

Dear Referee and dear Prof. Middelburg,

thank you very much for your very useful and thorough comments and corrections. We appreciate your contribution to the improvement of our study very much.

We will modify the text of the manuscript accordingly and we also provided detailed answers to your comments below (comments are in bold and our responses are in regular).

1. Having said that, while I feel that the paper presents interesting and novel data, I also strongly feel that it lacks conclusiveness to warrant publication in a top journal like Biogeosciences. My main reason for this somewhat harsh conclusion is that the results presented on stable isotope signatures of tardigrades, rotifers and cryoconite of three gletsjer systems can only be described and compared, but that virtually all data needed to explain the observed patterns are lacking.

We are aware that this manuscript is a pioneer descriptive study presenting the first view on stable isotopic composition of consumers and organic matter on the glacier surface with all limitations which it may pose on the generalization of our conclusions. Conclusions include parts where our results were overinterpreted and where our suggestions go beyond the safe ground provided by our data. We will change these parts accordingly.

2. Isotopic signatures of nutrient and OM subsidies are missing, and so are isotopic signatures of primary producers vs detritus vs heterotrophic bacteria. I perfectly understand that these are not easy to obtain, but it was foreseeable that such data would be required to explain observed patterns, and methods exist for determining each of the above factors.

We are aware that isotopic signatures of primary producers (ideally cyanobacteria and algae separately), heterotrophic bacteria and detritus in cryoconite holes are necessary to understand the trophic structure and processes leading to presented differences in isotopic signatures of cryoconite tardigrades and rotifers. However, the main purpose of our study was not to provide detailed description of trophic relationships and pathways in cryoconite holes but rather to obtain a general view on the stable isotopic composition of supraglacial tardigrades and rotifers and find out whether it is worth keeping this direction in further studies or not. The chosen approach exposed that the food sources of both consumers probably differ even though feeding experiments showed their ability to consume the same food (Střítecká and Devetter, 2015). We agree that there are other methods such as SIMS which may solve these problems. However, we did not choose such methods due to the quantity of material necessary for our purpose. We feel that we were not explicit in this subject and will modify the discussion accordingly.

3. I feel the authors should do an extra effort to make this manuscript better accessible and therefore more interesting for readers who are not familiar with the cryoconite holes. Aspects I wondered about, not knowing these specific systems, is what size and depth range such cryoconite holes have and how common they are, or better still, what % of a gletsjer's surface they make up.

We appreciate this suggestion very much. We will modify the abstract and the introduction to make the study better accessible for readers less familiar with the topic.

The diameter and depth of cryoconite holes are noticeably variable, but both usually range from a few centimetres to tens of centimetres (Gerdel and Drouet, 1960; Fountain et al., 2004; Zawierucha et al., 2019).

Cryoconite holes usually cover around 7 % of the ablation zone of glaciers (the area with an ice loss exceeding its increase), which still remains a relevant portion of the planetary surface (Bøggild et al., 2010; Fountain et al., 2004; Stibal et al., 2012a; Zemp et al., 2008). Their distribution and structure (e.g. size and depth) depend on many factors such as the size of the ablation zone, the insolation on the glacier surface, optical properties of the ice, temperature, sediment input (mainly airborne) and output (mainly with meltwater), type of sediment, type of adjacent area (terrestrial, marine) and the topography of the glacier surface.

The fact that the supraglacial sediment has an active biotic component contributing to its distribution and physical and chemical properties, makes it an important factor that has to be considered when assessing the functioning of biogeochemical processes in glaciated catchments and the impact on e.g. understanding ecological succession in deglaciated areas and the change of marine ecosystems in the Arctic.

4. It is one element I would need to answer the “so what” question: what could be the quantitative importance of these ‘miniature’ ecosystems in the ecology and biogeochemistry of gletsjers?

We appreciate this comment and we will modify the introduction accordingly.

As reported by Cameron et al. (2012) and Hodson et al. (2008) and explained previously here, cryoconite holes are the most nutrient-rich and biologically active habitats within the supraglacial environment. Therefore, their impact on glacier ecosystems nutrient pathways (e.g. carbon, nitrogen, and other microelements) and on downstream ecosystems is a key component to understanding the glacial ecosystems functioning (Anesio et al., 2010; Bagshaw et al., 2013; Telling et al., 2011). For example, the rate of photosynthesis in cryoconite holes is comparable with those in arctic polar lakes and consequently the rate of respiration and utilization of organic matter is very high (Hodson et al., 2008). Thus, cryoconite holes form an important net carbon sink or source in polar ecosystems which depend on the balance between autotrophic and heterotrophic production (Stibal et al., 2012b). Moreover, due to its high biological activity, cryoconite holes efficiently retain nutrients on the glacier surface (Bagshaw et al., 2013) and accumulated matter can consequently provide a source of important nutrients into adjacent areas where it is transported with the meltwater (Anesio et al., 2010; Porazinska et al., 2004).

Another importance of cryoconite holes comes from the dark colour of cryoconite granules which alters the albedo of the glacier surface and can lead to an increase in the surface melt and eventually to the expansion of the ablation zone (Ryan et al., 2018; Takeuchi et al., 2001). Due its accumulative nature, cryoconite holes are also used for the exploration and tracking of contamination (e.g. black carbon, radionuclides) in polar areas (e.g. Łokas et al., 2016).

Tardigrades and rotifers inhabiting cryoconite holes are most likely an important factor shaping the community of primary producers by grazing and nutrient recycling (Elser and Urabe, 1999; Vonnahme et al., 2016). Especially when considering their feeding rate (Střítecká and Devetter, 2015). The closest similar studies about stable isotopic composition of tardigrades and rotifers focused only on microbial mats and soil from Antarctica (Almela et al., 2019; Shaw et al., 2018; Velázquez et al., 2017). Due to the dominance of prokaryotic biomass which was in the main scope of

most of previous studies from supraglacial habitats, the ecology of cryoconite tardigrades and rotifers and their influence on the supraglacial system functioning is currently unexplored.

5. I would also have liked to read more clearly structured information about the different organic matter resources – both autochthonous and allochthonous – that tend to be present in cryoconite holes.

Thank you for this suggestion. We will modify the introduction accordingly.

Regarding allochthonous sources of organic matter, it is mostly dust from adjacent areas or snow which is transported to cryoconite holes with meltwater or wind. The components of allochthonous organic matter are mostly death organic matter, snow algae, remains of plants and organisms (Takeuchi et al., 2001) and bird guano (Vonnahme et al., 2016; Žárský et al., 2013).

The autochthonous sources of organic matter are mostly of microbial origin (from cryoconite bacteria, cyanobacteria, and algae) (e.g. Telling et al., 2012).

6. Now, there are no very clear goals, questions or hypotheses about such expected patterns, and I am left with the question: since you sampled glaciers in three different settings, how did you expect their food webs and fuelling resources to differ?

The heterogeneity of three chosen glaciers (size, adjacent areas, geological setting, distance from the sea) should demonstrate possible regional variability in stable isotopic composition of its cryoconite consumers and organic matter among various glaciers in central Svalbard. We expected that different geomorphological characteristics will be reflected in the input of organic matter (e.g. Svenbreen is surrounded by steep slopes) and thus in the composition of their consumers. Nevertheless, our selection should not be understood as a sufficient source of information for hypothesis-driven analysis of controls of the stable isotopic composition in our study.

Based on previous studies we knew that the composition of biota tends to differ between glaciers (e.g. Cameron et al., 2012; Edwards et al., 2013a; Edwards et al., 2013b). The main objective of our study was to use stable isotopic analyses as a tool which could reveal if the food source of cryoconite consumers differ and therefore give an indication whether tardigrades and rotifers can be reasonably expected to influence the cryoconite stoichiometry.

Thank you for this comment, we agree that we did not mark the goals of our study clearly and we will modify the text accordingly.

7. In lines 44-47, you are mentioning a correlation between the size distribution of primary producers and the community composition of consumers. In what way, and what is the relevance here?

Vonnahme et al. (2016) described that the abundance of rotifers correlates with larger and smaller microalgae (Chlorococcales and Zygnematales) concentrations and the abundance of tardigrades only with larger Zygnematales concentration. This study also revealed that the length of trichomes of Oscillatoriales (cyanobacteria) negatively correlates with the abundance of filtering rotifers. We felt that it is important to mention these findings because it indicates that grazing has likely an impact on

the structure of primary producers in cryoconite holes and by that presumably contributes to cryoconite nutrient levels.

We appreciate this comment and we will modify the text to make the meaning more explicit.

8. I was rather surprised to read the following final sentence of the conclusions section: “Another outcome of this study is the introduction of a modified technique of sample preparation avoiding procedures such as sugar centrifugation or oven drying.” While reading M&M, I did notice some minor differences in sample elutriation and sorting procedures compared to common practices, but nowhere did I see a clear statement about an important novel methodological approach to treating samples.

Thank you for this comment, we agree that we did not describe precisely why we modified the technique. We are also aware that our methodical approach did not present a fully novel method. We will modify the text accordingly.

The commonly used methods were modified because cryoconite invertebrates live in a very specific environment and we wanted to avoid alteration of their chemical composition during the preparation for isotopic analyses. Therefore, we chose the lyophilization instead of oven drying and we wanted to avoid any added component which could potentially contaminate our samples.

9. Given the subtitle ‘community structure’, I had somehow hoped to read a species or genus-level analysis of consumer communities, yet in the end, rotifers were just treated as rotifers, and tardigrades were largely left without a name and assigned to feeding groups, which are well known to be of very limited relevance to describe the actual feeding behaviours of tardigrades, particularly with respect to their potential to feed on microalgae.

Thank you for this comment, we will replace the community structure by the consumers composition and will change the text accordingly.

We are also aware that community structure description lacks detailed information about species composition. Regarding rotifers, the identification depends on the visibility of their coronal cilia which only actively filtering individuals display. We did not observe a sufficient number of filtering rotifers during the collection of rotifers for analyses and therefore other identification except few individuals identified as *Macrotrachella* sp. and *Adineta* sp. was impossible.

Regarding the species composition of tardigrades, the representative number of individuals was collected, mounted, and determined apart from individuals intended for analyses. We found *Pilatobius* sp., *Hypsibius* sp., *Hypsibius* cf. *dujardini*, *Isohypsibius* sp. and very rarely *Cryoconicus kaczmareki*. *Pilatobius* sp. was in the past identified as *P. recamieri* which inhabit Arctic tundra commonly. However, utilization of DNA barcoding revealed that suggested *P. recamieri* is a new species for science and it is not formally named yet. *Hypsibius* contains, according to DNA, few cryptic lines. *Grevenius* (previously identified as *Isohypsibius* sp.) is also new for science and not formally named. Moreover, because some species are cryptic and identified only based on DNA (morphologically similar), they most probably use the same food source. Due to the lack of information about the diet of particular species living in cryoconite holes, we chose the trophic group division based on already published knowledge about feeding behaviours and feeding apparatus morphology of related species and on the personal communication with specialists culturing relative species.

10. So, there is no info on community composition, only some more anecdotal statements as to certain abundantly present Cyanobacteria and algae. This is probably also why there is no statistical analysis of differences in community composition of either consumers or primary producers.

The data presenting the community structure of primary producers on each glacier were not incorporated into the manuscript because the preservation of the samples by freezing has usually a taxon-specific effect on the survival of the cells of phototrophs. Thus, it makes it impossible to provide reliable quantification comparable between taxa. For example, the cells of glacial algae withstand the repeated freeze-thaw cycles only with a low success, whereas cyanobacteria usually have no significant loss in observed cell numbers. Even though we agree that the information lacks further data, we felt that it is important to mention at least all information we were able to get from our samples. Due to these reasons, we excluded the data on primary producers from statistical analyses.

The community composition of consumers could not be statistically analysed since we were not able to provide sufficient data about the species composition of rotifers among glaciers.

11. Incidentally, I wondered why both a Spearman rank and a Pearson product-moment correlation were tested. I would expect that if the data fit the assumptions for parametric tests, one would choose the latter, and if not, the former.

We had to use both tests because some data did not have a normal distribution. However, we were not explicit in the methods that the tests have not been used both on the same data. We will modify the text to make the meaning clear.

12. I would have preferred to see absolute abundances of tardigrades and rotifers in table 1 instead of a general dominance-indication. That dominance indication is not very scientific, and it does not provide any relevant info on potential differences in abundance of consumer groups among gletsjer systems. Actually, since you sampled sufficient replicates in 2 out of 3 gletsjers, you could statistically underpin whether tardigrades were more or less abundant than rotifers in a specific gletsjer system.

Thank you for this suggestion. We will modify the table and add the statistics into the text.

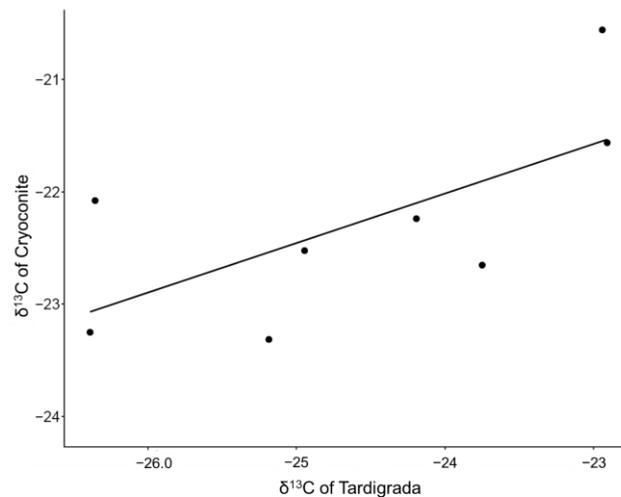
We chose visualisation with the dominance-indication due to an easier description and orientation in results for readers since the total number of collected animals from which the dominance was estimated is much higher than the number of animals necessary for analyses. Many counted animals were analysed in pilot experiments with no results. We have changed the table accordingly (presented below) and we will make the description more explicit.

Glacier	Tardigrades		Rotifers		Cryoconite		Dominances T:R
	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}^*$	
Sven	-3.55	-23.75	-1.57	-27.09	-2.20	-22.65	1030:627
	-4.04	-26.36	-1.81	-26.69	-2.17	-22.08	1062:2184
	-3.52	-26.33	-2.04	-31.16	-2.24	-24.09	1181:1381

	-4.39	-26.45	-1.04	-28.53	-1.64	-23.25	150:1021
Nordenskiöld	-4.39	-22.91	-2.20	-23.36	-3.58	-21.56	1172:1091
	-3.45	-23.30	-1.72	-23.25	-2.30	-20.56	1254:1355
	-3.76	-22.58	-2.30	-23.02	-2.98	-22.52	
	-4.15	-24.78	-3.02	-25.19			1225:1341
	-3.93	-25.11					
Ebba	-1.73	-24.19	0.69	-26.32	-2.30	-22.24	1086:2184
	-4.85	-25.22	-2.38	-25.13	-4.29	-23.31	2280:594
	-4.33	-25.15					

13. Figure only shows the correlation between cryoconite delta13C and rotifer delta13C. That of tardigrades is not shown because it was not statistically significant. I would then at least like to see the r and actual p-value for the tardigrade correlation, as well as an estimate of the slope of the regression for both rotifers and tardigrades.

Thank you very much for this suggestion, we will add all information into the text. The r in the correlation between $\delta^{13}\text{C}$ of decarbonized cryoconite and $\delta^{13}\text{C}$ of tardigrades is 0.67 and the p-value is 0.07. We will also add this value and suggested table (see below) into the results.



14. I would have started the results section with what is now 3.2. Cryoconite composition.

We appreciate this suggestion and we will incorporate the section 3.2 into the section 3.1.

15. Section 3.3: as mentioned above, table 1 should provide absolute abundances of consumers, and it should also provide info on the proportion of dormant consumers!

The proportion of dormant consumers is not possible to count during the sample preparation procedure because we use melted material and dormant tardigrades and rotifers are waking up during the whole time of the collecting for isotopic analyses.

16. I would be interested to read in one or two sentences to what extent other meiofauna or small invertebrates than tardigrades and rotifers were present (any Nematoda, Copepoda, Ostracoda, ...?).

Based on current knowledge, Arctic cryoconite holes are inhabited exclusively by tardigrades and rotifers. Currently, we have data from 20 glaciers from Svalbard which indicate that no other animals inhabit cryoconite holes in this region. For our investigation, we used material from many seasons which was analysed by students and experienced researchers and no other metazoans have been found. Moreover, only few groups of other animals inhabit cryoconite holes worldwide and most of these species are endemic. Crustaceans (Copepoda) were found only in Himalaya, insects (Chironomidae and Plecoptera) have been found in the Himalaya and Patagonia, recently mites have been found on one Antarctic glacier. Our unpublished meta-analysis suggests that tardigrades and rotifers are the most common cryoconite animals. We will correct the introduction and we will underline that exclusively rotifers and tardigrades play roles as apex consumer of cryoconite holes in the Arctic. We will cite adequate references as well.

17. At the end of the first discussion §, you finally provide some ‘expectation’, but it is not clear what this expectation is based upon. In the relatively lengthy and speculative discussion, I read virtually nothing about temperature effects on isotopic fractionation between consumers and resources.

Thank you for this suggestion, we will add the information into the discussion. We will also modify the discussion to make its meaning explicit.

The temperature in cryoconite holes is very stable (around 0 °C) and the fluctuation usually do not exceed tenths of °C (e.g. Säwström et al., 2002; Zawierucha et al., 2019). Any increase in the temperature of the sediment is efficiently buffered by ice at 0 °C because any added heat will lead to melting instead. Publications focusing on the temperature effect on the isotopic fractionation usually describe that the changes in fractionation begin with differences higher than 2 °C (e.g. Bosley et al., 2002; Degens et al., 1968; Hinga et al., 1994; Olive et al., 2003).

18. In section 4.2., dissolved organic matter suddenly becomes an important candidate food for these consumers. That may well be, but what results is this based upon here?

This suggestion is based on the description and explanation of observed distribution of $\delta^{13}\text{C}$ in consumers and DOC from cyanobacterial exudates in the study of Velázquez et al. (2017). This study focused, apart from microbial trophic interaction, on isotopic composition of tardigrades and rotifers from Antarctica as well. However, this is only one of more possible explanations. Therefore, we will modify the text to make this consideration more explicit.

19. 1) Line 71: “preferential excretion of $\delta^{14}\text{N}$ ” should be “preferential excretion of (light) ^{14}N ”. 2) Line 250: “rotifers revealed higher values of ^{15}N isotope” should be “rotifers had higher $\delta^{15}\text{N}$ ” or “rotifers had heavier stable nitrogen isotopic signatures’. 3) Line 251: “potential differences in $\delta^{15}\text{N}$ composition” should be “potential differences in N isotope ratios/signatures”.

Thank you very much for these corrections. We agree with all suggestions and we will modify the text accordingly.

Thank you very much once more and we will be pleased to continue the discussion if you have any further questions or concerns.

Yours sincerely,

Tereza Jaroměřská

(on behalf of the other authors)

References

Almela, P., Velázquez, D., Rico, E., Justel, A., and Quesada, A.: Carbon pathways through the food web of a microbial mat from Byers Peninsula, Antarctica, *Front. Microbiol.*, 10, 628, doi:10.3389/fmicb.2019.00628, 2019.

Anesio, A. M., Sattler, B., Foreman, C., Telling, J., Hodson, A., Tranter, M., and Psenner, R.: Carbon fluxes through bacterial communities on glacier surfaces, *Ann. Glaciol.*, 51, 32–40, doi:10.3189/172756411795932092, 2010.

Bagshaw, E. A., Tranter, M., Fountain, A. G., Welch, K., Basagic, H. J., and Lyons, W. B.: Do cryoconite holes have the potential to be significant sources of C, N, and P to downstream depauperate ecosystems of Taylor Valley, Antarctica?, *Arct. Antarct. Alp. Res.*, 45, 440–454, doi:10.1657/1938-4246-45.4.440, 2013.

Bøggild, C. E., Brandt, R. E., Brown, K. J., and Warren, S. G.: The ablation zone in northeast Greenland: ice types, albedos and impurities, *J. Glaciol.*, 56, 101–113, doi:10.3189/002214310791190776, 2010.

Bosley, K. L., Witting, D. A., Chambers, R. C., and Wainright, S. C.: Estimating turnover rates of carbon and nitrogen in recently metamorphosed winter flounder *Pseudopleuronectes americanus* with stable isotopes, *Mar. Ecol.-Prog. Ser.*, 236, 233–240, doi:10.3354/meps236233, 2002.

Cameron, K. A., Hodson, A. J., and Osborn, A. M.: Structure and diversity of bacterial, eukaryotic and archaeal communities in glacial cryoconite holes from the Arctic and the Antarctic, *FEMS Microbiol. Ecol.*, 82, 254–267, doi:10.1111/j.1574-6941.2011.01277x, 2012.

Degens, E. T., Guillard, R. R. L., Sackett, W. M., and Hellebust, J. A.: Metabolic fractionation of carbon isotopes in marine plankton—I. Temperature and respiration experiments, in: *Deep Sea Research and Oceanographic Abstracts*, 15, 1–9, Elsevier, doi:10.1016/0011-7471(68)90024-7, 1968.

Edwards, A., Douglas, B., Anesio, A. M., Rassner, S. M., Irvine-Fynn, T. D., Sattler, B., and Griffith, G. W.: A distinctive fungal community inhabiting cryoconite holes on glaciers in Svalbard, *Fungal Ecol.*, 6, 168–176, doi:10.1016/j.funeco.2012.11.001, 2013a.

Edwards, A., Rassner, S. M., Anesio, A. M., Worgan, H. J., Irvine-Fynn, T. D., Wyn Williams, H., Sattler, B., and Wyn Griffith, G.: Contrasts between the cryoconite and ice-marginal bacterial communities of Svalbard glaciers, *Polar Res.*, 32, 19468, doi:10.3402/polar.v32i0.19468, 2013b.

Elser, J. J. and Urabe, J.: The stoichiometry of consumer-driven nutrient recycling: theory, observations, and consequences, *Ecology*, 80, 735–751, doi:10.1890/0012-9658(1999)080[0735:TSOCDN]2.0.CO;2, 1999.

Fountain, A. G., Tranter, M., Nysten, T. H., Lewis, K. J., and Mueller, D. R.: Evolution of cryoconite holes and their contribution to meltwater runoff from glaciers in the McMurdo Dry Valleys, Antarctica, *J. Glaciol.*, 50, 35–45, doi:10.3189/172756504781830312, 2004.

Gerdel, R. W. and Drouet, F.: The cryoconite of the Thule area, Greenland, *T. Am. Microsc. Soc.*, 79, 256–272, doi:10.2307/3223732, 1960.

Hinga, K. R., Arthur, M. A., Pilson, M. E., and Whitaker, D.: Carbon isotope fractionation by marine phytoplankton in culture: the effects of CO₂ concentration, pH, temperature, and species, *Global Biogeochem. Cy.*, 8, 91–102, doi:10.1029/93GB03393, 1994.

Hodson, A., Anesio, A. M., Tranter, M., Fountain, A., Osborn, M., Priscu, J., Laybourn-Parry, J., and Sattler, B.: Glacial ecosystems, *Ecol. Monogr.*, 78, 41–67, doi:10.1890/07-0187.1, 2008.

Łokas, E., Zaborska, A., Kolicka, M., Różycki, M., and Zawierucha, K.: Accumulation of atmospheric radionuclides and heavy metals in cryoconite holes on an Arctic glacier, *Chemosphere*, 160, 162–172, doi:10.1016/j.chemosphere.2016.06.051, 2016.

Olive, P. J., Pinnegar, J. K., Polunin, N. V., Richards, G., and Welch, R.: Isotope trophic-step fractionation: a dynamic equilibrium model, *J. Anim. Ecol.*, 72, 608–617, doi:10.1046/j.1365-2656.2003.00730.x, 2003.

Porazinska, D. L., Fountain, A. G., Nysten, T. H., Tranter, M., Virginia, R. A., and Wall D. H.: The biodiversity and biogeochemistry of cryoconite holes from McMurdo Dry Valley glaciers, Antarctica, *Arct. Antarct. Alp. Res.*, 36, 84–91, doi:10.1657/1523-0430(2004)036[0084:TBABOC]2.0.CO;2, 2004.

Ryan, J. C., Hubbard, A., Stibal, M., Irvine-Fynn, T. D., Cook, J., Smith, L. C., Cameron, K., and Box, J.: Dark zone of the Greenland Ice Sheet controlled by distributed biologically-active impurities, *Nat. Commun.*, 9, 1–10, doi:10.1038/s41467-018-03353-2, 2018.

Sävström, C., Mumford, P., Marshall, W., Hodson, A., and Laybourn-Parry, J.: The microbial communities and primary productivity of cryoconite holes in an Arctic glacier (Svalbard 79 N), *Polar Biol.*, 25, 591–596, doi:10.1007/s00300-002-0388-5, 2002.

Shaw, E. A., Adams, B. J., Barrett, J. E., Lyons, W. B., Virginia, R. A., and Wall, D. H.: Stable C and N isotope ratios reveal soil food web structure and identify the nematode *Eudorylaimus antarcticus* as an omnivore–predator in Taylor Valley, Antarctica, *Polar Biol.*, 41, 1013–1018, doi:10.1007/s00300-017-2243-8, 2018.

Stibal, M., Telling, J., Cook, J., Mak, K. M., Hodson, A., and Anesio, A. M.: Environmental controls on microbial abundance and activity on the Greenland ice sheet: a multivariate analysis approach, *Microbial Ecol.*, 63, 74–84, doi:10.1007/s00248-011-9935-3, 2012a.

Stibal M., Šabacká M., and Žárský J.: Biological processes on glacier and ice sheet surfaces, *Nat. Geosci.*, 5, 771, doi:10.1038/ngeo1611, 2012b.

Střítecká, M. and Devetter, M.: Sledování filtrační activity vířníků v kryokonitech, Senior high school thesis, Česko-anglické gymnasium, České Budějovice, Czech Republic, 2015.

Takeuchi, N., Kohshima, S., and Seko, K.: Structure, formation, and darkening process of albedo-reducing material (cryoconite) on a Himalayan glacier: a granular algal mat growing on the glacier, *Arct. Antarct. Alp. Res.*, 33, 115–122, doi:10.1080/15230430.2001.12003413, 2001.

Telling, J., Anesio, A. M., Tranter, M., Irvine-Fynn, T., Hodson, A., Butler, C., and Wadham, J.: Nitrogen fixation on Arctic glaciers, Svalbard, *J. Geophys. Res-Biogeophys.*, 116, doi:10.1029/2010JG001632, 2011.

Telling, J., Anesio, A. M., Tranter, M., Stibal, M., Hawkings, J., Irvine-Fynn, T., Hodson, A., Butler, C., Yallop, M., and Wadham, J.: Controls on the autochthonous production and respiration of organic matter in cryoconite holes on high Arctic glaciers, *J. Geophys. Res-Biogeophys.*, 117, G01017, doi:10.1029/2011JG001828, 2012.

Velázquez, D., Jungblut, A. D., Rochera, C., Rico, E., Camacho, A., and Quesada, A.: Trophic interactions in microbial mats on Byers Peninsula, maritime Antarctica, *Polar Biol.*, 40, 1115–1126, doi:10.1007/s00300-016-2039-2, 2017.

Vonnahme, T. R., Devetter, M., Žárský, J. D., Šabacká, M., and Elster, J.: Controls on microalgal community structures in cryoconite holes upon high-Arctic glaciers, Svalbard, *Biogeosciences*, 13, 659–674, doi:10.5194/bg-13-659-2016, 2016.

Žárský, J. D., Stibal, M., Hodson, A., Sattler, B., Schostag, M., Hansen, L. H., Jacobsen, C. S., and Psenner, R.: Large cryoconite aggregates on a Svalbard glacier support a diverse microbial community including ammonia-oxidizing archaea, *Environ. Res. Lett.*, 8, 035044, doi:10.1088/1748-9326/8/3/035044, 2013.

Zawierucha, K., Buda, J., and Nawrot, A.: Extreme weather event results in the removal of invertebrates from cryoconite holes on an Arctic valley glacier (Longyearbreen, Svalbard), *Ecol. Res.*, 34, 370–379, doi:10.1111/1440-1703.1276, 2019.

Zemp, M., Roer, I., Käab, A., Hoelzle, M., Paul, F., and Haeberli, W.: WGMS (2008): global glacier changes: facts and figures, Zurich Open Repository and Archive, Zurich, Switzerland, 2008.