Arctic Biology Field Course 2015

ARKTISK
STATION

Qeqertarsuaq

Greenland

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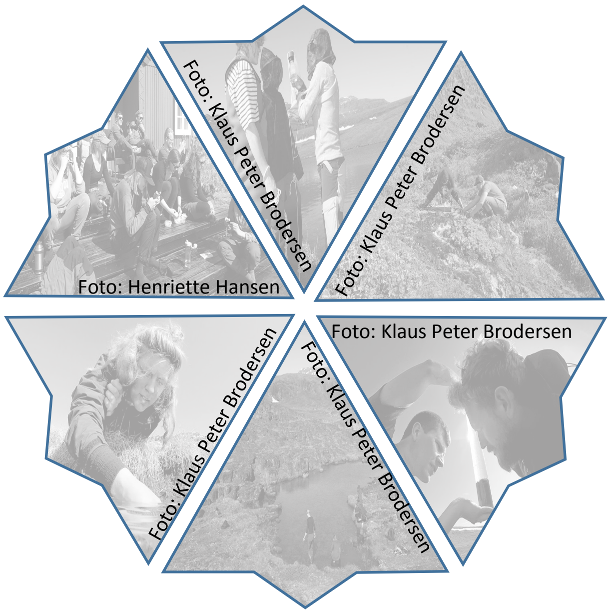

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For further information on Arctic Station, visit the website: www.arktiskstation.ku.dk

Preface

The Arctic is a unique environment of great interest, which has increased with the acquaintance of climate change, since global warming will effect the arctic environment the most. To preserve this unique environment, knowledge of the development of its landscape and the arctic flora and fauna is essential.

Arctic Station is located outside the town Qeqertarsuaq on the south of Disko Island, Greenland (69°15ˈN, 53°34ˈW). The station was founded by Morten P. Porsild in 1906, supported by Knud Rasmussen, Ludvig Mylius-Erichsen and Fridtjof Nansen, and has since then been crucial to the scientific research at Disko Island. The environment around Arctic Station is an ideal area to perform research, as many of the species found in Greenland are represented in the marine, terrestrial and freshwater ecosystems. Since 1953, the University of Copenhagen has operated at Arctic Station with the aim of promoting arctic research, and since 1973 educating within a biological, geological and geographical framework.

The purpose of Arctic Field Course is to get students acquainted with the arctic environment, they learned about in the course Arctic Biology at the Institute of Biology, and give them experience with the process of a scientific research from idea to a final journal. This included lectures and excursion to different location in the arctic environment nearby Arctic Station, by which the students gained a better understanding of the Arctic.

This report is the results of the scientific research performed 7th-17th July 2015. This year summer course focused on freshwater ecosystems with professors Kirsten S. Christoffersen (freshwater ecologist) and Klaus P. Brodersen (freshwater palaeontologist) as supervisors. Based on preapplication, 11 students (Anna Hansen, Ditte Ethelberg-Findsen, Emil Kristensen, Jesper R. Schultz, Ditte Marie Christiansen, Kirstine Thiemer, Simone M. Mortensen, Nanna S. Petersen, Casper A. Pedersen, Anne J. Dobel and Henriette Hansen) were selected to perform four different projects.

Before departure from Copenhagen, the students did theoretical research and prepared methods of sampling and laboratory analysis. The Field course took place during ten days in July 2015, where all the experimental setups were established, samples were collected and analysis performed in the laboratory. Few analysis were done in the laboratory at University of Copenhagen, as the students returned to Denmark. Here they also did the statistical analysis and wrote the scientific papers for this journal.

Arctic Field Course gave a better understanding of how unique this environment is by observing the arctic nature first-handed. During the course, all groups were challenged with different obstacles both in the field and during laboratory analysis, which gave insight to the process of research. The focused and intense work during the ten days at Arctic Station was a great experience.

Acknowledgement

The students thank Arctic Station for providing facilities, lending equipment and help by a great staff, specially scientific manager Christian Jungersen Jørgensen for assistance, instructions and presentation of his own research; station manager Kjeld Akaaraq Mølgaard; the crew on-board ‘Porsild’ Frederik Grønvold, Søren Fisker and Erik Wille.

Also a thank to Arctic Station, University of Copenhagen, for financial support to travel expenses.

We thank Kirsten S. Christoffersen and Klaus P. Brodersen for excellent supervision and help before, during and after the field trip. Their knowledge of and great interest in the arctic freshwater biology provided us with great impression and valuable scientific experience.

On behalf of all 11 students, Henriette Hansen, January 2016.

Foto: Klaus Peter Brodersen

Arctic Biology Field Course 2015

1) Anna Louise Hansen, 2) Anne Jo Dobel, 3) Ditte Ethelberg-Findsen, 4) Kirsten Sessetern Christoffersen (lærer), 5) Simone Møller Sørensen, 6) Ditte Marie Christiansen, 7) Nanna Slaikjer Petersen, 8) Casper Aggerholm Pedersen, 9) Henriette Hansen, 10) Emil Kristensen, 11) Jesper Rauff Schultz, 12) Kirstine Thiemer, 13) Klaus Peter Brodersen (lærer)

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Artssammensætning af Chironomidae i homoterme og heteroterme kilder på Disko, Grønland.

Casper Aggerholm Pedersen, Anne Jo Dobel & Henriette Hansen

Klimaforandringer er et væsenligt problem, og der er brug for yderligere studier til at belyse, hvordan økosystemer vil reagere på de stigende temperaturer, herunder specielt de arktiske, da temperaturændringerne vil være størst i disse områder. De homoterme og heteroterme kilder på Disko udgør en unik mulighed for at undersøge effekten af en temperaturstigning i ferske økosystemer, der over en længere periode har været udsat for højere temperaturer. I dette studie undersøger vi artssammensætningen af Chironomidae samt øvrige fauna fra fem homoterme og fem heteroterme kilder på Disko, Vestgrønland. Ved korrelation af fysisk-kemiske parametre var der, modsat vores forventninger, ingen signifikant forskel mellem homoterme og heteroterme kilder. Dette kommer ligeledes til udtryk i artssammensætningen, hvor resultaterne viser, at der ikke er en signifikant forskel mellem artsammensætningen i homoterme og heteroterme kilder. Der ses dog en tendens til, at Røde Elv udgør en barriere for udbredelsen af nogle Chironomidae arter samt øvrige fauna. Heraf må temperaturændring i og omkring kilderne derfor konkluderes til umiddelbart ingen signifikant effekt at have på artssammensætningen af faunaen. Dog anbefaler vi at udvide dette studie, således flere prøver bliver taget per kilde, samt flere kilder med en større variation i fysisk-kemiske parametre og over et større geografisk område tages med i analysen, da tidligere undersøgelser (Friberg *et al.*, 2001; Hodkinson *et al.*, 1996) har vist, at der er en effekt af temperaturændringer på Chironomidae.

Species composition of Chironomidae in homothermic and heterothermic streams on Disko Island, Greenland

Casper Aggerholm Pedersen, Anne Jo Dobel & Henriette Hansen

Abstract

Global warming is a significant problem and further studies in how ecological systems will respond to increasing temperature are needed. The homothermic streams on Disko Island offer a unique opportunity to investigate ecosystems that on a long-term basis have been exposed to an increase in temperature. These homothermic streams are comparable to the heterothermic streams found in the same environment. In this study, we investigate the species composition of Chironomidae from five homothermic and five heterothermic streams on Disko Island, West Greenland. However, our results do not show a significant difference in the species composition between the homothermic and heterothermic streams, but our data show a strong tendency that Røde Elv might form a barrier for the distribution of some Chironomidae genus and other fauna found.

Keywords: *Arctic limnology, Greenland, Disko Island, Streams, Chironomidae*.

Introduction

Freshwater ecosystems in the Arctic generally have low primary production due to the inflow of melt water, long ice cover and predominantly low temperatures because of short summers (Murray, 1998). As a response to these parameters, the food webs in arctic streams are often relatively simple and consist mostly of primary producers, primary consumers, decomposers and invertebrate predators (Gafner & Robinson, 2007)**.** The fauna has adapted to the extreme environment with adaptions such as high rates of food consumption, when it is available, and rapid conversion of food to lipids for energy storage (Kankaanpää & Huntington, 2001; Anonymous, 2012,).

In Greenland, the same general environmental conditions apply. The lotic freshwater ecosystems focused on in this study are streams, some of which are a result of geothermal activity. The geothermal surface manifestations are rare but are found in the basaltic areas of Scoresbysund in east Greenland and on Disko Island, west Greenland (Hjartason & Armannsson, 2010). Disko Island (20.000 km^2) has 12 areas with geothermal activity. The majority of these areas are found in basaltic lava pile, but three of them are found in Precambrian gneiss and one in Cretaceous sandstone (Hjartarson & Armannsson, 2010). The streams affected by geothermal activity maintain approximately the same temperature year round and do not freeze during winter despite that Disko Island belongs to the permafrost zone (Kristensen, 1987). Because of this, these streams are referred to as homothermic streams in this study.

The homothermic streams on Disko Island form unique and less harsh habitats for the organisms living there, in comparison to the heterothermic streams that freeze during winter (Kristensen, 1987). The flora around the homothermic streams is very diverse and luxuriant compared to the general vegetation on Greenland and resembles more southern vegetation. This is a result of the locally prolonged growth season provided by the homotermic streams in form of preventing the earth around the stream from freezing and allowing an early radiation from the sun to reach the plants in the spring (Kliim-Nielsen and Pedersen, 1974; Kristensen, 1987).

The average temperature is predicted to rise between 3.2-6.6°C in some parts of the Arctic due to global warming (Kaplan & New, 2006). The homothermic streams give an opportunity to study ecosystems and fauna that have been affected by a rise in temperature on a long-term basis (Eoin *et al.*, 2014).

An indicator used to investigate environmental change is the chironomids (Lods-Crozet *et al.*, 2001). In arctic and alpine streams the most dominating invertebrate species found, are from the family Chironomidae, also known as non-biting midges, which belong to the class Insecta, and the order Diptera (Friberg *et al.*, 2001; Gafner & Robinson, 2007). Chironomids are widespread, and the immature stages, the aquatic larvae, makes the Chironomidae the most distributed aquatic insect family in the world and the most successful insect family in the Arctic (Brodersen & Anderson, 2002; Bruun *et al.*, 2006; Ferrington, 2008). The immature larval stages of Chironomidae are mostly found in freshwater, where they live, until they are fully developed as flying midgets (Brodersen & Anderson, 2002). They have a relatively short generation time (Brooks, 2000), and their development depends on several environmental factors and parameters such as food availability, temperature and oxygen (Brodersen & Quinlan, 2006). Many chironomids are endemic and/or zoogeographic distributed, and those living under extreme conditions are highly adapted to the environment (Ferrington, 2008). This makes them very sensitive to environmental changes and thereby changes in freshwater ecosystems (Brodersen & Anderson, 2002; Brodersen & Quinlan, 2006). Environmental effects and other changes between years can be detected in the presence or absence of chironomid species in the sediment (Brooks, 2000). Chironomids have adapted to different species-specific temperatures, and due to this they can be used as climate proxies (Brodersen & Anderson, 2002).

In this article, we study the species composition of Chironomidae in homothermic and heterothermic streams, based on the hypothesis that the species composition is affected by temperature (Friberg *et. al.*, 2001). The homothermic streams are comparable to the heterothermic streams, as they are expected to have similar parameters during summer. The main differences are found during winter. In light of this, this study might be able to put into perspective, how the species composition will evolve in the majority of the streams on Disko Island, if the streams stop freezing during winter as a result of a climate change.

Based on the information above, 10 streams (5 heterothermic and 5 homothermic) have been investigated on Disko Island. The streams used were all located within a 10 km radius of Arktisk Station on the south side of Disko Island. The physical and chemical parameters included were water temperature, velocity, discharge, conductivity, total nitrogen (TN), total phosphorus (TP) and oxygen. These parameters were compared to the species found in the streams to see, what influences the composition of species the most. A comparison of the different species compositions found was made among the homothermic and heterothermic streams to prove any differences between the two. Another comparison made among the streams was to compare the streams from the east and west side of the river Røde Elv also concerning the species composition, in order to prove any differences between the two sides.

Materials & Methods

Data was collected from July 8th - 15th 2015 in the Qeqertarsuaq-area of Disko Island, Greenland (figure 1) on 10 different locations (figure 2). Coordinates and a general description of the individual streams with abbreviations can be found in appendix 1.

Field work

The 10 streams were selected on the premise of the shape - an area as straight as possible, the substrate (mud, sand, coarse gravel, stones, rock and moss) and a stable water flow assessed by eye. As the first thing, the locations were described. At the streams, coordinates (longitude and latitude), the weather, the course and shape of the streams including cross-sectional profile, substrates, the catchment area, the type of underground assessed by map and the surrounding vegetation was noted.

On the sampling location the width of the streams and depth profiles were measured from one edge

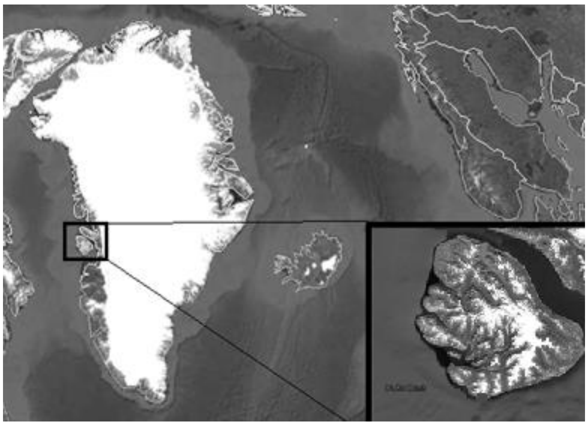

Figure 1: Location of Disko Island, Greenland. Source: Google Earth (24th of July 2015).

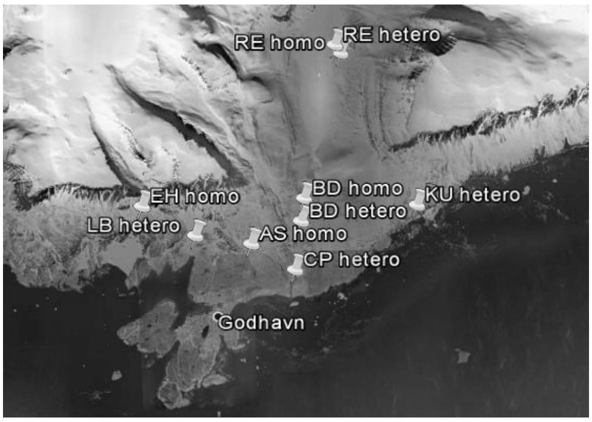

Figure 2: Overview of the 10 sampling locations on Disko Island shown with yellow marks. Source: Google Earth (24th of July 2015). The abbreviations are explained in appendix 1.

of the streams to the other with an interval of 20 cm and by using a tape measure and ruler.

The biotic samples of Chironomidae and other fauna were collected afterwards using the standard kick sampling method (Miljøstyrelsen, 1998) on the different substrate types by sweeping bigger rocks and gravel into a fine masked net (500 µm) and placing the net close to the bottom, just downstream from the kicking site.

A small amount of moss was sampled as well and was kept along with the net samples in a 100 mL container filled with water from the streams. The biotic samples were kept in the backpack until the return to the laboratory – this was done to keep the Chironomidae alive as best as possible. The fauna samples were not quantitative, but were enumerated semi-quantitatively in the laboratory.

Water samples for measuring TN and TP were collected in 50 mL containers and brought back to the laboratory. Oxygen concentration and saturation was measured directly in the streams using a *PASport Airlink 2*, and the application *SPARKvue* installed on an Apple Ipad. Afterwards the length of the chosen sampling-location in the streams was measured and noted. The conductivity was measured using a *PASport Airlink 2* downstream at the end of the sample locations. The flowrate measurements were carried out by pouring 0.5 kg dissolved salt (NaCl) in the streams and measuring it with *PASport Airlink 2*. The time was noted, when the conductivity had decreased closely to the starting level. In each stream a HOBO-data logger measuring temperature at an interval of 30 minutes was secured in a custom plastic tube to prevent the temperature being affected by radiation from the sun and placed under rocks. The data logger was collected after 24 hours to collect data on the diurnal variation of the temperature.

In the laboratory, the Chironomidae and other fauna were first sorted by eye. Then the Chironomidae were identified to the lowest possible taxanomic level (species if possible) using a stereolup and later determined to family or genus level by making a preparation with the head capsule and analysing it in a microscope. The preparation was done by decapitating the larvae and turning the head capsule with the ventral side upwards. By looking at the mentum, the ventromental plates and the shape of the

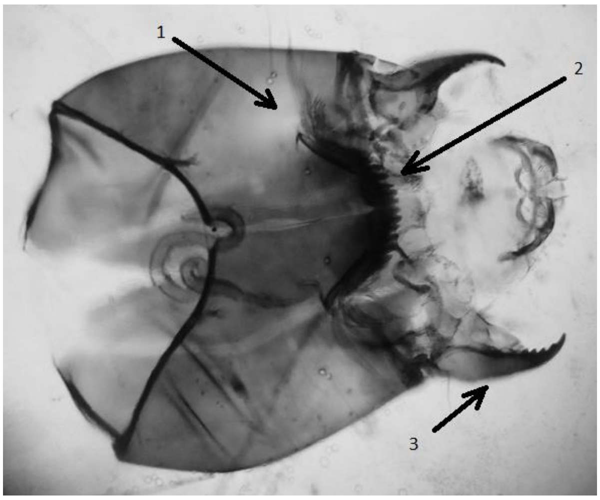

Figure 3: Head capsule of Chironomidae: 1) ventromental plates 2) mentum 3) mandible. Photo taken through microscope by Henriette Hansen.

Table 1: Physical and chemical parameters measured in the 5 homothermic streams: Arktisk Station (AS), Engelskmandens Havn (EH), Blæsedalen (BD$_1$), Kuannit (KU$_1$) and Røde Elv (RE$_1$) and the 5 heterothermic streams: Lyngmarksbugten (LB), Blæsedalen (BD$_2$), Campingpladsen (CP), Kuannit (KU$_2$) and Røde Elv (RE$_2$) on Disko Island, Greenland, 8th-15th of July 2015.

		Homothermic streams					Heterothermic streams				
		AS	**EH**	**BD$_1$**	**KU$_1$**	**RE$_1$**	**LB**	**BD$_2$**	**CP**	**KU$_2$**	**RE$_2$**
Temperature (°C)	Max.	6.0	8.2	5.9	7.2	7.2	3.3	6.0	10.1	4.8	4.4
	Average	4.2	6.1	4.6	5.0	3.9	2.5	4.4	7.3	4.5	3.2
	Min.	2.8	4.8	3.9	3.7	1.8	2.2	3.4	5.6	4.3	2.2
Velocity (m s^{-1})	Max.	0.83	1.00	0.13	1.67	1.75	1.00	0.45	0.50	0.75	1.33
	"Patch"	0.42	0.50	0.01	0.29	0.15	0.27	0.14	0.05	0.29	0.32
	Average	0.09	0.12	0.01	0.10	0.02	0.05	0.01	0.02	0.02	0.13
	Min.	0.02	0.03	0.00	0.03	0.01	0.02	0.00	0.00	0.01	0.02
	Range	0.81	0.97	0.13	1.64	1.74	0.98	0.45	0.50	0.74	1.31
Discharge (L s^{-1})		28	18	1	10	2	14	3	3	18	40
Oxygen conc. (mg L^{-1})		11.68	11.25	11.32	12.00	11.52	12.83	12.11	10.76	11.42	12.39
Oxygen saturation (%)		92	94	88	93	94	95	93	94	89	95
Conductivity (µS cm^{-1})		25	23	47	41	29	29	29	28	45	29
Nutrients (µg L^{-1})	TN	209	46	53	229	188	166	171	204	196	117
	TP	23	9	8	21	15	10	1	0	36	12

antennas and joints, the generic placement of the Chironomidae was determined (figure 3). This type of determination is possible, because Chironomidae have special features in every species. The determination literature used was Wiederholm (1983) and Brooks *et al.* (2007).

TN and TP were processed and analyzed by Emil Kristensen according to in house Freshwater Biological Laboratory standard methods (Søndergaard & Riemann, 1979).

Data analysis

Primer 5 was used for multivariate and numerical analysis. The similarities among the biotic samples were calculated using the Bray-Curtis similarity index (Clarke & Warwick, 1994). Data were transformed in the fourth root and standardised (percentage) to make the data more comparable and to avoid data sample bias. Euclidean distances were used for all abiotic data matrices, and the data were log transformed prior to analysis. Dendrograms and ordination diagrams (MDS analysis) were made for the biotic data with the data in different combinations: 1) “Chironomidae” 2) “Chironomidae + other fauna” and 3) “Other fauna”. The BIOENV procedure (Clarke & Warwick, 1994) was used to analyse the relationship between biotic and environmental data.

The study sites were categorised into groups by adding factors: 1) “type” (homothermic and heterothermic streams) and 2) geographical (East and West of Røde Elv). The last distinction was based on Røde Elv being a distributional barrier for Chironomidae and other fauna (elaborated in the discussion). Data divided by the factors were analysed using an ANOSIM (one-way randomised analysis of dissimilarities) test to find any possible difference between the streams using first the type factor and next the geographical division.

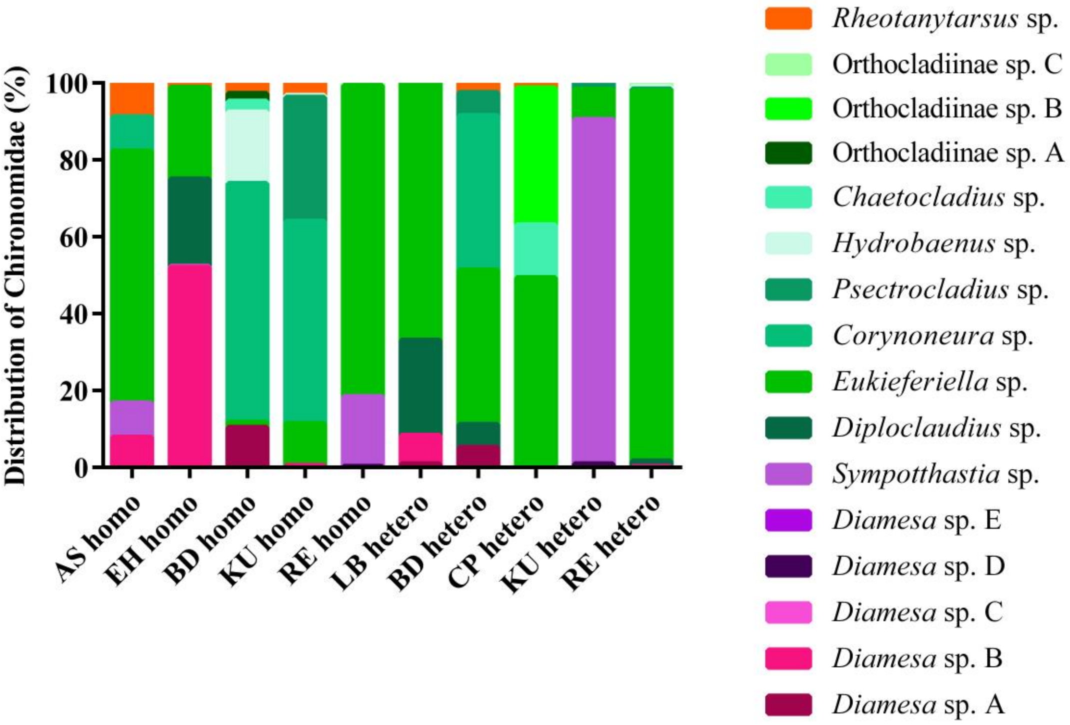

Figure 4: The distribution of Chironomidae (%) found in 5 homothermic and 5 heterothermic streams on Disko Island, Greenland, 8th-15th of July 2015. The different colour represents the subfamilies found (orange: Chironominae, green: Orthocladiinae and purple: Diamisinae).

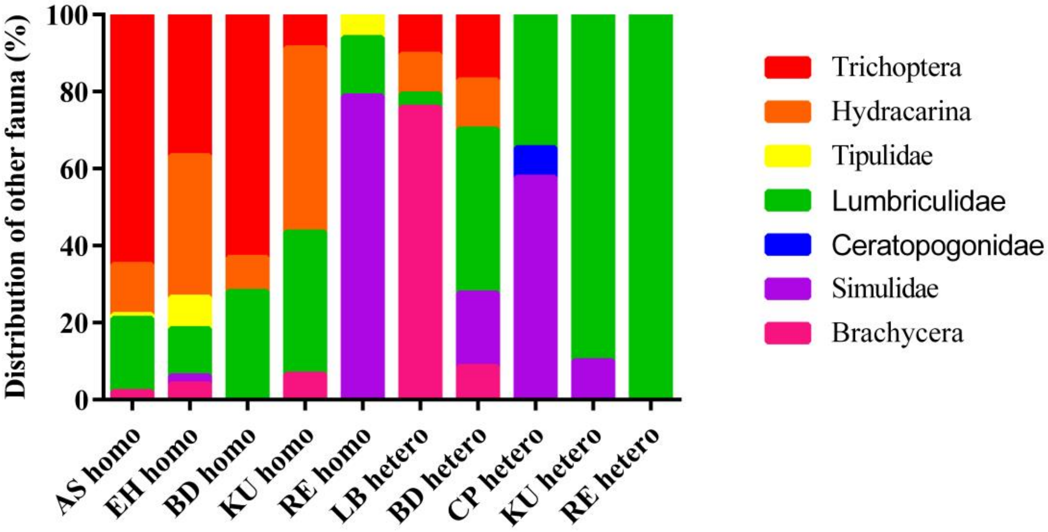

Figure 5: The percentage distribution of other fauna found in the 5 homothermic and 5 heterothermic streams on Disko Island, Greenland, 8th-15th of July 2015.

Results

Physical and chemical parameters

Temperatures were measured over periods of 24 hours, which showed a minimum temperature of 1.8°C in the homothermic stream “Røde Elv” and a maximum temperature of 10.1°C in the heterothermic stream “Campingpladsen”. The temperature, during the 24 hours measured, varied between 0.5-5.4°C among the streams (table 1). The range of velocity (the difference between maximum and minimum velocity) varied from 0.12-1.74 m s^{-1} (table 1). The discharge varied from 1-40 L s^{-1}. The maximum discharge in the “Røde Elv” heterothermic stream was much higher compared to any other of the streams (table 1). Conductivity varied from 23-47 µS cm^{-1} in the streams, and both the minimum and maximum values were found in the homothermic streams (table 1). The nutrient content varied among the streams with TN values ranging from 46-229 µg L^{-1} and TP from 0-36 µg L^{-1} (table 1). The oxygen concentration showed little variation among the streams, as it only varied from 10.7-12.8 mg L^{-1}. This gave a saturation varying between 88-95% in the streams (table 1).

Composition of invertebrates

A species list and a diagram of number of species can be found in appendix 2.

There was variation within the distribution of the three subfamilies: Orthocladiinae, Diamesinae and Chironominae (figure 4). Orthocladiinae was found in all of the streams and formed the majority of species found, except in the homothermic “Engelskmandens havn” and the heterothermic “Kuannit”. Diamesinae was especially abundant in these two streams, but only very few were found in the homothermic “Kuannit”, and the subfamily was completely absent in the heterothermic “Campingpladsen”. The Chironominae found (only one genus) was low in numbers in all streams and was present in 6 out of 10 streams.

The individual genus of Chironomidae showed that especially *Eukieferiella* sp. from the Orthocladiinae subfamily was common in the streams. None of the other species came close to having the same overall distribution as *Eukieferiella* sp. (figure 4).

Figure 6

Chironomidae

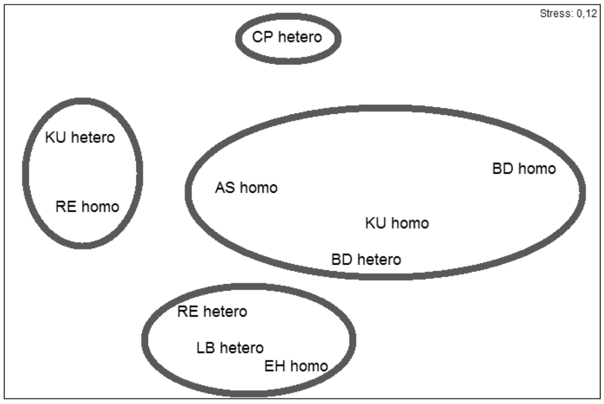

Figure 7

Chironomidae + Other fauna

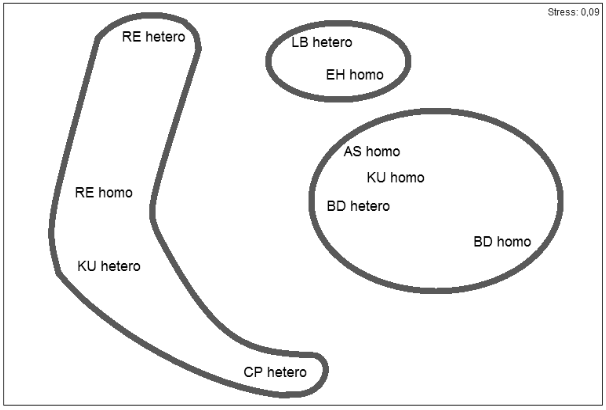

Figure 8

Other fauna

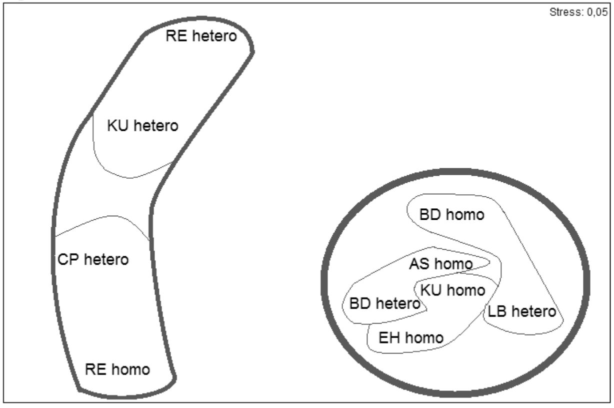

Figure 6-8: Ordination diagrams for the combinations “Chironomidae”, “Chironomidae + Other fauna” and “Other fauna” made by MDS analysis in Primer 5 with data from the 5 homothermic and 5 heterothermic streams on Disko Island, Greenland, 8th-15th of July 2015. The rings show the grouping from the Cluster analysis (appendix 3, figure 1-3).

Table 2: The three combinations of biotic data ("Chironomidae", "Chironomidae + Other fauna" and "Other fauna") correlated with the physical and chemical parameters, from the 5 homothermic and 5 heterothermic streams on Disko Island, Greenland, 8th-15th of July 2015.

Biotic combination	Highest corr. values	Related parameters	Corr. value with one parameter	Related parameter
Chironomidae	0.421	Conductivity (µS cm^{-1}) Minimum temperature (°C) Velocity patch (m s^{-1})	0.311	Oxygen saturation (%)
Chironomidae + Other fauna	0.314	Conductivity (µS cm^{-1}) Average temperature (°C) Minimum temperature (°C) Velocity patch (m s^{-1}) Velocity range (m s^{-1})	0.242	Oxygen saturation (%)
Other fauna	0.338	Oxygen saturation (%) Average temperature (°C) Minimum temperature (°C)	0.336	Average temperature (°C)

The distribution of the other fauna (figure 5) showed that Lumbriculidae dominated three out of ten streams (all heterothermic "Røde Elv", "Kuannit" and "Blæsedalen"). Brachycera dominated the heterothermic "Lyngmarksbugten". Hydracarina dominated the homothermic "Kuannit" and shared domination in "Engelskmandens Havn" with Tricoptera. Tricoptera also dominated the homothermic "Arktisk Station" and "Blæsedalen". Simulidae dominated the homothermic "Røde Elv" and heterothermic "Campingpladsen". Tipulidae was present in three homothermic streams, but always low in numbers compared to the other fauna found. In general, Lumbriculidae was most abundant in the heterothermic streams, and Hydracarina and Trichoptera was most abundant in the homothermic streams.

Similarity and clustering

The dendrograms showed different grouping between the three combinations of invertebrates, when running the Cluster analysis (appendix 3, figure 1-3). The MDS analysis showed similar results (figure 6-8). All ordinations had a stress factor between 0.05 – 0.12 indicating a good representation of sample similarities. In the combination "Chironomidae", the results were dispersed, which indicated a low similarity between the streams (figure 6). The dendrogram (appendix 3, figure 2) showed some grouping, which could also be seen in the ordination diagrams (figure 6).

The ordination diagram "Chironomidae + Other fauna" showed division between three groups (figure 7). In the most well defined group, the heterothermic "Campingpladsen", heterothermic

Table 3: The biotic data in three combinations ("Chironomidae", "Chironomidae + Other fauna" and "Other fauna") compared with each other when divided into "type" and "Geographical distribution" respectively.

	Type	Geographical distribution
Chironomidae	No significant difference (77.8% uncertainty)	No significant difference (10.5% uncertainty), almost a tendency
Chironomidae + Other fauna	No significant difference (38.1% uncertainty)	A strong tendency of a difference between the fauna in the different streams (5.2% uncertainty)
Other fauna	No significant difference (13.5% uncertainty)	No significant difference (16.2% uncertainty)

"Røde Elv", homothermic "Røde Elv" and heterothermic "Kuannit" had an increasing relationship. The second group consisted of homothermic "Engelskmandens Havn" and heterothermic "Lyngmarksbugten", and the remaining group consisted of homothermic "Blæsedalen", homothermic "Arktisk Station", homothermic "Kuannit" and heterothermic "Blæsedalen" with increased relationship (figure 7).

The ordination diagram based on the combination of "Other fauna" showed division in two distinct groups (figure 8). Left in the diagram, a superior group consisted of two subgroups. The heterothermic "Kuannit" and heterothermic "Røde Elv", and the second subgroup consisted of homothermic "Røde Elv" and heterothermic "Campingpladsen". In the other superior group, the streams were all closer together than in the first superior group (figure 8). This showed that this group was more similar in the composition of "Chironomidae + Other fauna", than the first group mentioned. The dendrograms showed some other relations compared to, what was shown in the ordination diagrams (appendix 3, figure 3).

Connecting biotic and environmental data

For the correlation analysis (BIOENV) between abiotic data and biotic data in the three different subgroup in the top of the diagram consisted of combinations, the highest correlation value was 0.421, which belonged to the combination "Chironomidae" (table 2). The most significant abiotic parameters for this combination were conductivity (µS cm^{-1}), minimum temperature (°C) and velocity patch (m s^{-1}). The minimum temperature was a significant parameter in all tests, but accompanied by different combinations of parameters (table 2). A list of the correlation values with 2, 3, 4 and 5 parameters for the three different combinations (appendix 4, table 1-4) - all had lower values.

Grouping of streams

The following factors were added to divide the data into groups: *type* (homothermic and heterothermic streams) and *geographical distribution* (east and west of Røde Elv). The results from the ANOSIM analysis showed only one tendency to a difference, which is shown in the combination "Chironomidae + Other Fauna", when grouped by geographical distributions (table 3).

Discussion

Physical and chemical parameters

The definition of a homothermic stream is that the water temperature is the same year around (Bruun *et al.*, 2006). The temperatures measured from the 8th to the 15th of July did not show distinct differences between the homothermic and heterothermic streams as expected. However, temperatures of the homothermic streams seemed less variable among each other compared to the heterothermic streams. This could be an expression of the homothermic streams being less influenced in temperature by the surrounding environment (sun radiation, shadow, air temperature etc.).

For the velocity data, the velocity range was important to notice, as this difference described the possible number of habitats within and among the streams, with the highest velocity range having the most habitats (Allan & Castillo, 2007). The measure of discharge reflected in the velocity of a stream, but also described the amount of water emerging from surroundings, and therefore the discharge could vary between years. The streams were chosen based on having the same velocity, assessed by eye, and a minimum of difference in velocity range among the streams was therefore expected, as was shown in the results.

Both the conductivity, TN and TP levels were as expected for streams in the Arctic (Friberg *et al.*, 2001). The nutrient concentration is in general very similar among the streams investigated, as is the oxygen concentration and saturation.

This little difference in physical and chemical parameters that were found among the streams could be due to the similar sizes of the streams (appendix 1) that makes them equally exposed to the surrounding during summer. Similar physical and chemical data were found on Disko Island by Friberg *et al.* (2001) with temperature ranging between 3.4-8.6°C and conductivity 41-54 µS cm^{-1} in the small and narrow streams measured, and in general little difference among these streams.

Homothermic vs. heterothermic streams

No significant difference in macroinvertebrate composition was found between the homothermic and heterothermic streams. Since no clear difference of physical and chemical parameters were found among any of the streams either, the non-freezing of the homothermic streams and freezing of the heterothermic streams during winter do not seem to have any major influence on the macroinvertebrate composition.

The three different compositions of Chironomidae species and other fauna (table 2) was mostly influenced by conductivity, temperature and velocity. As mentioned, the streams in this study had all low temperatures and conductivity. Both of these parameters limit organisms, because only few species have adapted to these arctic conditions, *Eukieferiella* sp. being one of the few. Velocity patch is an important variable looking at the stability of the streams, and due to the high number of *Eukieferiella* sp. found, *Eukieferiella* sp. is most likely able to cope with significant changes in the streams. A way of coping might be by producing several generations during summer season, which is often seen in many species of Orthocladiinae that *Eukieferiella* sp. belongs to (Pinder, 1986). This means that there is probably only little competition of the habitat investigated, and *Eukieferiella* sp. could more easily colonizes and dominates a large area.

The data for "Other fauna" (results, table 2) showed that oxygen saturation was a limiting factor as well. However the oxygen content is so high that it seems unlikely to be a limiting or influencing factor, except for any anaerobic organisms. It is therefore difficult to explain, why oxygen is one of the three variables describing the composition of "Other fauna".

Observations similar to this study have been made at Svalbard and Greenland (Lods-Crozet *et al.*, 2001; Friberg *et al.*, 2001). These studies investigated the macroinvertebrate community in streams with different origin, where glacial fed streams differed with significantly lower macroinvertebrate species richness and lower temperatures compared to the groundwater fed streams. Temperature is thought to be the variable affecting the abundance of Chironomidae and other invertebrates the most (Friberg *et al.*, 2001), but as mentioned, the results of this study did not show any clear differences in temperature between the homothermic and heterothermic streams. The reason for this could be that the Chironomidae living in these two types of streams were not affected by the fact that the heterothermic streams freezed during winter. Friberg *et al.* (2001) also found that origin of the stream and water source were both variables, highly influencing the composition of macroinvertebrates, but since these variables in this study were very similar between the homothermic and heterothermic streams, they were not affecting the macroinvertebrate composition in this study.

A geographical barrier - "Røde Elv"

For the geographical influence on the fauna, an increase in significance were found, when more fauna were added (table 3), but no significance was found.

The theory that Røde Elv posessed a barrier was supported by previous literature mentioned in the following. Most adult midges live for a few days, which limits the possibility to distribute to new areas and expand to new habitats as they, within these few days, need to reproduce (Pinder, 1986). Adult chironomids are, because of their size, affected by wind when flying (Peng *et al.*, 1992). Additionally, Delettre and Morvan (2000) have shown that Chironomidae communities in agricultural landscapes keep partly closer to the stream they emerge from, if the riparian surroundings have a lot of vegetation in the form of trees and hedges and that the riparian vegetation acts as both corridors for dispersal and barriers for the chironomids. This could influence the distribution to new streams. Compared to Greenlandic standards, the streams we investigated were all more or less densely surrounded by vegetation, especially the ones that had riparian *Salix*.

A reason for, why *Eukieferiella* sp. was present in all of the streams, could be that a homogenous chironomid species composition can be found at long distances from the nearest waterbody, while rare chironomids are mostly located along the same stream (Delettre & Morvan, 2000).

Climate change aspect

In this study there was no difference in species composition between the homothermic and heterothermic streams, but this was likely due to the missing differences in temperature. Despite this, a rise in temperature has been proven to affect Chironomidae in different ways. In the study of Friberg *et al.* (2001) a difference in the species composition of Chironomidae was detected between glacial fed and non-glacial fed streams, which showed more distinct differences in temperatures than the streams used in this study. Furthermore adult flying Chironomidae showed greater activity and greater cumulative biomass that could result in a depletion of adult Chironomidae before the end of the spring, compared to a more linear activity and biomass in a colder spring (Hodkinson *et al.*, 1996). This difference in activity and cumulative biomass could be an indicator of, how Chironomidae could react in response to an increase in temperature due to global warming.

Future studies

The dataset could be improved by sampling in more streams from different areas of Disko Island, so that any geographical differences of Disko Island was taken into consideration. It could also be interesting to include different gradients of the streams, as these gradients creates a change in the habitats down through the streams and makes a possibility for a diverse composition of Chironomidae and other fauna that might differ among the streams (Friberg *et al.*, 2001).

During identification of the Chironomidae, noteworthy differences in body size both between and within genus levels were noticed. This might be a result of temperature, as this generally increases the metabolism, whereas a larger amount of food can be ingested and the body size can increase (Gillooly *et al.*, 2001). Some Chironomidae species are also multivoltine, which means that they can produce more than two generations during summer (Pinder, 1986). As the Chironomidae larvae stages have different sizes, the different body sizes noticed in this study could be due to different larvae stages in different generations. More generations could also cause a species to dominate the streams. The importance of temperature for body size and number of generations can therefore be another relevant and interesting variable to investigate further in future studies.

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Appendix 1

Homothermic streams	Coordinates	Cross section profile	Substate	Catchment	Underground	Riparian vegetation	Width (m)	Average (cm)	Areal (m^2)
Arktisk station (AS)	69°15'27"N 53°31'12"W	Flat, shallow, relatively broad	Bryophyta, gravel, stone, boulders	Willow heath	Gneiss, basalt	Bryophyta, *Equisetum*, *Alchemilla*, *Salix*, *Drapa sp.*, *Phyllodoce caerulea*	0.73	0.11	0.08
Engelsk-mandens havn (EH)	69°15'50"N 53°34'10"W	Flat, shallow, low sides	Bryophyta, stone, mud,	Willow heath	Gneiss	Bryophyta, *Angelica archangelica ssp.*, *Equisetum*, *Alchemilla*, *Salix*	0.63	0.057	0.036
Blæsedalen 1 (BD_1)	69°15'55"N 53°29'46"W	Flat, shallow, very narrow	Bryophyta, stone, gravel, mud, mos, corse sand,	Willow heath, low vegetation	Basalt	Bryphyta, *Salix*, *Equisetum*, *Pedicularis sp.*, *Pedicularis dasyantha*	0.62	0.078	0.048
Kuannit (KU_1)	69°15'54"N 53°26'24"W	Flat, shallow, broad	Bryophyta, stone, gravel, rocks, mud	Willow heath/coastal area	Basalt	Bryophyta. *Salix*, *Alchemilla*, *Angelica archangelica*, *Equisetum*	0.80	0.042	0.033
Røde Elv 1 (RE_1)	69°17'24"N 53°28'47"W	Flat, narrow, high on one side	Bryophyta, stone, gravel, mud	Willow heath / valley	Basalt	Bryophyta, *Salix sp.*, *Equisetum*, *Taraxacum*,	0.49	0.031	0.015

Heterothermic streams	Coordinates	Cross section profile	Substrate	Catchment	Underground	Riparian vegetation	Width (m)	Average (cm)	Areal (m^2)
Camping-pladsen (CP)	69°15'11"N 53°30'01"W	Flat, relatively broad	Rocks, stone, gravel, Bryophyta	Willow heath, river banks	Basalt	*Salix*, Bryophyta, *Equisetum*	0.94	0.05	0.05
Lyngmarks-bugten (LB)	69°15'32"N 53°32'44"W	Flat, shallow, narrow	Stone, gravel, sand, Bryophyta	Willow heath	Gneiss	*Salix*, Bryophyta, *Alchemilla*, *Equisetum*, *Arabis sp.*, Marcantiophyta,	0.40	0.13	0.05
Blæsedalen (BD2)	69°15'41"N 53°29'51"W	Flat, shallow, varied in width, steep sides	Rocks, stone, gravel, Bryophyta	Heath, dry and nutrient poor	Basalt	*Equisetum*, *salix*, Bryophyta, *Alchemilla*. Little vegetation: signs of recent melted snow	0.45	0.04	0.02
Kuannit (KU2)	69°15'51"N 53°26'42"W	Flat, steep sides	Stone, rocks, gravel, mud	Willow heath, coastal area	Basalt	*Salix*, *Alchemilla*, *Taraxacum*, Poales, *Equisetum*, *Angelica archangelica*, Bryophyta	1.11	0.06	0.06
Røde Elv (RE2)	69°17'29"N 53°28'56"W	Flat, shallow, broad, high sides	Rocks, course and fine gravel, Bryophyta	Willow heath, valley	Basalt	*Salix*, *Equisetum*, Bryophyta, Poales	0.90	0.14	0.12

Appendix 2

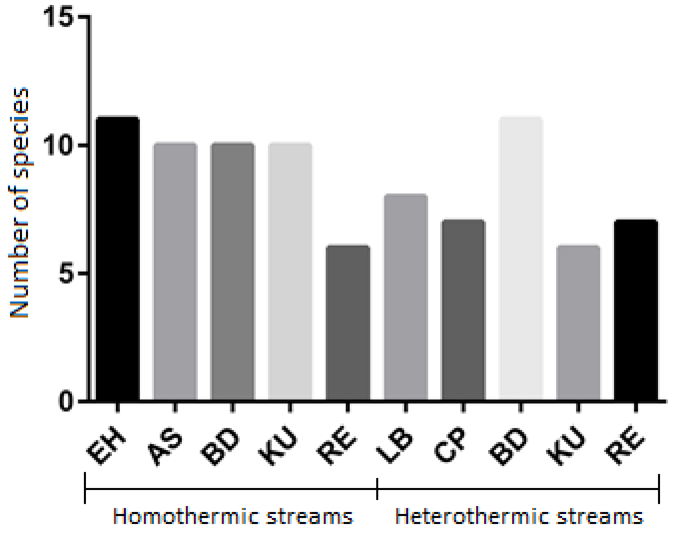

Figure 1: The number of Chironomidae species found in 5 homothermic and 5 heterothermic streams on Disko Island, Greenland sampled during 8th-15th of July 2015.

Table 1: Species list of fauna found in 10 streams on Disko Island.

		Homothermic					**Heterothermic**				
Chironomidae		Engelsk-mandens Havn (EH)	Arktisk Station (AS)	Blæseda-len (BD$_1$)	Røde Elv (RE$_1$)	Kuannit (KU$_1$)	Lyngmarks-bugten (LB)	Camping-pladsen (CP)	Blæseda-len (BD$_2$)	Røde Elv (RE$_2$)	Kuannit (KU$_2$)
Subfamilies	Genus										
Diamesiinae	*Diamesa* sp. A			15			2		6		
	Diamesa sp. B	176	7			1	17			1	
	Diamesa sp. C	1									
	Sympotthastia sp.		8								103
	Diamesa sp. D										1
	Diamesa sp. E				4						
Orthocladiinae	*Diplocladius* sp.	77					57		7	10	
	Eukieferiella sp.	81	59	2	459	23	154	36	47	666	9
	Corynoneura sp.		8	90		111			47		
	Psectrocladius sp.					68			7	3	2
	Hydrobaenus sp.			27		1				4	
	Chaetocladius sp.			4				10			
	Orthocladiinae sp. A			3							
	Orthocladiinae sp. B							26			
	Orthocladius sp.				4					7	
Chironominae	*Rheotanytarsus* sp.	4	8	4		7		1	3		
Other	Brachycera	2	2			3	22		4		
	Simulidae	1			26			15	9		1
	Ceratopogonidae							2			
	Lumbriculidae	6	19	16	5	17	1	9	20	1	9
	Tipulidae	4	1		2						
	Hydracarina	18	13	5		22	3		6		
	Trichoptera	18	65	36		4	3		8		

Appendix 3

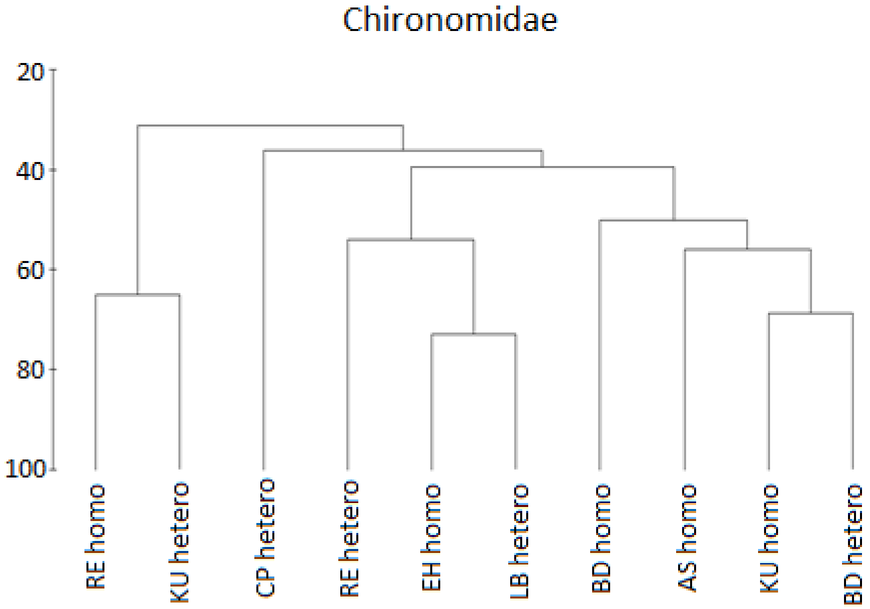

Figure 1: A dendrogram of the biotic data (combination: “Chironomidae”) from the 5 homothermic and 5 heterothermic streams sampled on Disko Island, Greenland sampled during 8th-15th of July 2015.

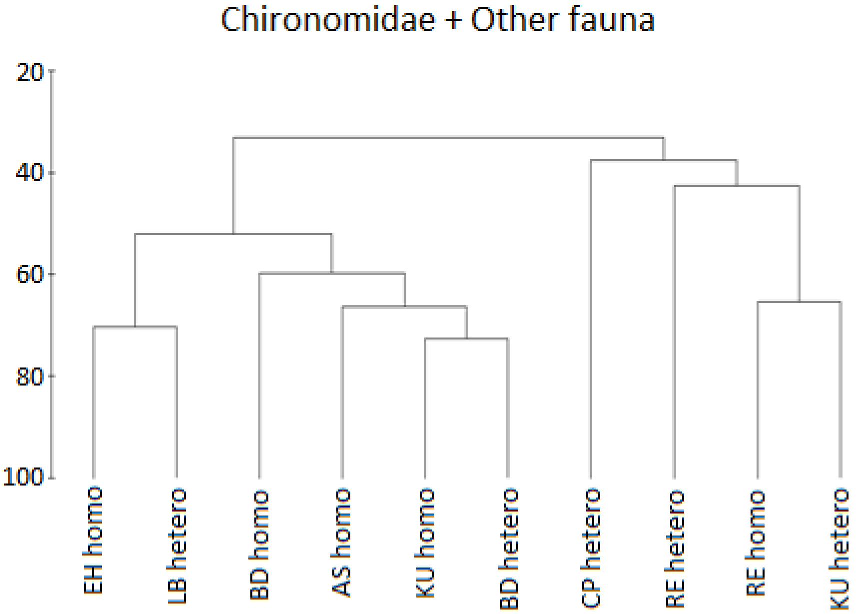

Figure 2: A dendrogram of the biotic data (combination: “Chironomidae + Other fauna”) from the 5 homothermic and 5 heterothermic streams sampled on Disko Island, Greenland sampled during 8th-15th of July 2015.

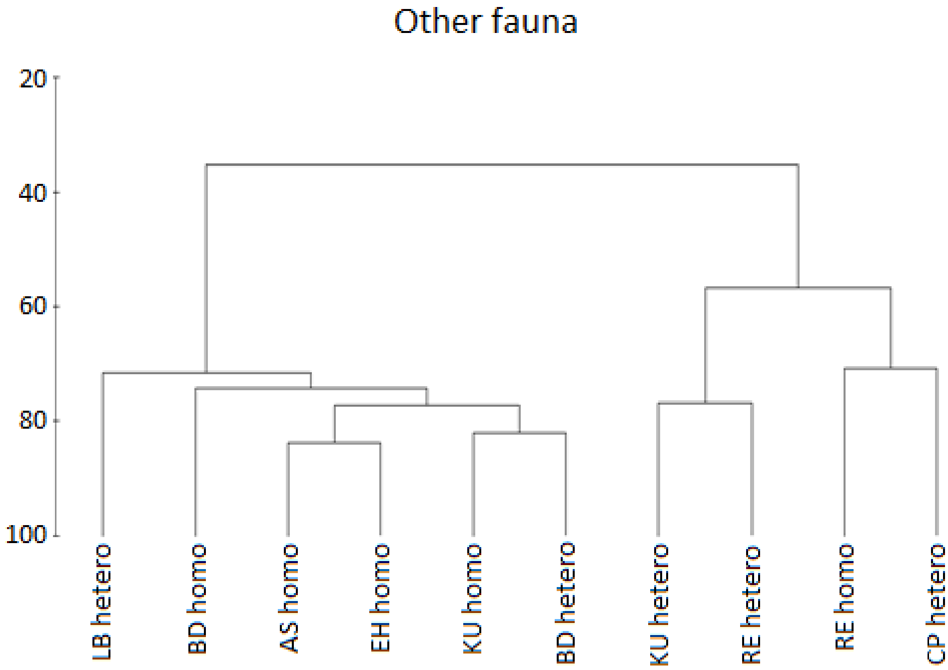

Figure 3: A dendrogram of the biotic data (combination: “Other fauna”) from the 5 homothermic and 5 heterothermic streams sampled on Disko Island, Greenland sampled during 8th-15th of July 2015.

Appendix 4

Table 1: A list of the parameters assigned with numbers used in the tables below for reference.

Variables	Parameter
1	Oxygen concentration (mg L^{-1})
2	Oxygen saturation (%)
3	Conductivity (µS cm^{-1})
4	Discharge (L s^{-1})
5	Maximum temperature (°C)
6	Average temperature (°C)
7	Minimum temperature (°C)
8	Maximum velocity (m s^{-1})
9	Patch velocity (m s^{-1})
10	Average velocity (m s^{-1})
11	Minimum velocity (m s^{-1})
12	Velocity range (m s^{-1})
13	Total Nitrogen (µg L^{-1})
14	Total Phosphorus (µg L^{-1})

Table 2: Correlation between the best fitting parameters in combination of 2, 3, 4 and 5 parameters for the biotic combination "*Chironomidae*".

Number of variables	Corr.	Selections
2	0.367	3, 8
3	0.421	3, 7, 9
4	0.424	2, 3, 7, 9
5	0.424	2, 3, 4, 7, 9

Table 3: Correlation between the best fitting parameters in combination of 2, 3, 4 and 5 parameters for the biotic combination "*Chironomidae*. + Other fauna"

Number of variables	Corr.	Selections
2	0.285	6, 7
3	0.301	6, 7, 9
4	0.307	3, 6, 7, 12
5	0.314	3, 6, 7, 9, 12

Table 4: Correlation between the best fitting parameters in combination of 2, 3, 4 and 5 parameters for the biotic combination "Other fauna".

Number of variables	Corr.	Selections
2	0.336	2, 6
3	0.338	2, 6, 7
4	0.338	2, 4, 6, 7
5	0.338	2, 4, 6, 7, 11

Systemmetabolisme i en arktisk sø og dam

Emil Kristensen og Jesper Rauff Schultz

Små søer og damme er mangfoldige i Arktis og er derfor vigtige dele i det globale kulstofkredsløb. De arktiske vandområder er særligt vigtige, fordi de forventede klimaforandringer sandsynligvis har størst indvirkning her, hvilket kan medføre en øget frigivelse af drivhusgasserne CO_2 og CH_4. Formålet med projektet var at måle døgnets iltsvingninger i en sø og en dam på Disko i Grønland for at kvantificere fluksen af karbon. Fra iltmålingerne kunne vi beregne økosystemets nettoproduktion (NEP), bruttoproduktion (GPP) og respiration (R). Det viste sig, at både søen og dammen hovedsagligt var autotrofe i prøvetagningsperioden dog med en enkelt heterotrof dag. Dammen havde en højere NEP end søen, når vi sammenlignede de volumetriske puljer (2,3 mod 0,8 mmol O_2 m^{-3} d^{-1}), men på grund af sin lave dybde havde dammen en lavere NEP udtrykt pr areal (0,4 mod 0,8 mmol O_2 m^{-2} d^{-1}). Det meste af bruttoproduktionen i søen foregik på bunden, men da der også var en høj bentisk respiration var produktionen lavere her end i pelagiet målt pr. kvadratmeter søoverflade. I dammen fandt vi den højeste produktion i mos-begroede områder, hvilket påviste en høj heterogenitet over korte aftande, selv i en lille, lavvandet og vind-udsat dam. Det årlige estimerede kulstofbudget for søen og dammen, baseret på lys-data viste, at søen ændres fra autotrof til heterotrof afhængigt af den frie vandvolume under isen om vinteren. Her fandt vi at en tykkelse af isen på 1 m betyder at søen årligt frigiver 16,4 kg C år^{-1}, hvorimod en istykkelse på 2 m betyder, at søen har en optagelse af karbon på 36,6 kg C år^{-1}. Dammen har et årligt optag af kulstof på 0,33 kg C år^{-1} og en længere sommer, grundet global opvarmning, vil betyde et estimeret optag på 0,37 kg kulstof.

Whole system metabolism in an Arctic lake and a small pond

Emil Kristensen and Jesper Rauff Schultz

Abstract

Small lakes and ponds are abundant throughout the Arctic and are accordingly important in the global carbon cycle. The Arctic water bodies are especially important due to climate changes which could increase their release of CO_2 and CH_4. To quantify the metabolism in aquatic environments, we measured diurnal oxygen changes in a small lake and a pond on Disko Island, Greenland. From these measurements we were able to calculate the net ecosystem production (NEP), the gross primary production (GPP) and the respiration (R). We found that both the lake and pond were overall autotrophic during our period of sampling, although heterotrophic days occurred. The pond had a much higher NEP than the lake when comparing the volumetric rates (2.3 vs. 0.8 mmol O_2 m^{-3} d^{-1}), but because of the shallow nature of the pond it had a lower area NEP (0.4 vs. 0.8 mmol O_2 m^{-2} d^{-1}). Most of the GPP in the lake took place in the benthic, but since the benthic also had higher respiration rates we found a lower benthic production than in the pelagic per square meter. In the pond, we found a higher production in the moss-covered areas showing high heterogeneity even in a small, shallow and wind exposed water body. The estimated yearly carbon budget for the lake and pond, based on light data, showed that the lake changed from autotrophic to heterotrophic depending on the water volume during winter related to the thickness of the ice. We estimated that 1 meter of ice resulted in a release of 16.4 kg C y^{-1} and 2 meters of ice resulted in an uptake of 35.6 kg C y^{-1}. The pond showed a yearly uptake of 0.33 kg C y^{-1} or 0.37 kg C y^{-1} with a prolonged summer related to climate change.

Keywords*: Low Arctic, metabolism, pond, lake*

Introduction

Freshwater lakes and ponds are common throughout the Arctic, with a large variation in size and depth - although most are small and shallow (Downing *et al.*, 2006). Many types of lakes are found in the Arctic, ranging from thermocasts to tundra ponds. These lakes are highly affected by the surrounding catchment area which influence both physical and chemical states (Rautio *et al.*, 2011). The pH of Arctic lakes are often neutral, but humic acids from peatland can lower the pH and increase the concentration of colored dissolved organic matter (CDOM) (Vincent & Laybourn-Parry, 2008).

CDOM originating from peatland, ferns or other water locked areas can influence the light attenuation in lakes and ponds. High concentrations of CDOM can limit photosynthesis, but also protect microorganisms and zooplankton against harmful UV-radiation (Rautio *et al.*, 2011). The strong light attenuation can also promote stratification in the water column when more heat is absorbed in the top layer. The concentration of CDOM or inorganic materials can influence whether the lake is dominated by pelagic or benthic primary production (Vincent & Laybourn-Parry, 2008; Ask *et al.*, 2009; Rautio *et al.*, 2011).

The primary production in oligotrophic Arctic lakes are often dominated by benthic production contributing as much as 80-98 % of the total production (Rautio *et al.*, 2011). The benthic production derives from microbial mats on the sediment with nutrient rich interstitial water or as biofilm on rocks and pebbles (Vadeboncoeur *et al.*, 2003). The ultra-oligotrophic Arctic lakes, if low in CDOM or silt, allows solar radiation to penetrate the water column all the way to the bottom. For the primary producers this is preferable, but the

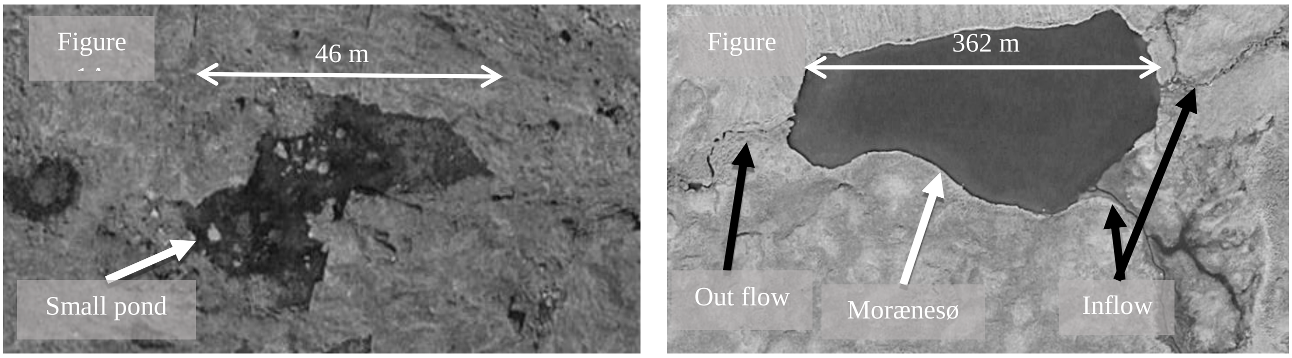

Figure 1A: Picture showing the small pond (white arrow) without any inflow or outflow. Size of the pond is shown just above. Figure 1B: Morænesø (white arrow), the two inflows and the out flow (black arrow). The size of the lake is shown at the top.

seasonal variation in solar radiation due to ice cover and the trajectory of the sun together with nutrient limitations shortens the growth season in many of the lakes (Vincent & Laybourn-Parry, 2008). Often high levels of UV-radiation and photosynthetic active radiation (PAR) can result in DNA degradation and photoinhibition. CDOM can protect against the damage, but high concentrations of CDOM also result in an increase in corresponding dissolved organic carbon (DOC). High DOC concentrations can favor bacterial biomass, but is not always seen in Arctic lakes (Sobek & Algesten, 2003; Rautio *et al.*, 2011). The increase in DOC has been found to enhance bacterial respiration in temperate lakes, which is an important factor when determining whole lake metabolism (Hanson *et al.*, 2003; Staehr *et al.*, 2010).

The net ecosystem production (NEP), gross primary production (GPP) and the respiration (R) can be calculated from diel oxygen changes, temperature, wind and light data (Staehr *et al.*, 2010). Determining whole lake metabolism has become more accessible in the last decade as technology has gotten cheaper and more reliable (Staehr *et al.*, 2010). Calculating the metabolism of aquatic systems gives insight in productivity, respiration rates and organic carbon assimilation (which is near a 1:1 molar ratio between O_2 and CO_2) and tells us if the lake is net heterotrophic or autotrophic (Hanson *et al.*, 2003).

A GPP < R often suggest inflow of allochthonous material while a GPP ≈ R suggest autochthonous production. A higher total phosphorous (TP) can increase GPP while DOC and allochthonous carbon, which is anticipated to rise in future, will increase R (Crump *et al.*, 2003; Hanson *et al.*, 2003; Rautio *et al.*, 2011). The respiration of bacteria is often correlated to a Q_{10} value of 2 (Den Heyer & Kalff, 1998), but the Q_{10} can be higher at low temperature enhancing the remineralization in cold Arctic water bodies even more (Pace & Prairie, 2005).

Small shallow ponds often release more CO_2 than larger lakes, due to high wind exposure and turbulence related to their size - thus resulting in a negative NEP (Staehr *et al.*, 2011). While this is true for most ponds, some oligotrophic water bodies with very low organic content may have a positive NEP during summer (Christensen *et al.*, 2013).

It is important to understand the aquatic carbon cycle as freshwater lakes, wetlands, and ponds have been found to store large amounts of terrestrial fixed carbon (Cole *et al.*, 2007; Sand-Jensen & Staehr, 2011). Aquatic systems are important when determining global carbon fluxes both now and in the future where global warming brings higher temperatures, decreased ice cover, higher inflow of nutrients and organic matter, resulting in increased CH_4 production (Schuur *et al.*, 2009; Rautio *et al.*, 2011). However, an increase in temperatures will also enhance evaporation rates which may lead to water bodies drying out and thereby lowering the release of CH_4 (Rautio *et al.*, 2011).

Whole system metabolism has usually been estimated by measurements from a single oxygen sensor in the deepest part of the lake, but shallow and littoral habitats show more dynamic O_2 fluctuations in periods without wind (Van de Bogert *et al.*, 2007). The diel oxygen method is more reliable compared to measurements of CO_2, which quickly change state at high pH to HCO_3^- and CO_3^{2-}.

In this study, we examine whole system metabolism in a shallow lake and a small pond in the low Arctic, at Disko Island, using the diel oxygen measurements. To our knowledge this has not been done in the Arctic water bodies before. Arctic waters differ from temperate waters by having a very short summer season, midnight sun and often low nutrient concentrations (Vincent & Laybourn-Parry, 2008). The whole lake metabolism will be related to the bathymetry, concentration of nutrients (nitrogen and phosphorous), CDOM and to chlorophyll *a* concentration. This will give us the opportunity to evaluate the possible reasons for differences in the production. The estimates of metabolism will tell us if the water bodies are autotrophic or heterotrophic on a day-to-day basis. Measuring the metabolism also makes it possible to determine if the water body is a sink or source of carbon. We use the results from the lake and the pond to discuss the consequences of a 10-week open-water period and a frozen water body (1.5-2 meter) during winter (Christoffersen, 2006).

Materials and methods

To investigate metabolism in Arctic water bodies we conducted an experiment on Disko Island in western Greenland. Here we chose a small shallow lake, Morænesø (69°16'11.93"N, 53°28'30.55"W), and a small rock basin pond (< 1 ha) with a heavy growth of mosses (69°15'15.69"N, 53°31'37.18"W) (figure 1A and 1B). Morænesø is located next to a moraine and receives water from a wetland next to the lake while the pond is precipitation fed, both waterbodies was relatively clear. To calculate the area, water volumes, maximum depth, and mean depth as well as generating a bathymetric map of sediment type and water depth, we used a Lowrance HDS-12 Gen2 Touch chartplotter and sonar. Data collection was done while crossing the lake by boat and compiled in ReefMaster 1.8 PRO. The shallow nature of the pond made it impossible to use sonar equipment. As a result, the area of the pond was found using GPS waypoints obtained while walking around it. The GPS waypoints were exported to Google Earth and the area calculated using the http://www.zonums.com/online/kmlArea/ web

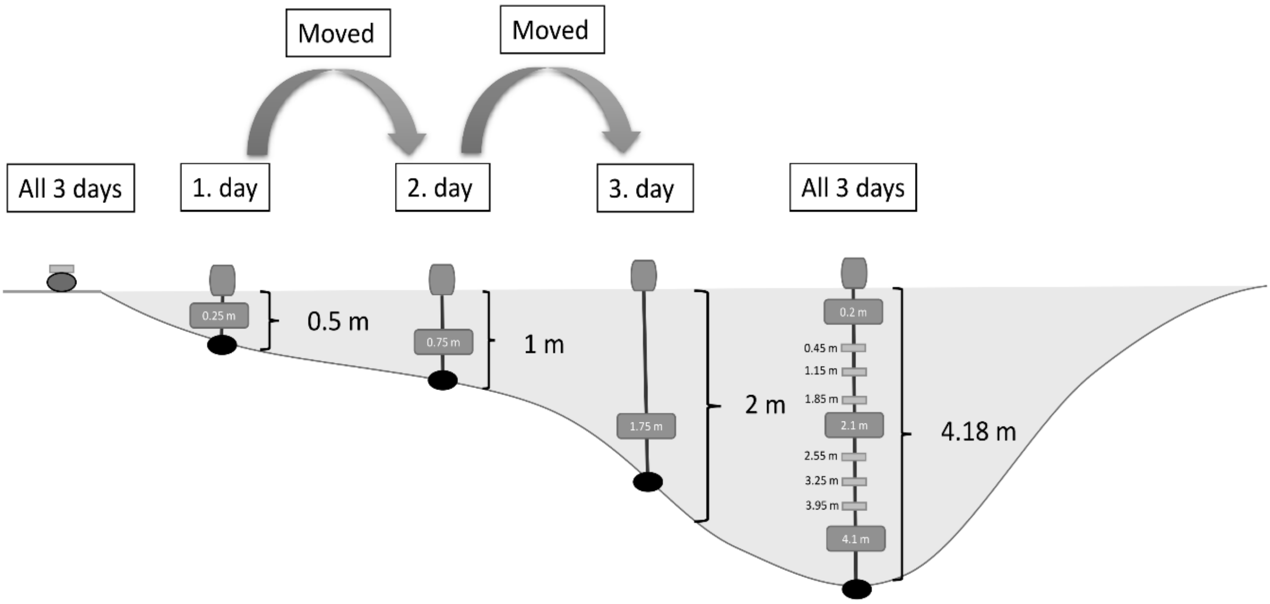

Figure 2: A drawing showing the placement of the HOBO loggers (small rectangles) and miniDOTS (large rectangles) at Morænesø. The stationary loggers (3 days) were placed at the shore and at the deepest part of the lake. One miniDOT logger was moved between the 1st and 2nd day and between the 2nd and 3rd day and the measuring depth is showed inside the rectangle.

tool. The mean depth was calculated from point measurements taken directly in the small pond with a ruler.

To measure diurnal changes in light we used Onset HOBO loggers while we used PME MiniDOT O_2 loggers to measure dissolved oxygen and temperature in 10-minute intervals. Before setting up the HOBO loggers we inter-calibrated them to a LI-COR LI 1000 PAR logger with a LI-COR LI 192SA sensor head on a clear sunny day.

In Morænesø, we placed a HOBO logger at the shore to measure above water irradiance, and below the surface, we placed one logger at 0.45 m of depth and the rest in intervals of 0.7 m down to a total depth of 3.95 m (figure 2). The miniDOT loggers were placed at 0.2, 2.1 and 4.10 meters of depth and secured, together with the HOBO loggers, to a rope. The rope was anchored to a stone and a buoy to keep them vertical in the water column. On the second day, we put a transparent freeze bag around the miniDOT logger at 2.1 m and closed it firmly. This was done to measure pelagic oxygen production and respiration. We placed a fourth miniDOT at low depth and moved it each day (0.26, 0.73 and 1.73 m) to record diurnal oxygen variation in the littoral zone (figure 2). We recorded data over 3 days in the period from 9/7-2015 to 13/7-2015.

In the small pond, we placed the loggers at two spots, in an open spot and in an area with heavy moss growth. In the open area, we placed HOBO loggers at 5, 15 and 17.5 cm and miniDOT loggers at 7 and 23 cm (both locations are shown at the frontpage). In the area with moss we placed HOBO loggers at 1.5, 10, 15 cm and the miniDOT loggers at 6 and 19 cm, we also placed a HOBO logger at the surface. In the pond we chose not to measure pelagic oxygen changes due to the low production in the shallow waterbody. The distribution of the open water and the moss-covered areas, were determined by a thorough visual evaluation to a 1/1 ratio. We collected data over 3 days in the period from 13/7-2015 to the 17/5-2015. Data from all loggers were extracted with HOBOware and miniDOT plot software, exported to Excel and shown using Graphpad Prism 6.0.

Metabolic rates from the lake and pond were determined from miniDOT data (mg O_2 L^{-1} and temperature), mean wind data (m/s) measured at 9.5 meters of height with an Aanderaa wind speed sensor (model 2740) at Arctic station, and light data from HOBO loggers (LUX converted to PAR via intercalibrated values). The metabolism of the water body can be described with eq. 1. $\Delta O_2/\Delta t$ is the change in oxygen concentration over time (NEP), GPP is the gross primary production, R is the respiration, F is the diffusion of oxygen from or to the atmosphere and A is any other process that consumes oxygen (such as photooxidation of CDOM - which is often neglected as it is only a small part of the respiration in the water body).

To calculate the individual factors, we calculated the maximum solubility of oxygen in water at a given temperature. Firstly, we converted mg O_2 L^{-1} and then found the maximum saturation with temperature data from the miniDOT loggers using eq. 2 and converted it to µmol O_2 L^{-1}. The Schmidt's number (Sc) relating the oxygen diffusion rate and viscosity of water was calculated from eq. 3. To acquire the gas flux we initially calculated K600 (piston velocity with a Sc of 600) with empirical tested data (Theis Kragh unpublished) for each 10-minute interval at an hourly basis. The actual piston velocity (K) was found (eq. 5), and the physical gas flux (F) was calculated as the difference between the measured O_2 and the maximum O_2 saturation multiplied with K and the mean depth (eq. 6). This was done for surface measurements as the flux between the atmosphere and the water body takes place there. From this, we can calculate the net accumulative oxygen production (µmol O_2 L^{-1}) eg. the measured production ± the flux (eq. 7). NEP is initially calculated as the mean slope for each 10 min^{-1} intervals during “daylight” from the accumulated oxygen data. The daytime NEP is then calculated by multiplying this with the day fraction and 24 h (eq. 8). The respiration is calculated as the slope in accumulated oxygen during “darkness” which we decided to be < 20 µmol photons m^{-2} s^{-1}. Others has defined darkness as < 10 µmol photons m^{-2} s^{-1} (Hanson *et al.*, 2003) which is not usable in the Arctic during summertime with midnight sun. Measuring respiration when there is still primary production will underestimate the respiration.

Table 1: Equations used in the calculation of NEP, GPP and R. First column shows the parameters calculated, the second column the equations used, the third column the reference for the equation and the fourth column the equation number.

Parameter	Equation	Reference	Eq.
General equation	$\frac{\Delta O_2}{\Delta t} = GPP - R - F - A$	(Odum, 1956)	(1)
Oxygen saturation as a function of temperature (T, kelvin) and numbers are constants	$O_{2sat}(\mu mol\ L^{-1}) = (e^{C})\ 1.423\, mg\ O_2\ mL^{-1}$ $C\left(ml\ O_2\ L^{-1}\right) = -173.4292 + 249.6339 \left(\frac{100}{T}\right) + 143.3483\ ln\left(\frac{T}{100}\right) - 21.8492 \left(\frac{T}{100}\right)$	(Weiss, 1970)	(2)
The Schmidt coeefient related to temperature (t, Celsius)	$Sc = 0.047608\, t^3 + 3.7818\, t^2 - 120.1\, t + 1800.6$	(Wanninkhof, 1992)	(3)
Piston velocity with a Sc of 600. (K600)	$K600\left(m\ h^{-1}\right) = \left(\left(\left(wind\ (m\ s^{-1})\ 0.2481 + 0.1832\right) - 1.08\right) + 3\right)$	(Kragh unpl.)	(4)
Actual piston velocity (K), where m is meter	$K(cm\ 10\ \min^{-1}) = \frac{(k_{600}(m\ h^{-1})/100)\ (Sc/600)^{-0.5})}{6}$	(Jähne *et al.*, 1987)	(5)
Physical gas flux	$F\left(\mu mol\ O_2\ L^{-1}\ 10\ \min^{-1}\right) = K \cdot mean\ depth\ \left(O_{2\,mea} - O_{2\,sat}\right)$	(Staehr *et al.*, 2010)	(6)
Cumulative gas flux	$Net\ accum\ (\mu mol\ L^{-1}\ 10\ \min^{-1}) = F\left(\mu mol\ \mathrm{O}_2\ L^{-1}\ 10\ \min^{-1}\right) + \mathrm{O}_{2\ \mathrm{mea}}\ (\mu mol\ L^{-1})$	(Cole *et al.*, 2000)	(7)
NEP as 10 min intervals	$NEP\left(\mu mol\ O_2\ L^{-1}\ 10\min^{-1}\right) = \Delta O_2\left(\mu mol\ L^{-1}\ 10\min^{-1}\right) - F$	(Staehr *et al.*, 2010)	(8)
NEP$_{daytime}$	$NEP_{daytime}\left(\mu mol\ O_2\ L^{-1}\ daylight\ period^{-1}\right) =$ $mean\ NEP\ hr\ during\ daylight \cdot dayfraction \cdot 24\ h$	(Cole *et al.*, 2000)	(9)
R	$R_{day}\left(\mu mol\ O_2\ L^{-1} d^{-1}\right) = R\ 10\ \min^{-1}\ 6 \cdot 24\ h$	(Staehr *et al.*, 2010)	(10)
GPP	$GPP\left(\mu mol\ O_2\ L^{-1}\ d^{-1}\right) = NEP_{daytime} + R_{day}$	(Staehr *et al.*, 2010)	(11)
NEP	$NEP\left(\mu mol\ O_2\ L^{-1}\ d^{-1}\right) = GPP - R_{day}$	(Staehr *et al.*, 2010)	(12)

Also, respiration will probably be higher during the day time underestimating the daily respiration (Staehr *et al.*, 2010). Day two from the small pond had high irradiance during night and only allowed for 30 min of darkness. This resulted in an extremely low R^2 value when testing the slope with linear regression. Thus, we prolonged the dark period (up to < 25 µmol photons m^{-2} s^{-1}) which resulted in a higher R^2 value and a more probable result. The calculated respiration slope is then multiplied with 6*24 and the day fraction under the assumption that $R_{daytime}$ is equal to R_{night} (eq. 10) (Cole *et al.*, 2000). The gross primary productionu in the system is then calculated as the difference between NEP and respiration (eq. 11). The total NEP can then be calculated as the difference between GPP and the daily respiration (eq. 12).

The GPP and thus the NEP was normalized to the daily irradiance (PAR µmol photons m^{-2} s^{-1}) as the photosynthesis is related to this. Oxygen measurements from miniDOT's at different depths were rated as the percentage of the water column they represented and a mean was calculated. The pelagic NEP in Morænesø was determined from measurements in the freezebag and related to NEP on the corresponding day. Production in carbon was calculated as a 1:1 molar ratio between O_2 and CO_2 (Hanson *et al.*, 2003).

To scale up we divided the pond and lake into two seasons – summer and winter, with temperature and light data from 2 meters of depth in Morænesø (Unpublished data). From this information and our measurements, we tried modeling the respiration from the water column below 1 and 2 meters of ice, which is seen during winters (Christoffersen, 2006). We calculated the NEP from the date when Morænesø froze, and thereby inhibit the PAR reaching the waterbody, until the date of thawing and the return of the sun (8/10 till 15/7 a total of 250 days). In this period, we expect no primary production and only respiration in the non-frozen water under the ice – although some respiration takes place at very low rates in the ice (Bakermans & Skidmore, 2011). We used a $Q_{10} = 2$ to estimate the respiration at winter conditions. The same dates (15/7 till 8/10, a total of 115 days) were used to estimate summer NEP. The same estimates were used for the pond, but with no winter respiration in the non-frozen water because of a completely frozen water body.

Calculations for a longer summer of 130 days were done as a proxy for earlier ice melt as a result of global warming, which could have a more pronounced effect on the small, wind exposed pond.

Intercalibrated HOBO light data was used to calculate the vertical extinction coefficient k_d as the slope between LN transformed PAR data and depth. By isolating z in eq. 13 and setting incoming light to 100% and light at depth Iz as 10% and 1%, we found the compensation depth of aquatic plants and phytoplankton.

$$I_z = I_0\, e^{-K_d z} \qquad (13)$$

(Kalff, 2002)

To measure pelagic chlorophyll *a* (chl *a*) we collected a water sample from the middle of the lake and filtered through a GF/C filter (Whatman®). The filters were frozen at -18 °C until the analysis. Water samples for total nitrogen (TN) and total phosphorous (TP) were collected and frozen as well. To relate benthic chlorophyll *a* to the measured oxygen production we collected samples consisting of pebbles and soft sediment from different depths. Samples were stored in ziplock bags and frozen.

TN and TP samples were thawed and 5 mL of sample and 5 mL of potassium persulfate reagent were added to an acid-rinsed autoclave vial. The samples were autoclaved for 45 minutes and after cooling, we added 2.5 mL of borate buffer and stored them at 5 °C. We analyzed the samples with a SEAL AutoAnalyzer 3 HR together with blanks and an internal standard row. CDOM was measured from water samples filtered through a GF/F filter (Whatman®) and the absorbance was measured with a SHIMADZU UV-1800 spectrophotometer at a wavelength of 440 nm. The g440 m^{-1} was calculated from the absorption (Davies-Colley & Vant, 1987).

To calculate benthic Chlorophyll *a* values, we submerged the pebbles (collected in triplicates) in 96% ethanol to extract the chlorophyll. After a 48-hour extraction, we filtered the ethanol through a 47 mm GF/C filter, and collected it in a graduated cylinder. Prior to the filtering the samples were sieved, to remove the pebbles and to avoid damage to the filter. The extraction volume was noted (E_{vol}) and transferred to a cuvette for spectrophotometry. The spectrophotometer (SHIMADZU UV-160A) was baseline corrected with 96% ethanol and the absorbance of the sample was measured at 665 nm and 750 nm. The chlorophyll *a* (µg cm^{-2}) was found using equation (14).

$$Chlorophyll\ a\left(\mu g\ cm^{-2}\right) = \frac{Abs(665-750)\ E_{vol}}{0.0834\ A_{sum}} \qquad (14)$$

Where Abs $_{(665-750)}$ is the absorbance at 665 nm and 750 nm, E_{vol} is the volume after extraction (mL), 0.0834 is the specific absorption-coefficient for chlorophyll *a* (mL μg^{-1} cm^{-1}) and the A_{sum} is the surface areas (cm^2) of stones in the sample. A_{sum} of the stones from each sample (A_1, A_2, A_3) was calculated using eq. 15.

$$A_{sum} = \frac{\sum A_1 + A_2 + A_3}{2} \qquad (15)$$

The calculated values were divided by 2 assuming that the sun only illuminated half of the stone. The surface area of each individual stone was found using eq. 16,

$$Area\,(cm^2) = (LW) + (LH) + (WH)\ 1.15 \qquad (16)$$

(Graham *et al.*, 1988)

where L = length, W = width and H = height in cm.

Sediment samples were collected with a core-sample-tube (Ø=2.95 cm) by carefully pushing the sampler into the soft sediment, closing the lid and pulling it out slowly. The top 1 cm were then

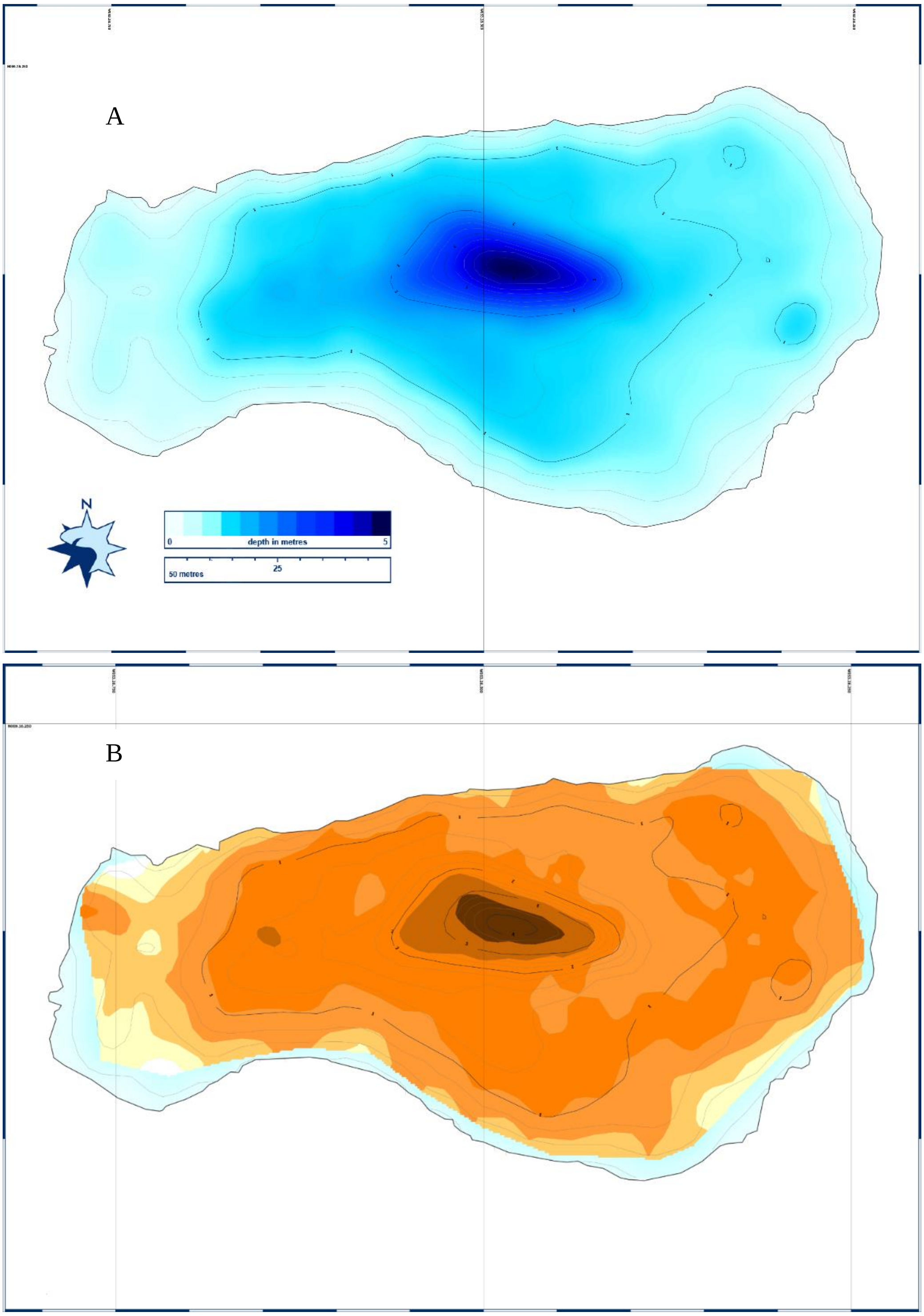

Figure 3A: Bathymetric map of Morænesø showing depth from shallow (light blue) to deep (dark blue). The lines represent <1, 1-2, 2-3 and 3-4 meters of depth. Figure 3B: A map showing the thickness of the sediment from light (low) to dark (high). Most of the soft sediment is located at the deepest part of the lake.

carefully collected in a ziplock bag, and frozen at the day of sampling. This was done at multiple depths (0.5 to 2 meters) in MoræMnesø and in both open and moss-covered areas in the pond. In the laboratory, we extracted the chlorophyll with 96% ethanol by unloading the entire sample into 50-100 mL beakers and filling the beakers until the entire sample was covered. Extraction, handling and spectrophotometry was performed as earlier described. Chlorophyll *a* (µg cm^{-2}) was calculated using eq. 14 where A_{sum} is the area of the core-sample-cylinder.

Pelagic chlorophyll samples from Moræmesø were collected on a windy day at a depth of 30 cm and brought back to the Arctic Station. Later the same day we filtered 1000 mL of sample water through a 47 mm GF/C filter which was frozen after filtration (n=2). Extraction of the chlorophyll was done in 14 mL glass vials, wherein the folded filters were covered by 96 % ethanol for 48 h. The extraction volume was noted (E_{vol}) and spectrophotometry was performed. The same procedure was applied to the samples from the pond, although the volume of filtered water was 500 mL and 700 mL (n=2). Chlorophyll *a* was determined with eq. 14, where the filtered volume (F_{vol}) was used instead of A_{Sum}.

Table 2: Volumes (m^3), the area (m^2) of the water masses at depths from 0-1, 1-2, 2-3, 3-4, 4-5 meter and the sum of these.

Lower (m)	Upper (m)	Volume (m^3)	Area (m^2)
0	1	38609	48385
1	2	8134	20841
2	3	2244	3331
3	4	737	1373
4	5	15	166
Total		49738	48385

Results

The compiled sonar data from Moræmesø showed a lake area of 4.8 ha, a mean depth of 1 m, a max depth of 4.18 m and a total water volume of 49739 m^3 (tab. 2). The bathymetric map (figure 3A) showed a deeper zone in the upper middle of the lake corresponding to the part of the lake, which

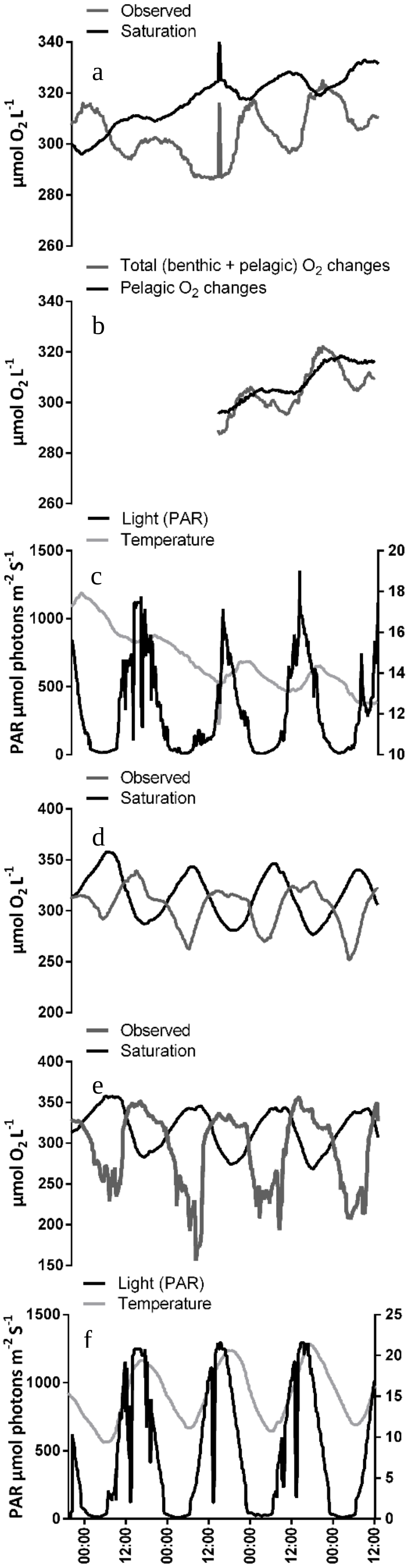

*Figure 4: **a)** The observed surface O$_2$ concentration and the calculated O$_2$ maximum saturation in Moræmesø. **b)** Surface temperature (°C) and light (PAR) showing a drop in temperature and long days. **c)** The isolated pelagic and the total changes in O$_2$. **d)** The observed surface O$_2$ concentration and the calculated O$_2$ maximum saturation in the open area. **e)** The observed surface O$_2$ concentration and the calculated O$_2$ maximum saturation in the moss-covered area. **f)** Temperature and light (PAR).*

has the thickest sediment (figure 3B). Data from the HOBO loggers revealed that 10% light was left at 2.6 m while there was 1% of incoming light down to the bottom of the lake within the sampling period. The temperature data showed a decrease from ≈ 18 °C to 13 °C due to lower air temperature (figure 4c). No thermocline was observed during our sampling period. Surface light data showed long days with light and only a short period of darkness after 00:00 o'clock (avg. 3h, n=3) (figure 4c). The lake was mostly O_2-undersaturated during the time of sampling which indicates a high level of respiration (figure 4a). This becomes clearer from the mean variations of O_2 in the lake and the isolated pelagic changes indicating that most of the respiration is benthic (figure 4b)

Based on GPS data the small pond has an area of 540 m^2. By manual measurements we found a mean depth of 19 cm (n = 480) and a maximum depth of 47 cm, resulting in a water volume of 104 m^3. The HOBO loggers measured high light intensities all the way to the bottom at the open spots, while light attenuated fast in the moss-covered area. The temperature of the pond had daily fluctuations with a maximum and minimum of 11 °C and 22 °C (figure 4f) and only short periods of darkness occurred (avg. 2h, n=3) (figure 4f). Changes in dark periods between locations are related to topography and cloud cover.

Oxygen measurements showed that the pond varied between undersaturation during the night and oversaturation during the day (figure 4d). Measurements from just above the moss-covered area showed clear differences in diurnal O_2 fluctuations when compared to the open area (figure 4e).

Morænesø had an estimated mean total (pelagic and benthic) daily NEP of 0.8 ± 0.9 mmol O_2 m^{-3}. In the pond, we found a daily NEP of 2.3 ± 2.7 mmol O_2 m^{-3} resulting in a daily production almost 3 times higher than Morænesø on a volumetric basis (figure 5a). The GPP and R was estimated to be 35.3 ± 12.0 and 33.0 ± 9.4 mmol O_2 m^{-3} or 6.9 and 7.7 times higher than Morænesø. Negative NEP in the pond was observed on the first day of sampling (not shown) which might have been a result of upwelling materials during the setup of sensors and measurements of depth the next day. Disregarding this day, the estimated mean total

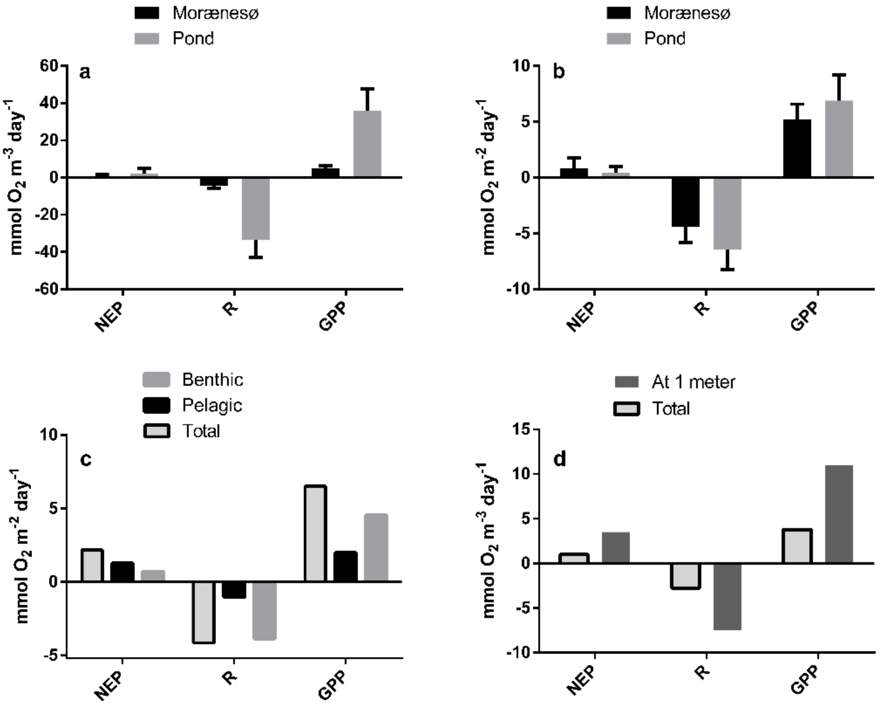

*Figure 5: **a)** Volumetric net ecosystem production (NEP), respiration (R) and gross primary production (GPP) shown for Morænesø and the pond. **b)** Areal NEP, R and GPP measurements from Morænesø and the pond. **c)** NEP, R and GPP measurements from Morænesø showing the benthic, pelagic and total production on the third day. **d)** NEP, R and GPP from measurements in the deepest part of the lake and measurements at 1 m.*

NEP is 3.8 ± 0.5 mmol O_2 m^{-3} and almost five times more productive than Morænesø. The total GPP in Morænesø was estimated to be 5.1 ± 1.3 mmol O_2 m^{-3} and the respiration to be 4.3 ± 1.3 mmol O_2 m^{-3}. The estimated pelagic production in Morænesø was calculated from the enclosed measurements during the third day (figure 5c). Here we found the NEP to be 1 mmol O_2 m^{-2}, the GPP to be 2 mmol O_2 m^{-2} and the respiration to be 1 mmol O_2 m^{-2}. Thus, at the third day the benthic GPP was 4.4 mmol O_2 m^{-2}, the R was 3.7 mmol O_2 m^{-2} and the NEP was 0.7 mmol O_2 m^{-2}. Given our estimates, we found that on the third day 58% of the NEP took place in the pelagic together with 21% of the R and 30% of the GPP. The low percentage of respiration in the pelagic shows that respiration must be high in the sediment, corresponding to the sediment data from figure. 3B. We found the respiration rates in the lake to be higher with the estimates done at a depth of 1 meter (figure 5d). This shows that the total sediment volume does not determine the respiration rates, but it is rather the organic compounds in upper centimeters of the sediment. At 1 meter we found that NEP (3.5 mmol O_2 m^{-3}), GPP (11.0 mmol O_2 m^{-3}) and R (7.5 mmol O_2 m^{-3}) were higher than the mean measurements taken in the middle of the lake (figure 5d).

A comparison of the metabolism expressed in m^2 shows that Morænesø has a NEP of 0.8 ± 0.9 mmol O_2 m^{-2}, GPP of 5.2 ± 1.3 mmol O_2 m^{-2} and a R of 4.4 ± 1.3 mmol O_2 m^{-2}. In the pond we estimated a NEP of 0.4 ± 0.5 mmol O_2 m^{-2}, a GPP of 6.8 ± 2.3 mmol O_2 m^{-2} and a R of 6.3 ± 1.8 mmol O_2 m^{-2} (figure 5b). The estimated net production of carbon in Morænesø was 9.9 g C m^{-2} d^{-1} resulting in 476 g C d^{-1} for the entire lake. Measurements from the third day showed a total NEP of 19.7 while the pelagic part was NEP 11.4 mg C m^{-2} d^{-1}. The pond had a production of 5.3 mg C m^{-2} d^{-1} or 2.8 g C d^{-1} for the entire pond.

Table 3: Chlorophyll a measurements derived from Morænesø. Data is shown for the different sampling depths, substrate (pebbles, sediment and pelagic water) and are expressed as milligrams of chlorophyll a per square meter ± the standard deviation.

Substrate	Depth (m)	Chl *a* (mg m^{-2})
Pebbles	0.5	25.0 ± 14.8
Pebbles	1	18.2 ± 10.3
Sediment	0.5	38.4 ± 16.3
Sediment	0.9	64.6 ± 7.6
Sediment	2	80.1 ± 6.3
Pelagic	-	2.0 ± 0.02

Estimated annual assimilation of carbon is highly dependent on the unfrozen water volume in Morænesø. If the ice is 2 m thick, then the water volume of the lake decreases dramatically resulting in a lowered respiration during winter. The outcome is a total system assimilation of 35.6 kg C y^{-1} making the system autotrophic. Estimates of production with an ice thickness of 1 m alters the system to heterotrophic releasing 16.4 kg C y^{-1}. The pond had a positive NEP during our sampling. With the assumption that there is no respiration in ice, and the pond is entirely frozen, we found that it assimilated 0.33 kg C y^{-1}. With a longer summer period of 130 days, the total assimilation would be 0.37 kg C y^{-1}.

The nutrient levels from the small pond showed a concentration of 511 µg N L^{-1} and 8.1 µg P L^{-1}. In Morænesø we found a concentration of 302 µg N L^{-1} and 9.6 µg P L^{-1}, which shows that both the lake and pond were nitrogen limited at the time of sampling (molar ratios of 70 and 140 N to P). CDOM measurements showed a g440 of 2.1 and 2.5 abs m^{-1} in the lake and pond.

Measurements of benthic Chlorophyll *a* (mg m^{-2}) from different depths in Morænesø showed that the highest value of Chlorophyll *a* was found in the sediment at 2 m, and the lowest was found on pebbles at 1 m (table 3). The values ranged from 36.4 mg Chlorophyll *a* m^{-2} to 80 mg Chlorophyll *a* m^{-2} with a 200-fold ratio to the pelagic Chlorophyll *a* concentration (0.19 mg Chlorophyll *a* m^{-2}). Chlorophyll *a* measurements from the small pond (table 4) show a pelagic concentration of 0.11 mg

Table 4: Chlorophyll a measurements derived from the pond. Data is shown from sampling in the open area (n=3), moss-covered area (n=3) and in the pelagic (n=2) expressed as milligrams of chlorophyll a per square meter ± the standard deviation.

Substrate	Site	Chlorophyll mg m^{-2}
Sediment	Moss	28.2 ± 3.9
Sediment	Open	41.3 ± 12.4
Pelagic	-	0.2 ± 0.05

Chlorophyll *a* m^{-2} , while the benthic concentration was 140-200 fold higher (moss-patch 28.2 and open area 41.3 mg Chlorophyll *a* m^{-2}).

The lower Chlorophyll *a* concentration in the moss-patch does not correlate with the measured GPP which were higher in the open spot. The mean chlorophyll *a* values from the pond and lake, illustrates that the lake holds 63% more chlorophyll *a* m^{-2} than the pond. However, the GPP is 30% higher in the pond than in Moränesø.

Discussion

Light penetrates to the bottom of Moränesø which provide enough light for benthic production. The production of aquatic plants will probably be limited to the upper 2 m where there is at least 10% light left. Our data showed that 58% of the NEP, 21% of the R and 30% of the GPP takes place in the pelagic, meaning that the pelagic is more productive than anticipated.

In Moränesø there was 3.5 times higher NEP, 2.7 times higher respiration and 3 times higher GPP at 1 meter compared to measurements from the deepest part of the lake. With a mean depth of 1 m, there is a possibility that the data from our 1 m sampling might be more representative than from the deep, but small area in the lake. In the pond we found differences between the moss-covered area and the open area which have been weighted in the final result. If separating these two spots, we find that the NEP is 4 times higher, the GPP is 2.4 times higher and the R is 2.3 times higher in the moss spot than in the open area. This is unexpected as the sensors are 2 m apart in the small and wind exposed pond which is expected to be fully mixed. Our data shows that heterogeneity is indeed also present in much smaller water bodies. This implies a general need for applying more O_2 loggers to produce better results. The same conclusion has been made for larger lakes where the NEP ranged from -132 to 250 mmol O_2 m^{-2} d^{-1} with data from four randomly placed loggers (Van de Bogert *et al.*, 2012).

Chlorophyll data showed a higher mean concentration in Moränesø than the pond. This does not correspond to our GPP values, which were highest in the pond. This could be explained by heterogeneity in the sediemts.

CDOM showed a higher absorbance at 440 nm in the pond than in the lake. Our expectations, that CDOM could alter the systems´ predominant production from benthic to pelagic, was not confirmed in this study as the concentrations are lower than the reported absorptions elsewhere (Davies-Colley & Vant, 1987; Kirk, 1994). CDOM have to some degree been correlated to respiration (Coloso *et al.*, 2011), but the differences in respiration between the pond and Moränesø is high (7.7 fold in the pond) and we do not think CDOM is the only explanation. Perhaps most of the pond respiration originates from the use of easy accessible carbohydrates from primary production. The difference in TP between Moränesø and the pond was insignificant and do not explain the difference in GPP. The production is probably strongly coupled to the benthic production which have a nutrient supply in the rich pore water (Vadeboncoeur *et al.*, 2006).

As stated in the materials and methods, we probably underestimated the respiration due to primary production during “night”, as a result of work in the Arctic where there is midnight sun during the summer. True respiration rates could be found using dark bottle incubations in the lake, but would only show pelagic rates. The benthic respiration could possibly be obtained in an open mesocosm with a stationary tube to avoid sediment disturbance prior to sampling, which can then be closed and kept dark during sampling. Sampling could also take place in the start or ending of the season where we have dark periods during the day.

The production of both the lake and pond was in the same range as in previous Arctic studies where phytoplankton production was measured in ponds (14.5 and 21 mg C m^{-2} d^{-1}) and two lakes (3 and 2.3 mg C m^{-2} d^{-1}) in Bylot Island 73 N and Barrow, Alaska 71 N (Rautio *et al.*, 2011). The total NEP would often be higher than phytoplankton production, which is at least seen in the Moränesø.

Benthic chlorophyll *a* measurements from Moränesø showed an increased concentration towards the deeper part of the lake. We speculate if the reason for this was windy conditions the day before sampling, which might have suspended and moved particles – especially in the shallow area. The measurements from the moss-covered area showed a lower Chlorophyll *a* concentration than in the open spot, which might be related to the sampling method. We used a small tube to collect the sample, which probably pushed mosses to the sides rather than "cutting through it", therefore minimizing our collected Chlorophyll *a* in the sample. To combat this we should probably have used a much bigger tube and related the production to the biomass found in the tube.

To relate our study to the ongoing changes in the Arctic and sub-arctic climate, we tried to evaluate what consequences the projected longer summer season would have on the lake and pond (Prowse *et al.*, 2012; Surdu *et al.*, 2014). We found that the thickness of the ice could alter the system from autotrophic to heterotrophic releasing 16.4 kg C y^{-1}. This trend would make Moraenesø more heterotrophic in the future where thinner winter ice is expected (Surdu *et al.*, 2014). This heterotrophic state is found with 1 m of ice corresponding with other studied lakes where benthic habitats have a negative annual NEP due to the absence of benthic primary production during winter (Karlsson *et al.*, 2008). Our estimates are very rough though, as our calculations are built on data derived over 3 days and during the midnight sun, which underestimate the respiration.

The respiration under the ice is also related to the pools of organic carbon which can be both autochthonous and allochthonous, thus changing over time (Karlsson *et al.*, 2008). Furthermore, the increase in temperatures will probably bring more nutrients into freshwater systems (Rautio *et al.*, 2011). While the increase in nutrients do not seem to increase benthic production (Daniels *et al.*, 2015), it could increase the pelagic production resulting in more anaerobic activities at the bottom of the lake due to breakdown of organic matter. The anaerobic respiration will result in a buildup of the potent greenhouse gas CH_4, especially during winter, which will be released to the atmosphere if not reoxidated. The nutrient input is often related to an input of particulate organic carbon (POC) and DOC. This will increase the respiration in the lake and pond, but the POC will also be subject to some sedimentation. Thus, we can have a lake acting as a carbon sink without an increase in NEP (Lovett *et al.*, 2006; Ask *et al.*, 2009). The DOC will increase respiration in the water body resulting in some release of CO_2 (Sobek *et al.*, 2005)

The estimation of metabolism in Arctic aquatic systems shows differences to temperate systems. Issues with long days during summer will make it difficult to measure respiration, long and cold winters makes it difficult to set up equipment and the often high benthic production makes it important to do whole lake estimates and not only measure pelagic production. Our study also showed high heterogeneity in NEP from loggers only a few meters apart in a small wind exposed pond. Future measurements on metabolic rates must consider this. Finally we demonstrated, that a lake could alter its state from autotrophic to heterotrophic depending on the ice thickness. The consequences of global warming will probably have an effect on ice thickness here and in many other lakes. The coupling between season-length and ice-cover could have an impact on the carbon assimilation in Arctic lakes.

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Drepanocladus trifarius – en velegnet indikator for ændret klima?

Ditte Marie Christiansen, Nanna Slaikjer Petersen, Simone Møller Mortensen & Kirstine Thiemer

Primærproduktionen i arktiske søer og damme er ofte domineret af mosser. Mosser er karakteriseret ved apikal vækst, hvilket for udvalgte arter muliggør en rekonstruktion af væksthistorien. I Østgrønland er den årlige vækst i *Drepanocladus trifarius* styret af ændringer i lysforhold. I dette studium undersøger vi, om de samme klimatiske faktorer kontrollerer væksten af *D. trifarius* i Vestgrønland, og derfor om *D. trifarius* er en velegnet indikator for vækstbetingelser i arktiske damme. Mosindivider fra to damme blev indsamlet og en rekonstruktion af væksthistorien blev foretaget. Resultaterne viste en signifikant forskel i længde og biomasse mellem årsskuddene, hvor væksten af årsskud fra 2012 var bemærkelsesværdigt større end de foregående år. Ved korrelation af hhv. længde og biomasse med vejrdata fra 2009-2014, var sommertemperaturen den betydende faktor for vækst. I modsætningen til vores forventninger var der ingen sammenhæng med andre klimavariable. Desuden indikerer vores resultater, at der udover sommertemperatur også er en miljøeffekt fra dammene, hvilket betyder, at andet end klimaforhold kan være bestemmende for mossernes årlige vækst. På baggrund af vores resultater foreslår vi således, at flere undersøgelser af *D. trifarius* er nødvendige for at afgøre, om det er universelle indikatorer for vækstforholdene i arktiske damme.

Drepanocladus trifarius – an appropriate indicator for altered climate?

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Abstract

Mosses often dominate primary production in Arctic lakes and ponds, which make them an essential contributor for primary production in Arctic water bodies. Mosses are characterised by apical growth and for some species, reconstruction of growth history is possible. In East Greenland, annual growth in *Drepanocladus trifarius* is controlled by change in light conditions. In this study, we examine if the same climatic factors are controlling growth in *D. trifarius* in West Greenland, and therefore if *D. trifarius* is an appropriate indicator for growth conditions in Arctic ponds. Moss individuals from two ponds were collected and reconstruction of growth history was made. The results showed a significant difference in length and biomass between annual growth segments, where growth segments from 2012 were remarkably larger than previous years. When correlating annual segments with weather data a significant relationship between the length and mean summer temperature was found. Contrary to expectations no other relationships were significant suggesting that other factors are influencing growth. Finally our results indicate, that besides summer temperature, there is also an effect from the ponds and the relative growth between the two ponds was different. We therefore suggest that further examinations of *D. trifarius* as an indicator of growth conditions is needed.

Keywords: *Aquatic moss, Drepanocladus trifarius, annual growth segments, Arctic ponds.*

Introduction

The Arctic region has been described as the "World's largest wetland" (Kling, 2009), for its many freshwater ecosystems. Lakes and ponds are abundant and diverse, with a broad range of habitats, which makes them important for the overall biodiversity in the Arctic (Rautio *et al.*, 2011). Arctic lakes and ponds can be of different types, where the most common ones are post-glacial lakes and thermokarsts (lakes and ponds developed in depressions of thawing permafrost) (CAFF 2013). In this study we will focus on shallow ponds where climate has a great influence on ecosystem dynamics and where benthic macrophyte communities are considered to be very important for primary production (Priddle 1980a in Riis *et al.,* 2014). Arctic ponds are often classified as oligotrophic, due to their low nutrient concentrations. The inflowing water usually originates from melt-water runoff, which is low in nutrients such as nitrogen and phosphorous (Vincent & Laybourn-Parry, 2008). These nutrients are one of the limiting factors for primary production in the Arctic, as they generally occur at non-saturating concentrations for production (Sand-Jensen *et al.,* 1999). Primary producers in the Arctic experience a great variation in both temperature and available light due to periods of polar night and midnight sun (Rautio *et al.,* 2011; Bonilla *et al.,* 2005). Furthermore they have to cope with small amounts of incoming light, which are greatly affected by ice-cover and the low angle of incoming radiation (Lacoul & Freedman, 2006). Arctic lakes and ponds are covered with ice most of the year, with thicknesses recorded up to 2.5 meters (Christoffersen, 2008). This means that most ponds freeze solid during winter (Rautio *et al.,* 2011), forming a barrier between atmosphere and water. Thus the ice blocks the exchange of gases and other material (Bertilson *et al.,* 2013) and prevents the penetration of light into the water column. Furthermore, in the presence of snow only 10% of the surface photosynthetic active radiation reaching the surface is available in the water column. The described environmental factors discussed above set a narrow window for primary production in Arctic ponds (Christoffersen *et al.,* 2008) and are influential on the community structure of photosynthetic organisms (Bonilla, 2005). Future climate changes are expected to have great influence on the Arctic biodiversity (CAFF, 2013). Changes in temperature are predicted to cause an increase in nitrogen and phosphorous concentrations in Arctic lakes. This is due to increased run-off from the catchment, as an effect of higher summer temperatures and melt of permafrost (Elberling *et al.,* 2008; Riis *et al.,* 2010). The increase in nutrient concentrations can account for an increase in phytoplankton biomass and reduce light penetration to the bottom. Here submerged vegetation including aquatic mosses is located. Another prediction of climate change in the Arctic is increased precipitation including snow. Elevated nutrient concentrations and increased snow cover will reduce the light penetration into the water column and extend the period of ice coverage as a result of insulation. In the future primary producers in ponds may experience a higher availability of nutrients and a reduced growing season as a result of the extended ice coverage and light reduction (Riis *et al.,* 2010). Therefore, biological indicators can be useful tools to examine the effect of altered climate within the ecosystem.

Mosses as indicators

The vegetation in Arctic lakes and ponds is mainly dominated by mosses, which are an essential contributor to primary production of the whole lake (Sand-Jensen *et al.,* 1999, Hawes *et al.*, 2002; Riis *et al.*, 2010). This dominance may be caused by adaptation to low temperatures, low light conditions and low nutrient concentrations resulting in slow growth and decomposition rates (Riis & Sand-Jensen, 1997). In general aquatic mosses in the Arctic are of the genera; *Calliergon, Drepanocladus, Warnstorfia* and *Scorpidium* (Sand-Jensen *et al.*, 1999; Hawes *et al.*, 2002; Riis *et al.*, 2010). Due to apical growth of most mosses it has been suggested that the growth plasticity of certain species can be used to demonstrate growth history (Collins, 1976 in Riis *et al.*,1997; Callaghan *et al.,* 1997; Riis & Sand-Jensen, 1997). This has previously been demonstrated in perennial terrestrial plants, where seasonal and inter-annual growth segments can be separated morphologically (Warren-Wilson, 1964 in Riis *et al.*,1997; Callaghan, 1980; Riis & Sand-Jensen, 1997). The study of Riis *et al.* (2014) used growth segments of the bryophyte *Drepanocladus trifarius* (F. Weber & D. Mohr) as a technique to record historic growth. Year segments in *D. trifarius* are illustrated in figure 1.

Figure 1: Annual growth segments from 2009-2015 in D. trifarius collected in Arctic Station pond, July 2015. Photo: Klaus P. Brodersen.

This method was validated by comparing growth segments with the growth of mosses grown *in situ* for one year. Additionally their study showed an influence of different climatic conditions on annual growth. With bryophytes being the most abundant primary producer in Arctic lakes and ponds, it can be a useful organism to use as an indicator of altered climate in the Arctic.

Drepanocladus trifarius

D. trifarius is a semi-aquatic bryophyte occurring in well-lit and constantly moist, wet or submerged habitats. It is most frequently found in weakly acidic to sub-neutral habitats. Most Arctic lakes where bryophytes are distributed remain nutrient-poor, although they can also inhabit nutrient-rich regions (Hedenäs & Bisang, 2012). The occupied niche of *D. trifarius* concerning nutrients and pH is therefore quite broad, and climatic conditions such as temperature and light may be a more influential factor for the growth of the bryophyte. However, there have only been few studies evaluating aquatic mosses in the Arctic and there has been no overall consensus about how growth segments in aquatic mosses can be used as an appropriate indicator for altered climate, why further studies has to be conducted (Bisang *et al.* 2008).

In this study we analyse annual growth of *D. trifarius* (F. Weber & D. Mohr) in two Arctic ponds and relate the net production to environmental and climatic factors. We expect the growth of *D. trifarius* to increase with higher mean summer temperature and larger net-radiation in ice-free periods. Finally we expect growth to decrease with prolonged ice-coverage and increased maximal snow-depth.

Study site

The study was conducted in the period of the 7th to the 17th July 2015 in two small ponds at Disko, West Greenland (69° 16’ 13’ N’, 53 28’ 34’’ W); one pond is located behind the Arctic Station in Qeqertarsuaq (69° 15’ 13” N, 53° 31’ 29” W) and the second pond in the area of Kangaarsuk (69° 15’ 59” N, 53° 49’ 42” W) (figure 2). The ponds hereafter called Arctic Station pond and Kangaarsuk pond are small and shallow (213 m^2, mean depth 23 ± 12 cm; 1151 m^2, mean depth 36 ± 28 cm respectively). *D. trifarius* was found in Arctic Station pond previously in 1962 (Røen, 1962). Both ponds are ice-free during summer (in this study defined as 1th June to 30th September) and freeze solid in winter (based on data from Arctic Station Automatic Weather Station). Both ponds are fishless and receive water from snowmelt in the catchment and have no anthropogenic disturbance. They are located near the coast: Arctic Station pond is situated on a plateau (Altitude: 35 m.a.s.l.), whereas Kangaarsuk pond is on a small peninsula and thus more exposed to the sea (Altitude: 17 m.a.s.l.).

Methods

Physical and chemical conditions

Water samples for chlorophyll *a*, total nitrogen (TN), total phosphorous (TP), pH and alkalinity were collected in a 5 L bottle and returned to the

Figure 2: Location map of Disko, Greenland. The two study sites are located at the southern part of Disko. Left: Kangaarsuk pond: 1151 m^2. *Right: Arctic Station: 213* m^2 *(From NunaGIS).*

laboratory for further analysis.

Conductivity was measured using a conductivity meter (LF 340, WTW, Germany). Light extinction and diurnal variation in temperature were measured in Arctic Station pond with HOBO-loggers mounted above and under the water surface in two depths. Each HOBO-logger had prior to mounting been inter-calibrated to a PAR-sensor (Quantum sensor LI-190, Li-cor Biosciences, UK) and individual LUX to PAR conversion factors calculated by linear regression. Due to lack of matching time points in the light measurements the light extinction coefficients were calculated based on mean light intensities measured by the HOBO-loggers during the period. Due to technical problems, it was not possible to measure and calculate light extinction coefficient in Kangaarsuk pond.

The areas of the ponds were measured with an area tool in NunaGIS. Three transects (25%, 50% and 75% of the pond width) were made across the ponds to determine mean depth and frequency of substrates, categorized as moss, rock, mud, mire or terrestrial plants. In the laboratory water samples for TN and TP analyses were poured in 100 ml vials and kept frozen until the return at Freshwater Biological Laboratory, University of Copenhagen. Here samples were thawed and analysed for TN and TP with a SEAL AutoAnalyzer 3 HR according to standard method (modified from Limnologisk metodik, Ferskvandsbiologisk Laboratorium, 1977). pH were measured with a standard pH meter (pHM 210, MeterLab, Radiometer analytical). Water for determination of chlorophyll *a* content was filtered on a 47 mm GFC filter in triplicates and frozen until the return to Denmark. Here chlorophyll α ($\mu g\ l^{-1}$) were determined by overnight ethanol extraction according to Jespersen & Christoffersen (1987) and measured on a spectrophotometer (Shimadzy UV spectrophotometer. UV-1800). Total alkalinity was determined by titration with 0.1 M HCl to pH 4.7 (modified from Limnologisk metodik, Ferskvandsbiologisk Laboratorium, 1977).

Reconstruction of annual growth

D. trifarius was present in both Arctic Station pond and Kangaarsuk pond and was only found in the shallower parts. Species identification has been confirmed by Kristian Hassel (Natural History University Museum, Norges teknisk-naturvitenskapelige universitet, Tronheim), Irene Bisang and Lars Hedenäs (both Swedish Museum of Natural History, Stockholm). In Kangaarsuk *D. trifarius* was found between dense stands of *Scorpidium scorpioides* (Hedw.) Limpr. A list of additional finding locations is found in appendix 1. The shoots of *D. trifarius'* annual growth segments can be distinguished visually by the clear separation of parts consisting of short and closely spaced leaves separated by parts with longer and more distinct leaves. The most recent annual shoot appears bright green in colour (figure 3) (Riis *et al.,* 2014).

Figure 3: Separation of growth segments in D. trifarius. Node starts a new segment and spaced leaves indicate the apical part of the shoot. Photo: Klaus P. Brodersen.

Random sampling of the mosses was performed, and 100 individuals from each study site were collected and transported to the laboratory for further analyses. In total 100 individuals with 587 segments were sampled in Arctic Station pond and 100 individuals with 517 segments in Kangaarsuk pond. We chose to incorporate individuals from 2009-2014 in the further analysis to secure a full growth season and sufficient replicates.

As far as possible, mosses without branches were selected for measurements. If a moss had a branch, which that was clearly of this year growth, the branch was dismantled and marked as part of the annual segment. 17 individuals of *D. trifarius* had side branches in Kangaarsuk pond compared to one individual in Arctic Station pond. The effect of side branches on annual growth has been taken into consideration in the analysis, and the effect of branching was tested with a two-way ANOVA with year and side-branches as different factors. In the laboratory, shoots of *D. trifarius* were gently brushed to remove epiphytes prior to handling. The layer of epiphytes on *D. trifarius* was visually estimated to be greater in Kangaarsuk pond, but no measurement was made. For each moss individual, the length of the annual segments was measured to the nearest half millimetre using a stereoscopic microscope (Olympus Model SZX12- IllK200, Nikon Model SMZ1B). Annual segments were dried in an oven at 60 °C for 24 hours. Biomass (mg DW) of each segment was weighed with a microbalance (Mettler AT261 DeltaRange) to the nearest 0.01 mg.

Climate data

Climate data from 2009-2014 was provided by Arctic Station (Automatic Weather Station AWS-1. 69° 15' 11" N, 53° 31' 13" W, 24 m.a.s.l). In this study we use daily average measurements of air temperature (°C), precipitation (mm) and in- and outgoing radiation (W m^{-2}). The summer period was defined from 1th June to 30th September, and from this period the mean summer temperature was calculated. Frost days were defined as number of days with temperature below 0°C and used to indicate the period where the ponds were covered by ice, and thus a reduction in incoming radiation. Snow depth (cm) was measured daily by the Arctic Station personnel as a part of the stations monitoring programme. Since the Weather Station measures 2-9.5 m above terrain and is not located next to the ponds, climate data will only be a proxy for the climatic conditions in the ponds. Values of climatic conditions are shown in appendix 2.

Data analysis

We used one-way ANOVA and Bonferonni as *post hoc* to test for differences between annual growth segments. The assumptions for using ANOVA, variance homogeneity and normal distribution of data, were tested with Bartlett's test and D'Agostino test, respectively. At the time of sampling, annual growth segments from 2015 was incomplete and therefore not included in any statistical analyses. Difference in annual segment length, biomass and the effect of ponds were tested using a two-way ANOVA. Impact of side branches on annual growth was also tested using a two-way ANOVA. Finally relationship between annual segments (length and weight) and environmental and climatic data (net radiation, snow depth, summer temperature, length of ice-coverage and precipitation) were tested with Pearson Production Moment correlation. Significant correlations were tested with linear regression. Confidence interval was at a 95% level. All statistical analyses were performed using GraphPad Prism, version 6.0.

Results

Physical and chemical conditions

Arctic Station pond and Kangaarsuk pond are both nutrient-poor, clear-water ponds with a low concentration of chlorophyll *a*, indicating a limited biomass of phytoplankton (table 1). The two ponds differ in size, mean depth, conductivity and substrate distribution (%). The sheer size and depth of the pond in Kangaarsuk is larger compared to Arctic Station pond. A higher proportion of moss as substrate was found in Kangaarsuk pond, and here *D. trifarius* was found between high densities of *S. scorpioides*. Conductivity varied between the two ponds with the highest levels in Kangaarsuk pond, suggesting a higher amount of dissolved inorganic compounds in the water, which may originate from the greater marine exposure. The light extinction coefficient was calculated to be 3.2 m^{-1} for Arctic Station pond. This means that, with a mean depth of 23.3 (± 11.8) cm, light is present through the whole water column. In Arctic Station pond diurnal fluctuations in temperature were large, ranging from 9.3 °C to 21.5 °C. All values are present in table 1.

Table 1: Environmental parameters for Arctic Station pond and Kangaarsuk pond, measured July 2015. NA indicates that data was not available. Mean values (± SD).

Mean values (± SD)	Arctic Station pond	Kangaarsuk pond
Mean depth (cm)	23.3 (± 11.8)	36.3 (± 27.6)
Mean water temp (°C)	13.1(± 5.3)	13.6
Substrate (%)		
Moss	21.6	35.6
Rock	62.2	45.2
Mud	10.8	0
Mire	5.4	15.1
Terrestrial plants	0	4.1
pH	7.7	7.32
Conductivity (µS cm^{-1})	13 (±1)	66
Alkalinity (meq l^{-1})	NA	0.09
Chlorophyll α (µg l^{-1})	0.39	0.54
TN (µg l^{-1})	401.33	544.91
TP (µg l^{-1})	8.38	6.86

Annual growth segments and climatic conditions

Annual growth segments were identified up to 22 years in one *D. trifarius* individual, but for most of the individuals only the past 6 years were sampled (figure 4). In Arctic Station pond average growth year^{-1} across segments from 2009 to 2014 was 2.47 ± 0.31 cm year^{-1} with corresponding biomass 2.56 ± 0.39 mg DW year^{-1}. In Kangaarsuk pond average annual segment length was 1.76 ± 0.34 cm with a corresponding biomass of 1.53 ± 0.29 mg DW. Inter-annual variation occurred in both Arctic Station pond and Kangaarsuk pond, and in both ponds annual growth segment from 2012 was significantly larger (One-way ANOVA, P<0.0001, n=100) (figure 4), suggesting better conditions for growth in 2012.

Some individuals of *D. trifarius* sampled from Kangaarsuk pond showed many side branches (17 individuals), assumed to originate from overgrowth with *S. scorpioides*. No significant effect of side branches on the mean length of the mosses was found (Df=1, P=0.5415), but instead a significant effect of year (Df=5, P<0.0001). In addition, no significant effect of side branches on mean biomass was found (Df=1, P=0.4654), why including all individuals from Kangaarsuk in further analysis seems reasonably.

The relationship between climatic factors and annual growth segments was tested with Pearson Product Moment Correlation. When correlating the mean length of annual growth segments with different climatic conditions, a positive relationship between annual growth segments and mean summer temperature was found in both

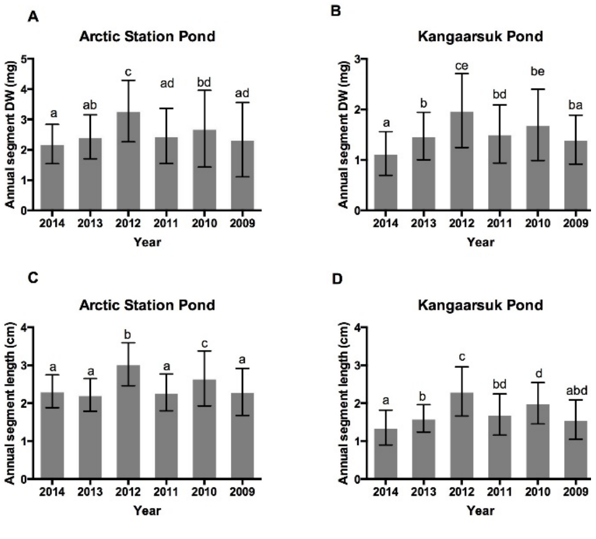

Figure 4: Mean annual segment biomass (DW) (A, B) and length (cm) (C,D) in D. trifarius collected in Arctic Station pond and Kangaarsuk pond, Disko, in July 2015. Error bars indicate ± SD and letters indicate significant differences between years (one-way ANOVA, F=16-39, P<0.0001, n=17-100, Df=5).

Arctic Station pond and Kangaarsuk pond (figure 5A and 5B). This indicates, that with a higher temperature the longer the annual growth segment. Using linear regression, mean summer temperature explains 86% of the variation in length of the annual growth segments in Arctic Station pond (Linear regression, P=0.007) and 77% in Kangaarsuk pond (Linear regression, P = 0.021). Same trend was seen with biomass (DW), but no correlations were significant (figure 5G and 5H). This suggests that biomass of *D. trifarius* may depend on factors other than temperature; possibly epiphyte growth, degradation with age and potentially herbivory. Therefore, we chose not to consider the biomass measurements in our further analysis.

In contrast to predictions, no significant relationship existed when correlating annual length and annual biomass with net-radiation in June (figure 5C and 5D), frost days (figure 5E and 5F), in- and outgoing radiation and snow depth (appendix 3). Even though relationships were non-significant, a tendency was seen between outgoing radiation and the length of annual growth segments from Kangaarsuk pond. Here 56% (90% confidence interval) of the variation in length of the annual growth segments was explained by outgoing radiation. All correlation coefficients are present in table in appendix 3.

In general absolute measurements of length (cm) were larger in individuals from Arctic Station pond compared to Kangaarsuk pond. To allow a comparison between annual segment length and biomass between the two ponds, the relative growth year^{-1} as a percentage of the total length of the moss from 2010-2014 was calculated (figure 6). This showed that, *D. trifarius* from Kangaarsuk pond in 2012 grew relatively faster than in Arctic Station pond, 35% and 27% respectively. The SD of relative growth was generally higher in Kangaarsuk than Arctic Station pond, ranging 3.6-8.0% and 3.2-4.5% respectively. The higher SD values in Kangaarsuk pond indicate more heterogenic conditions within the pond.

We tested if relative growth in the two ponds was significantly different and if the pond itself showed an effect on the relative length. A two-way ANOVA showed a significant effect of year (Df=4, P<0.0001) as well as of the "pond" (Df=1, P<0.0001) on the relative lengths. This suggests that the environment in the pond affects the growth of these mosses and they do not respond equally to climatic conditions.

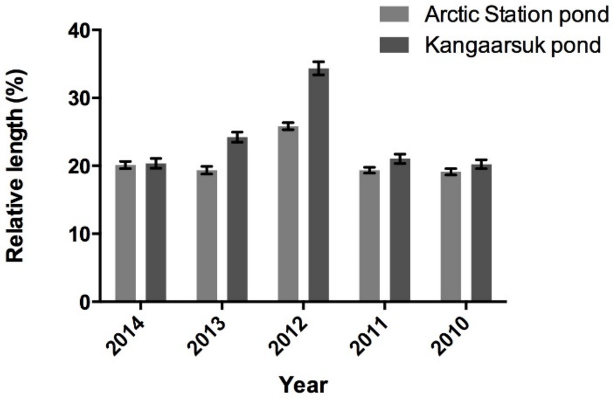

Figure 6: Relative length (%) of annual growth segments in Arctic Station pond and Kangaarsuk pond. Error bars indicate ±SD.

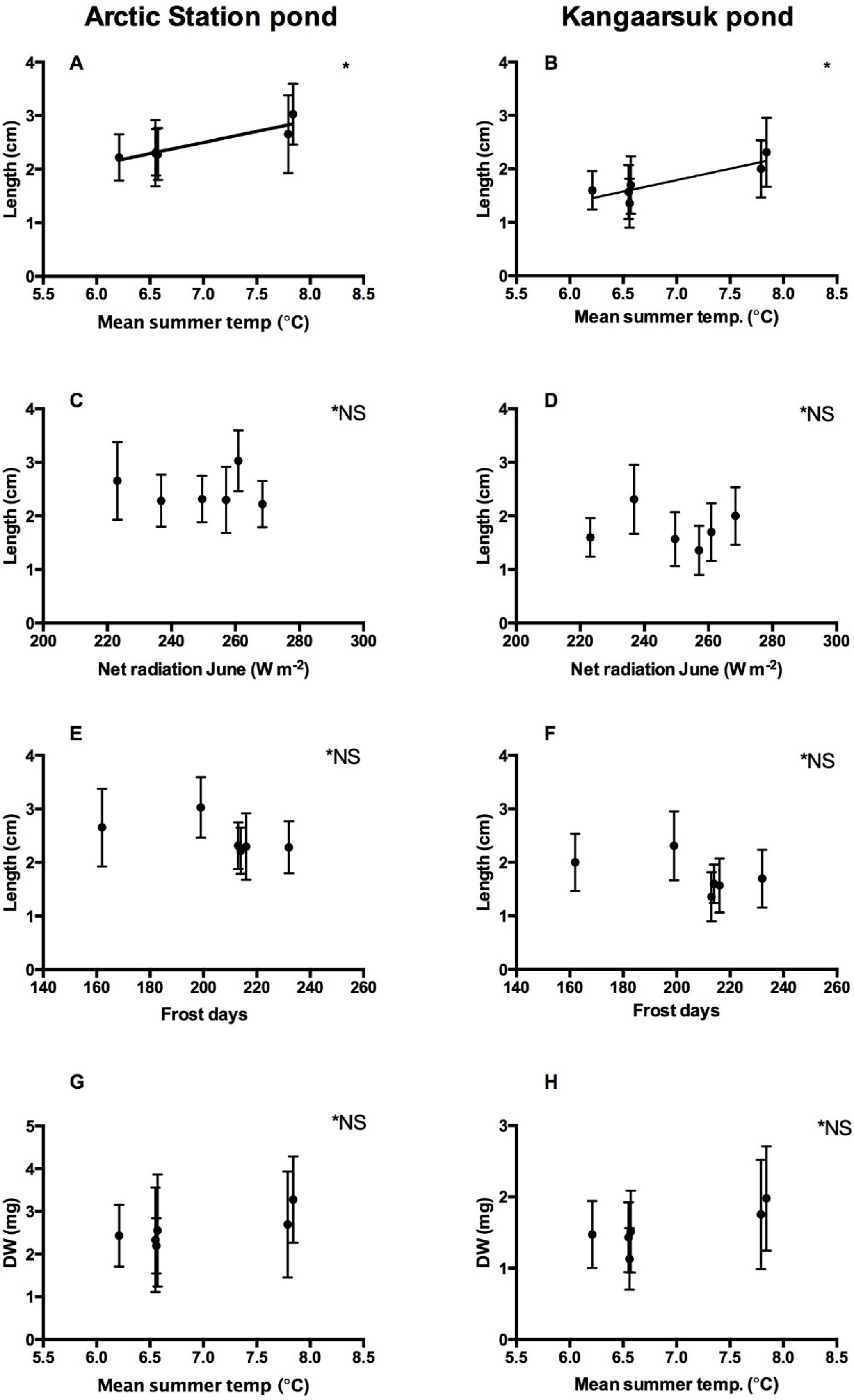

*Figure 5: Relationships between climatic conditions and mean annual growth segment in D. trifarius from Arctic Station pond (right column) and Kangaarsuk pond (left column). Figure A-F show relationship between environmental factors and annual length and G-H show relationship with biomass. * indicates significant relationship P<0.05 and *NS indicates a non significant correlation. Error bars indicate ±SD.*

Discussion

Differences in growth

The growth reconstruction technique of *D. trifarius* allowed determination of annual growth segments up to 22 years back. A period from 2009-2014 was chosen for further analysis, to secure a large and more even numbers of replicates. Length and weight of annual growth segments were comparable to other studies of annual growth in aquatic mosses in the Arctic and Subarctic regions; *D. trifarius* in Lake Sommerfuglesø (Riis *et al.* 2014), *D. revolens* var. *intermedius* in Char Lake (Sand-Jensen *et al.* 1999), *C. gigantheum* in Colour Lake (Hawes *et al.* 2002) and *D. trifarius* from northern Lappmark (Bisang *et al.* 2008).

We found individuals from Arctic Station pond were generally larger compared to Kangaarsuk pond and when comparing the growth of the mosses from the years 2009-2014, we found that *D. trifarius* grew significantly slower in Kangaarsuk pond compared to Arctic Station pond. These findings suggest better conditions for growth of *D. trifarius* in Arctic Station pond compared to Kangaarsuk pond. The effects might be due to different environmental conditions in the two ponds as the presence of *S. scorpioides* in Kangaarsuk pond. *S. scorpioides* is known to inhabit more mineral-rich habitats (Hedenäs & Eldenäs 2008), which is consistent with the higher conductivity that we found in Kangaarsuk pond (66 µS cm^{-1}). In addition elevated salinity and conductivity levels will occur during the ice-in period, which might favour growth of *S. scorpioides* even more.

Correlation to climatic conditions

Despite the difference in growth rate in *D. trifarius* between Arctic Station pond and Kangaarsuk pond, the between-year differences were significantly different in both ponds, where segments from 2012 were greater than previous years. This is in contrast to the study of Sand-Jensen *et al.* (1999) where no between-year variations were found. The authors suggest that this result is due to low variation in climatic conditions. The climate conditions at our locations in 2009-2014 varied significantly (see appendix 2 for exact values). This variation in climate may be useful as a proxy for bryophyte growth.

When correlating length to climatic conditions, temperature could explain 77% and 86% of the between-year variation of annual growth segments in Kangaarsuk pond and Arctic Station pond respectively. This is similar to studies of Callaghan *et al.* (1997), who found a positive relationship between temperature and growth in *Hylocomium splendens* (Hedw.) Br. Eur. The relationship between length and temperature was found to be positive, with temperature as a determining factor for growth.

An interesting observation was found when comparing the relative growth of the mosses. Here we found that Kangaarsuk pond had a higher variation between years than in Arctic Station pond (figure 6). Growth segments from the year 2012 made out 35% of the total length (year segments from 2010-2014) in Kangaarsuk pond and 27% in Arctic Station pond. Even though temperature shows good correlation with the different annual growth segments, the larger relative variance in years found in Kangaarsuk pond could indicate that growth is determined by other conditions than climate. Here we hypothesize the presence of *S. scorpiodes* to have an influence on the growth. The high abundance of *S. scorpioides* may have resulted in unstable conditions for growth in Kangaarsuk pond. If there were less favourable conditions for *S. scorpioides* in 2012, there may have been more space and less competition to promote *D. trifarius*. The increased climatic stability and reduced competition in Arctic Station pond may have resulted in increased growth.

We hypothesized that altered light conditions would affect growth segments of *D. trifarius*. As described in the introduction a reduction in light will occur when ice- and snow coverage is prolonged. Contrary to our expectation and the study of Riis *et. al.* (2014), the growth segments of *D. trifarius* did not correlate directly to frost days and maximum snow depth. This picture could have been blurred by the fact that the measured incoming light does not represent the light regime in the pond. Moreover, only in cases of high number of frost days will ice coverage limit penetration of light into the water column. Additionally the former study of McIntire *et al.* (1994) showed that mosses can survive at 0.1-2% of surface irradiance (McIntire *et al.* 1994 in Hawes *et al.* 2002). Our findings also support the results from the study of Hawes *et al.* (2002), where persistence of ice coverage had no relation to length of the growth segments. Hawes *et al.* (2002) have previously questioned length of mosses as an indicator of growth, since moss stems have the ability to etiolate under low-light conditions (Priddle 1980a in Hawes *et al.* 2002). Thus bryophyte stems can elongate under ice coverage and annual segments can therefore be longer as a response to low light. However, ponds are expected to freeze solid during winter and therefore photosynthesis in the mosses decreases and growth stops. Thus elongation may not be the reason for the low explanatory coefficients. When correlating climatic conditions with biomass (DW) no significant relationships were found, thus biomass seems a less suitable descriptor of growth. The poor correlations with biomass may be caused by epiphyte growth on the mosses. Extensive epiphyte growth was observed on Kangaarsuk individuals and as epiphytes can exert massive shading on the mosses and competition for light it may have impact on the biomass (Sand-Jensen, 1977). Also the ability of *D. trifarius* to reallocate nutrients from older year segments to new growth may have an impact on the biomass and may be the reason for the low explanatory coefficients. Given the low level of concordance between annual growth segments and environmental conditions with measurements of both length and biomass, it is essential to evaluate if *D. trifarius* is an appropriate indicator for altered climate.

Challenges of using *D. trifarius* as an indicator for altered climate

Side branches

Another challenge with using *D. trifarius* as a biological indicator is that it produces side branches. Currently there exists little guidance on how to overcome this problem. Side branches are assumed to increase the variation in-between samples by focusing growth in two directions instead of one, and thereby lower the direct response to altered climate. It is very difficult to know exactly which year the side branch is from. Therefore including them will increase the variation in the measurements. Therefore we would expect growth measured as length to be lower in individuals with side branches. From Kangaarsuk we sampled 17 individuals with side branches out of 100. We tested the effect of including the individuals with side branches in our analyses compared to excluding them. There was no significant effect of including the individuals with side branches, and thus we have included all individuals in our analyses. The fact that it was only 17 individuals with side branches out of 100 could have an impact on the conclusion of the significance, but for this study it did not affect our results.

Reallocation

Even though bryophytes are nonvascular organisms, evidence exists that *D. trifarius* possess the advantage of resource allocation (Bisang *et al.* 2008, Riis *et al.* 2014). This may affect the productivity in the individual annular segments, and influence annual growth (Bisang *et al.* 2008). Studies have also been made for other bryophytes, where the nutrient content in segments of every age and depth was low, but the content of carbon, nitrogen and phosphorous was higher in the youngest apical segments (Sand-Jensen *et al.*, 1999). This trait is a big advantage in oligotrophic conditions, and sets back the importance of nutrient concentrations in the surrounding environment. Even though resource allocation is an advantage, it also makes the individual annual segments more challenging to interpret, especially when using the moss as a biological indicator. Reallocation of nutrients means that the biomass of older annual segments might decrease, and thereby change the connection to the specific environmental conditions that year. It is therefore important to take these considerations into account when reconstructing mosses.

Sampling methods

There seems to be no consensus in the literature in how to sample aquatic mosses. Bisang *et al.* (2008) states, that mosses should be sampled from a single spot to minimize sampling and comparison of potentially different microclimates. However this makes the samples non-independent. The ponds were also small and the environmental heterogeneity, if any, was very limited. Furthermore the mosses did not appear in dense stands, which could maybe make the microclimates significant. Therefore we chose to sample the moss individuals randomly. For Kangaarsuk pond it could be argued, that there may be different microclimates or conditions for *D. trifarius'* growth, because of the high abundance of *S. scorpioides*. This was seen by the higher occurrence of side-branch-individuals, where the mosses had redirected the growth in two directions, possibly to avoid shading from *S. scorpioides*. Callaghan *et al.* (1997) used the most vigorously growth shoots to show climate variation, because subdominant growth shoots could show an indirect response of climate due to the dominance of the vigorous individuals. When testing our data, we saw no effect of leaving out individuals with side branching. We are aware of the potential bias in selecting individuals without side branches.

Conclusion

In this present study we evaluated the use of *D. trifarius* as an indicator for altered climate. We found that temperature was a highly influential factor determining growth. In both Arctic Station pond and Kangaarsuk pond annual growth segment from 2012 was remarkably larger, indicating a warmer growth season this year. In contrast to our expectations and the former study in East Greenland by Riis *et al.* (2014) no relationship existed between length of annual growth segments and duration of ice coverage and snow depth. Furthermore, comparing biomass with climatic conditions showed no significant relationship, which can be caused by the extensive epiphyte grown and the ability to reallocate nutrients. Thus biomass seems a less suitable descriptor of growth. We observed variation in the relative length of growth segments between the two ponds and suggest that competition from *S. scorpiodes* may be the main contributor to the difference in growth between the two ponds. This observation suggest that using *D. trifarius* as an indicator for altered climate is not independent of the environment in the pond or lake it origins from, and competition with *S. scorpioides*.

Using *D. trifarius* as an indicator of altered climate is not without its challenges. One of the main issues is that *D. trifarius* produces side branches. However, in this study we found no effect on the differences in annual growth between years when including individuals with side branches. It is important to note that in this inclusion only 17% of the individuals had side branches and an increase in the percentage might alter the result. The general low levels of concordance with both length and biomass suggest that not only climate is controlling the growth of *D. trifarius*. Therefore it is essential to include other factors such possibly epiphyte growth, degradation with age, competition and potentially herbivory when using *D. trifarius* as an indicator for altered climate.

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Appendix 1: Findings of *Drepanocladus trifarius*

Drepanocladus trifarius

Findings are not verified.

Kangaarsuk pond:
Lat 69° 15’ 59” N
Lon 53° 49’ 42” W
Altitude (ft): 56

Ilulissat:
Lat 69° 16’ 02” N
Lon 53° 48’ 58” W
Altitude (ft): 15

Qeqertarsuaq:
Near Engelskmandshavn
Lat 69° 15’ 20” N
Lon 53° 32’ 26” W
Altitude (ft): 97

Plateau behind Arctic Station:
Pond 1
Lat 69° 15’ 17” N
Lon 53° 31’ 22” W
Altitude (ft): 110

Pond 2
Lat 69° 15’ 14” N
Lon 53° 31’ 24” W
Altitude (ft): 108

Coffee pond
Lat 69° 15’ 14” N
Lon 53° 31’ 25” W
Altitude (ft): 134

Arctic Station pond
Lat 69° 15’ 13” N
Lon 53° 31’ 29” W
Altitude (ft): 116

After coffee pond
Lat 69° 15’ 13” N
Lon 53° 31’ 32” W
Altitude (ft): 85

Appendix 2. Climatic conditions measured at Arctic Station’s Automatic Weather Station AWS (1 69°15'11.0" N. 53°31'13.0". 24 m asl). Summer is defined as the period from 1th June to 30th September and frost days as number of days with temperature below 0°C.

	Mean summer air temp. (°C. 200 cm)	**Mean year temp. (°C. 200 cm)**	**Mean summer precipitation (mm Water EQ)**	**Year precipitation (mm Water EQ)**	**Frost days (temp <0 °C)**	**Max. snow depth (cm)**	**Incoming shortwave radiation annual mean (W m^{-2})**	**Outgoing shortwave radiation annual mean (W m^{-2})**	**Net radiation annual mean (W m^{-2})**
2009	**6.55**	**-2.2**	**NA**	**NA**	**216**	**23**	**131**	**40**	**91**
2010	**7.79**	**1.0**	**1.47**	**1.01**	**162**	**48**	**117**	**NA**	**NA**
2011	**6.57**	**-2.6**	**NA**	**NA**	**232**	**32**	**118**	**39**	**79**
2012	**7.84**	**-2.2**	**1.64**	**0.85**	**199**	**25**	**115**	**28**	**86**
2013	**6.21**	**-1.8**	**1.08**	**0.49**	**214**	**32**	**121**	**26**	**95**
2014	**6.56**	**-1.9**	**2.01**	**0.77**	**213**	**50**	**118**	**33**	**85**

Incoming shortwave radiation summer mean (W m^{-2})	**Outgoing shortwave radiation summer mean (W m^{-2})**	**Net radiation summer mean (W m^{-2})**	**Mean June air temp. (°C. 200 cm)**	**Mean June precipitation (mm Water EQ)**	**Incoming shortwave radiation June (W m^{-2})**	**Outgoing shortwave radiation June (W m^{-2})**	**Net radiation June (W m^{-2})**
225	**29**	**196**	**5.14**	**NA**	**287**	**30**	**257**
197	**23**	**173**	**6.23**	**NA**	**252**	**29**	**223**
201	**27**	**174**	**5.41**	**NA**	**277**	**40**	**237**
194	**21**	**174**	**8.07**	**NA**	**294**	**33**	**261**
205	**22**	**183**	**6.27**	**NA**	**298**	**29**	**268**
196	**22**	**174**	**6.57**	**NA**	**277**	**28**	**250**

*NA indicates data not available

Appendix 3. Pearsons Product Moments Correlation coefficients from correlation of different environmental conditions to annual segment length and biomass in *D. trifarius* from Arctic Station pond and Kangaarsuk pond. Summer is defined as the period from 1th June to 30th September and frost days as number of days with temperature below 0°C.

		Mean summer air temp. (°C. 200 cm)	**Mean year temp. (°C. 200 cm)**	**Mean summer precipitation (mm Water EQ)**	**Year precipitation (mm Water EQ)**	**Frost days (temp <0 °C)**	**Max. snow depth (cm)**	**Incoming shortwave radiation Annual mean (W m^{-2})**	**Outgoing shortwave radiation Annual mean (W m^{-2})**
Arctic Station pond	**Length**	**0.86***	**0.07**	**0.03**	**0.42**	**0.33**	**0.01**	**0.29**	**0.17**
	DW	**0.64****	**0.16**	**0.01**	**0.16**	**0.14**	**0.13**	**0.29**	**0.15**
Kangaarsuk pond	**Length**	**0.77***	**0.08**	**0.72**	**0.72**	**0.29**	**0.08**	**0.17**	**0.01**
	DW	**0.66****	**0.07**	**0.11**	**0.19**	**0.26**	**0.14**	**0.14**	**0.10**

***P<0.05**
****P<0.1**

		Net radiation Annual mean (W m^{-2})	**Incoming shortwave radiation Summer mean (W m^{-2})**	**Outgoing shortwave radiation Summer mean (W m^{-2})**	**Net radiation Summer mean (W m^{-2})**	**Mean June air temp. (°C. 200 cm)**	**Incoming shortwave radiation June (W m^{-2})**	**Outgoing shortwave radiation June (W m^{-2})**	**Net radiation June (W m^{-2})**
Arctic Station pond	**Length**	**0.04**	**0.24**	**0.26**	**0.19**	**0.64**	**0.01**	**0.00**	**0.01**
	DW	**0.03**	**0.20**	**0.18**	**0.17**	**0.53**	**0.01**	**0.09**	**0.00**
Kangaarsuk pond	**Length**	**0.16**	**0.12**	**0.00**	**0.17**	**0.01**	**0.02**	**0.56****	**0.00**
	DW	**0.00**	**0.00**	**0.03**	**0.00**	**0.28**	**0.00**	**0.06**	**0.01**

***P<0.05**
****P<0.1**

Zooplankton i arktiske søer – effekten af Fjeldørred (*Salvelinus alpinus*)

Ditte Ethelberg-Findsen & Anna Louise Hansen

Formålet med dette studie var at undersøge zooplanktonsamfundene i arktiske søer samt at undersøge forskellen i zooplanktonsammensætningen i søer med og uden fjeldørred (*Salvelinus alpinus*). Fem søer på den sydlige del af den grønlandske ø Disko blev undersøgt. Fjeldørred (*S. alpinus*) var til stede i tre af søerne, mens de to sidste søer ikke indeholdt fisk.

Vores forventninger til studiet var, at der i de fiskefrie søer ville være en større andel af store zooplanktonarter, mens der i søerne med fisk ville være en dominans af mindre arter. Denne forskel forventede vi ville komme til udtryk i Bray-Curtis og Sørensens similaritets-indeks, hvor der ville være større similaritet mellem søer inden for grupper (med eller uden fisk) end mellem grupperne. Ydermere forventede vi en tilstedeværelse af damrokker (*Lepidurus arcticus*), som har en prædationseffekt på de bundlevende zooplankton arter, i søerne uden *S. alpinus*.

Der blev taget plankontræk i de fem undersøgte søer, og alle zooplankton organismer blev identificeret. Fisk blev fanget i to af søerne for at undersøge fiskenes maveindhold og om muligt at afklare prædations-præferencer.

Similaritets-indeksene viste ingen forskel i zooplanktonsamfundet i de undersøgte søer, afhængig af tilstedeværelsen af fjeldørred (*S. alpinus*) .Damrokker (*L. arcticus*) var til stede i den ene fiskefrie sø, men blev ikke observeret i den anden fiskefrie sø. Årsagen til at vores observationer ikke stemte overens med vores forventninger, skyldes formentligt abiotiske faktorer, der har en indvirkning på søerne. Ved inddragelse af flere søer ville interne forskelligheder formodentlig betyde relativt mindre.

Zooplankton in arctic lakes – the influence of Arctic char (*Salvelinus alpinus*)

Ditte Ethelberg-Findsen & Anna Louise Hansen

Abstract

The aim of this study was to investigate the zooplankton communities in arctic lakes and to examine the differences in zooplankton composition in lakes with and without arctic char (*Salvelinus alpinus*). Five lakes on the southern part of Disko were investigated. Fish were present in three of the lakes, while absent in the two remaining. Our expectations to this study were that the lakes without fish would contain a high fraction of larger zooplankton species, while the lakes containing fish would be dominated by smaller species. Furthermore, we expected that the absence of *S. alpinus* would promote the presence of *Lepidurus arcticus,* which in turn could have an effect on zooplankton because of a predatory effect on the benthic living zooplankton species. Zooplankton samples were taken with a plankton net, and in two of the lakes, fish were caught by net and rod in order to investigate feeding preferences of the fish from analyzing stomach content. The Bray-Curtis and Sørensen similarity indexes did not show a difference in zooplankton community in the study lakes, depending on the presence of *S. alpinus*. *L. arcticus* was only present in one of the fishless lakes. The reason for our observations not being consistent with our expectations is probably the abiotic factors of the lakes. The differences between the lakes within the same group (with fish or without fish) would presumably be smaller if more lakes were included in the study.

Keywords: *zooplankton, lake, arctic char (Salvelinus alpinus), arctic, Greenland*

Introduction

The arctic climate is generally characterized as cold, dry and windy, with mean water temperatures not exceeding 10°C during the warmest month (July). Despite this rough climate life adapted to these conditions exists, both on land and in water (Thomas *et al.*, 2008).

Lakes in the arctic are very abundant and in some regions they cover up to 90 % of the area. A general characteristic of the arctic lakes is that they are oligotrophic and have short growth seasons, primarily due to the climate (Thomas *et al.,* 2008; Rautio *et al.,* 2011). Arctic lakes are covered with snow and ice for most of the year except for a couple of months during summer (Christoffersen *et al.,* 2008a; Rautio *et al.,* 2011). With a thick layer of ice with snow on top, light cannot penetrate to the water underneath, and photosynthesis is therefore only possible when the ice is transparent and snow is thin enough for the light to penetrate. The small amount of light in the spring is enough for the phytoplankton to grow under the ice, even before all the ice has melted (Christoffersen *et al.,* 2008b). As a result of this, the zooplankton also peaks under ice. Before the lakes are completely ice free the abundance of both phytoplankton and zooplankton is on a decline again, due to the low nutrient concentrations in the water (Hobbie *et al.,* 1999 in Christoffersen *et al.*, 2008b).

Both abundance and diversity of zooplankton species is low in arctic lakes compared to temperate lakes (Christoffersen, 2006; Christoffersen *et al.,* 2008a; Rautio *et al.,* 2011). The low diversity is related to the harsh conditions in the arctic, such as the short growth season, high exposure to UV radiation and for shallow lakes and ponds solid freezing during winter, making it impossible for some species to survive (Rautio *et al.,* 2011).

One way to cope with this harsh environment is to have dormant stages in the life cycle. These dormant stages can either be an obligatory stop in development in a certain life stage (i.e. diapause), or a stop in development caused directly by environmental factors (i.e. quiescence), which can be expressed in all stages. Cladocerans and calanoid copepods can produce diapause eggs, helping them survive during winter, and thereby disperse in time. Adult copepods and copepodits can also have a break in development if environmental conditions are not favorable (Gyllström & Hansson, 2004). Another adaption to the harsh environment can be observed in *Daphnia* sp. having a specialized pigmentation that protects them from the UV radiation (Rautio *et al.,* 2011).

Fish can be present in arctic lakes, however the shallow lakes with a depth below 3 meters freeze solid during winter, and these conditions make it impossible for fish to survive during winter (Riget *et al.,* 2000). The structure of food webs is highly affected by the presence of fish, and they affect both the size and abundance of the zooplankton species (Jeppesen *et al.,* 2001).

The predation pressure from fish is highest on the large-bodied zooplankton individuals, because they are more visible for the fish. When fish are not present in a lake it allows the larger zooplankton species to be more abundant, and their abundance can increase 2-5 times compared to a lake with fish (Jeppesen *et al.,* 2001; Rautio *et al.,* 2011). In addition to this, studies on stomach content of Arctic char, *Salvelinus alpinus,* have shown that large bodied zooplankton and Chironomidae larvae and pupae were dominating their diet composition (Svenning *et al.,* 2007). However, other studies on zooplankton communities did not find this relationship; e.g. O'Brien *et al*. (1979) found no relationship between presence of fish and distribution of zooplankton into small and larger species in 10 of 11 lakes in Alaska.

Fish are not the only predators that affect the distribution and abundance of zooplankton in arctic lakes. The tadpole shrimp *Lepidurus arcticus* is feeding on the zooplankton as well (Christoffersen, 2001). Studies has shown that when *L. arcticus* is present, the benthic living zooplankton such as *Alona* sp. and *Macrothrix* sp. are present only in low numbers, probably due to *L. arcticus* predation. (Jeppesen *et al.,* 2001). *L. arcticus* is however only present in lakes without fish, as the fish feed on tadpole shrimp (Jeppesen *et al.,* 2001)

The purpose of this study is to examine the zooplankton community in arctic lakes and to evaluate effects of *S. alpinus* on the species distribution. When fish are present, we expect to see a dominance of the smaller crustaceans such as Copepoda and the smaller genus of Cladocera, and only few large crustaceans such as *Daphnia sp.* and *L. arcticus*. We expect to observe the reverse pattern when fish are absent, and to find larger species of Cladocera in the stomach contents of *S. alpinus*. Furthermore *L. arcticus* is expected to have an effect on the smaller and benthic cladocerans as *Alona sp*. and *Macrothrix hirsuticornis*, and our expectations are to observe this in the fishless lakes with *L. arcticus*.

Materials and methods

Study sites

All sites are located at the southern part of Disko, Greenland (figure 1). Physical factors for the five studied lakes are summarized in table 1. Thygesen sø is located in an inhabited area (Qeqertarsuaq), and Kangersuk sø (shallow) and Kangersuk sø (deep) were connected though a small stream, running from Kangersuk sø (shallow) to Kangersuk sø (deep).

Sampling

Zooplankton was collected with a plankton net with mesh size 80 µm, which will retain all development stages. For Morænesø, Porsild sø, Kangersuk sø (shallow) and Kangersuk sø (deep) samples were made from 10 plankton throws. For Thygesen sø the sample was made of 5 plankton throws due to a lot of organic material in the water, and other factors that made sampling difficult.

L. arcticus were searched for visually and with a sieve on a stick along the banks at each site. Thygesen sø was not searched because the water was too deep and turbid to see the bottom. *S. alpinus* were caught in Kangersuk sø (deep) and in the stream connecting the two Kangersuk lakes with a fishing pole and a small net and brought to the laboratory for analyses.

Figure 1: Map of the southern part of the island Disko with the five study lakes shown with white numbers. 1: Moræne sø, 2: Porsild sø, 3: Thygesen sø, 4: Kangersuk sø (shallow) and 5: Kangersuk sø (deep). Insert left: The island Disko. Insert right: Greenland. Map showing lakes and insert left are from Google maps, insert right is from mapsofworld.com.

Table 1: Characteristics of the sampling sites.

	Moræne sø	**Porsild sø**	**Thygesen sø**	**Kangersuk sø (shallow)**	**Kangersuk sø (deep)**
Sampling date	July 8th	July 9th	July 11th	July 14th	July 14th
Coordinates	69.273263N 53.472134W	69.399525N 53.802184W	69.245609N 53.538356W	69.272217N 53.834679W	69.269731N 53.829756W
Water clarity	Clear	Clear	Turbid	Clear	Clear
Lake bed	Hard	Like quiksand	Muddy, like quiksand	Sandy, like quiksand	Sandy
Shore	Steep bank	Sandy, like quicksand. Slightly sloping	Steep bank	Slightly sloping, sandy bank	Steep bank
Approximate sampling distance from shore, meter	7	0	6	15	4
Approximate depth at sampling	0.5	0	1.1	0.5	0.7
Fish	Absent	Dead, rotting fish on the shore and in shallow water	Absent	Present	Present

Duplicate water samples were collected at a depth of approximately 30 cm from the surface for analyses of chlorophyll, pH and total N and total P.

Laboratory analysis

The zooplankton samples from each lake received 5-10 drops of acid Lugol´s solution to kill and preserve the zooplankton. Zooplankton was analyzed with stereo microscopes (OLYMPYS SZX12 and Leica WILD M3C) and microscope (OLYMPUS BX51) and identified using Böcher (2001) and Enckell (1980). Analyses were carried out until all species in the water sample were identified. Zooplankton were analyzed to highest possible taxonomic level, and the number of individuals in each group was either counted directly or estimated from subsamples. For each site the zooplankton composition in the sample was assumed to resemble the zooplankton composition in the lake. Based on the number of individuals in each category, the percentage distribution of the zooplankton community was estimated for each site. The total findings for each site are shown in table A1 in appendix.

Fish were dissected, stomachs and otoliths were removed. Stomachs were then frozen and at least one otolith from each of the eight fish was found. Stomachs and otoliths were brought to Copenhagen for analysis.

Fish stomachs were thawed and cut open. Contents from stomach, intestine and esophagus were placed in a petri dish. The mass was analyzed for identifiable items such as shells of Cladocera, *Daphnia* ephippias, head capsules of Chironomidae and more or less digested parts of mixed crustaceans with stereo microscope (OLYMPUS SZX12 and LEICA MS5).

Otoliths were gently cleaned between two fingers and placed in a petri dish, covered with demineralized water to improve optical properties. The petri dish was placed on a black surface, and age-rings were counted using a stereo microscope (OLYMPUS SZX12) (figure A1 in appendix), as described in (Nielsen, 2011).

Water samples for chlorophyll measurements were filtrated through GF/C filters the same day as sampled. The filters were frozen until analyzed in Denmark following standard chlorophyll extraction methods (Jespersen & Christoffersen, 1987). PH was measured in lab with pH meter (PHM210) after calibration. Water samples for total nitrate (TN) and total phosphorus (TP) measurements were frozen and analyzed in at Freshwater Biological Laboratory of Copenhagen. The samples were thawed and 5 ml sample water and 5 ml potassium persulfate reagent was added to acid rinsed autoclave vials. The samples were autoclaved for 45 min and after cooling, 2.5 ml borate buffer was added, and the samples were stored at 5 °C. The samples were analyzed with a SEAL AutoAnalyzer 3 HR with blanks and an internal standard row (E. Kristensen, pers. comm.).

Data analysis

As limited time only allowed us to sample 5 lakes, we were not able to test potential differences between lakes with and without fish. We are, however, able to evaluate our results with similarity indexes. For this purpose we used Bray-Curtis and Sørensen similarity indexes.

Bray-Curtis similarity index is calculated from the equation:

$$BC_{jk} = 1 - \frac{\sum \left| n_{ij} - n_{ik} \right|}{\sum n_{ij} - n_{ik}}$$

where n_{ij} is the proportion of individuals of species *i* at location *j* and n_{ik} is the proportion of individuals of species *i* at location *k*. BC_{jk} ranges from 0 to 1, where 0 is no similarity and 1 is identical. This index both takes into account the similarity of species present and the abundance of the species.

Sørensens similarity index is calculated from the equation:

$$Sø_{jk} = \frac{2a}{b + c}$$

where *a* is the number of similar species on the two locations, *b* is the number of species on location *j* and *c* is the number of species on location *k*. $Sø_{jk}$ ranges from 0 to 1, where 0 is no similarity and 1 is identical. This index only takes presence and absence of species into account, while the number of individuals of a specific species on the locations is not considered.

Results and discussion

Zooplankton distribution

We found 13 different taxa of zooplankton in the five lakes, ranging from 3 to 8 per lake (table A1 in appendixes). The lakes were generally dominated by copepod nauplii and copepodits, but also different species of Cladocera occurred (figure 2 and 3). Thygesen sø and Kangersuk sø (deep) contained approximately half the number of species compared to the other three lakes.

Also other crustaceans were observed. In Moræne sø one mature *L. arcticus* was found on the lake bed while 46 *L. arcticus* larvae were found in the plankton throws. In Thygesen sø *Brachionecta paludosa* were very abundant, but not counted due to problems with the sampling method.

To give an overview of what was found in the lakes we grouped the species and life stages of zooplankton in the lakes (figure 3).

In Thygesen sø we observed a relatively high percentage of *Daphnia longispina* compared to the other lakes. As no fish were present in Thygesen sø, this observation is in agreement with our expectations. However, we also expected a high percentage of *Daphnia sp*. in Moræne sø, which was not observed. Previous studies (O'Brien *et al.*, 1979) also found no relationship between presence of fish and distribution of zooplankton in small and large species.

When fish are absent *L. arcticus* has the opportunity to be present. Hence, we expected *L. arcticus* to be present in Moræne sø and Thygesen sø. We only found *L. arcticus* in Moræne sø, while *B. paludosa* was observed in Thygesen sø.

In Jeppesen et al. 2001 it was observed that when *L. arcticus* is present there are only few microcrustaceans, such as *Alona sp.* and *Macrothrix sp*. In Moræne sø, where *L. arcticus* was observed, we found a higher fraction of the small zooplankton species than what we expected.

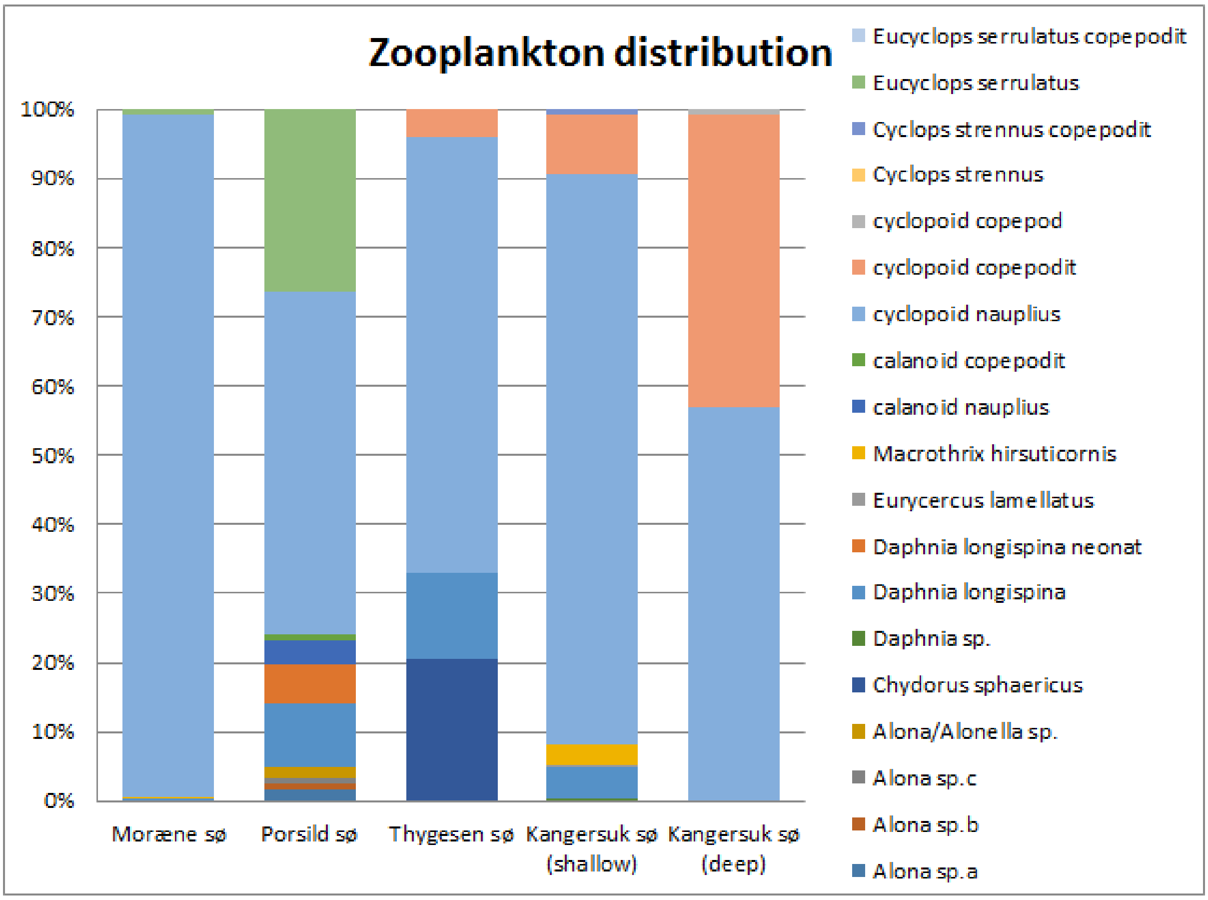

Figure 2: The percentage distribution of all zooplankton (including all species and life stages) found in the lakes.

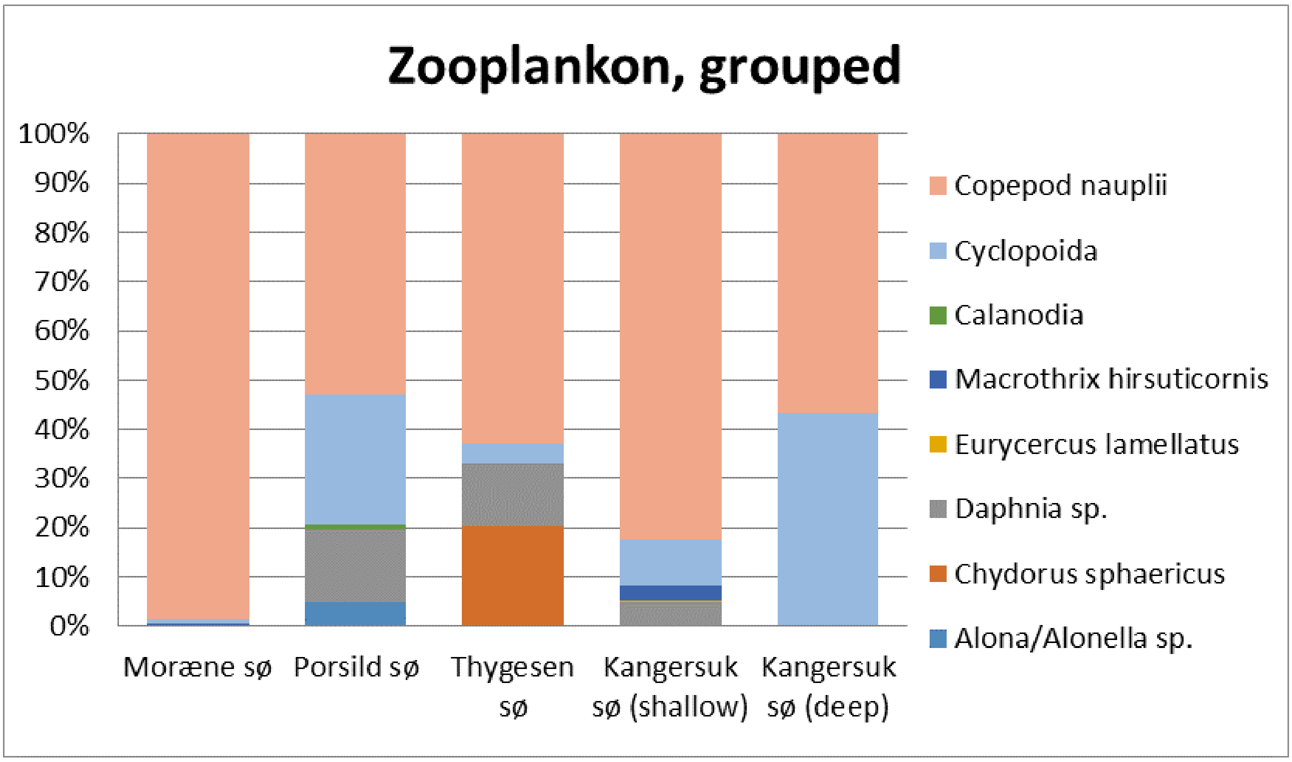

Figure 3: Zooplankton taxa found in the lakes. All life stages of each taxon are grouped to show an overview of the organisms present.

The diversity of species found in Thygesen sø and Kangersuk sø (deep) is lower than the other three lakes and it can perhaps be explained by a high abundance of fish in Kangersuk sø (deep) and a higher nutrient concentration in Thygesen sø sompared to the other lakes (see table A2 in appendix). Thygesen sø is located in the middle of Qeqertarsuaq, with dogs resting around it. The chlorophyll concentration was markedly higher in Thygesen sø than the other lakes, which implies more food for the zooplankton.

Similarity indexes

Bray-Curtis similarity indexes show that Moræne sø and Kangersuk sø (shallow) are the most similar lakes, with a similarity index of 0.83. Furthermore it seems that Moræne sø, Thygesen sø and Kangersuk sø (shallow) are all somehow similar in zooplankton composition. All remaining indexes are around 0.5 to 0.65 (table 2). A huge part of this similarity is due to the enormous amount of nauplii in four of the lakes. This partly explains why Porsild sø shows little similarity to any of the other lakes, as it only contains 49.6 % cyclopoid copepod nauplii. Kangersuk sø (deep) shows little similarity to the other lakes as well mainly due to an extremely large amount of cyclopoid copepodits.

Table 2: Bray-Curtis similarity indexes between the lakes.

Bray-Curtis	*Moræne sø*	*Porsild sø*	*Thygesen sø*	*Kangersuk sø (shallow)*
Porsild sø	0.51			
Thygesen sø	0.63	0.59		
Kangersuk sø (shallow)	0.83	0.54	0.72	
Kangersuk sø (deep)	0.57	0.50	0.61	0.65

Table 3: Sørensen similarity indexes between the lakes.

Sørensen	*Moræne sø*	*Porsild sø*	*Thygesen sø*	*Kangersuk sø (shallow)*
Porsild sø	0.42			
Thygesen sø	0.57	0.27		
Kangersuk sø (shallow)	0.78	0.21	0.57	
Kangersuk sø (deep)	0.43	0.27	0.80	0.57

To avoid similarities due to huge amounts of nauplii and copepodits, we calculated the Sørensens similarity index (table 3). This index only takes absence and presence of species into account, while the abundance of individuals is not considered. According to this index Thygesen sø and Kangersuk sø (deep) are very similar due to the same number of species and only two in difference. Moræne sø and Kangersuk sø (shallow) still show some similarity, but a bit less than when the abundance of individuals is taken into account. Porsild sø shows very little similarity to any of the other lakes due to 6 species (and life stages) found only in this lake. There are, however, only a few of each of these observations, which is why we did not see the same poor similarity between Porsild sø and the other lakes in our Bray-Curtis similarity index.

Due to the predation preferences from arctic char we expected to find high similarity between Porsild sø, Kangerssuk sø (deep) and Kangerssuk sø (shallow) and between Thygensen sø and Moræne sø, while the similarity between those groups were expected to be low.

However, Bray-Curtis and Sørensen similarity indexes show that the similarity in these two groups is not higher than between the groups. This indicates that other factors played a role for the zooplankton community composition. These factors can be nutrients, food source, length of ice cover, lake depth and hiding places for zooplankton.

One of the two interconnected lakes at Kangersuk (Kangersuk sø (shallow)) was very shallow with a flat sandy bottom and no vegetation along the edge, for at least half the lake. The deeper lake contained vegetation all the way around the lake. The shallow lake had fewer copepods than the deep lake, but it had *Eurycercus lamellatus* and *Chydorus sphaericus*, which was not present in the deep lake.

The shallow lake is shallow enough to freeze solid during winter and the growth period is not as long as in the deep lake, where the nauplii can peak under the ice. This is also supported by the high amounts of copepodits in the deeper Kangersuk lake. The vegetation in Kangersuk sø (deep) contributed to more habitats for the zooplankton in form of hiding places. *E. lamellatus* is adapted to living around plants (Böcher, 2001), and it is therefore curious that *E. lamellatus* was found in the shallow Kangersuk lake, where no vegetation was observed, while no was found in the deeper Kangersuk lake. This is possibly due to a lower predation rate in the shallow lake, as the fish population depends on dispersal of fish from the deeper lake to the shallow lake, as fish cannot survive through winter in the shallow lake.

pH, chlorophyll and nutrients

The pH in the lakes ranged from 6.80 to 7.65, being lowest in Porsild sø while pH was similar in the remaining four lakes. The chlorophyll concentration was 23.03 µg L^{-1} in Thygesen sø while the other lakes had concentrations ranging from 2.92 to 4.03 µg L^{-1}. Also the concentrations of total N and total P was clearly highest in Thygesen sø (table A2 in appendix).

Fish stomach contents

Eight Arctic char were caught in the Kangersuk lakes. They ranged from 11.3 to 39.5 cm in length and in age from approximately 2 to 8 years, based on otoliths (table 4 and figure A1 in appendix). There were clearly differences in the colour of the flesh. The two smallest fish had light, transparent flesh, two fish of middle length had orange flesh, while the four largest fish had light orange flesh. The orange colour of the flesh is due to the diet, The stomachs were mainly dominated by digested

Chironomidae larvae. Items from Cladocera were found in 5 of the fish, and a copepod was found in one. These findings correspond to the finding in other studies (Svenning *et al.*, 2007; Jeppesen *et al.,* 2001). The numbers in table 4 refer to subjective division of items into abundance-groups from “not present” (0) to “very dominating” (10), and the numbers can therefore not be accumulated to a total. For some of the fish, the stomach contents were much digested and objects were hard to distinguish. Thus, we may have overlooked objects in the digested mass (figure A2.1 to A2.3 in appendix).

The mystery of Porsild sø - the fish who lived

When we arrived at Porsild sø 9th July there were dead fish along the banks, caused by such extensive fish death is probably a long ice coverage period leading to the water underneath the ice slowly getting low in oxygen content. If all the fish died in the spring due to this assumed long period with ice, we would expect the amount of Cladocera to rapidly increase from resting eggs in the sediment. As we only found 18 individuals (15%) of *Daphnia* in 10 plankton throws in Porsild sø, we believe that some fish may have survived.

Conclusion

Generally, copepod nauplii dominated the samples from all five lakes. This is probably related to the timing of sampling in the early summer season. Large bodied zooplankton, such as *D. longispina* and *E. lamellatus* and small bodied zooplankton as *Alona* sp, *C. sphaericus* and *M. hirsuticornis* were also abundant.

Former studies (Jeppesen et al. 2001) have shown feeding preferences of fish towards larger Cladocera and *Lepidurus.* In light of this we expected to see no or few *L. arcticus*, *Daphnia sp.* and *E. lamellatus* in lakes with Arctic char, while we did not expect *Alona/Alonella sp.*, and *M. hirsuticornis* to be affected by the presence of *S.*

Table 4: Data from the eight Arctic char (S. alpinus) caught in Kangersuk.. Fish 1 to 5 were caught in the stream connecting the two lakes while fish 6 to 8 were caught in Kangersuk sø (deep). Age was determined from otoliths. The contents of the stomach, intestine and esophagus were subjectively given a number from 0 to 10 depending on the frequency of the object. Zero was given for objects not present and 10 for objects that dominated the sample.N.K. = not known.

	Fish 1	***Fish 2***	***Fish 3***	***Fish 4***	***Fish 5***	***Fish 6***	***Fish 7***	***Fish 8***
Lenght, cm	11.7	11.3	21.0	20.6	22.1	33.9	33.8	39.5
Weight, g	11.27	16.65	81.15	78.81	92.82	356.06	408.13	581.30
Gender	N.K.	N.K.	male	male	male	female	male	female
Colour of flesh	light, transparent	light, transparent	orange	orange	pale orange	pale orange	pale orange	pale orange
Age, years	2	2	3	3 to 4	3	6 to 7	5 to 6	7 to 8
Stomach contents								
Chironomidae larvae	10	10	10	10	8	9	8	10
Eurycercus sp.	0	2	1	0	0	0	0	0
Daphnia sp.	0	0	1	0	0	0	0	0
Daphnia ephippie	0	0	0	1	1	0	0	1
Cladorera shell	0	0	0	1	2	0	0	0
Cocon	0	0	0	0	1	1	6	1
Copepod	0	0	0	0	0	0	0	1
Fly	0	0	0	0	3	1	1	1
Plant material	0	0	0	3	2	0	0	0
Long green unknown	0	0	0	0	0	1	1	0
Little green unknown	0	0	0	0	0	1	1	0
Intestinal worm	0	0	0	1	0	0	1	0

alpinus. *Daphnia sp*. were found in all the lakes, and the numbers do not suggest a higher amount of *Daphnia* sp. in lakes without fish. Neither did *E. lamellatus* or *M. hirsuticornis* suggest a relationship with the presence of fish. Furthermore we only found a few large-bodied cladoceran shells in the stomach contents of the fish.

As fish feed on *L. arcticus*, we only expected this species to be present in fishless lakes, where it would have an effect on smaller cladocerans as *Alona* sp. and *M. hirsuticornis*. However this pattern was not observed in this study.

The similarity indexes showed no difference in zooplankton community between lakes with and without *S. alpinus*. Possibly other factors such as lake depth, length of ice cover, food source, vegetation and sediment play a role in zooplankton community and the presence of fish might not be the most important factor.

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Appendixes

Table A1: Number of individuals of crustaceans found in the lakes. There was subsampled for Copepod nauplii in Morœne sø and for mature Copepods, copepodits and copepod nauplii in Kangersuk sø (deep). Analysis are based on 10 throws with a plankton net in Morene sø, Porsild sø and the two Kangersuk lakes, and 5 throws in Thygesen sø. Present = species present but not counted.

	Moræne sø	Porsild sø	Thygesen sø	Kangersuk sø (shallow)	Kangersuk sø (deep)
Artropoda					
Crustacea					
Branchiopoda					
Anostraca					
Branchinecta paludosa			present		
Notostraca					
Lepidurus arcticus	47				
Phyllopoda					
Cladocera					
Alona sp. a		2			
Alona sp. b		1			
Alona sp. c		1			
Alona/*Alonella* sp.	4	2			
Chydeous sphaericus	2		381	6	
Daphnia sp.				6	4
Daphnia longispina	23	11	233	177	123
Daphnia longispina neonat		7			
Eurycersus lamellatus				10	
Macrothrix hirsuticornis	22			121	
Maxillopoda					
Copepoda					
Calanodia					
calanoid nauplius		4			
calanoid copepodit		1			
Cyclopoida					
cyclopoid nauplius	9409	60	1174	3198	39035
cyclopoid copepodit	15		74	335	29177
cyclopoid copepod					570
Cyclops strennus			1		
Cyclops strennus copepodit	5			32	
Eucyclops serrulatus	62	32		2	
Eucyclops serrulatus copepodit	2				
Insecta					
Coleoptera					
Dystiscidae larvae			present		
Total	9591	121	1863	3887	68909

Table A2: pH, Chlorophyll, total N and total P in the five lakes. All values are means from duplicates.

	Moræne sø	**Porsild sø**	**Thygesen sø**	**Kangersuk sø (shallow)**	**Kangersuk sø (deep)**
pH	7.44	6.80	7.59	7.59	7.65
Chlorophyll (µg L^{-1})	3.52	2.92	23.03	4.03	3.23
Total N (µg L^{-1}) NO_3	332.47	275.83	950.24	405.15	272.33
Total P (µg L^{-1}) PO_4	15.36	23.57	242.66	51.18	25.58

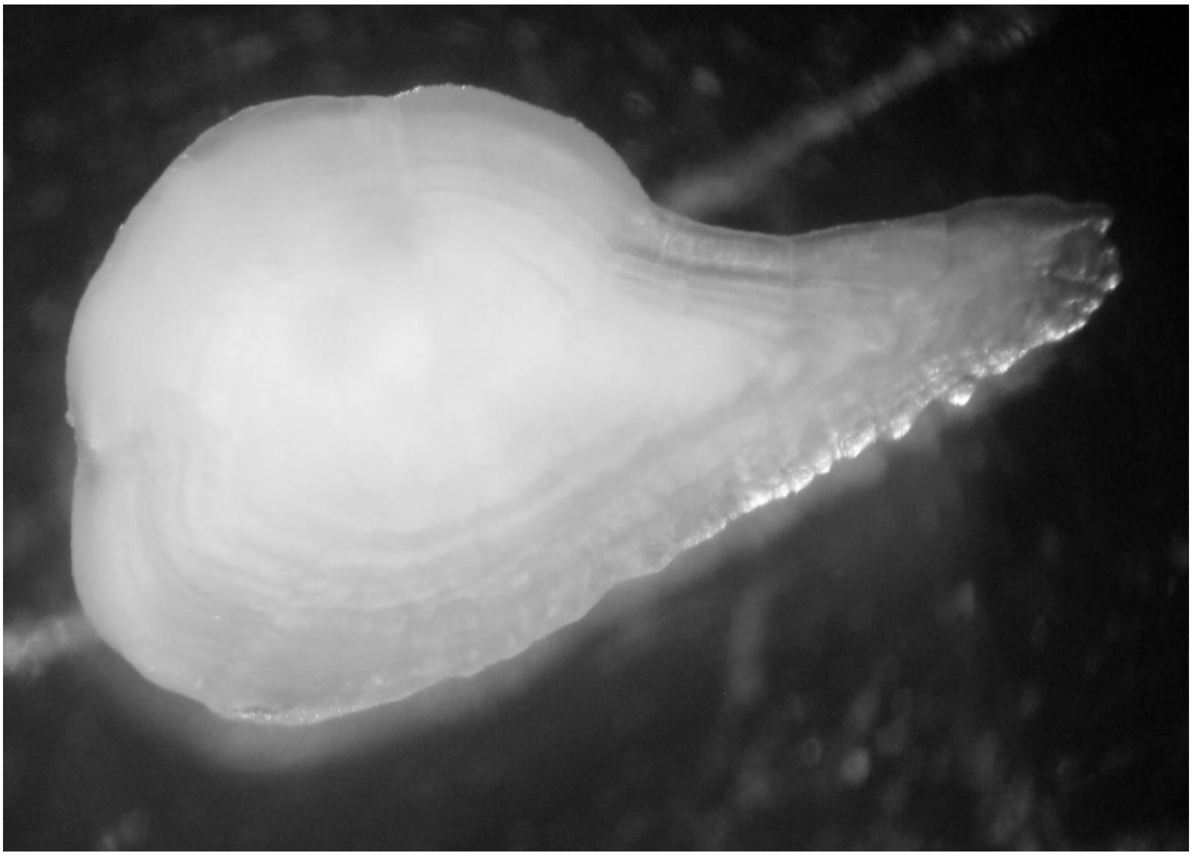

Figure A1: Otolith from an Arctic char from the deep Kangersuk lake. White rings represent the growth in the summer season, while dark rings represent the growth in the winter season.

Figure A2.1: Stomach, intestine and esophagus from S. alpinus from Kangersuk sø (deep).

Figure A2.2: Stomach content from S. alpinus from Kangersuk sø (deep).

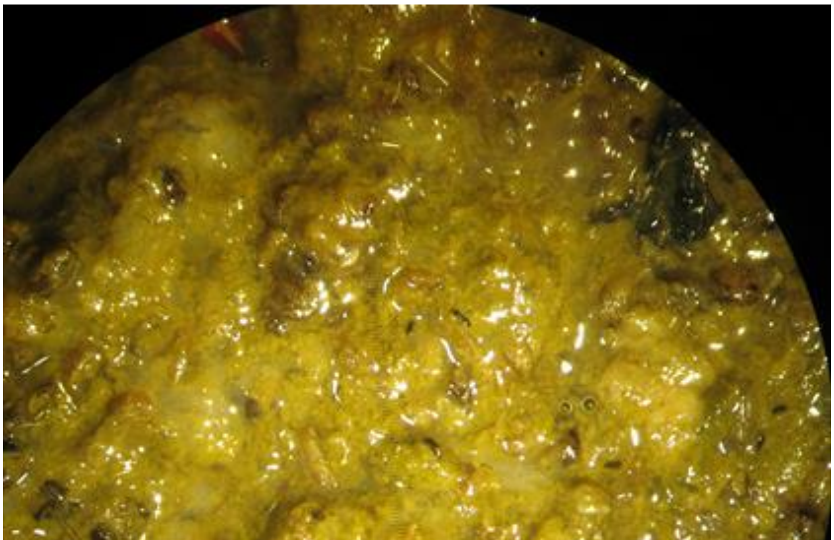

Figure A2.3: Cladoceran shells found in stomach contents from S. alpinus from Kangersuk sø (deep).

Dagbog for Arktisk Feltkursus 2015

Mandag 6. juli – Så er vi i gang (Kirsten S. Christoffersen)

Afgang fra København mandag morgen og med ankomst til Kangerlussuaq tidligt på formiddagen på grund af tidsforskellen. Efter et par timer fløj de fleste af os videre til Aasiaat, mens de resterende fortsatte til Ilulissat for at overnatte på henholdsvis hotel og Sømandshjem, inden vi alle skal afsted næste morgen med Diskoline til Qeqertarssuaq. I både Kangerlussuaq og Aasiaat/Ilulissat blev der tid til nogle korte gåture rundt i byerne. Man fornemmede allerede her, at myg er en ret fremtræden organisme på disse kanter!

Nu følger 10 hektiske dag, hvor alle grupper skal nå at skaffe data til deres rapporter, og vi skal se og opleve så meget som muligt. Disko, here we come…

Tirsdag 7. juli - Ankomst til Diskoøen (Nanna Slaikjer Petersen)

Trods en første overnatning med midnatssol fik vi alle sovet godt og var klar til den videre tur mod Arktisk Feltstation på Diskoøen. Den storslåede sejltur mod øen bød på observation af både sæler og flere pukkelhvaler – og ingen påtrængende myg. Det var en utrolig smuk tur, der først ledte os igennem et hav af is og derefter langs Diskos kyst, hvor de vulkanskabte basaltfjelde majestætisk hævede sig over havoverfladen.

Da vi ankom til havnen, blev vi mødt af stationsforvalteren Akaaraq, som var venlig at hjælpe os med at transportere baggage samt udstyr frem til stationen. Vi var alle enormt spændte på at se det sted, vi skulle tilbringe de næste 10 dage, og man må sige, at stedet levede fuldt op til vores forventninger. Med isbjerge og pukkelhvaler som udsigt kan man ikke klage. Efter velkomst og et par korte briefinger blev vi også budt velkommen af stationslederen, Christian, som gav os en rundvisning på stationen.

Resten af dagen stod på udpakning af udstyr, planlægning af forsøgslogistik og et par tiltrængte kopper kaffe. Efter en dejlig aftensmad og et sidste kig på den fantastiske udsigt fra stationen, skulle der indhentes lidt søvn, som stadig var en smule påvirket af de 4 timers forskel i tid.

Onsdag 8. juli – Opstart (Jesper Rauff Schultz)

Efter en veloverstået nat i stationens famøse ”hestebåse” vågnede vi op til den første feltdag på Disko. Nogen startede dagen ud med, hvad de påstod, skulle blive en fast morgenbade-rutine i Diskobugten, hvor de store isbjerge skræmte de mere bekvemme typer væk. Andre brugte hvert et sekund i sengen for at indhente den søvn, der blev ofret for nattens fisketur.

Første punkt på dagens program var morgenmødet, som vi kommer til at have hver dag for at gøre status og skabe overblik. Dagens første tur var en lille byvandring i den smukke by Qeqertarsuaq, hvor træhusene stod i mange forskellige farver, og slædehundene lå bundet til kæder og ventede på, sommeren skulle ende. Her fortalte Kirsten løst og fast i forhold til byens historie, Grønlandsk kultur og de levevilkår, der er på disse kanter.

Efter frokosten var alle spændte på at få prøvet deres forsøgsopstilling og feltevner af. Rygsækkene blev pakket, og grej-nørderne kunne flashe myggenet og jakker, som i disse dage er i meget høj kurs hos kursisterne. Søgruppen tog hurtigt afsted, da deres søer lå langt oppe i fjeldet og indebar krydsning af en lille elv foruden mange højdemeters vandring. Imens gik resten af gruppen mod Morænesøen, som er den mest velundersøgte sø i området. Den ligger for foden af Skarvefjeldet ved siden af en flot grøn moræne og kun 40 minutters gang fra stationen. Det er en oplagt sø til mange af gruppernes projekter og et godt sammenligningsgrundlag, da den er blevet moniteret i en del år af Kirsten. Gruppen, der skal undersøge ”varme” kilder, forlod hurtigt gruppen og bevægede sig i stedet op igennem den fredede og smukke Østerlien, hvor man i toppen kan finde varme kilder, som er områdets biologiske hotspots.

Efter en lang dag mødtes vi alle sammen til aftensmad, hvor vi fik snakket dagens bedrifter igennem. Her måtte flere erkende, at feltarbejde i det arktiske terræn ikke nødvendigvis kan planlægges til punkt og prikke fra computeren i København. Da Sø-gruppen, som var på bjergvandring, fandt is på søerne, da vi endelig kom op i terrænet, måtte vi gå den lange vej hjem med en flad fornemmelse. Mos-gruppen havde svært ved at finde den mos, som, de havde læst sig til, fandtes i Moræneosøen, og Zooplankton-gruppen måtte indse, at en tung gummibåd ikke er nem at slæbe rundt på. Alt dette er vigtige felterfaringer, men i første hug lidt af en kamel at sluge.

Efter dage som disse ligger aftensmaden rigtig godt i maven – særligt når menuen er torsk af egen fangst. Det kunne vi takke en af stationens andre sommer-residerende, Marty, for, da han havde været fremsynet og husket fiskegrej. Det er der store perspektiver i for resten af opholdet.

Torsdag den 9. juli – Nu er vi alle i gang (Henriette Hansen)

De første par dage havde gået med introduktion til området og prøvetagning, så i dag startede alle grupperne med at gå i felten fra morgenstunden, så dataindsamlingen for alvor kunne begynde.

Zooplankton-gruppen tog med Porsild til Porsilds sø tidligt morgen i forhåbning om at fange fisk. Ved ankomst fandt de dog søen stærkt ildelugtende, og samtlige fisk lå døde i vandkanten. Dette skyldtes formentligt en lang isvinter, hvilket havde forårsaget iltsvind i søen, som fiskene ikke overlevede. Gruppen kunne dog tage de nødvendige målinger af vandet og zooplanktonet. Mos-gruppen brugte formiddagen på at undersøge Moræneseøen for den bestemte mos, hvorpå man kan se årsskud. De fandt dog ikke mossen i Morænesøen og besluttede derfor at ændre projektet fra at omhandle mos i søer til mos i damme, idet de aftenen før havde observeret den pågældende mos i en dam nær Arktisk Station. Sø-gruppen tog ligeledes til morænesøen for at udsætte dataloggere samt udføre diverse prøvetagninger. Kilde-gruppen var på tur til Engelskmands Havn for at tage prøver i et homotermt vandløb. På grund af et meget tidskrævende laboratoriearbejde, besluttede gruppen at nedsætte antallet af prøvestationer i hvert vandløb fra 3 til 1. Dette ændrede dog ikke det store i projektets udgangspunkt, men lettede blot arbejdsbyrden.

Efter endt feltarbejde blev aftenen brugt af de fleste grupper på arbejde i laboratoriet, hvor prøverne blev undersøgt og analyseret nærmere. Trods en lang dag i felten og laboratoriet, tog Emil og Jesper ud på aften-fisketur, hvor de fik en god fangst af havkat.

Fredag den 10. juli – Alle har travlt (Kirstine Thiemer)

Morgenbadeklubben startede fredagen med en dukkert i havet med isbjerge i baggrunden og blev efter endt badetur mødt med duften af nybagte boller ved Arktisk Station. Efter morgenmad havde vi det daglige morgenmøde, hvor alle grupper kort fortæller, hvad de har lavet dagen før, om der har været problemer og i givet fald, hvordan disse løses. Mødet giver et indblik i, hvad de andre grupper har lavet, og her er mulighed for at spørge indtil projekterne og få gode råd, da vi ikke alle ses i løbet af dagen.

Dagens program for Kilde-gruppen var prøvetagning i en heteroterm kilde beliggende i Lyngmarksbugten, analyse af prøver samt indsamling af dataloggere i Engelskmands Havn. Udsortering og bestemmelse af prøven fra den heteroterme kilde i Lyngmarksbugten syntes allerede at vise, at fordelingen af myggelarver er forskellige mellem heteroterme og homoterme kilder. Både Zooplankton-gruppen og Mos-gruppen brugte hele dagen i laboratoriet. Zooplankton-gruppen artsbestemte og talte zooplankton fra Morænesøen, som blandt andet viste en dominans af nauplielaver af copepoder. Mos-gruppen begyndte målingen af årsskudslængder fra den indsamlede mos (*Drepanocladus trifarius).* Her blev årsskud fra 100 individer målt og klippet af til måling af biomasse. Foreløbige analyser viser, at der er en forskel mellem årsskudene, hvilket bliver spændende at sammenholde med klimadata. Sø-gruppen tog til Morænesøen for at lave morfometriske undersøgelser, ændre på opsætning af loggere samt tage bundprøver, men den stærke vind muliggjorde ikke sejlads, hvilket betød, at gruppen ikke fik prøver med hjem i dag.

Til trods for de manglende prøver lavede Emil og Jesper lækker aftensmad bestående af Fish and Chips med selvfanget havkat!! Dagen sluttede af med visning af film i fjernsynsstuen og bagning af rugbrød og boller til morgenmad og frokost dagen efter.

Lørdag den 11. juli – Tid til at finde det varme tøj frem (Emil Kristensen)

Hverdagen og rutinerne er ved at sætte ind på Arktisk Station, hvor isbjergene driver hurtigt forbi, knager, brager og vender sig. Vi vågnede op til koldere vejr, hvor tågen omsvøbte bjergene, og de hold, der skulle på tur, fandt deres lange underbukser og huer frem inden afgang.

Sø-gruppen skulle til Morænsøen for at opmåle søen og flytte nogle loggere, der havde rykket sig under gårsdagens kraftige blæsevejr. Da de kom til søen, var der heldigvis meget mindre vind, som gjorde det muligt at sejle rundt i søen uden besvær. Søen blev oversejlet på kryds og tværs med en sonar, der måler position og dybde, som gør det muligt, at kortlægge søens dybde og størrelse. Desuden blev der taget sedimentprøver, som skal undersøges for mængden af klorofyl/grønkorn. I den forbindelse blev overtøjet smidt for at kunne nå ned til bunden, som her var 65 cm – svarende til længden på Jespers arm og halvdelen af hans hoved, hvilket Emil var så hensynsfuld at forevige i et billede!

Kilde-gruppen tog ind i Blæsedalen for at finde homoterme kilder og måtte krydse en lille elv på vejen. Vandføringen i kilderne måler de ved at hælde kraftig saltvand i vandløbet og måle ledningsevnen, indtil den når ned til baggrundsniveauet. Halvdelen af Mos-gruppen stod for morgenmaden, hvilket betød, at de missede morgenbadningen. Dette viste sig at skabe store problemer, da badet normalt forhindrer morgensurhed. Derved opstod, der nogle ”misforståelser”, som der dog hurtigt kunne grines af, da situationen blev genfortalt fra begge sider. Resten af dagen arbejdede de både i laboratoriet og i deres lille dam, som både blev opmålt og fik bestemt substrat fordeling. Det lykkedes holdet at finde et ”lykkehjul”, som sørger for opblanding af inkubations prøver. Her blev der sat fotosyntese forsøg i gang, hvor afklippede skud fra mosserne blev placeret i små glasflasker og belyst. Derefter blev iltkoncentrationen målt både før og efter forsøget for at bestemme, hvor meget planterne producerede. Zooplankton-gruppen var ude i den lokale by-sø for at tage prøver og ville i den forbindelse informere ordensmagten omkring deres tilstedeværelse i søen. Det viste sig dog, at den flinke politimand var meget uforstående og ikke anede, at der lå en sø midt i byen, men de fik selvfølgelig lov til at undersøge den. I søen fandt de blandt andet fe-rejer, som er nogle superseje smådyr. Resten af dagen gik med bestemmelse af de zooplankton-arter, de havde indsamlet.

Dagen blev afsluttet med en overlækker aftensmad bestående af snekrabber lavet af Marty og Allison, som er to amerikanere, der også er på Disko for at udføre feltarbejde. Til dessert var der lækre cookies. Senere på aftenen blev der spillet whist og arbejdet i laboratoriet helt til midnat.

Søndag den 12. juli – Gudstjeneste og feltarbejde (Anne J. Dobel)

Søndagen startede som den slags gør bedst: med en dukkert for de morgenfriske og efterfølgende bacon, æg og pandekager med sirup. Efter festmåltidet og det daglige morgenmøde gik gruppen mod byens smukke trækirke for at deltage i gudstjenesten. Alle sangene blev selvfølgelig sunget på grønlandsk, også af de studerende, som kæmpede en brav kamp med de særegne lyde i det grønlandske sprog. Pianisten var på ferie, hvilket ikke gjorde fornøjelsen mindre.

Efter kirkegang gik grupperne raskt i gang med dagens dont. Laboratoriet blev brugt flittigt af flere grupper.

For Zooplankton-gruppen bestod arbejdet af at identificere arterne fundet i byens sø og fodre vandkalvelarven med fe-rejer. Hen på aftenen gik pigerne på nattevandring til endnu en sø for at nyde naturen og komme lidt væk fra identifikationsarbejdet. Mos-gruppen tilbragte det meste af dagen i laboratoriet med at tørre årsskud og gentænke deres strategi for fotosynteseforsøget. Udstyret i laboratoriet viste sig nemlig ikke at være stærkt nok til at give resultater på deres mos. De fremtidige planer blev derfor at lave fotosynteseforsøget *in situ* (i felten). Gruppen gik mod dammen i Østerlien og fik sat forsøget i gang. Dette skal køre i 24 timer, og alle er meget spændte på de kommende resultater! For Sø-gruppen gik turen ud mod Morænesøen, hvor kortlægningen af søen er godt i gang. Dagens arbejde bestod af at tage sedimentkerner fra to meters dybde til klorofylmåling. Gruppen tager sedimentkerner fra forskellige dybder i søen og måler klorofyl i vandsøjlen. På denne måde kan et estimat over procentfordelingen gives af søens produktion. Kilde-gruppen krydsede i dag elven i Blæsedalen for sidste gang for at hente deres data-loggere. Derefter blev der taget prøver i en strøm nær byens campingplads med efterfølgende identifikationsarbejde af dagens dansemyggefangst. Endnu en ny art blev fundet, og holdet er blevet skarpere og hurtigere til at genkende de svære dansemyggelarver. Med denne sidste prøvetagning er målet med tre ensvarme og tre vekselvarme kilder nået, og gruppen har derfor besluttet at udvide projektet med endnu to kilder.

Dagens afslutning blev chili con og sin carne lavet af professoren Kirsten herself. Derefter nattevandring og dataanalyser for nogle, og kortspil for andre.

Mandag den 13. juli – Tur til Kuannit (Ditte M. Christiansen)

Mandag startede som altid med (for nogen) morgenbadning og (for alle) morgenmadning efterfulgt af morgenmøde. Formiddagen gik med en fællestur til Kuannit, som er et område fyldt med basaltsøjler og klipper. Der er en spektakulær udsigt ud over havet med isbjerge og teister (arktisk sort/hvid fugl med røde ben) og rindende vand ned fra klipperne. Området ligger en times gang fra vores midlertidige hjem, så der var god tid til at udforske området, hvilket vi gjorde på hver vores måde; Casper fik kastet nogle sten i noget vand, nogen fik klatret lidt på klipper, en del fik taget en masse billeder, og andre fik drukket kaffe. Alle fik nydt udsigten! I området var der også homoterme kilder, som tydeligt kan ses i landskabet, da der langs kilden vokser lysegrønne planter, som lyser op blandt de andre mørkere grønne planter. Kilde-gruppen gik derfor afsted på egen hånd for at lede efter passende lokaliteter til videre prøvetagning.

Efter frokost fortsatte arbejdet for alle grupperne. Mos-gruppen delte sig op, da de var nået til at skulle veje tørvægten for hvert skud af deres 100 mosser. Det vil sige 4-500 vejninger af i gennemsnit 2-3 mg per skud. Langsommeligt arbejde, men ikke en firemandsbeskæftigelse, og halvdelen af gruppen fik derfor fri og gik en tur til Engelskmandshavn, hvor der blev badet og klatret på kystnære isbjerge! Zooplankton-gruppen nøglede dyr resten af dagen i laboratoriet. Der var et kort øjebliks jubelskrig fra gruppen, da de havde nøglet nogle af dyrene til nogle ret så seje arter, men lidt efter viste det sig, at de ikke var så seje alligevel, men ret normale. Sø-gruppen tog med Kirsten ud til Morænesøen, hvor de hentede loggere. Emil og Jesper satte deres ud i en af de små damme omme bag stationen og Kirsten skulle downloade næsten 2 års data fra sine loggere. Sø-gruppen elsker at fiske og de tog igen ud om aftenen for at fiske ved hvalkirkegården. Som regel er der god fangst, hvilket hele gruppen har nydt vældig godt af gennem hele kurset. Næsten hvert måltid står på friskfanget fisk!

Og hurra for det! Foruden at samle prøver ind ved Kuannit, grov- og finsorterede Kilde-gruppen flere dansemyg og andre invertebrater og havde det samtidig skønt med Mos-gruppen i laboratoriet, hvor der blev sunget med til alle Frank Ocean og Arctic Monkeys sange.

Dagen blev sluttet af med indisk linseret, Dahl, med hjemmebagt naanbrød – en af de få dage uden fisk, men det smagte godt alligevel! Bagefter var der foredrag om paleolimnologi af underviser Klaus Brodersen. Det handlede om at bruge dansemyg som en indikator for klima, og hvilke forbehold man skal have ved brugen af denne.

Tirsdag den 14. juli – Tur til Kangerssuk (Anna Hansen)

Tirsdag morgen startede igen med en morgendukkert for de friske morgenbadere efterfulgt af morgenmad og det daglige morgenmøde. Efter morgenmaden drog det meste af holdet og undervisere mod Qeqertarsuaqs lille havn, hvor vi steg ombord på Arktisk Stations kutter Porsild. Derefter blev kursen sat mod Kangerssuk, som ligger en lille times sejlads fra Qeqertarsuaq. Ved Kangerssuk er der to søer, som zooplankton gruppen skulle indsamle prøver i. Prøveindsamlingen inkluderede også indsamling af fjeldørred, som skal benyttes til videre undersøgelser af fiskenes maveindhold. Først prøvede gruppen at fange fisk med fiskestang, men uden held. Derefter blev gruppen, sammen med Klaus Brodersen, kreative, og opfiskningen blev i stedet foretaget i et lille vandløb mellem de to søer med et planktonnet. Her blev der fanget 5 mindre ørred. Samtidig var Sø-gruppen, med Emil og Jesper, ude og hjælpe Zooplankton-gruppen med at fange fisk i søerne, og de fik hevet tre større ”landlocked” fjeldørreder op. Efter at have hjulpet Zooplankton-gruppen, fiskede de resten af tiden efter havørred. Det lykkedes dem at fange nogle fine store fisk, som de har planer om at grille til aftensmad onsdag. Også Mos-gruppen var med ude i Kangerssuk. De havde dagen forinden haft mindre held med deres fotosynteseforsøg, og planen for dagens udflugt var at finde endnu en dam med deres mos. De var heldige at finde samme art af mos i en lille dam ved Kangerssuk og fik indsamlet prøver, der skal tælles årsskud på.

Totredjedele af Kilde-gruppen var ikke med på dagens tur, men var i stedet ude i Blæsedalen for at lede efter en heteroterm og en homoterm kilde, som det efter lang tids søgen lykkedes dem at finde. Trods en lang gåtur havde Kilde-gruppen nået at lave en lækker fiskesuppe, der blev serveret til aftensmad.

Aftenens program bestod af fremlæggelser for hver af grupperne med de foreløbige resultater af projekterne. Det er for de flestes vedkommende ikke helt det samme projekt, som var planlagt hjemmefra, men alle grupper har spændende og brugbare resultater og projekter. Efter fremlæggelserne var der for nogle af grupperne videre arbejde i laboratoriet, hvor der blandt andet blev målt og vejet mos og fisk.

Onsdag den 15. juli – Det lakker mod enden (Casper Aggerholm Pedersen)

Arktisk Feltkursus 2015´s skønne ophold på Arktisk Station her på Disko er ved at lakke mod enden. Med kun 2 dage tilbage før hele gruppen forlader den smukkeste, grønlandske ø (ifølge matros og handyman Erik), blev der ikke arbejdet mindre hårdt. Kilde-gruppen vandrede et godt stykke ind i Blæsedalen for at hente dataloggere og tage prøver i endnu en hetero- og homoterm kilde, som skal udgøre deres sidste kilder. Undervejs nød de det fantastiske syn af floden Røde Elv, som bugtede sig i forskellige løb i den flade Blæsedal. Det gode vejr og de mange myg blev nydt til fulde, og glæden var stor, da der blev observeret små fjeldørreder i et af sideløbende. Prøvetagningen i kilderne foregik uden problemer, og gruppen begav sig hurtigt tilbage mod stationen hungrende efter kaffe. Mos-gruppen arbejde hele dagen i laboratoriet, hvor de fortsat klippede, målte, vejede og pakkede mossernes skud for bagefter at tørre dem i en varmeovn natten over. Gruppen fik behandlet de 100 mosser, de havde håbet på at nå igennem, og fik dermed afsluttet denne del af deres projekt. Zooplankton-gruppen knoklede ligeledes i laboratoriet med at identificere de uendeligt mange nauplier og andre invertebrater i deres prøver. De er ved at være i mål, men mangler endnu at bearbejde data fra den sidste sø, de tog prøver fra. Sø-gruppen sejlede rundt i deres sø (som er en dam) nr. 2, hvor de foretog dybdemålinger og forsøgte at kortlægge søen.

Alle grupper inklusiv undervisere mødtes til en lækker aftensmad forberedt af Sø-gruppen med hjælp fra Marty. Menuen stod på grillede fjeldørred, amerikansk kartoffelsalat og bønnesalat – det smagte fortrinligt. Marty er en amerikansk kandidatstuderende også residerende på Arktisk Station, som arbejder sammen med Allison (PhD) på et projekt om en arktisk copepod-art, som er essentielt for det marineøkosystem, der findes i Grønland. Efter aftensmad gav Allison et spændende foredrag om hendes tidligere arbejde om copepoders rolle i den marine fødekæde. Efter foredraget begav Kilde-gruppen sig tilbage til laboratoriet for at identificere dagens dansemyggelarver med uundværlig assistance fra underviseren Klaus - dette resulterende i 1 ny art. Ved midnatstid, da Kilde-gruppen begav sig tilbage fra laboratoriet til hovedbygningen, var der faldet ro over Arktisk Station, og der hørtes dybe vejrtrækninger i sovesalene (hestestaldene). Endnu en skøn dag på Arktisk Station sluttede.

Torsdag den 16. juli – Plan A, B, C, D og E (Simone M. Mortensen)

At stå op til duften af nybagte boller, som spreder sig i hele huset, det gør det ligesom lidt lettere at få de efterhånden ømme ben svunget ud af sengen. Morgenbadeklubben nåede et hidtil uset højt antal medlemmer, og hvem havde regnet med, at vi kunne bade mellem isbjerge hver dag. Vi har virkelig været heldige med vejret! Da turen snart går hjemad, galt det om at få de sidste prøver i hus.

Zooplankton-gruppen satte hårdt ind og fik optalt alle deres prøver fra deres 5 prøvetagningssøer. Prøven fra Kangersuk var lidt en hård nyser, da de 20 ml vand fra søen viste sig at indeholde 39.000 nauplii og mindst 10.000 copepoditter! Det skal siges, at man ikke tæller alle individer, men laver en ”sub-sampling” på et lille volumen og udregner den samlede prøve derfra.

To fra Kilde-gruppen fik mulighed for at tage med på en tur med Arktisk Stations båd, Porsild, og fik en flot og gyngende tur på havet, hvor de så finhval. Casper hjalp Kirsten med at opsætte data-loggere til lysintensistet og temperatur i Morænesøen. Data-loggerne skal ligge i søen helt til næste sommer, så vi følge med i, hvornår isen lægger sig og går i løbet af det næste år.

Mos- og Sø-gruppen udnyttede lidt luft i programmet til at bestige Lyngmarksfjeldet. Turen til toppen bød på stejle stigninger og betagende udsigter hele vejen, og da de nåede toppen ca. 700 m over havet, belønnedes de med det vildeste panorama-view.

På sådan et feltkursus finder man ud af, at alt det, som man troede kunne lade sig gøre hjemmefra, ikke altid kan lade sig gøre i felten. Man må ændre i planer, tage andre prøver, gå til andre steder af andre stier og i et hele taget være beredt på en plan A, B, C, D og E. Det har tvunget alle grupperne til at ændre lidt i projektet, tænke kreativt og rette til undervejs. Det har været meget lærerigt, og vi kommer alle hjem med projekter, som er anderledes end dem, vi havde udtænkt hjemmefra! Her når man ser tilbage, så er det netop, når man møder udfordringer, at man revurderer og tænker kritisk. Der hvor man sætter spørgsmålstegn ved projektet, repeterer teorien og forhåbentlig lagrer erfaringen til næste gang.

Vi afsluttede dagen med stil og 3 retters middag. Stykker af dampet hellefisk i fiskesuppe toppet med strandarve plukket lige ud foran stationen. 10 kg snekrabber med alskens tilbehør og til dessert traditionel sønderjysk brøtort og Kirstens hjemmelavede lakrids-is med tilhørende lakridsmarengs og lakridssirup. Et ægte festmåltid, hvor der blev skålet og råbt hurra for hele holdet!

Fredag den 17. juli – De sidste hektiske göremål (Ditte Ethelberg-Findsen)

Den sidste morgen på Arktisk Station startede vanen tro med morgenbadning for badeklubben, der nu er helt oppe på 10 medlemmer. Dagen stod i pakningens tegn, og al det praktiske blev organiseret på det daglige morgenmøde. Udstyr blev demonteret, vasket og pakket, og grupperne fik ordnet de sidst ting til projekterne. Zooplankton-gruppen fandt ortolitter (øresten) i de sidste fisk, som bliver taget med hjem sammen med fiskemaverne til analyse i København. Mospigerne skiftedes til at veje deres ca. 235 manglende årsskud helt indtil afgang, men måtte tage de sidste årsskud med til færdig vejning derhjemme. Sø-gruppen hentede dataloggere fra damme, og Kilde-gruppen tog billeder af dansemyggelarver i stereoluppen.

Med al udstyret pakket, sænkede roen sig over Arktisk Station, hvor de studerende nu udnyttede arbejdspausen til at flade ud i fællesrummet, se på isbjerge og hvaler, gå tur, bade i havet og generel afslapning.

Bådturen fra Qeqertarsuaq til Ilulissat var flot og kold. Tiden gik med at se på hvaler og isbjerge, synge og spille kort. Jo tættere vi kom på Ilulissat, des større og hyppigere var isbjergene, der kunne studeres på helt nært hold.

Efter indlogering på Hotel Hvide Falk med smuk havudsigt tog de studerende ud i byen for at fejre deres sidste aften sammen på en bar. Her blev der drukket dyr grønlandsk moskusokse-øl, snakket med de lokale, danset til og sunget med på sange spillet af et grønlandsk band og festet ”til solen stod op”.

På vej hjem til hotellet blev de studerende mødt af et hav fyldt med isbjerge så langt øjet rakte, og måtte erkende, at man efter knap to uger i den grønlandske natur stadig må stoppe op og fascineres.

Lørdag den 18. juli – Og så er det slut – næsten (Kirsten S. Christoffersen)

I dag rejser nogle af os til København, mens andre bliver en stund endnu i Grønland for at udforske lidt mere af landet og naturen. Flybilletten er jo betalt, og udstyret med telt og Trangia kan man leve rimeligt billigt. De der bliver (Mos- og Kilde-gruppen) har planlagt ture og aktiviteter omkring Ilulissat og senere ved Kangerlussuaq. Os, der rejser sydover, har en fin tur omend med lidt forsinkelse.

Projects of 2015

Species composition of Chironomidae in homothermic and heterothermic streams on Disko Island, Greenland

Whole system metabolism in an arctic lake and a small pond

Drepanocladus trifarius - an appropriate indicator for altered climate?

Zooplankton in arctic lakes – the influence of Arctic char (*Salvelinus alpinus*)

Foto: Henriette Hansen