Holocene environmental history of Northeast Svalbard

2016 - 2019

Final Report

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Front page photo:

View to the east looking up Ringhorndalen. Threshold lake Sånnjavatnet in the foreground with outlet glaciers Ringhorndalenbreen and Royal Societybreen in the background.

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SVALBARD ENVIRONMENTAL PROTECTION FUND

Holocene environmental history of Northeastern Svalbard
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Holocene environmental history of northeast Svalbard

Abstract

Our understanding of the Holocene glacier, sea level and environmental history on Svalbard continues to develop as we target key unknowns with newly developed research techniques and multidisciplinary approaches. Through the last three years, valuable data have been collected under the project *Holocene environmental history of northeast Svalbard* (16/35) which results in direct components of one masters, one post-doctoral and four doctoral projects. The Ringhorndalen field campaign was greatly successful at collecting a range of key data that are being used to better understand environmental changes through the Holocene time period on Svalbard. Data analysis has connected the fields of glacial geology, botany, geochemistry and microbiology to enhance our understanding of landscape and environmental development in an understudied region of Svalbard. A substantial amount of work has been invested in analysis and findings will soon be ready to publish and continue to be disseminated. These types of projects that strive to better understand climate change and its effects on the natural environment are important on Svalbard and valuable for all. Natural beauty and landscape aesthetics are accentuated by our enhanced understanding of processes, formation and development.

Foreword

The project grant *Holocene environmental history of northeast Svalbard* (16/35) from the Svalbard Environmental Protection Fund has financially supported three field campaigns on Svalbard during summers 2016-2018. The funding primarily supported an eight-day field campaign to Ringhordalen in August 2016 which is the primary focus of this report. Remaining finances assisted in the cost of provisions and transportation for the following two field campaigns.

Table 1. Funding distribution of grant 16/35 for specific field campaigns.

Field Campaign	Year	Support	16/35 support	Primary funder (project #)
Ringhorndalen	2016	Primary	130 K NOK	Svalbard Miljøvernfond (16/35)
Isfjorden	2017	Partial	6 K NOK	Arctic Field Grant SSF (10122)
Vassfarbukta	2018	Partial	30 K NOK	Svalbard Miljøvernfond (17/114)

(Additional financial support for the later field campaign was granted to Schomacker, Farnsworth and Brynjólfsson by Arctic Research and Studies)

Introduction

This project addresses the Holocene glacier, sea level and environmental history in an understudied region of Svalbard where relatively little is known about the changes that have taken place following deglaciation. In this project we have collected and analyzed lacustrine sediments from threshold lakes which can provide detailed glacial chronologies as well as potential high resolution temperature and hydroclimate reconstructions (Alsos et al. 2017; Balascio et al. 2018; van der Bilt et al. 2018). Additionally, regions will be mapped, studied and surveyed for Holocene driftage (i.e. shells, driftwood and whalebones). Once dated, this can be used to reconstruct Holocene sea level curves which provide projections of the rates and timing of local sea level regression as well as relative sea ice distribution (Häggblom, 1982; Hole & Macias-Fauria 2017). These data are critical for getting a holistic understanding of the Holocene on Svalbard.

Objectives- The primary objectives of the project *Holocene environmental history of northeast Svalbard* were to better develop our understanding of glacier and climate history from the Svalbard Holocene by targeting under-studied regions of the archipelago. Initial investigations were developed in a doctoral thesis by Farnsworth (2018), while a complimentary, doctoral project will focus on data collected in Wijdefjorden during summer field campaigns 2016-2018 (Allaart 2017-2021). Key goals for the Ringhorndalen campaign were to i) create detail maps of the Ringhorndalen tributary valley as a means of characterizing its landscape development through the Holocene. ii) Collect and analyze lacustrine sediment cores collected from mapped catchments of threshold lakes to enhance our understanding of glacier and climate history in the region. iii) Subsample a population of driftwood deposited along the modern coast of Wijdefjorden to use in validating driftwood occurrence as a proxy for sea ice conditions.

Setting- The primary study site is located in northeastern Svalbard along the central eastern region of Wijdefjorden, a 120 km long north-south oriented fjord-system. Ringhorndalen is one of the many east-west oriented tributary-valleys to Wijdefjorden, roughly 8 km long and between 1 – 4.5 km wide (Fig. 1). The two outlet glaciers Ringhorndalenbreen and Royal Societybreen flow from the southeastern margin of the plateau icecap Åsgardfonna (>1000 m a.s.l.) and terminate at the head of Ringhorndalen around 115 m a.s.l.

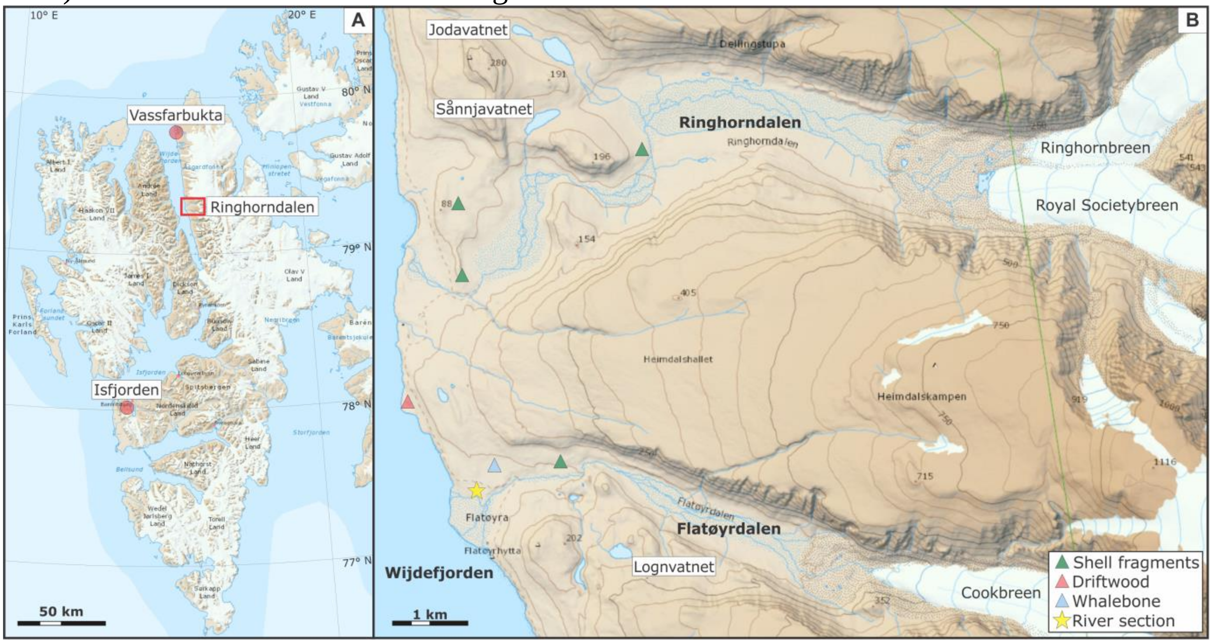

Figure 1. Map of study sites. A) Field campaign locations indicated on overview map of Spitsbergen. B) Detailed topographic map of Ringhorndalen and Flatøyrdalen located along central eastern Wijdefjorden. Sample sites and key threshold lakes identified. Maps modified from *Toposvalbard* from the Norwegian Polar Institute (https://toposvalbard.npolar.no/).

A braided river system from the two outlet glaciers drains through bedrock, glacial sediments and raised marine deposits located in Ringhorndalen before running out to Wijdefjorden (Fig. 1).Several lake basins are located in the western extent of Ringhorndalen and Flatøyrdalen to the south (Fig. 1). Lakes sediments were collected from three threshold lake basins ranging in elevation from 115 – 175 m a.s.l. (Fig. 1).

Methods

Field Investigations

Lake sediments were collected with a lightweight piston-coring system with 60 mm diameter coring tubes that enable us to obtain overlapping 200 cm long sediment cores at water depth up to 50 m. Short gravity cores (up to 100 cm) with undisturbed mud-water interfaces were also collected from each lake. The coring was conducted out of a small inflatable non-motorized raft (Fig. 2). The coring was performed through a hose in the floor of the raft, which was anchored in a stable position on the lake surface. A Hondex PS-7 Transducer LCD Digital Sounder was used for depth sounding of the lake, and cores were obtained from the central, deepest part of the lake basins.

In the field the landscape was surveyed by foot, with GPS, camera and compass. Particular notice was given to raised-marine sediments, natural stratigraphic sections, the occurrence of shells, whalebones and glacial fingerprinting (Fig. 2). Field notes, photographs, GPS tracks and waypoints are uploaded compared with aerial imagery in a digitized format within the ArcGIS mapping program.

Driftwood was sub-sampled along the modern coastline with a bow-hand saws and a small rotary saw (Fig. 1). Cross-sections of trunks were subsampled roughly 3-4 cm in width in order to see growth rings of the trees. Only logs with root systems, appearing natural and un-worked were sub-sampled (Fig. 2).

Laboratory Analysis

Lake sediment cores were split open, logged and analyzed in the sediment lab and ITRAX core facility at the U. of Copenhagen. Sub-samples for ancient DNA analysis of the lake sediment cores were taken in a clean lab directly after splitting the cores and prior to any other analysis to avoid contamination. The lithology and stratigraphy of the cores were visually inspected and logged after sub-sampling for aDNA. ITRAX scanning was run on each of the sediment cores to record visual and radiographic imagery, and elemental profiles from X-ray fluorescence (XRF; Kylander et al., 2011). Regular intervals of the lake sediments were also sampled for leaf wax hydrogen isotope analysis to improve our understanding of palaeo-hydroclimate (Sachse et al. 2012).

To establish the chronology of the sediment cores, we sampled macrofossils retrieved from residues of 0.5 mm sieving, identified and isolated using a binocular microscope. Radiocarbon ages were obtained through accelerator mass spectrometry (AMS) at the Ångström Laboratory, Uppsala University and Lund University Radiocarbon Dating Laboratory, Sweden. All (marine) radiocarbon ages have been (corrected), calibrated and are presented in calibrated years before present (cal. yr BP) using Calib 7.1.

Tree rings from driftwood samples were analyzed and chronologies developed at the University of Oxford. Additionally, to enhance driftwood provenance and strengthen sea ice reconstructions, Strontium radiogenic isotopic analysis of driftwood tissue is being conducted (Reynolds et al. 2005; Hole & Macias-Fauria 2017).

Preliminary results

During the 2016 field campaign in Ringhorndalen, sediment cores were collected from three threshold lakes, Sannjavatnet, Jodavatnet and Lognvatnet (Table 2). Lake sediment cores were split, and logged for each basin. The Jodavatnet lake sediment record has been selected as the key core for ancient DNA and leaf wax hydrogen isotope analysis.

Figure 2. Photo mosaic of Ringhorndalen field campaign, presenting an overview of the mapped landscape and sub-samples of lake sediments, whalebone, shells and driftwood (images by Farnsworth and Macias-Fauria).

Table 2. Threshold lakes cored during the 2016 Ringhorndalen field campaign.

Lake	Elv.	Depth	Chronology	Log
Sånnjavatnet	115 m	16 m	X	X
Jodavatnet	137 m	6.4 m	X	X
Lognvatnet	175 m	9.5 m	X	X

A chronology was developed for the composite sediment record with 12 radiocarbon ages from terrestrial and aquatic macrofossils (Table 3). We present high resolution imagery of the lake cores alongside the lithostratigraphic log of the composite record (Figure 3). Detailed lithostratigraphic logging allows for the division of the sediment record into five main units (Fig. 3). Lithological descriptions, composite depth intervals and general interpretation of depositional environment are presented for each unit (Table 3).

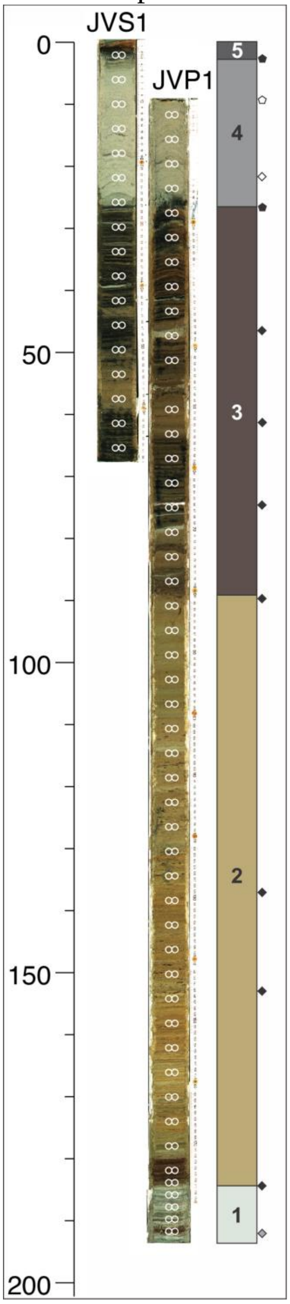

Figure 3. Detailed imagery of Jodavatnet surface (JVS1) and piston (JVP1) sediment cores with aDNA sampling intervals. Lithostratigraphic log divides composite sediment sequence into Units 1-5. Location of radiocarbon dated macro fossils indicated to the right of the log.

Table 3. Jodavatnet composite sediment description

Unit	Composite depth	Lithological description	Interpretation of depositional environment
1	194-184 cm	Light grey – very light green, clayey silt with interlaminated organic material.	Minerogenic-rich sedimentation driven by inflow of glacial meltwater across the eastern threshold of the Jodavatnet catchment.
2	184-89 cm	Tan brown – light olive grey, silty gyttja with sporadic interlaminated organic material. The bedding transitions from well stratified to crudely stratified from the base of the unit towards the top.	Accumulation of organic material with minimal minerogenic input. The transition from Unit 1 to 2 indicates an abrupt termination of glacial meltwater inflow.
3	89-27 cm	Dark tan – very dark brown silty gyttja with organic-rich lamina interrupted by occasional light tan silt beds.	Accumulation of organic material interrupted by increasing episodic variability and minerogenic input.
4	27-3 cm	Light grey – light tan weakly laminated silty fine sand with occasional laminae of brown organic material.	Minerogenic-rich sedimentation with minimal biogenic accumulation. The sediment source is interpreted as nival or aeolian or a combination of both.
5	3-0 cm	Dark grey – very dark brown laminated silty gyttja, with a transitional lower boundary.	Accumulation of organic material.

Jodavatnet lacustrine sediment record spans from present back to over 12,000 years before present (Table 3). Unit 1 at the base of the sequence is a minerogenic-rich clayey silt unit interpreted to result from an extended Ringhorn-Royal Societybreen glacier draining into the eastern margin of the palaeo-jodavatnet.

Table 4. Radiocarbon dates from Jodavatnet sediment surface and piston cores.

Core	Depth (cm)	Sample ID	Sample material	^{14}C age (yr BP)	Median age (cal. yr BP)	Age range 2σ (cal. yr BP)
Surface	3	Ua-55367	Terrestrial MF	112 ± 21	112	21 − 267
Surface	9.5	Ua-55368	Terrestrial MF	519 ± 29	534	508 − 624
Piston	12.5	Ua-55361	Terrestrial MF	279 ± 24	369	286 − 431
Surface	27	Ua-55369	Terrestrial MF	196 ± 21	175	145 − 294
Piston	37-38	Ua-55362	Terrestrial MF	767 ± 26	693	671 – 729
Piston	52-53	Ua-55363	Terrestrial MF	1977 ± 25	1926	1879 − 1988
Piston	66	LuS-14000	Aquatic bryophyte	3010 ± 40	3200	3072 – 3341
Piston	81	LuS-14001	Aquatic bryophyte	3945 ± 40	4397	4250 – 4518
Piston	129	Ua-55364	Terrestrial MF	4968 ± 34	5692	5605 − 5853
Piston	145	LuS-14002	Aquatic bryophyte	8335 ± 45	9358	9147 – 9472
Piston	177-178	Ua-55365	Terrestrial MF	9512 ± 40	10813	10660 − 11077
Piston	185-186	Ua-55366	Aquatic bryophyet	10426± 42	12303	12100 − 12525

A stratigraphic section located north of the river at the mouth of Flatøyrdalen was investigated while mapping (Fig. 1). A lithostratigraphic log has been constructed displaying the depositional history at that site (Fig. 4). Three radiocarbon dates constrain deglaciation and Early Holocene glacier history. The location appears to have become ice free sometime after 11.2 cal. ka BP. The section generally displays a coarsening upwards sequence. These regressional sequences are commonly found around Svalbard and are suggestive of shallowing ocean conditions during rapid post-glacial uplift as the land rebounds from the release of ice loading (Farnsworth et al. 2017; Alexandersson et al. 2018). Around 10.4 ka BP the regional sequence is interrupted by pulses of coarse gravels cobbles and boulders. This large change in depositional environment is believed to be related to Early Holocene glacier fluctuations within the tributary valleys. Furthermore, the identification of the thermophile mollusc, *Mytiuls edulis* (blue shell) suggests ocean conditions in Wijdefjorden were warmer than present during this time interval. This age was shared with the authors of the recent review on thermophile molluscs from Svalbard and has been published in their database (Mangerud & Svendsen 2017).

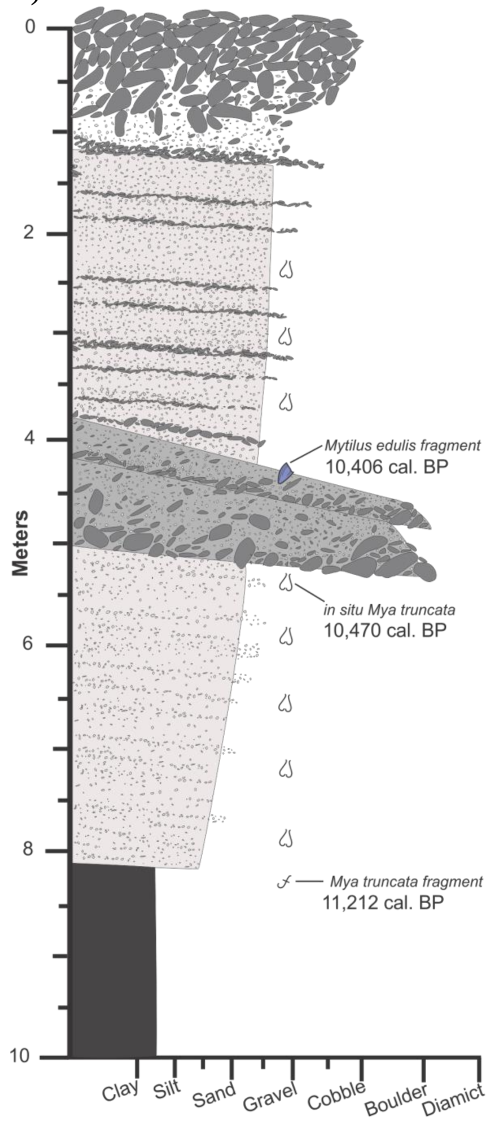

Figure. 4. Lithostratigraphic log of a river section at the mouth of the Flatøyrdalen valley.

The geomorphological fingerprints of the relative sea level history and deposition of marine organisms (shells and whalebones) is complicated in the Ringhorndalen region by re-advancing glacier systems during the Early Holocene both from the Wijdefjorden fjord-system and the tributary glaciers. The post-glacial marine limit is believed to be just below 80 m a.s.l. however the exact age is unknown. Eight early Holocene radiocarbon dates from *in situ*, reworked shells and whalebones found at elevations between 12 m a.s.l. and up to 73 m a.s.l. tell a complex story of glacier dynamics during the Early Holocene deglaciation (Table. 5).

Table 5. Radiocarbon of field samples from Ringhorndalen and Flatøyrdalen

Sample material	Elv. (m)	Sample ID	Latitude & Longitude	Sample & median	^{14}C age (yr BP)	Median age (cal. yr BP)	Age range 2σ (cal. yr BP)
Shell fragment	42 m	LuS-10803	79.3082°N 15.9817°E	Sands & gravels	9480 ± 50	10253	10140 − 10417
Shell fragment	73 m	LuS-10804	79.3174°N 15.9775°E	Sands & gravels	10460 ± 55	11476	11229 − 11772
Whale-bone	39 m	LuS-10805	79.2863°N 16.0082°E	Raised beach	9805 ± 55	10639	10478 – 10839
Shell fragment	67 m	LuS-10806	79.2872°N 16.0436°E	Poorly sorted diamict	10185 ± 55	11118	10931 − 11243
Shell fragment	12 m	LuS-10807	*79.2833*°N 15.9938°E	*Mya truncate* Clay-silt, section	10290 ± 55	11212	11064 – 11393
Shell fragment	17 m	LuS-10808	*79.2833*°N 15.9938°E	*Mytilus edulis* gravel section	9615 ± 50	10406	10240 − 10553
Shell fragment	70 m	LuS-10809	79.3231°N 16.0977°E	Poorly sorted diamict	9390 ± 50	10159	9933 – 10271
Paired shell	16	Ua-56090	*79.2833*°N 15.9938°E	*Mya truncate* sand section	9663 ± 40	10470	10288 – 10600

Summary

The Ringhorndalen field campaign was greatly successful at collecting a range of key data that are being used to better understand environmental changes through the Holocene time period on Svalbard. A significant amount of work has been invested in the data analysis, findings will soon be ready to publish and disseminate.

The development of the Ringhorndalen landscape, glacier and sea level history will be further detailed in a manuscript presenting terrestrial and marine maps from inner Wijdefjorden (Farnsworth et al. in prep.). The manuscript will present a new post-glacial relative sea level curve and enhance our understanding of the dynamic deglaciation from the fjord and tributary valleys draining outlet glaciers from the high mountain plateau ice-caps characteristic of northeastern Svalbard. This manuscript will be a part of a doctoral project by Lis Allaart at UiT, The Arctic University of Norway.

The lake sediment records collected during the Ringhorndalen field campaign are initially being written up into three individual manuscripts. The first manuscript was a master’s project (Linn Voldstad, MNBU) where ancient environmental DNA (sedaDNA) collected from the Jodavatnet lake sediment cores outlines the vegetation history in outer Ringhorndalen over the last 12,000 years. Results suggest directly after the lake experienced glacial inflow, there was a diverse flora within the catchment and thermophile (warm-loving) species existed during the early Holocene (Voldstad et al. in prep.). The second manuscript from the lake record is part of a doctoral thesis (Sofia Kjellman, UiT) and will present leaf wax hydrogen isotope data from several Wijdefjorden lakes including Jodavatnet. The leaf wax record will detail the palaeo-hydroclimate for the region and potentially suggest if Early Holocene warmth, indicated by the presence of thermophile plants and shells, coincided with relatively wet conditions (Kjellman et al. in prep.). The third manuscript using the Jodavatnet lake record will compare Holocene methane production within Arctic lakes to other Arctic lake basins (Rouillard et al. in prep.). This study is part of a post-doctoral project from

University of Copenhagen, where Alexandra Rouillard is focusing on ancient microbes and methane dynamics in the Arctic.

The final manuscript focuses on the occurrence and provenance of driftwood on modern Svalbard coasts. The data set from the coast of Ringhorndalen will be compared to a data series from northern Wijdefjorden (Vassfarbukta) and the Seven Islands. Strontium isotopic analysis of driftwood subsamples from Svalbard are being used as a case study and method validation to improve our understanding of palaeo-sea ice conditions and Arctic ocean currents (Hole et al. in prep). This work is a key component of a doctoral project by Georgia Hole at the University of Oxford.

Planned production

While initial results have been presented at different international conferences (Rouillard et al. 2018; Voldstad et al. 2018), more recent abstracts have been accepted for additional presentation at other international conferences this summer (Farnsworth et al. 2019, Kjellman et al. 2019). There are currently five manuscripts in preparation all in various forms of progress. The goal is to have these submitted by the end of 2019.

Manuscripts in progress

Farnsworth, W.R., Ingólfsson, Ó., Forwick, M., Brynjolfsson, S., Allaart, L., Schomacker, A. (*in prep.*): Deglaciation and Early Holocene glacial fluctuations of inner Wijdefjorden, Svalbard (planned submission to The Holocene; Spring 2019).

Voldstad, L.M., Farnsworth, W.R., Schomacker, A. Håkansson, L., Rouillard, A., Kjellman, S.E., Alsos, I.G., Eidesen, P.B. (*in prep.*): The Holocene history of an isolated, high Arctic hot spot of plant diversity. (planned submission to Quaternary Science Reviews; Spring, 2019).

Kjellman, S.E., Schomacker, A., Thomas, E.K., Håkansson, L., Duboscq, S.M., Farnsworth, W.R., Cowling, O. (*in prep.*): Leaf wax hydrogen isotope reconstruction of Holocene hydroclimate in High Arctic Svalbard. (planned submission TBD; Summer 2019).

Rouillard A., *et al.* (*in prep*): Past methane dynamics in Arctic lakes affected by climate change retrieved through genetic profiles of ancient microbes. (planned submission TBD).

Hole, G., *et al.* (*in prep.*): Driftwood as a sea ice proxy: Validation and case study from Svalbard. (planned submission TBD).

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