskos* (Jørgensen, 1905), same specimen. NAP10t Deep #12. 7–11. *Pseudodictyophimus clevei* (Jørgensen, 1900). 7, 8, 9. *Pseudodictyophimus clevei*, same specimen. NAP10t Deep #12. 10, 11. *Pseudodictyophimus clevei*, same specimen. NAP10t Deep #12. 12–13. *Pseudodictyophimus gracilipes gracilipes* (Bailey, 1856), same specimen. NAP10t Deep #12. 14–19. *Pseudodictyophimus* spp. juvenile forms. 14, 15. *Pseudodictyophimus* indet., juvenile forms same specimen. NAP10t Deep #12. 16, 17. *Pseudodictyophimus* indet., juvenile forms, same specimen. NAP10t Deep #12. 18, 19. *Pseudodictyophimus* indet., juvenile forms same specimen. NAP10t Deep #12. 20–23. *Pseudodictyophimus gracilipes* (Bailey, 1856) *bicornis* (Ehrenberg, 1862). 20, 21. *Pseudodictyophimus gracilipes bicornis*, same specimen. NAP11t Deep #4. 22, 23. *Pseudodictyophimus gracilipes bicornis*, same specimen. NAP11t Deep #4.

Scale bar= 100 µm for all figures.

Plate 7. 1–3. *Pseudodictyophimus gracilipes* (Bailey, 1856) *multispinus* (Bernstein, 1934) 1, 2. *Pseudodictyophimus gracilipes multispinus*, same specimen. NAP10t

Shallow #2. 3. *Pseudodictyophimus gracilipes multispinus.* NAP11t Shallow #2. 4–12. *Pseudodictyophimus plathycephalus* (Haeckel, 1887). 4, 5, 6. *Pseudodictyophimus plathycephalus,* same specimen. NAP10t Deep #12. 7, 8. *Pseudodictyophimus plathycephalus,* same specimen. NAP10t Deep #12. 9, 10. *Pseudodictyophimus plathycephalus,* same specimen. NAP10t Deep #12. 11, 12. *Pseudodictyophimus plathycephalus,* same specimen. NAP11t Deep #4. 13–14. *Tetraplecta pinigera* (Haeckel, 1887), same specimen. NAP10t Deep #12.

Scale bar= 100 μm for all figures.

Plate 8. 1–10. *Tripodiscium gephyristes* (Hülsemann, 1963). 1, 2. *Tripodiscium gephyristes*, same specimen. NAP10t Deep #12. 3, 4, 5 *Tripodiscium gephyristes*, same specimen. NAP10t Deep #12. 6, 7, 8. *Tripodiscium gephyristes*, same specimen. NAP10t Deep #12. 9, 10. *Tripodiscium gephyristes*, same specimen. NAP10t Deep #12. 11–18. Plagiacanthidae gen. et sp. indet. 11, 12. Plagiacanthidae gen. et sp. indet. juvenile, same specimen. NAP10t Deep #12. 13, 14. Plagiacanthidae gen. et sp. indet., same specimen. NAP10t Deep #12. 15, 16. Plagiacanthidae gen. et sp. indet., same specimen. NAP10t Deep #12. 17, 18. Plagiacanthidae gen. et sp. indet. juvenile, same specimen. NAP10t Deep #12. 19–22. *Artostrobus annulatus* (Bailey, 1856). 19, 20. *Artostrobus annulatus*, same specimen. NAP10t Deep #12. 21, 22. *Artostrobus annulatus*, same specimen. NAP10t Deep #12. 23–30. *Artostrobus joergenseni* (Petrushevskaya, 1967). 23, 24. *Artostrobus joergenseni*, same specimen. NAP10t Deep #12. 25, 26. *Artostrobus joergenseni*, same specimen. NAP10t Deep #12. 27, 28. *Artostrobus joergenseni*, same specimen. NAP10t Deep #12. 29, 30. *Artostrobus joergenseni*, same specimen. NAP10t Deep #12.

Scale bar= 100 μm for all figures.

Plate 9. 1, 2. *Cornutella stylophaena* (Ehrenberg, 1854), same specimen. NAP10t Deep #12. 3, 4. *Cornutella longiseta* (Ehrenberg, 1854), same specimen. NAP10t Deep #12. 5–9. *Cycladophora davisiana* (Ehrenberg, 1862). 5. *Cycladophora davisiana*, NAP11t Deep #4. 6, 7. *Cycladophora davisiana*, same specimen. NAP10t Deep #12. 8, 9. *Cycladophora davisiana*, same specimen. NAP10t Deep #12. 10–11. *Lithocampe a_. furcaspiculata* (Popofsky, 1908). same specimen. NAP10t Deep #12. 12–13. *Lithocampe platycephala* (Ehrenberg, 1873). 12. *Lithocampe platycephala*. NAP10t

Deep #13. 13. *Lithocampe platycephala*. NAP11t Deep #14. 14–21. *Sethoconus tabulatus* (Ehrenberg, 1873). 14, 15. *Sethoconus tabulatus*, same specimen. NAP10t Deep #12. 16, 17. *Sethoconus tabulatus*, same specimen. NAP10t Deep #12. 18, 19. *Sethoconus tabulatus*, same specimen. NAP10t Deep #12. 20, 21. *Sethoconus tabulatus*, same specimen. NAP10t Deep #12. 22–33. *Amphimelissa setosa* (Cleve, 1899). 22, 23. *Amphimelissa setosa*, same specimen. NAP10t Deep #12. 24, 25. *Amphimelissa setosa*, same specimen. NAP10t Deep #12. 26, 27. *Amphimelissa setosa*, same specimen. NAP10t Deep #12. 28, 29. *Amphimelissa setosa*, same specimen. NAP11t Deep #4. 30, 31. *Amphimelissa setosa*, same specimen. NAP10t Deep #12. 32, 33. *Amphimelissa setosa*, same specimen, apical view. NAP11t Deep #4. 34–39. *Amphimelissa setosa* juvenile. 34, 35. *Amphimelissa setosa* juvenile, same specimen. NAP11t Deep #14. 36, 37. *Amphimelissa setosa* juvenile, same specimen. NAP10t Deep #12. 38, 39. *Amphimelissa setosa* juvenile, same specimen. NAP11t Deep #14. 40–41. *Lirella melo* (Cleve, 1899), same specimen. NAP10t Deep #14. 42–43. *Protocystis harstoni* (Murray, 1885), same specimen. NAP10t Deep #18.

Scale bar= 100 µm for all figures.