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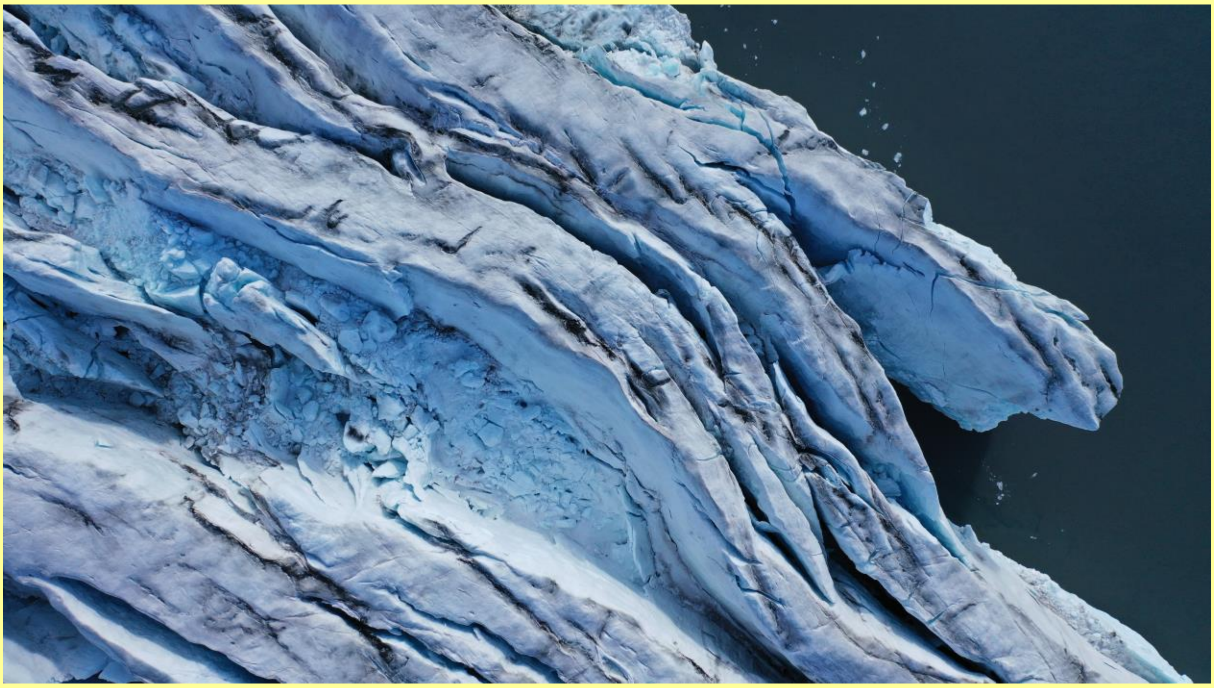
455 (P-5)

BOOK OF ABSTRACTS

40th International Polar Symposium – Arctic and Antarctic at the Tipping Point, 4–7 November 2025, Puławy, Poland

Editors:
Mirosław Rurek, Krystyna Kozioł, Mateusz Moskalik, Marzena Czarnecka



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40th International Polar Symposium – Arctic and Antarctic at the Tipping Point, 4–7 November 2025, Puławy, Poland

Preface

Dear Readers, Dear Polar Researchers and People Connected to the Arctic and the Antarctic,

The Polar Symposium is a recurrent conference, typically occurring every two years, dedicated to Arctic and Antarctic topics, with a long tradition dating back to 1972. Since then, these meetings have been an excellent opportunity for integrating the polar community, exchanging experiences, and a discussion between Polish and international polar researchers representing various scientific disciplines. The Polar Symposium is currently co-organised by the Committee of Polar Research, Polish Academy of Sciences, and the Polish Polar Consortium, and until recently it has also been co-organised by the Polar Club of the Polish Geographical Society. Instead, during the 40th International Polar Symposium, a new Polish Polar Club will debut as an independent association, thus continuing the functioning of the Club since 1974.

The 40th jubilee Symposium on 4–7 November 2025, and the following editions, will take place at an exceptional location: the Museum for Polar Research in Puławy, the first Polish museum of polar research, established in 2020. This location enabled the organisation of various supporting outreach events on polar research, such as public lectures, film screenings, art, and science exhibitions. The possibility to organise Symposia at the Museum results from the efforts of the late Dr. Andrzej Piotrowski, aiming at establishing the Museum, and of Dr. hab. Piotr Zagórski, who supported the Museum and the organisation of Symposia at this set location. We are also grateful to the Director of the Museum, Dr. Piotr Kondraciuk, and the Museum Team, for hosting the Polar Symposium and cooperation on organisational matters.

In 2025, the honour of co-organisation of the 40th International Polar Symposium, entitled "Arctic and Antarctic at the tipping point", has been given to the Kazimierz Wielki University in Bydgoszcz, which has been a member of the Polish Polar Consortium since 2024. This honourable occassion aligns with the 30-year jubilee of geography at the University in Bydgoszcz.

During the plenary session on 5 November, we will have the opportunity to listen to four lectures of the invited speakers. During the entire conference, on 5 and 6 November, five special sessions and further 6 thematic sessions will take place. The conference will encompass 87 contributions by speakers representing 19 research units from Poland and 9 international research units. The Symposium will host a total of 62 oral presentations and 25 posters, with topics spanning Earth Sciences, biological sciences, chemical sciences, arts and humanities, social science, and including education and outreach.

We hope that the 40th International Polar Symposium will open the floor for animated discussions, exchange of ideas, and forging new scientific connections. We are pleased to present the „Book of abstracts" of the 40th International Polar Symposium to the Readers.

On behalf of the Organisers,
Krystyna Kozioł and Danuta Szumińska

& The Scientific Committee of the 40th International Polar Symposium:

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40th International Polar Symposium – Arctic and Antarctic at the Tipping Point, 4–7 November 2025, Puławy, Poland

Przedmowa

Szanowni Państwo, Drogie Polarniczki i Polarnicy,

Sympozjum Polarne to cykliczna, odbywająca się typowo co dwa lata konferencja dedykowana tematyce polarnej, o długiej tradycji sięgającej 1972 roku. Spotkania te od lat stwarzają doskonałą sposobność do integracji, wymiany doświadczeń i dyskusji między polskimi i zagranicznymi badaczami rejonów polarnych, reprezentującymi rozmaite dziedziny naukowe. Opiekę nad Sympozjum sprawują obecnie Komitet Badań Polarnych PAN oraz Polskie Konsorcjum Polarne, do niedawna również Klub Polarny PTG. Podczas 40. Sympozjum Polarnego nastąpi debiut na tej konferencji Polskiego Klubu Polarnego jako samodzielnego stowarzyszenia, które jest kontynuacją funkcjonowania Klubu od 1974 r.

40. jubileuszowe Sympozjum w dniach 4–7 listopada 2025 roku, a także kolejne jego edycje, będą odbywały się w wyjątkowym miejscu, w powołanym w 2020 roku Muzeum Badań Polarnych w Puławach, pierwszym w Polsce muzeum polarnictwa. Pozwoliło to na zorganizowanie dodatkowych wydarzeń popularyzujących wiedzę o obszarach polarnych w formie wykładów, pokazów filmów i wystaw popularno-naukowych. Możliwość organizacji Sympozjów w Muzeum wiąże się ze staraniami ś.p. dra Andrzeja Piotrowskiego, zmierzającymi do otwarcia Muzeum, oraz ś.p. dra hab. Piotra Zagórskiego, który wspierał powstanie Muzeum i dążył do stałej organizacji Sympozjów w tej lokalizacji. Jesteśmy wdzięczni panu Dyrektorowi dr. Piotrowi Kondraciukowi i Zespołowi Pracowników Muzeum za podjęcie się funkcji gospodarza miejsca posiedzeń i współpracę organizacyjną.

W roku 2025 zaszczyt organizacji 40. Sympozjum Polarnego zatytułowanego „Arktyka i Antarktyka w krytycznym punkcie zmian” przypadł Uniwersytetowi Kazimierza Wielkiego w Bydgoszczy, który od 2024 r. jest członkiem Polskiego Konsorcjum Polarnego. Ta wyjątkowa rola organizacji towarzyszy obchodom 30-lecia funkcjonowania geografii na Bydgoskiej Uczelni.

Podczas sesji plenarnej w dniu 5 listopada wysłuchamy 4 wykładów zaproszonych gości, a w tym i kolejnym dniu Sympozjum w trakcie 5 sesji specjalnych i 6 sesji tematycznych – 87 wystąpień uczestników reprezentujących 19 jednostek naukowych z Polski i 9 jednostek naukowych z zagranicy. W trakcie Sympozjum zaprezentowane zostaną 62 referaty oraz

25 posterów, obejmujących tematykę z zakresu nauk o Ziemi, nauk biologicznych, nauk chemicznych, nauk humanistycznych i społecznych, a także edukacji i popularyzacji nauki.

Mamy nadzieję, że tegoroczne Sympozjum Polarne pozwoli na ożywioną dyskusję, wymianę myśli i nawiązanie nowych kontaktów naukowych. Z przyjemnością przekazujemy na Państwa ręce „Książkę abstraktów" 40. Sympozjum Polarnego zawierającą streszczenia wystąpień referatowych i posterów.

W imieniu Organizatorów,
Krystyna Kozioł oraz *Danuta Szumińska*

wraz z Komitetem Naukowym 40. Sympozjum Polarnego:

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Plenary Session:
Invited Talks

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Land to Sea Biogeochemical Fluxes in a Changing Arctic: Insights from Svalbard

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Our understanding of cryosphere-biosphere coupling in the polar regions is arguably weakest in the context of glaciers and their influence upon marine ecosystems. Major reasons include the lack of cross-disciplinary interaction and the sometime extreme difficulty faced by those trying to conduct field work where glaciers or glacial runoff meet the sea. This presentation therefore addresses this science gap with new insights into nutrient transport by glacial meltwaters into Svalbard coastal ecosystems. A particular emphasis is placed upon nitrogen, because it is a key, productivity-limiting nutrient and because the nitrogen cycle includes atmospheric, organic and even geogenic inputs to the glacial system that were defined for the first time by fieldwork conducted in Svalbard a quarter of a Century ago (e.g. Hodson et al. 2005; Wynn et al. 2007).

In spite of clear knowledge gaps in our understanding of the origins, magnitude and fate of nutrients transported by glacial runoff into Arctic coastal ecosystems, there have still been some major conceptual advances, such as:

1) It's the productivity-limiting nutrient(s) that matter most, and in Svalbard this means nitrogen and (less so?) silica. Both have received significant attention in recent years (e.g. Duarte et al. 2025; Halbach et al. 2019), although mostly in one location (Kongsfjord) whose representativeness deserves scrutiny.
2) Increasing glacial runoff volumes can dilute the concentrations of nitrogen in the photic zone, and even make photosynthesis more difficult due to high turbidity (e.g. Hopwood et al. 2020). Therefore the "big nutrient flux must count" theory for glacial runoff often seems naïve.
3) Particles responsible for the high turbidity constitute a very large proportion of the labile nutrient flux, especially for adsorbed NH_4 and amorphous Si particles (e.g. Wadham et al. 2016; Hendry et al. 2025).

4) Subglacial runoff from marine terminating glaciers with grounding lines deep beneath the fjord surface exerts a major influence upon nitrogen supply to the photic zone because its buoyant rise also entrains nitrogen-rich bottom waters and sends them towards the photic zone (e.g. Meire et al. 2017; Hoshiba et al. 2024).

Of the above, 4) has been particularly important because it redefined our understanding of how glacial runoff influences nitrogen availability in the photic zone. The intensity and the longevity of the buoyancy-driven circulation process is also intricately linked to climate, and so a lot of research attention is currently directed towards what happens after tidewater glaciers have retreated onto land (e.g. Meire et al. 2023; Santos-Garcia et al. 2022). Such a retreat is expected to result in an estuarine-type circulation process, wherein riverine inputs fail to induce the vertical mixing and therefore struggle to deliver sufficient nutrient supplies to sustain high primary production in the upper water column. However, whilst the retreat of marine-terminating glaciers onto land is an important aspect of projected future change, it is arguably less important in Svalbard than it is in Greenland. This is because several of Svalbard's fjords already underwent this transition during the Holocene in response to isostatic uplift: a process that outpaces rising sea level in West Spitsbergen even today. Others are very close to this transition, and have shallow grounding lines that are unlikely to see the development of strong buoyancy-driven upwellings. There is also the fact that not all Svalbard glaciers enter the sea via fjords, as is indeed the case near other Arctic archipelagos.

Multi-year, multi-site analysis of nitrogen concentrations, fluxes and stable isotope composition in Svalbard runoff reveal two critically important processes require consideration before the role of glacial runoff in the provision of productivity-limiting nitrate is to be fully understood: i) atmospheric nitrate release by snowmelt in early summer, and ii) microbial nitrate production by nitrification from mid-summer onwards. As a consequence of the latter, the nitrate content of glacial runoff is dominated by microbial production almost everywhere once the winter snow resource has been released by snowmelt (Wynn et al. 2007; Ansari et al. 2013). However, the impact of nitrification is far from spatially uniform, and there exist very significant "hotspots" in the vicinity of large bird colonies and in catchments underlain by shale-rich bedrock. The former is more localized, well-known, and effectively involves the recycling of marine nitrogen via guano (e.g. Finne et al. 2024; Zmudczyńska-Skarbek and Balazy 2017). However, the latter has received almost no attention to date (Dixon 2019; Polukhin et al. 2021), yet it occurs in landscapes that cover more than one third of the archipelago's land area. In extreme cases, new data show that the nitrate yields of shale-influenced glacier basins are enhanced by > 20 times those that would be expected from atmospheric nitrate alone. The erosion of shale by glacial and periglacial processes across much of Central and Eastern Svalbard therefore produces flowpaths highly conducive to the transformation of geological ammonium to nitrate during the melt season. This transformation is highly likely to respond to climate-driven changes in the thaw depth, rainfall infiltration and meltwater percolation in future.

Going forwards, we need to be able to predict atmospheric and microbial nitrate delivery to runoff if we want to forecast the future state of Svalbard fjord ecosystems. Atmospheric nitrate release via snowmelt demonstrates clear sensitivity to climate change, with earlier, smaller fluxes likely across much of the archipelago due to a shorter accumulation season and the earlier onset of melt (Osuch et al. 2022). However, it is also notable that snow cover is undergoing a recent increase in Heer Land and parts of Torell land, most likely due to enhanced moisture supply from local sources as a consequence of sea ice failure along the East coast. The atmospheric nitrate resource is therefore likely to be growing here as a consequence, although more needs to be done to understand the regional variations in the nitrate chemistry of snowcover before this can be predicted with any certainty. With respect to nitrate supply from nitrification, there exist greater challenges due to its requirement for ground thaw to proceed and for shallow groundwater and subglacial flow paths to open before it becomes influential (e.g. Wynn et al. 2007; Ansari et al. 2013). However, nitrification is important because it has the capacity to extend the duration of primary production after the winter nitrate and early summer snowmelt resources have been depleted. As a consequence, nitrification can compensate for the loss of supply via nitrate-rich bottom waters that occurs after the retreat of tidewater glaciers onto land. An understanding of the supply of reduced nitrogen that is required to sustain the process is also required, which will depend upon both extrinsic factors linked to climate and intrinsic factors linked to hydrological evolution of subglacial and proglacial drainage systems, permafrost change and soil development. Of particular importance is the redox evolution of high throughput shallow groundwaters in glacial and periglacial sediments. Will they shift toward more reducing conditions and thus favour nitrate removal via denitrification, or will they be conducive to nitrification by remaining oxic? At the time of writing, the overwhelming evidence is that the major rivers entering fjords largely show the latter and are thus predominantly sustained by flowpaths conducive to nitrification. By contrast denitrification in Svalbard seems most important in the active layer wetlands of lowland permafrost environments with low water yields and thus minimal influence upon fjord biogeochemistry. As a consequence, it is not surprising that a positive correlation between runoff and indices of primary production (Chlorophyll a) in Svalbard fjords and coastal waters has been found, even in places where deep subglacial inflows from marine-terminating glaciers are absent (Dunse et al. 2022).

In conclusion, while we can easily predict meltwater production in response to seasonal snowpack and glacier ablation, we still have a long way to go before we can predict the nutrient composition of this meltwater as it enters the sea. This is not so much due to a lack of empirical data resources but instead a lack of appropriate models that account for non-conservative nutrient behaviour following the onset of summer meltwater production. Recent focus upon marine nutrient resources (via the buoyancy-driven entrainment of bottom waters) has been important, but means that the importance of riverine inputs has been overlooked, which is not helpful in the case of nitrogen.

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What's Happening in Antarctica? A Greening Story

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Abstract

Antarctica is the most extreme continent for life on Earth, and it is also one of the regions most threatened by climate change. Areas like maritime Antarctica and the Antarctic Peninsula have experienced significant temperature increases, with an average rise of 0.1 °C per decade over the past 50 years. Future predictions are equally concerning, with temperatures expected to rise by 0.5–1.5 °C over the next two decades (Steig et al. 2009; Turner et al. 2016;

Jones et al. 2019; Bozkurt et al. 2021; González-Herrero et al. 2022). These temperature increases could also significantly alter water and nutrient cycles in Antarctic soils, ultimately affecting nutrient availability for plants. Moreover, it is crucial to consider that in Antarctica, just as in the rest of the world, the atmospheric CO_2 (the essential carbon source for photosynthesis and a major greenhouse gas leading global warming), has risen dramatically since the Industrial Revolution, from 260 to 410 ppm today (Nunes 2023). Together, the changes in these abiotic factors are profoundly shaping the lives of terrestrial autotrophic organisms in Antarctica.

Interestingly, Antarctica holds another unique biological record: it is the continent with the lowest number of native vascular plant species—just two—in an environment primarily dominated by mosses and lichens (Ramírez et al. 2024; Colesie et al. 2023). However, recent studies have described the expansion of these angiosperms over the last few decades, especially the grass *Deschampsia antarctica* (Cannone et al. 2016, 2022). Rising temperatures and more frequent heat waves predict changes in the ecological balance, facilitating the proliferation of vascularized species that previously struggled to establish themselves under these conditions (Carrasco et al. 2021). This indicates that plant communities may undergo a significant transformation, influenced by global climate change (González-Herrero et al. 2022). Species expansion, and the concept of Antarctica "greening", is a complex process that integrates both abiotic factors and the species' ecological competence, and currently becoming an important scientific hotspot to technically assess accurately these changes at a regional scale (Roland et al. 2024; Walshaw et al. 2024, Colesie et al. 2025; Amaral et al. 2025). In any case, for autotrophic organisms in such a harsh and extreme environment as Antarctica, any expansion must be driven by increased net carbon gain throughout the year. In other words, favorable weather should enhance the physiological and photochemical drivers of photosynthesis, leading to higher carbon assimilation rates (Sáez et al. 2018a,b; Clemente-Moreno et al. 2020a,b; Gago et al. 2025; Lee et al. 2013).

However, these theoretically beneficial conditions do not mean the Antarctic region is close to becoming a paradise for plant life. Even with these favorable changes, the still harsh conditions imply that ecological success relies not only on improved growth and photo-synthetic rates, but also on enhanced stress tolerance mechanisms. These are crucial for plants to successfully cope with the challenging Antarctica growing season characterized by extremely variable temperature and light conditions, strong winds, freezing events and accompanied by reduced water and nutrient availability in the soil (Gago et al. 2023, 2025; Lee et al. 2013; Min et al. 2024, 2025; Ricco et al. 2025; Sanhueza et al. 2022; Sáez et al. 2024; Vallejos et al. 2025; Basile Dazzi et al. 2025). Therefore, could the improved carbon gains and nutrient acquisition also be key factors in the success of vascular species by enabling them to divert these increased resources toward stress tolerance, rather than solely toward growth?

Here, in this work we will review the main molecular ecophysiological factors that could be crucial for the expansion of vascular plants in Antarctica, specially focused on *Deschampsia antarctica*, as a model species, to promote the discussion about the future climatic change scenarios that the Antarctic continent is facing.

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Topographic and Atmospheric Controls on High-latitude Dust Deposition – An Example from James Ross Island, Antarctica

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1. INTRODUCTION

The Antarctic Peninsula (AP) is one of the well-known regions with high climate variability, recent atmospheric warming and related consequences to the cryosphere (Davies et al. 2014). The largest annual and winter air temperatures increase of 0.46 °C and 0.89 °C/decade was reported along the coast of AP (Turner et al. 2020). Changes in summer air temperature largely contribute to major part of the interannual variability of all cryospheric components, i.e. glacier mass balance, permafrost temperature or active layer thickness (Kaplan Pastíriková et al. 2023; Engel et al. 2024).

Historical observations suggest an increasing intensity of westerlies and their poleward shift since 1950s (Spence et al. 2014). The climatic forcing will cause a massive retreat of glaciers resulting in expansion of ice-free areas, especially in the AP region (Lee et al. 2017). The bare land left by retreating glaciers will be exposed to external agents shaping the landscape such as fluvial or aeolian processes. With the massive glacier mass loss recorded within the AP region (Cook et al. 2005), the fluvial processes were dominant. This is however likely to change when the glacier peak water is reached in the catchments affected by important glacier melt and the runoff declines (Huss and Hock 2018). Such drying of the landscape may consequently mean that the aeolian processes will become the leading factor shaping the deglaciated landscapes.

2. ARID ANTARCTIC LANDSCAPES DEVELOPMENT – JAMES ROSS ISLAND EXAMPLE

Despite the general observed trend of greening around the Antarctic Peninsula (AP) region (Roland et al. 2024), James Ross Island does not completely follow the trend. The greening i.e.

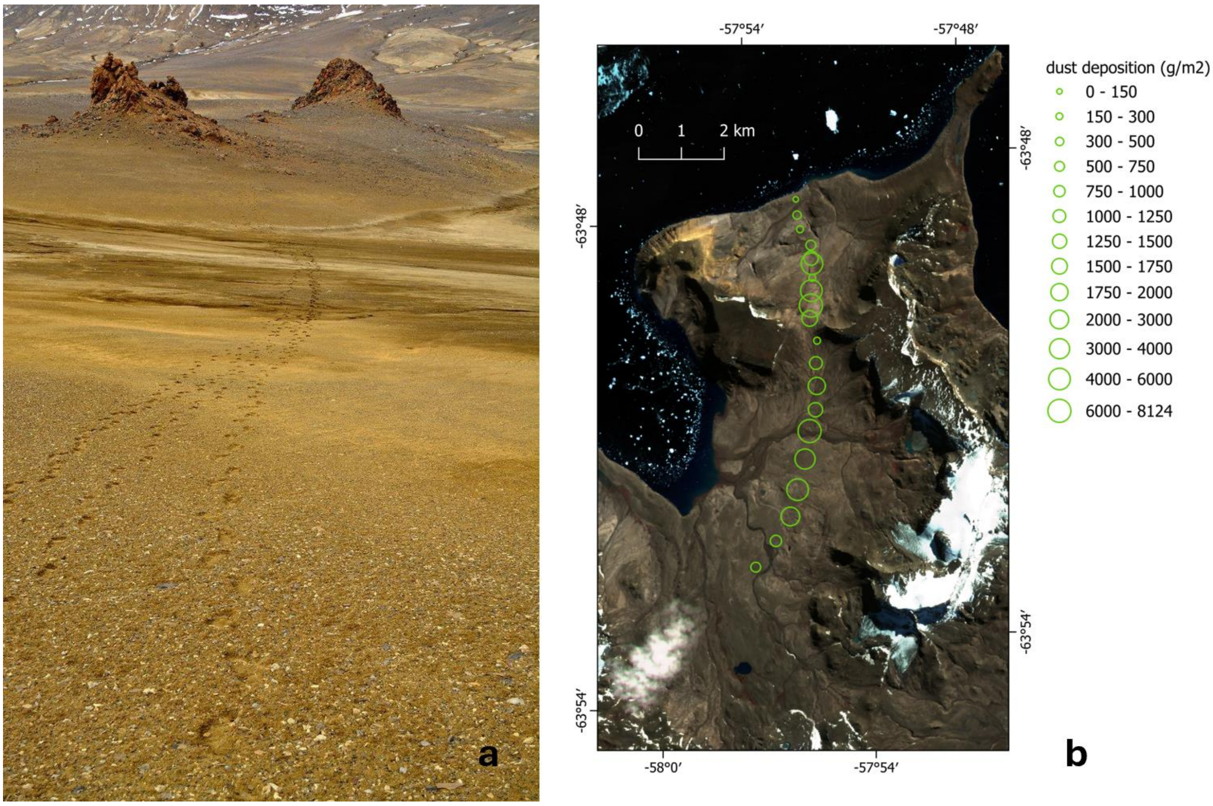

Fig. 1: (a) Dust deposition on the wet surface in the braidplain; (b) dust deposition pattern during the antarctic summer 2017/2018.

spreading of moss vegetation is observed in the western AP region influenced by increase of precipitation (Vignon et al. 2021) likely connected to increased intensity and frequency of atmospheric rivers (Maclennan et al. 2025). On the contrary, James Ross Island, located in the precipitation shadow of the AP mountain range, exhibits equally dramatic warming, but no trend in precipitation at all. This leads to prolonged snow free periods during summer, when the only source of freshwater is glacier/permafrost melt (Nedělčev et al. 2025). Recent warming is also reflected in persistent melt of local glaciers (Engel et al. 2023). The prolonged periods of snow free surface exposure during the summer resulted in increased likelihood of dust emissions and dust transport events as the surface dries out, supporting the uplift of mineral particles (Kavan et al. 2018), recorded also on the glacier surface (Kavan et al. 2020). The enhanced aeolian activity is also visible in the relief, where landforms typical for arid desert-like landscape can be found (Fig. 1a).

Transport of material by wind seems to be negligible on the first sight. However, our long-term measurements in passive aeolian samplers show that the amount of material transported by wind is approximately equal to fluvial transport in local streams. Moreover, based on the elemental composition analyses of fluvial and aeolian samples around the Bohemian Stream catchment, we hypothesize that aeolian material is by far the most important source of material further transported in the stream (Kavan et al. 2017; Kavan 2022; Stringer et al. 2024). Results from the network of passive aeolian samplers clearly indicated the areas where dust deposition was highest – the leeward sides of mountain ridges. Contrastingly, we recognized the river valleys as significant dust deposition centres with only minimum dust deposition on the leeward side of the streams (Fig. 1b).

3. FUTURE PERSPECTIVES

The continuous warming will likely result in significant differentiation between the western (maritime) and eastern (more continental) parts of the AP region. Prolonged snow-free periods will likely cause important surface drying and consequent intensification of the aeolian processes. One can assume that with the retreat and disappearance of local glaciers in the coming decades this process will become even more important.

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Arctic Beach Dynamics under a Changing Climate

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1. INTRODUCTION

Elevated water levels at the shore, that result from a combination of sea level rise, tides, storm surges and waves, cause coastal erosion, wave overtopping and flooding, threatening communities and infrastructure (Woodworth et al. 2019). More frequent, longer and more severe storm events observed in the North Atlantic sector of the Arctic (Feser et al. 2015; Wojtysiak et al. 2018) bring more energetic waves to beaches. Decreasing extent and duration of the sea ice cover increases potential fetch, the distance over which wave-generating wind blows, which leads to larger (higher and longer) waves (Overeem et al. 2011). Arctic-wide sea ice extent has been decreasing by 12.8 ± 2.3% per decade (Meredith et al. 2019), while at the shore, the number of ice-free days per year doubled between 1979 and 2012 (Barnhart et al. 2014). Coasts that were protected from waves by ice are becoming exposed perennially or over longer time. Modelling suggests that in future sea ice will continue to decrease while the storminess will further increase (Forbes 2011). Better understanding of the role of sea ice conditions and offshore wave transformations on wave energy delivery to the Arctic shores is needed to predict coastal hazards under changing climate.

2. SEA ICE, WIND WAVES, AND COASTAL EROSION IN HORNSUND, SVALBARD

Analysis of near-daily binary maps of ice/open water at 50 m resolution in Hornsund fjord, Svalbard over 2014–2023 showed a great inter-annual variability in ice timing, extent and coverage with no clear long-term trend. The coldest and iciest seasons were 2019/20 and 2021/22. In the main basin the ice coverage was the highest in March which was ascribed to the presence of pack ice drifting in cold Sørkapp Current from the Barents Sea/Storfjorden area. In the inner bays of Hornsund – Burgerbukta, Brepollen, and Samarinvågen – the ice coverage was highest in April, likely representing fast ice. There was a secondary peak in October which was associated with glacier ice from calving tidewater glaciers (Swirad et al. 2024).

In 2012–2023, 53% of the fjord ice cover was drift ice, 35% was fast ice, 8.5% was glacier ice while the rest was uncertain or masked. Longer sea ice seasons corresponded to lower winter water temperatures, while higher ice coverage was related to lower winter air temperature.

Colder summer temperatures favored glacier ice persistence in the fjord waters (Swirad et al. 2025).

Longer-term analysis suggested that until 2005 pack ice was present outside Hornsund annually over an extended time period, while after 2005 it appeared episodically. This regime shift implies that recently energetic waves from the open Greenland Sea have had an access to the shores over longer time period (Herman et al. 2025). Comparison of a spectral wave model results (Herman et al. 2019) with nearshore wave measurements in Hornsund (Swirad et al. 2023) shows that sea ice attenuates wave energy decreasing wave energy flux and significant wave height, and increasing wave period (Herman et al. 2025).

An increase in the number and duration of storms was observed outside Hornsund for 1979–2015 (Wojtysiak et al. 2018). Moreover, an acceleration in coastal retreat was observed between 1960–1990 and 1990–2011 (Zagórski et al. 2015). It is critical to monitor and model sea ice and wave conditions, and coastal change to better forecast the hazard of coastal flooding and erosion, as well as the risk of infrastructure damage.

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Special Session:
Progress in the Study of Coastal Zone Changes in Polar Regions – Rate, Landforms and Threats – Session Dedicated to the Memory of Piotr Zagórski

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Piotr Zagórski – A Pioneer in Contemporary Coastal Change Research

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During the jubilee 40th Polar Symposium, one of the thematic sessions is devoted to advances in research on coastal zone changes in polar regions. In addition to the presentation of the latest research results from the cold coasts of the world, session will honour academic life and works of Dr. hab. Piotr Zagórski, who passed away in 2024. Piotr Zagórski, a professor at the Maria Curie-Skłodowska University (UMCS) in Lublin, was a renowned researcher in the field of geomorphology and contemporary morphogenetic processes in polar regions. In the polar community, Piotr is commemorated as an exemplary leader of UMCS Polar Expeditions, as well as an exceptional photographer and a man with an extraordinary sensitivity to the aesthetic appeal of Spitsbergen. For a considerable timespan, Piotr was a head of the UMCS "CALYPSO" Polar Station in Spitsbergen, to which he was deeply attached. It was in the vicinity of the station on Calypsostranda that he initiated and conducted the most accurate monitoring of coastal changes in Spitsbergen, which he maintained for a period exceeding two decades, inspiring similar observations by partners from other polar stations, scattered across the island. He was also the first to provide a comprehensive description of the relationship between the rapidly retreating Recherchefjorden glaciers and the coasts fed by glacial sediments. This seminal work laid the foundations for a model of paraglacial coasts evolution on Spitsbergen. In his latest article, he characterised one of the fastest-growing deltas in the Arctic near his favourite glacier, Recherchebreen. Piotr's research agenda included the continuation of his work along the Hornsund coast, where he served as a leader of the 41st Polar Expedition of the Institute of Geophysics of the Polish Academy of Sciences, including the rapidly deglaciating coasts of Brepollen. In his capacity as a member of the Polar Research Committee of the Polish Academy of Sciences, the Polish Polar Consortium, the Association of Polish Geomorphologists and the chairman of the Polish Geographical Society (PTG) Polar Club, he played a pivotal role in the establishment of the Polar Research Museum in Puławy. His dream was to establish Puławy as the permanent location for the organisation of Polar Symposiums. In honour of Piotr, his scientific partners and friends wish to pay tribute to him by establishing a regular coastal session at the present and subsequent editions of the Polar Symposium in Puławy in order to create a forum for the presentation of the findings of research on polar coasts, for which Piotr's observations with a documented regularity were of fundamental importance.

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Long-term Transformation of the Polar Coast Environment in NW Spitsbergen based on Modern Photogrammetric Measurements and Remote Sensing Techniques

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Abstract

The polar zones, the Arctic and Antarctic, are considered to be areas where global warming is particularly pronounced and the rate of change is up to 4 times faster. In the global approach, an important aspect of scientific research is also the analysis of changes in the coastline in the High Arctic. The dynamics of changes in the polar areas, caused, for instance, by a longer period without ice phenomena, irregular outflows of meltwater rivers, the variable nature of coastal currents (a set of hydro-oceanic processes), or permafrost thawing, lead to cyclical, often short-term changes. On the other hand, the recession of the tidewater glaciers, and at the same time their frequent surge phenomenon (occurring in 13% in Svalbard, about 1% in the world), leads to the discovery and transformation of huge new areas of the coastline, islands, and straits. To assess the changes observed in the north-western part of Spitsbergen, a number of remote sensing and photogrammetric tools (UAVs, CoastSat modules, DSAS) and data on which they were based (archival NPI aerial imagery, Landsat 5-8, Sentinel 2 and Pleiades satellite images, Digital Terrain Models and Orthomosaics made with UAVs) were used. The main area of research was located near the Polar Station of the Nicolaus Copernicus University, in the northern part of the Kaffiøyra Plain (Fig. 1). Neighboring areas such as Sarsøyra Plain and Prins Karls Forland are also included. This research was carried out in this part of the Svalbard Archipelago for several main reasons: the Kafføyra lowland is a distinctive research material due to its low degree of human transformation, its specific location (along the Forland Strait, surrounded by the island of Prins Karls Forland and the Løvenskioldfonna mountain area, far from the permanent settlements of the Svalbard archipelago), as well as access to the polar station and its extensive database of materials concerning this environment (geomorphological, meteorological, hydrological or glaciological). The main objective of the analysis of shoreline changes was the use and evaluation of the usefulness of remote methods of shoreline extraction and the determination of the main zones of accumulation and erosion of the shores. In this study, the authors tried to explain the causes of changes

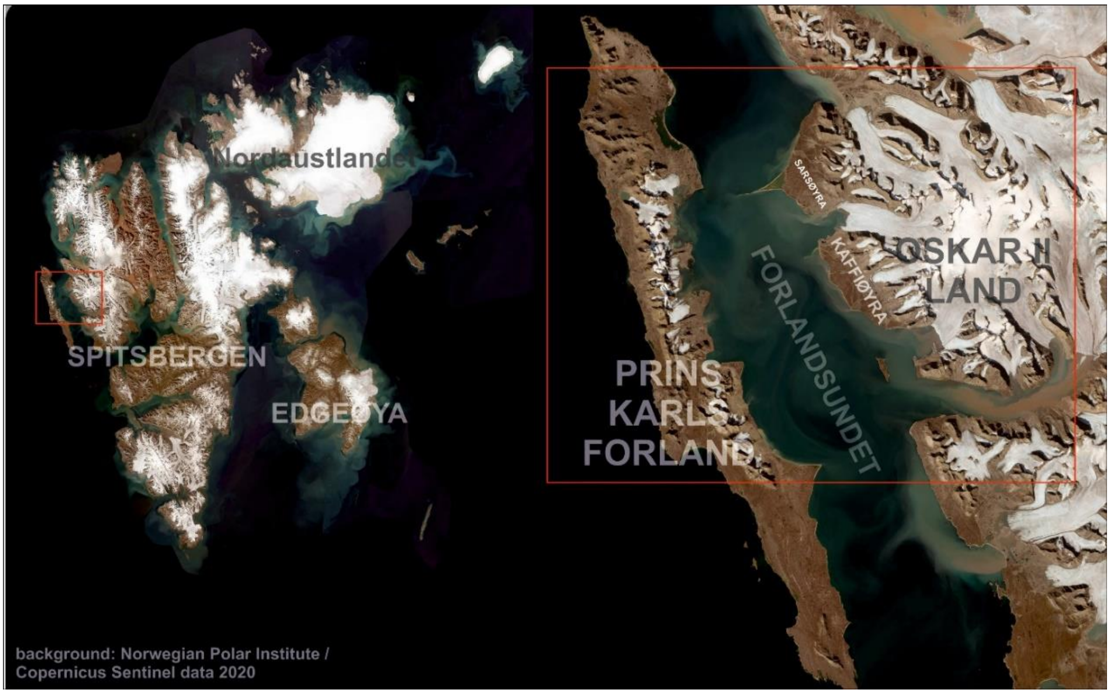

Fig. 1. Area of interest. NW Spitsbergen.

in the polar environment by analyzing topographic and oceanic aspects. The average rate of coastline retreat in the adopted AOI ranged from –0.24±0.16 m yr^{-1} to 0.70±0.16 m yr^{-1} (1966–2021) and from –0.03±0.39 m yr^{-1} to a maximum of 0.92±0.68 m yr^{-1} (approx. 1990–2024). The main directions of changes in the shoreline were determined, as well as the zones of dynamic changes over 50 years were determined: the variable nature of the estuary, the formation and transformation of new lakes, spits, and bays were traced. The seasonal rate of changes in the nature of the Waldemar estuary (change of the direction of the estuary, over-building), the dynamism of the Hornbæk zone in connection with the recession and the surge of the Aavatsmarkbreen, the build-up of spits, or the formation of coastal lakes were recorded.

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Morphology and Genesis of Very Deep Channel Forms ("Deep Scour Holes") in the Arctic River Deltas of the Mackenzie and Kolyma

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1. INTRODUCTION

The lack of systematic observational data means that the dynamics and morphology of distributary channels in Arctic deltas remain poorly understood. This is primarily due to the fact that these areas are covered by ice and snow for most of the year, significantly hindering regular field measurements. Our recent studies have shown that large distributary channels within these deltas may exhibit unusual morphometric characteristics, including locally occurring significant depths. In the Mackenzie and Kolyma deltas, channel forms exceeding 20 meters in depth have been identified, commonly referred to in English-language literature as scour holes or deep scour holes (Beltaos et al. 2011; Lapointe 1986; Fassnacht and Conly 2000). Field measurements conducted over the past four years confirm that these forms exhibit diverse morphologies — they occur as kettles, craters, and trenches. The presence of permafrost in these regions suggests that one of the factors contributing to their formation may be thermo-erosion.

The aim of this study is to provide a detailed morphometric characterization of 43 identified deep scour holes occurring within distributary channels of the Mackenzie and Kolyma deltas. These investigations seek to better understand the mechanisms responsible for their formation and their role in sediment dynamics and geomorphological transformation of Arctic deltas.

2. METHODS

During the summer seasons of 2021, 2023, and 2025, depth mapping of selected channel sections in the Mackenzie and Kolyma deltas was carried out. Measurements were conducted using the infrastructure of two research stations: the North-East Science Station in Chersky (Russia) for the Kolyma, and the Aurora Research Institute, Western Arctic Research Centre in Inuvik (Canada) for the Mackenzie.

Fieldwork on water was carried out using 200 kHz single-beam echo sounders mounted on motorboats and geodetic-grade GNSS receivers. Surveys were conducted along pre-established cross sections spaced every 100 meters. In regions where significant depths were detected, the measurement coverage was densified.

3. STUDY AREA

The Mackenzie River is the fourth largest Arctic river in terms of average annual discharge (approx. 316 km³/year), while the Kolyma ranks sixth (approx. 136 km³/year). In the Kolyma basin (Yakutia, Russia), permafrost covers 100% of the surface and is classified as continuous permafrost. In contrast, the Mackenzie River basin (Northwest Territories, Canada) is approximately 82% underlain by permafrost.

Both deltaic plains are characterized by high lake density — with approximately 49,000 lakes in the Mackenzie Delta region (Burn 2010). The Kolyma River stands out for its exceptionally long ice-cover period — exceeding 210 days per year — which significantly complicates regular hydrological monitoring.

Both deltas are located north of the Arctic Circle, where the average annual air temperature ranges from –8 to –4 °C (Sakai et al. 2016; Emmerton et al. 2007). Ice breakup usually occurs rapidly at the end of May. During its degradation, river discharges may increase abruptly — from 2,000–3,000 m³/s up to as much as 30,000 m³/s.

4. RESULTS

Along a 40-kilometer section of the main distributary channel in the Kolyma Delta, 7 deep scour holes were identified. Notably, all of these features exhibited very similar maximum depths in the range of 25–27 m, differing only in length and width (with an average length of 500 m and width of 300 m).

In the eastern part of the Mackenzie Delta, 36 deep channel forms were identified. In the Middle Channel, 11 such forms were mapped, with a maximum depth reaching up to 48 m. In the Inuvik region, within the East Channel, 21 forms were identified with more varied depths — ranging from 22 to 36.8 m (Fig. 1).

Identified forms were classified based on their basic morphometric parameters, morphogenetic characteristics, ice dynamics associations, and sediment transport characteristics. A common feature of deep scour holes in both the Kolyma and Mackenzie deltas is the presence of very steep side slopes, ranging from 50° to 85°. In the Mackenzie, most forms resemble kettles, while in the Kolyma they are more trench-shaped.

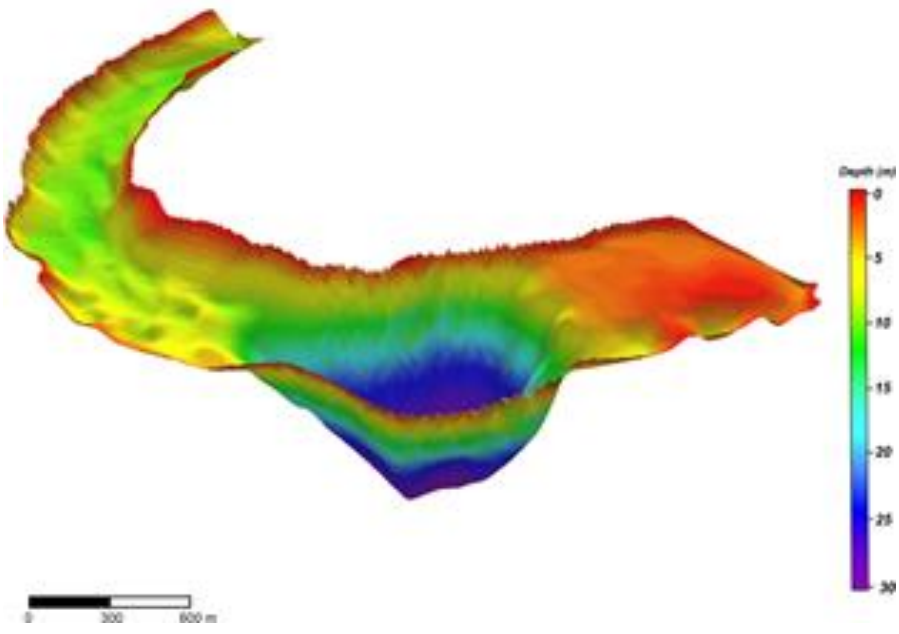

Fig. 1. One of the "deep scour holes" mapped in August 2023 within the East Channel of the Mackenzie River. Maximum depth during low flows: 29 m.

5. CONCLUSIONS

The occurrence of deep channel forms known as deep scour holes in Arctic deltas is not a marginal phenomenon, as evidenced by their high density along the randomly selected distributary channel sections analyzed. Numerous forms of considerable depth (up to 48 m), large spatial extent, and exceptionally steep side slopes have been identified in both the Kolyma and Mackenzie deltas. All analyzed deep scour holes create unique morphological conditions for flowing water, confirming their significant impact on sediment transport dynamics within Arctic deltas.

Not all identified forms occur within tidal delta channels, which allows the exclusion of contemporary marine processes as a major factor in their formation. The characteristic abundance of lakes in the studied deltas suggests that their capture by river channels may represent a key mechanism initiating the development of these features.

Preliminary analysis indicates that their genesis results from the interaction of multiple factors. The most important include: incision-related erosion linked to ice dynamics (e.g., ice jams and sudden meltwater surges), the presence of Holocene lacustrine sediments and organic-rich dendritic material, and thermoerosional processes triggered by permafrost degradation.

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Glacial-derived Waves Impact Morphodynamics of Arctic Coasts, Greenlandic and Svalbard Cases Studies

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Abstract

Ongoing climate warming is leading to rapid changes in the Arctic environment, including significant alterations to the cryosphere. The recent rapid retreat of marine-terminating glaciers has exposed new coastlines (e.g. Kavan et al. 2025). The calving of these glaciers often causes tsunami-like waves that pose a serious threat to the local environment. These powerful waves can move the glacial debris in front of ice cliffs, redistribute icebergs and flood, and reshape local cliffs and beaches (e.g. Kostrzewa et al. 2024). Another type of wave clearly related to cryospheric processes is the iceberg roll wave observed in the natural conditions during the transport of broken parts of the glacier in Arctic waters (e.g. MacAyeal et al. 2009). Melting causes icebergs to rotate, sway, capsize and collapse to find new equilibrium, creating waves that can hit the coast.

We present a multi-decadal analysis of changes to the coastal zone associated with the impact of waves from glacier calving, using examples from Eqip Sermia in Greenland and Hansbreen in Svalbard. An analysis of the coast at the Eqip Sermia glacier showed that waves from glacial calving play a dominant role in transforming lateral moraines and forming a system of beaches and spits. Additionally, our multi-decadal analysis revealed significant erosion of unconsolidated cliffs on the opposite side of the bay, at a rate of ~0.53 m per year from 1985 to 2023 (Kostrzewa et al. 2024). A single wave from a glacial calving event can reshape the beach surface by entrainment of up to 1.8-m-diameter boulders and the erosion of the beach surface by washing away sand and gravel from rocky outcrops (Kostrzewa et al. 2024).

In the case of the Hansbreen coast (Svalbard), the impact of waves from glacial calving is more subtle. As a result of glacier retreat, the shoreline length of the bay increased on average 220 m/year (years: 2011–2020). The analysis of beach surface sediments from these shores showed an increase in the proportion of coarse-grained sediments with distance from the glacier front. We suggest that wave action, mainly from glacial calving, leads to the washing of fine-grained beach sediments.

Additionally, we present the results of our study on the impact of waves from iceberg roll on weathering patterns in the rocky bay of Zion Church (Ilulissat, Greenland). The main result of the study is a significant reduction in rock resistance in the zone above the high-tide level. We relate this result mainly to waves generated by iceberg roll events.

Our findings suggest that waves resulting from glacial calving and iceberg roll play a significant role in the transformation of local coasts, converting glacial forms into littoral ones or intensifying weathering processes on rocky coasts by weakening their surfaces. Our study represents an important advance towards understanding paraglacial coastal evolution in regions characterised by rapid marine-terminating glaciers' retreat.

Keywords: paraglacial coastal, calving waves, marine-terminating glaciers, Greenland, Svalbard.

Funding: The research is supported by the National Science Centre in Poland (project: "GLAVE- transformation of paraglacial coasts by tsunamis – past, present and warmer future", No. UMO-2020/38/E/ST10/00042).

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Post-Little Ice Age Evolution of Moraine-controlled Paraglacial Lagoons in Svalbard – Rates, Landforms and Geoecological Significance

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A b s t r a c t

Often overlooked, Arctic lagoons are the silent guardians of a rapidly changing polar world. These dynamic coastal ecosystems are crucial conduits between land, sea, and atmosphere. They are facing significant threats due to climate change. Their stability is closely linked to the interplay of storm waves, ocean currents, sediment supply, and fluctuating sea levels. However, a significant knowledge gap remains: the processes that shape their evolution in the Arctic are largely unknown (Owczarek 2025).

Satellite imagery, alongside the 1930s aerial photographs and orthophotographs, was used in our groundbreaking study to address this critical knowledge gap. This comprehensive approach enabled us to comprehensively map the formation of lagoons and systematically classify their typologies across Svalbard. Our database covers over 430 lagoons, revealing a geomorphological transformation. Since the end of the Little Ice Age, an astonishing 98 new lagoons have been formed, contributing to Svalbard's current coastal landscape of 434 lagoons, spanning an impressive 147 km². A particularly compelling discovery is the emergence of the "moraine-controlled paraglacial lagoon" – a new lagoon type, spreading rapidly across the archipelago. These distinctive formations are a direct consequence of glacial retreat, as the sea inundates the terrain that has been newly exposed between moraines and the ice cliffs of retreating glaciers.

Despite exposure to Arctic storms, a considerable number of lagoon barriers on Svalbard have demonstrated remarkable resilience, thereby indicating that their formation is the consequence of protracted and stable geomorphological processes. This finding provides novel insights into the rapid and substantial changes occurring in the Arctic, while establishing urgent research directions to understand the fundamental processes governing these critical yet enigmatic polar ecosystems.

Keywords: paraglacial lagoons, coastal changes, glacier retreat, Arctic.

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The Youngest Coasts on Earth – How Accelerated Post-Little Ice Age Deglaciation Reshaped Coastal Landscapes of Arctic and Subarctic Regions

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Abstract

The rapid retreat of most Northern Hemisphere marine-terminating glaciers since the post-Little Ice Age (LIA) is a direct consequence of escalating climate warming. Today, the dominant form of ice loss is calving, where massive chunks of ice break off from glacier fronts, significantly contributing to global sea-level rise. Despite extensive global research on glacier retreat and mass balance changes, the crucial impacts of deglaciation on adjoining coastal geomorphology are often overlooked. Once exposed, these paraglacial coastal environments are sculpted by a complex interplay of nearshore marine, coastal, and terrestrial geomorphic processes. These forces rework glacial sediments, leading to the emergence of novel coastal paraglacial systems. In this study, we provide a comprehensive review of the paraglacial processes, landforms, and landscapes that have formed in front of the Northern Hemisphere's most rapidly retreating glaciers. Our particular attention is given to juvenile beaches, deltas, and lagoons. Furthermore, we assess the profound influence of extreme waves, including tsunamis caused by landslides, calving waves, and iceberg roll waves, on the ongoing reshaping of these young, recently ice-abandoned coastlines. This review is dedicated exclusively to Svalbard and Greenland, with illustrative examples also drawn from Iceland, Alaska, and the Canadian Arctic Archipelago. We characterize these nascent coasts based on their rock type, current climatic conditions, and geographical location, with a specific emphasis on the permafrost zone. These environmental variables are critical in driving the evolution of newly initiated paraglacial coasts and allow us to pinpoint areas with anticipated dynamic coastal geomorphological changes.

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Tsunamigenic Landslides from Freshly Exposed Arctic Slopes – Preliminary Pan-Arctic Susceptibility Assessment

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A b s t r a c t

Accelerated climate warming has caused the majority of marine-terminating glaciers in the Northern Hemisphere to retreat significantly during the 21st century (Kochtitzky and Copland 2022). Recently published digital inventory of new exposed coasts shows that a total of 2466 ± 0.8 km of new coastline was exposed in period 2000–2020, giving an average length of 123 km every year. Two-thirds of this coastline was exposed in Greenland with shorter sections in Canadian Arctic Archipelago, Russian Arctic, Svalbard, and south-western Alaska (Kavan et al. 2025).

Juvenile paraglacial slopes are hotspots in the Arctic in terms of geohazards. They are known to be unstable after releasing from glacier ice and therefore prone to landsliding (Ballantyne 2002). What is more, massive landslides entering water can trigger tsunami-like waves, which were already recorded in the fiords of Greenland and Alaska in 21st century (Dahl-Jensen et al. 2004; Buchwał et al. 2015; Higman et al. 2018; Paris et al. 2019; Bloom et al. 2020). The process calls for hazard assessment studies as it poses a real danger to local communities as well as tourists visiting such sites. For example, the wave recorded in Karrat Fjord (West Greenland) in 2017, caused substantial infrastructure damage and loss of life in the settlement of Nuugaatsiaq (Strzelecki and Jaskólski 2020). The highest recorded Arctic landslide tsunami (Lituya Bay, Alaska, in 1958) reached a runup height of over 500 m (Miller 1960)! Ongoing climate change may lead to increased frequency of extreme waves in the region.

The objective of this ongoing study is to deliver a preliminary tsunamigenic landslide susceptibility assessment for all coastlines that have recently emerged recently from glacier ice, in areas where infrastructure or tourist activity is present. Analysis involves the utilisation of remotely sensed, topographic, and environmental data that is available to the public, with the objective of identifying areas of heightened susceptibility to specific phenomena.

Key words: new coasts, landslides, tsunamis, susceptibility assessment.

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Coastal Landscape Dynamics of Eastern Svalbard since the End of the 20th Century

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An exceptionally strong climate warming (Arctic amplification) has led indirectly to intensive coastscape transformation in East Spitsbergen and the East Svalbard islands.

There are three main processes through which climate warming affects the coastal landscape: (1) recession of tidewater glaciers which abandoned large areas from ice; (2) shortening of the sea ice season, which allows for more frequent and more intense sea storms; (3) deeper thawing of the permafrost active layer.

The effects of these processes were observed during the research cruise of the yacht "Ocean A", implemented as part of the project "HarSval – Bilateral initiative for harmonisation of the Svalbard cooperation", financed by "Norway grants", led by University of Silesia and Dariusz Ignatiuk personally.

For this purpose, twelve coastal areas were explored from 20th to 30th August.

In four of them – located in the central-eastern and southeastern Spitsbergen – the main reason for the landscape transformation was the recession of tidewater glaciers. This recession has led to: (1) flooding of the depressions in the glacier bedrock by the Barents Sea (i.e., the formation of new or the enlargement of old sea bays); (2) appearance of new landscapes in areas abandoned by glaciers. Such transformation was observed in the following coastal areas: Hambergbukta and Hambergbreen, Diabastangen and Backlundbreen, Straumslandet and Pedašenkobreen (Fig. 1), Kapp Weyprecht and Hochstetterbreen.

In six coastal areas – located in Edgeøya, Berentsøya, Von Otterøya, westernmost Nordaustlandet, northernmost Spitsbergen – which are raised above 4–5 m above sea level, undercutting from below by storm waves is the main factor changing their coastlines slowly. The contour of these shorelines remains almost unchanged but behind the beaches low cliffs were formed (Fig. 2).

In the next two explored coastal areas – in Berentsøya at the front and east of the Freemanbreen glacier, and near Sjutnes – all the mentioned landscape transformations occurred.

Deeper thawing of the permafrost active layer contributes to acceleration of sliding and creeping (including solifluction) on the slopes. This process is causing the shoreline to recede

Fig. 1. Straumslandet north of Heleysundet, Central-East Spitsbergen: the marginal zone of the Pedašenkobreen glaciers with the new sea bay, formed after 2004.

Fig. 2. Diskobukta at the foot of Muen, Edgeøya: the mountain coast with the new low cliff behind the beach.

in the places where the slopes covered with weathering or morainic material descend directly to the sea, e.g., in Hambergbukta and nearby.

The results of the observations could be quantified thanks to comparisons with previously released maps, satellite images and papers (among others: Szupryczyński 1963; Lefauconnier and Hagen 1991; Hagen et al. 1993; Bondevik et al. 1995; Dowdeswell and Bamber 1995; Ziaja et al. 2007, 2009; Cygankiewicz-Truś and Ziaja 2021; Ziaja et al. 2023).

In the near future, the East Svalbard coastscape transformation caused by recession of tide-water glaciers will be continued due to a relatively low elevation of their (highest) accumulation zones which are in risk of being below the rising snow and equilibrium (of their net mass balance) lines.

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Is Sørkapp Land an Island? The Hornbreen–Hambergbreen Coast Formation in Svalbard in Light of the Cosmocentric Principle

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One of the most interesting scientific issues in recent years related to the response of cryosphere elements to atmospheric warming is the issue of the separation of Sørkapp Land from the rest of Spitsbergen as a result of the retreat of the Hornbreen–Hambergbreen glacier system. Although the issue is not new in the study of the glacial cryosphere in Svalbard (Szupryczyński 1968; Ziaja and Ostafin 2015; Kavan et al. 2022), in recent years it has been given special attention on Spitsbergen due to the fact that the break of the ice bridge formed by the Hornbreen–Hambergbreen glaciers may occur relatively soon. All empirical studies devoted to this issue focus on predicting the approximate date of the separation of Sørkapp Land from the rest of Spitsbergen as a result of the retreat of the glaciers and to other natural consequences that may result from it. The years given here are between the end of the 20th century and 2065 (Saferna et al. 2023).

Empirical studies undertaken for years have been characterizing the process of retreat of these two glaciers more and more accurately, using geophysical methods and remote sensing on a large scale (Saferna et al. 2023). Unfortunately, the issue of importance for which this spectacular example can be an excellent illustration is still overlooked. So far, no one has taken a position on what basis we should claim that frozen water, such as glaciers, an extremely unstable and easily melting material, and therefore classified as part of the hydrosphere, would have a leading role to play here. If we are talking about the separation of two parts of the land, this means the separation of two parts of the lithosphere, not the hydrosphere. If there is an over-deepening under the Hornbreen–Hambergbreen glacier system, which has been clearly confirmed by radar studies (Grabiec et al. 2018), then the connection of Sørkapp Land with the rest of Spitsbergen relies solely on the existence of an ice bridge created by these two glaciers. If ice is classified as part of the hydrosphere, it cannot be land – lithosphere – at the same time. This classification is disjoint. This leads to a rather simple conclusion: Sørkapp Land, according to the definitions commonly accepted in science, is already an island at the present time. Therefore, there is no need to wait another few decades for the separation of ice from the land, which the authors write about when giving the approximate time of the island's formation.

The situation changes essentially when, in accordance with the tradition of the last 100 years (Dobrowolski 1923, 1931; Shumskiy 1964), ice is classified as a mineral and a rock. Then it should be consistently classified in the lithosphere, where it forms the lightest rock. This postulate was put forward quite a long time ago (Dobiński 2006). However, it is a necessary condition for the mentioned process to be described as the separation of two parts of the land. The spectacular example of the role of the Hornbreen–Hambergbreen glaciers in the evolution of the island of Spitsbergen allows us to return to this postulate with new force, presenting a very strong argument.

However, changing this paradigm still meets with resistance that cannot be justified by anything other than long-term habit resulting from the perception of ice in low latitudes, where it is indeed unstable. And although the duration of glaciation on Earth now and in the past can be counted in millions of years, the direct experience of ice on Earth for the vast majority of people is quite different.

At this point, unexpected help appears from a scientific field that seems to be completely separate from Earth sciences due to its subject of research. It is worth noting, however, that planetary science – because that is what we are talking about – is in its essence only a transfer of research methods and hypotheses characteristic of Earth, to a completely new, distant environment, on the basis of analogy. The amount of knowledge gathered about other celestial bodies in the field of planetary science is so large that it not only allows for learning about the geology, geomorphology or cryosphere of other planets, but also for unambiguous determination of what is common and what is exceptional in this respect.

But it is obvious and has been known for a long time that it is the Earth that constitutes a unique element among the planets of the Solar System. It is for this reason that it cannot be a point of reference in an analogous knowledge of the Cosmos, because this knowledge would be extremely geocentric, leading to the recognition of the exception as a general rule. It is therefore necessary to reverse the cognitive analogy, which applies particularly in relation to the Earth's cryosphere. The principle should be:

The Earth is not the reference point in analogous studies of the natural environment of the celestial bodies. It is the Cosmos and celestial bodies that constitute the reference area for the Earth, and for the study of its natural environment.

This is a cosmocentric principle, introduced into the global scientific circulation recently (Dobiński 2024), the essence of which is to break with the geocentrism still prevailing in the world of Earth sciences, by reversing the cognitive analogy. The example of ice, which is commonly found in space, best shows that it always constitutes an icy lithosphere there and is also treated as a mineral and rock. Although the Earth's icy lithosphere currently occupies a small part of it – it still remains so. Ice cannot be treated as an "additional body" (Dobrowolski 1931) or "fourth state of matter" (e.g. Hauck et al. 2011). It is in a completely literal sense a component of the lithosphere and only its treatment in Earth sciences allows for a correct and fully spectacular explanation of the process taking place on Spitsbergen, the main participants of which are the Hornbreen–Hambergbreen glaciers.

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First Approach Toward Assembly and Annotation of the Complete Mitochondrial Genome of *Colobanthus Quitensis* (Kunth) Bartl. (Caryophyllaceae)

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1. INTRODUCTION

The genus *Colobanthus* (Caryophyllaceae) includes 26 species. These plants are primarily found in the southern hemisphere, including the islands of the South Pacific, Australasia, central and southern South America, Antarctica, and the subantarctic islands (West 1991; Sneddon 1999; Gray 1976). The most famous representative of this genus is *Colobanthus quitensis*, which is one of only two flowering plants, along with *Deschampsia antarctica* E. Desv., considered native to Antarctica (Skottsberg 1954). *C. quitensis* has become a model species in the study of plant adaptation to the extremely difficult environmental conditions of the Antarctic, which include not only low temperature but also its rapid changes (cyclical melting and freezing), short vegetation period, strong winds, the phenomenon of polar night and day, and strong UV radiation (Gianoli et al. 2004; Navarrete-Gallegos 2012).

Despite numerous morpho-physiological studies aimed at exploring the process of *C. quitensis* adaptation to polar conditions, genetic data on this issue are very limited. Our previous studies, in which we reported the results of comparative characterization of the complete chloroplast genome sequences of *C. quitensis* (sequence acquired from the GenBank) and six other *Colobanthus* species from areas characterized by a milder climate (sequences of our authorship), did not confirm the unique character of the *C. quitensis* plastome (Androsiuk et al. 2020).

Although mitochondrial DNA is widely used in phylogeography, it has been shown that environmental stressors, nutrient availability, and climate can have a significant impact on mitochondrial genomes, favoring the persistence of particular haplotypes to meet the metabolic demands of the local environment (Noll et al. 2022; Shen et al. 2022).

During the project realization, it is planned to obtain for the first time, a complete sequence and conduct a detailed characterization of the mitochondrial genome of *C. quitensis*. The mitogenome sequence of the *C. quitensis* will provide data necessary for further studies aimed at explaining the role of mitochondria in the development and evolution of mechanisms responsible for adaptation of the species to polar conditions. It will also become the reference sequence, which will facilitate the development of mitochondrial genomes of other *Colobanthus* species.

2. RESULTS AND DISCUSSION

Here we present the preliminary results obtained during the realization of our project which was launched in March 2025. Due to the specific nature of the plant mitochondrial genome (size even over 10 Mb, possible multichromosomal structure, relatively small number of genes and large share of non-coding regions and repetitive sequences), the Oxford Nanopore Technology platform generating single reads up to 30 Kb long was used to sequence and assemble the complete mitochondrial genome of *C. quitensis*. The library preparation and long-read DNA sequencing was performed according to procedure described in Krawczyk et al. (2025).

Nanopore sequencing generated 2.9M raw reads up to 450 kb with N50 = 11.4 kb. Basecalling with SUP model and Herro based correction enable mean *Q*-score at 27.8. Out of obtained read, 4.7% were identified as mitochondria resulted in 33x mean coverage. The *C. quitensis* draft mitochondrial genome was characterized by a complex, multichromosomal structure. The assembly results revealed that the complete *C. quitensis* mitochondrial genome is 2.2 Mbp bp in length with a GC content of 41% and consists of 9 contigs (pseudochromosomes), each could be mapped as a circular molecule due to flanking repeats. The size of these pseudochromosomes range from 133 to 566 kb. However, ca. 5% of mapped reads supports potentially different topology, suggesting presence alternative assembly paths.

Our observations are concordant with previously published data pointing at high variation in size and structure of mitochondrial genomes within Caryophyllales. In this respect the genus *Silene* (Caryophyllaceae) is especially well-studied. The genus *Silene* includes species with simple and slowly evolving mitochondrial genomes, e.g. *S. latifolia* (253 kb) and *S. vulgaris* (427 kb), as well as taxa whose mitogenomes are large, have a multichromosomal structure and a high mutation rate, e.g. *S. noctiflora* (6.7 Mb) and *S. conica* (11.4 Mb) (Sloan et al. 2012).

The gene composition of *C. quitensis* mitogenome is very conservative with obligatory set of core protein genes and 2 genes representing various, facultative ribosomal protein mitochondrial genes. Among these sequences, there were genes for four subunits of ATP synthase (*atp1*, *atp4*, *atp6*, and *atp9*), four genes associated with cytochrome c biogenesis (*ccmB*, *ccmC*, *ccmFc*, and *ccmFn*), a gene for ubiquinol cytochrome c reductase (*cob*), three genes for subunits of cytochrome c oxidase (*cox1–3*), a maturase gene (*matR*), a sequence for transport membrane protein (*mttB*), sequences for nine subunits of NADH dehydrogenase (*nad1–6*, *nad7*, *nad9*, and *nad4L*), sequences for three components of the small subunit of the ribosome (*rps11–13*), Moreover, we annotated full set of sequences for tRNAs and rRNAs genes which were detected in five clusters, scattered along 3 pseudochromosomes. Among protein-coding genes, *rps12*, *rpl5*, *cob* and *ccmFn* were duplicated in one of scaffolds. Assembly of mitochondrial genome enabled identification of three plastid do mitochondrion transfer events, ranging from 1.5 to 4 kbp.

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Stress Resilience of the Polar Streptophyte Green Microalga *Klebsormidium Flaccidum* from Svalbard, High Arctic

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Abstract

Polar regions are generally considered to have extreme environmental conditions: nutrient-deficient soils, low temperatures and frequent freeze-thaw cycles in winter, and desiccation in summer. These factors are highly demanding for biological soil crusts microalgae to develop various adaptation strategies. The novel experimental strain of the widespread green streptophyte microalga *Klebsormidium flaccidum* CCALA 1182, found in terrestrial and freshwater habitats, was isolated from biological soil crusts in Svalbard (High Arctic). The study aimed to explore *Klebsormidium flaccidum* CCALA 1182 stress resilience to desiccation, nitrogen starvation, low temperatures, and freezing using laboratory-simulated conditions that mimic natural, through a physiology and transcriptomic approach. We discovered that metabolic activity was altered by nitrogen limitation, whereas low temperatures and desiccation had a more subtle effect. Furthermore, low temperature hardening stimulated resilience to desiccation and freezing, in contrast to nitrogen deficiency, which intensified the detrimental effect of these treatments. Overall, the experimental strain *Klebsormidium flaccidum* CCALA 1182 demonstrated its ability to acclimate to unfavourable conditions, with constant stress-related gene expression, and highlighted the limited information available about the mechanisms of resistance to freezing stress of this microalga.

Keywords: polar biological soil crusts, desiccation, *Klebsormidium flaccidum*, nitrogen starvation.

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Contemporary Climatic and Non-climatic Disturbances Affect the Heterogeneous Growth of *Salicaceae* in Spitsbergen

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1. INTRODUCTION

Dwarf shrubs growing in the High Arctic tundra are very sensitive to environmental changes and are therefore very important ecological indicators. The variation in the width of annual increments is linked to several complex factors, climatic and non-climatic, such as geomorphological, soil, and habitat (Owczarek et al. 2013; Opała-Owczarek et al. 2018; Owczarek et al. 2021). However, the driving factors influencing tundra plant growth are not yet fully understood. It is thus evident that a comprehensive study integrating ground-based observations and their linkage to a large variety of environmental factors is crucial. This is particularly important for observing the contemporary trend of growth and increasingly frequent climatic, biotic, and physical extremes (Phoenix et al. 2025). Considering the above scientific problems, we pose a main research question: What factors are responsible for the inconsistent growth of polar willow in different morphological zones of central Spitsbergen?

2. STUDY AREA AND METHODS

The study was conducted in the central part of Spitsbergen, the largest island in the high Arctic Svalbard archipelago. The study sites were located in the morphologically diverse Adventdalen area. To accurately assess how topographical diversity and local factors influence the growth variability of *Salix polaris*, we sampled plants from climatically diverse sites: from plateau (elevation 400–450 m a.s.l.) and valley bottom (50–70 m a.s.l.) (Fig. 1). At each site, we randomly collected approximately 15–32 plant specimens of *Salix polaris*, depending on local availability. For laboratory analysis, we adapted well-established microscopic techniques for examining dwarf shrubs (Gärtner and Schweingruber 2013). Each research area, including the surroundings of designated vegetation plots, was subject to detailed geomorphological mapping and soil analysis. For the research, we paid special attention to landforms and processes that could either hinder or promote vegetation growth and plant productivity.

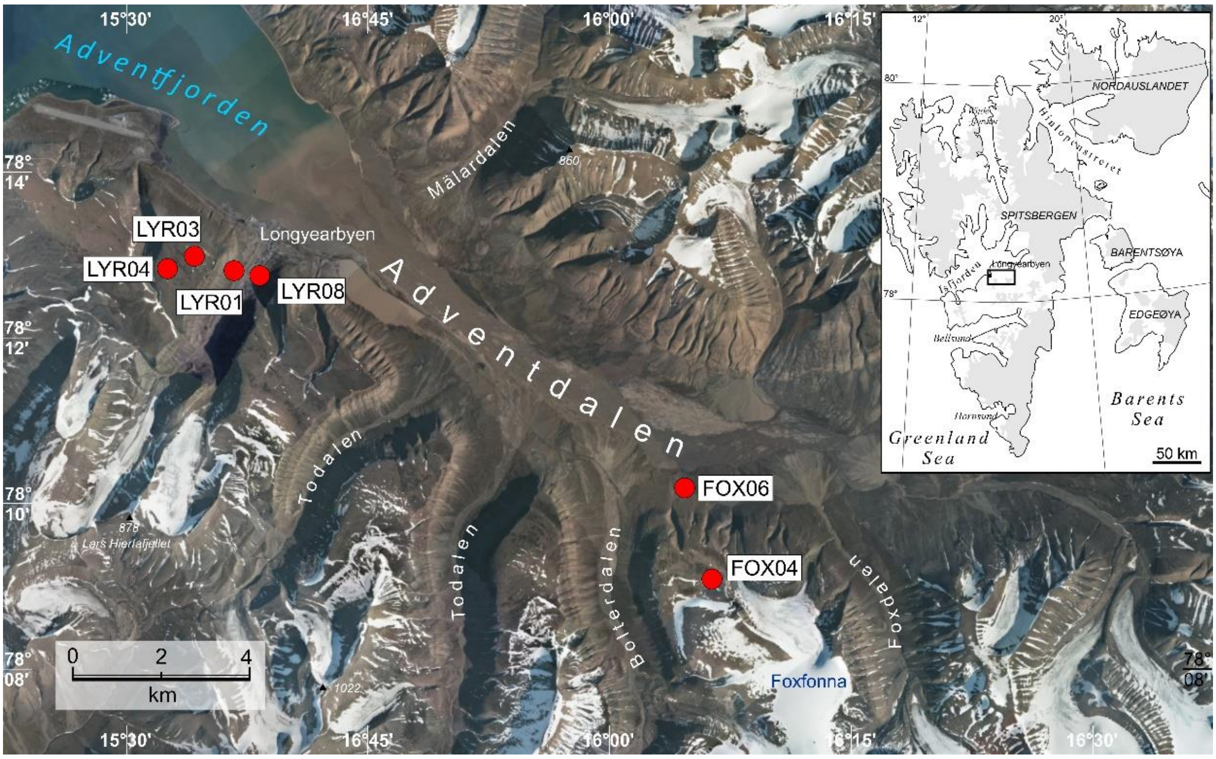

Fig. 1. Location of the study sites in Central Spitsbergen, Svalbard.

3. RESULTS AND CONCLUSIONS

High-resolution digital images of *Salix polaris* cross-sections from six sites enabled the construction of reliable growth-ring chronologies at high and low elevations. Dendroclimatic analyses at different sites yielded diverse results, enabling insightful interpretations of the factors influencing polar willow growth in Central Spitsbergen. Although the sites were close to each other, it was found that the dendrochronological scales varied, meaning that the growth of the polar willow was heterogeneous (Fig. 2). Our analysis of various microsite conditions suggests that the growth response of this species is influenced by more factors than a single climate driver. Dendrochronological analyses revealed that low-elevation valley-bottom sites showed a strong positive correlation between June temperatures and ring growth, supported by high soil moisture and nutrient-rich soils. In contrast, higher elevations experienced delayed yet sustained growth in mid-to-late summer, supported by permafrost moisture retention despite colder early summers. In addition, numerous traces of physical and climatic disturbances affecting modern dwarf shrub growth were found in microscopic cross-sections. Examples include the occurrence of reaction wood in areas of increased solifluction movements (Fig. 3A), numerous wounds and eccentric growth associated with mass movements, including aeolian erosion (Fig. 3B) or narrow growth rings associated with rain-on-snow events (Fig. 3C). These disturb-

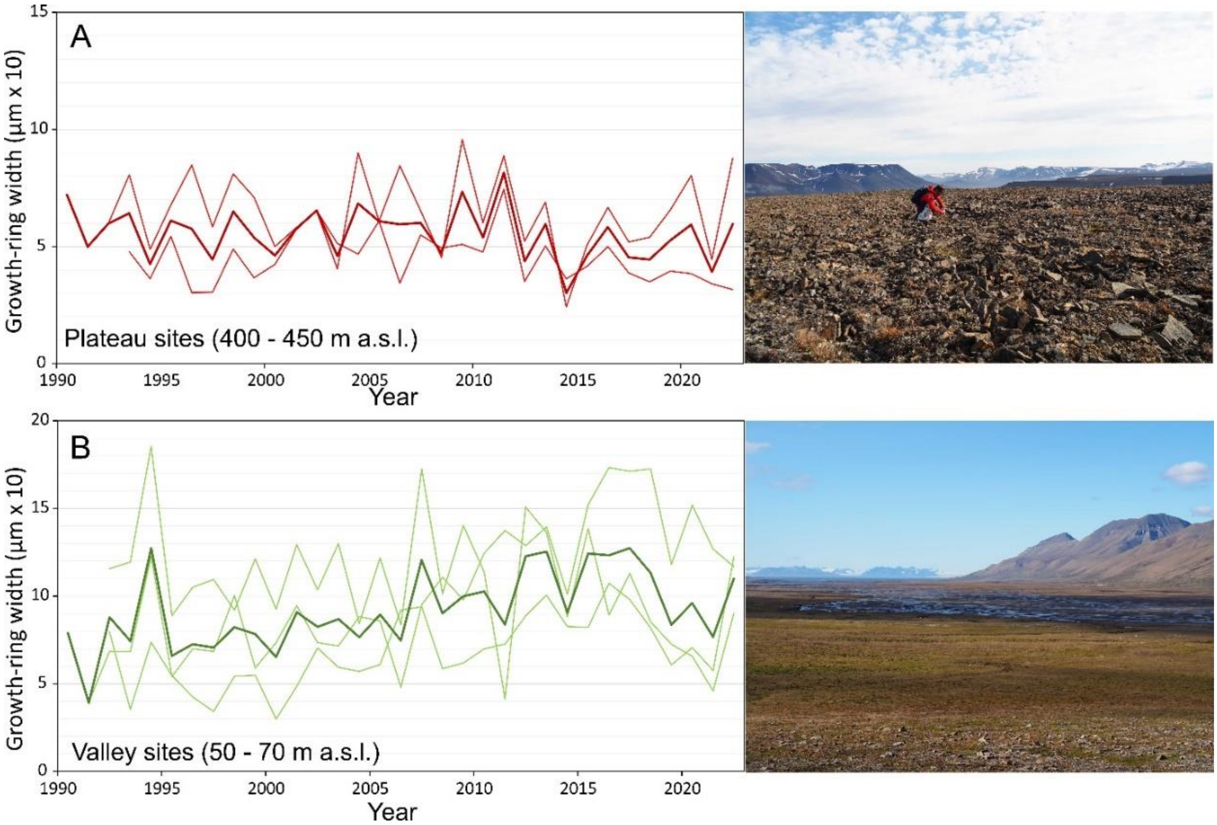

Fig. 2. Chronologies of growth rings of *Salix polaris* growing at high (A) and low (B) altitudes with general views of the study areas showing their topographical and geomorphological characteristics.

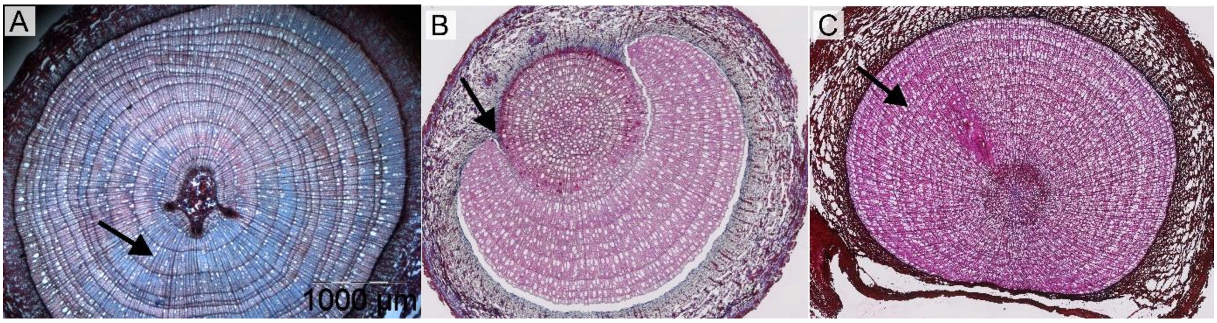

Fig. 3. Examples of growth disturbance in polar willow cross sections: A) reaction woods that develop as a result of mechanical stress (e.g. creeping) are stained blue through the use of dyes, B) wounds and eccentric growth associated with mass movement activity, and C) growth ring connected with extreme climatic events – rain-on-snow.

ances can occur locally and affect their growth differently even in adjacent sites. Our research has demonstrated the impact of various factors on the growth of polar willow and its heterogeneous growth pattern. We have shown that the combination of dendrochronological data from High Arctic sites on a regional scale is subject to significant error, due to the impact of microhabitat and microclimatic factors. Local factors are crucial in influencing local tundra productivity trends.

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What Do We Know about the Future of Biodiversity in Glacier and Adjacent Ecosystems?

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1. INTRODUCTION

Glacier retreat has consequences for diverse ecological functions, from nutrient cycling, energy flow to species interactions and likely decline of glacier related psychrophiles. The vanishing of glaciers also determines a change in the diversity and distribution of organisms, including potential extinction of glacier specialists (i.e. supraglacial organisms). Global biodiversity is declining at rates faster than at any other time in human history. While much research has focused on documenting the spatio-temporal changes in biodiversity following glacier retreat, better understanding of the biodiversity of glacial habitats, and the response to elevated temperatures of glacial specialist is crucial for anticipating future actions protecting biodiversity in situ or ex situ, and to identify refugia.

2. AIMS

(i) catalogue the diversity of eukaryotes and prokaryotes in glacial habitats, (ii) test their physiological capability to tolerate higher than on glacier surface temperatures, and (iii) investigate their potential refugia during future warming.

3. PRELIMINARY RESULTS

We identified by morphology and DNA-based approaches some invertebrates, bacteria and algae taxa from glacier and glacier adjacent habitats in mountains and polar regions. Tardigrades are glacier-specific species while rotifers include both glacial-obligate species and other inhabiting both glacial and non-glacial habitats. Representatives of both taxa survive higher temperatures than those on the ice surface but die at specific thresholds. Preliminary studies on eukaryotic green algae and cyanobacteria indicate the presence of both specialists and opportunistic species on glaciers. Heterotrophic bacteria from cryoconite grow in low and high temperatures and show physiological versatility. Finally, the historical vanishing of some glaciers indicates that a number of glacial taxa survived previous warm periods in cold refugia. Snowfields, debris-covered glaciers and glacierets are candidates as long-term refugia. Preliminary data indicates that invertebrates found on the snow could be divided into wind-blown (accidental) faunal elements and specialists inhabiting both glacial and snow ecosystems and that the later environment could seasonally support psychrophiles.

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Long Term Trends of Freeze – Thaw Cycles in North America, Europe and Asia

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Abstract

This study analyses changes in the frequency of freeze-thaw cycles in high-latitude and mountainous regions of the Northern Hemisphere. The aim is to evaluate thermal conditions conducive to frost weathering processes, considering the spatial variability of climate characteristics and trends observed over the period 1971–2020. We selected 30 meteorological stations representing polar, alpine, subpolar oceanic, and subarctic climates. Using daily mean and extreme air temperatures, we calculated long-term averages for the number of freeze-thaw days (FTD), ice days (ID), frost-free days (FFD), and other related parameters. These metrics formed the basis for clustering the stations to identify similarities in climatic conditions favourable to frost-related processes. As a result, the stations were grouped into four distinct clusters. Our analysis indicates that global warming contributes to a universal decline in the number of ID. However, trends in FTD vary: they are increasing in the coldest regions and decreasing in the warmest ones. Notably, long-term trends in FTD exhibit significant variability, influenced by seasonal changes, climate zone, proximity to oceans, and regional orographic features. In winter, warming leads to more frequent freeze-thaw cycles and increased occurrences of “rain-on-snow” events and the formation of various surface ice deposits such as hoarfrost, glaze ice, and black ice.

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The Discovery of the Oldest Junipers in Iceland Revealed Temperature Changes of the Past Millennium

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1. INTRODUCTION

Iceland, situated in the central Arctic sector of the Atlantic, plays a pivotal role in identifying the direction of contemporary environmental changes associated with the rapid warming of the polar regions, termed Arctic amplification. The observed changes in the course of natural and anthropogenic processes demonstrate that Iceland is uniquely environmentally sensitive, thereby rendering the climatic reconstructions from this area particularly relevant. This relevance extends beyond the realm of climate change, encompassing human-climate interaction and the response to extreme environmental processes (Huhtamaa and Ljungqvist 2021). To properly determine the direction of these changes, a reliable reconstruction of climatic conditions is required. Despite the indisputable value of written sources (as can be found in sagas and annals) as a primary source of pre-instrumental data, particularly in the context of climatic anomalies and natural disasters, these sources must be treated with caution (Ogilvie 1984). A variety of natural archives have been also used to reconstruct past climate variability, providing data to study long-term trends. Interesting material were provided by annual growth increments in the shell of the long-lived bivalve clam, sedimentary proxies from lacustrine environments, chironomid-based reconstruction, lichenometric and glacial extension studies. However, it should be noted that the accuracy and resolution of these proxies may be limited.

Iceland is an example of a fragile northern ecosystem where enormous changes in vegetation cover and soil degradation took place since permanent human settlement. This close and coupled human-climate interaction distinguishes Iceland from other Arctic regions. Contextualising recent trends and extremes against past ranges is, however, limited by a lack of high-resolution temperature reconstructions. The search for new sources of climate proxies is therefore crucial for precise, annually resolved multi-century long dendroclimatic reconstructions.

2. MATERIALS AND METHODS

2.1 Study area

An unexpected and Arctic-unique field of old junipers was discovered in 2024 in the northeastern part of Iceland. The area has a varied relief resulting from the direct influence of both volcanic and glacial processes. The volcanic relief is dominated by two volcanic systems, Þeistareykir and Krafla. Between these two zones, there are wide depressions filled with differentiated lavas and sands of glacial and glaciofluvial origin. Even though Iceland's climate is generally described as maritime and fairly mild, our study area, located in the interior of north-eastern Iceland, is characterised by a typical tundra climate. The long-term climate of the study area is best represented by a meteorological station Grímsstaðir á Fjöllum, with average annual temperature 0.9 °C and upward trend of the annual mean temperature by about 0.78 °C/decade. Notably, in this region a cold record (of –38 °C) has been set for Iceland. The study area received the lowest precipitation levels (363 mm compared with 1000–4000 mm in southern Iceland).

2.2 Wood material, laboratory preparation and dendroclimatic analysis

Dry and living juniper were sampled during field campaigns in 2023, 2024, and 2025 (Fig. 1). Particularly noteworthy is the discovery of a large amount of relict wood buried in windblown volcanic ash. Samples were also taken from contemporary growing specimens to calibrate with meteorological data. A comprehensive anatomical analysis was conducted on both type of samples (adopted from Gärtner and Schweingruber 2013). Due to the presence of very narrow rings (less than 50 μm), microscopic preparations were necessary. Climatologically indicative anatomical wood anomalies: Blue Ring (unlignified axial tracheids visible in blue after the double-staining thin sections reflecting past rapid cooling (Piermattei et al. 2015) and Frost Rings (frost

Fig. 1. Examples of centuries-old junipers *Juniperus communis* var. *saxatilis* Pall. (living and dead) discovered in 2024 in north-east Iceland (photo by Piotr Owczarek and Magdalena Opała-Owczarek).

induced irregular cellular areas filled with wound parenchyma (LaMarche and Hirschboeck 1984)) were emphasised using a complex laboratory procedure. Individual sequences of growth ring width were compiled into a chronology using cross-dating method (the high occurrence of so-called "signatures" was particularly important for dating, since these are patterns specific to only one period in time (Douglass 1941) and the presence of anatomical irregularities like BRs and FRs as independent time markers. To identify the climate signal embedded in the annual rings, a screening was performed in the treeclim R package. Next, a transfer function was established to reconstruct past temperatures over the whole period of the last thousand years.

3. RESULTS AND DISCUSSION

An outstanding site in northern Iceland is characterized by an unusual abundance of juniper specimens, occurring in an area restricted to Late Pleistocene age Þeistareykir lavas. Our dendrochronological research has discovered the oldest living organisms in Iceland. The substantial sample length for both living (mean = 248 years, max = 460 years) and dry wood (mean = 226 years, max = 465 years) contributed to the efficacy of this study, which resulted in the construction of a millennium-long growth ring chronology. Expeditions carried out in subsequent years have collected more and more older specimens, including some over 700 years old. This is also unique as a whole population of such old specimens has been found, and not just single junipers as has been reported from other parts of the arctic so far. The temperature of the short arctic summer is the dominant growth-limiting factor. Our new summer temperature reconstruction provides evidence for the late Medieval Warm Period (circa 1260s to 1370s) and various Little Ice Age Type Events (between circa 1380s and 1810s). The recent warming over northern Iceland is comparable to pre-industrial warm phases during the first half of the 18th century and the 1550s–1590s. Our wood anatomical investigation reveals reductions in cell wall lignification (i.e. Blue Rings) following volcanic eruptions. By synthesising textual accounts, dendrochronological markers, archaeological data, and socio-cultural insights, the research will construct a comprehensive timeline of environmental changes and their possible effects on Icelandic society (Opała-Owczarek et al. 2025).

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Air Temperature Conditions in SW Greenland in the Period 1806–1813

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In this paper, we present preliminary research findings on the thermal conditions of south-western Greenland (based on data from Godthåb [now Nuuk]) for the period from 1 November 1806 to 16 August 1813 (Fig. 1). As part of the ongoing NCN research project titled "Reconstructions of climatic and bioclimatic conditions in Greenland and Labrador/Nunatsiavut ca. 1770 to 1939 from Moravian Missionary observations (MORCLIM)", we discovered a handwritten manuscript (MA/154) in the archives of the Royal Society in London containing previously unknown meteorological measurements from Godthåb for the aforementioned period (Fig. 2). The meteorological observations were carried out by the German mineralogist Dr. Charles Lewis Giesecke (born Johann Georg Metzler [1761–1833]) (Fig. 3), or at least this is what the title page of the manuscript and the Royal Society catalogue describing the source suggests. However, given the numerous biographical accounts of his stay in Greenland (e.g., Monaghan 1993; Jørgensen 1996; Wyse Jackson 1996; Whittaker 2001), there is some doubt as to whether he conducted the meteorological observations alone. During that time, he undertook numerous research expeditions along the south-western coast of Greenland, from Upernavik in the north to Cape Farewell in the south. The purpose of these expeditions was geological research, particularly the collection of minerals. Someone must have been assisting him with the meteorological measurements, given that, over the six-year period (August 1807 – July 1813), there exists an almost complete series of observations taken three times a day (morning, midday, and evening). It is possible that the Moravian missionaries present in the area, who had extensive experience in conducting meteorological observations (Przybylak et al. 2024), were involved. Another possibility is that Giesecke conducted all his geological research during the first year of his stay in Greenland (as he had originally planned), and that, unable to return to Denmark due to the outbreak and continuation of the Napoleonic Wars (Whittaker 2001), he

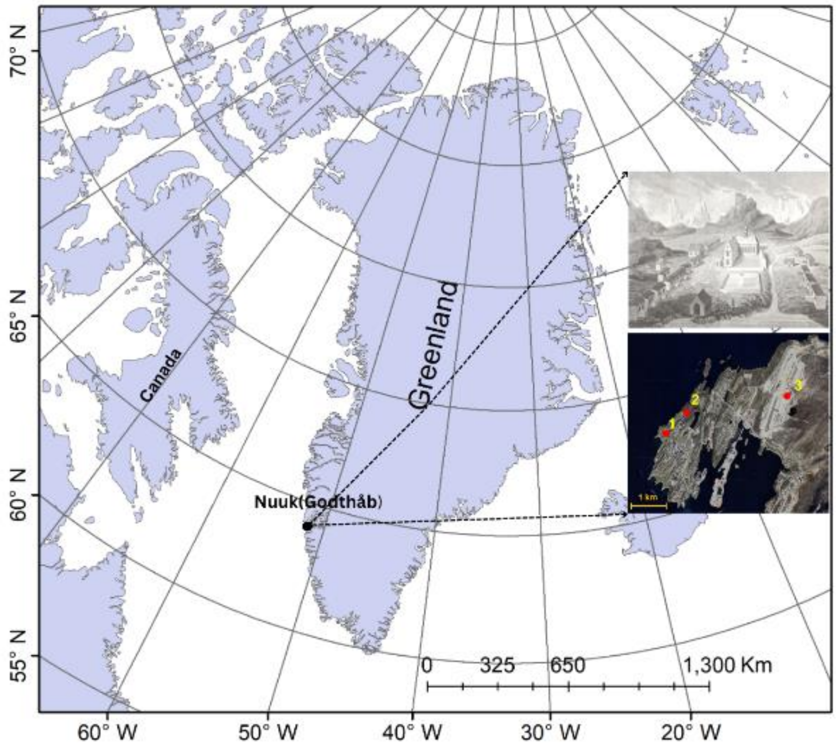

Fig. 1. Study area and location of historical and contemporary sites of meteorological measurements. Explanation: 1 – historical site Godthåb (1806–1813), 2 – 4250 Nuuk (1991–2020), 3 – 4254 Mittarfik Nuuk (2001–2020). Upper photo source: Neu-Herrnhut (Crantz 1820). Map data for location of sites: © Google Earth; images © 2023 Maxar Technologies, © 2023 Airbus, and © 2023 Asiaq.

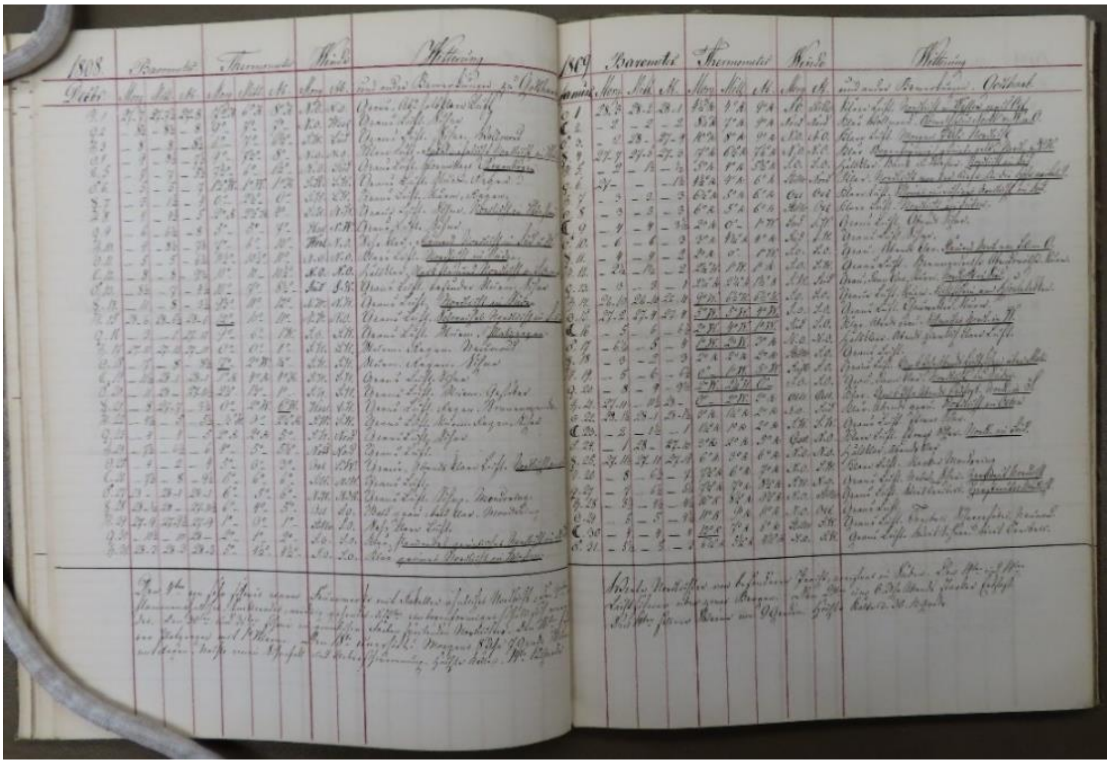

Fig. 2. Examples of manuscript presenting meteorological observations in Godthåb (1 November 1806 – 16 August 1813) (data presented in the manuscript: 1 December 1808 to 31 January 1809). Source: Archives in the Royal Society in London, MA/154.

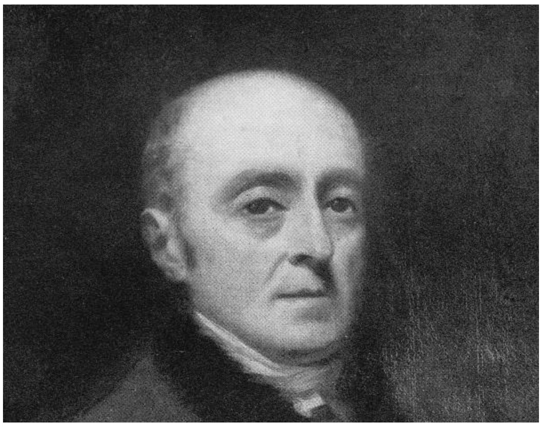

Fig. 3. Portrait of Sir Charles Lewis Giesecke (1761–1833), by the Scottish painter Raeburn (after Whittaker 2001).

decided to begin systematic meteorological observations starting in August 1807. He arrived in Greenland on 31 May 1806, and began meteorological observations only on 1 November 1806, which continued regularly until April 1807. From then until August, the observations were intermittent and irregular. It is therefore likely that he carried out his geological research during the periods of June–October 1806 and then May–July 1807.

As Fig. 2 shows, Giesecke conducted measurements and observations of the following meteorological elements: atmospheric pressure (morning and evening), air temperature (morning, midday, and evening), and wind direction (morning and evening). In addition, in the meteorological register, he briefly described the weather conditions for each day. At the end of each month, he also included a short summary of the weather conditions (at the bottom of the table of meteorological data). Unfortunately, the register does not provide information about the units used for the measurements, nor does it include details about the thermometer's exposure. It is assumed that the thermometer was placed on the north-facing wall outside the building where Giesecke lived. However, in the Arctic, where there is polar day during summer months, such placement does not fully eliminate the influence of solar radiation unless the thermometer is properly shielded.

In the article, we present the thermal conditions prevailing during that time. The unit used for air temperature measurements (°C) was determined by comparing the recorded values with parallel temperature observations conducted in another location in Godthåb during the years 1811–1812 (Vinther et al. 2006). The exact times of temperature measurements are unknown. Nevertheless, we calculated daily mean temperatures using a weighted average: $(T_{morning} + T_{midday} + 2 \times T_{evening}) / 4$. The obtained results were compared both with earlier temperature observations from the years 1784–1792 (Przybylak et al. 2024) and with later records, including modern observations from the period 1991–2020.

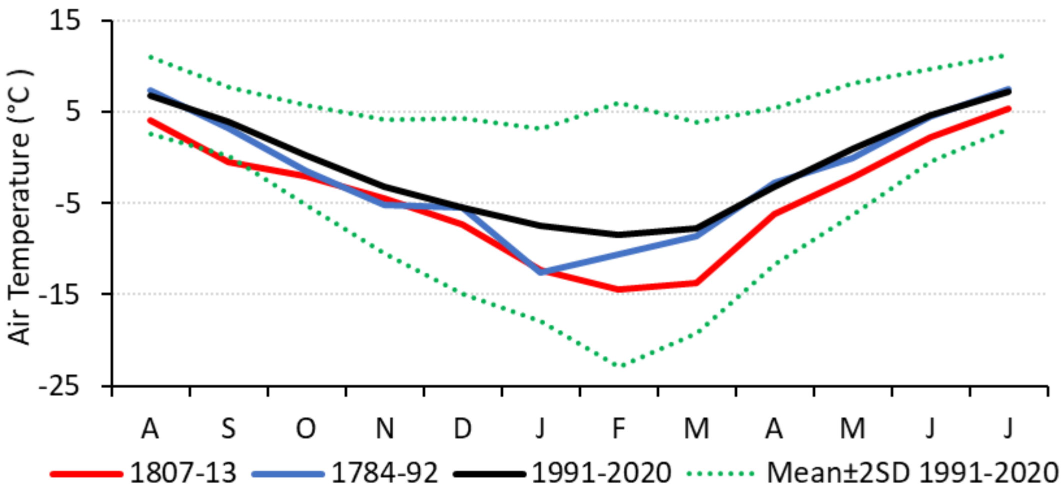

Fig. 4. Annual cycles of air temperature in the historical periods (1784–1792 and 1807–1813) and at present (1991–2020). Data for 1784–1792 taken from Przybylak et al. (2024).

Due to the irregularity of meteorological observations between 1 November 1806 and 31 July 1807, we present here an analysis for the period of regular observations, i.e. August 1807 – July 1813 (6 full years). The average annual temperature reached –4.0 °C, the coldest year was 1811 (–7.3 °C), and the warmest was 1809 (–1.8 °C). In the annual cycle, the coldest temperature occurred in February (–14.4 °C) and the warmest in July (5.3 °C) (Fig. 4). In the daily cycle, the highest average annual temperature was noted at midday (–2.1 °C) and the lowest in the evening (–5.1 °C). For all sub-daily measurement times, the warmest month was July, while the coldest was February (midday and morning) or March (evening). The highest temperature was observed on 16 July 1810 (18.5 °C), while the lowest was on 21–24 February 1812 (–36.5 °C). The temperature in the historical period was on average 3 °C colder than today (1991–2020). In the warmest month (July) in both comparative periods, this difference reached 1.7 °C, whereas in the coldest (February) it was 6.1 °C (Fig. 4). This was the greatest difference of all months.

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Ice on Hold: A Late Holocene Tale from the Barents Sea

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1. INTRODUCTION

The Barents Shelf is among the most dynamic sectors of the Arctic Ocean system, acting as a climatic frontier where polar and Atlantic influences meet. While the broader Arctic experienced sea-ice intensification from ~5 ka BP onwards—largely attributed to orbitally forced Neoglacial cooling (Wanner 2021)—our study reveals a distinctly delayed response on the northwestern Barents Shelf. This finding challenges traditional expectations of synchronous cryospheric change across high northern latitudes and raises questions about the role of regional oceanography in modulating sea-ice cover.

Earlier paleoclimate records, including glacier re-advances on Svalbard (Farnsworth et al. 2020) and declining summer insolation (Laskar et al. 2004), suggest atmospheric conditions had long become favorable for ice growth. Yet, the northwestern Barents Shelf remained largely ice-free until well into the Late-Holocene. Here, we investigate the underlying mechanisms of this delay using multi-proxy analyses of a sediment core.

2. MATERIALS AND METHODS

Our reconstruction is based on sediment core JM09-020, retrieved from Storfjordrenna, south of Svalbard (Fig. 1, 76°19′N, 19°42′E; 253 m water depth). The core was sampled every 4–6 cm and subjected to dinoflagellate cyst (dinocyst) analysis. The cyst assemblages were used to infer changes in sea-surface conditions, seasonal ice presence, and Atlantic Water (AW) inflow. Auxiliary proxy datasets include alkenone-based sea surface temperature (SST) reconstructions (Łącka et al. 2019), stable carbon isotopes of benthic foraminifera, and XRF-derived Ba/Ti ratios as a proxy for organic productivity (Łącka et al. 2015). Chronological control was achieved through radiocarbon dating and recalibration using the Marine20 calibration curve (Heaton et al. 2020) and a local reservoir correction.

To validate our findings regionally, we compared our results with biomarker-derived sea-ice records from the Olga Basin (core NP05-11-70GC) using the $P_{III}IP_{25}$ index (Berben et al. 2017). Details of the methodology can be found in Telesiński et al. (2024).

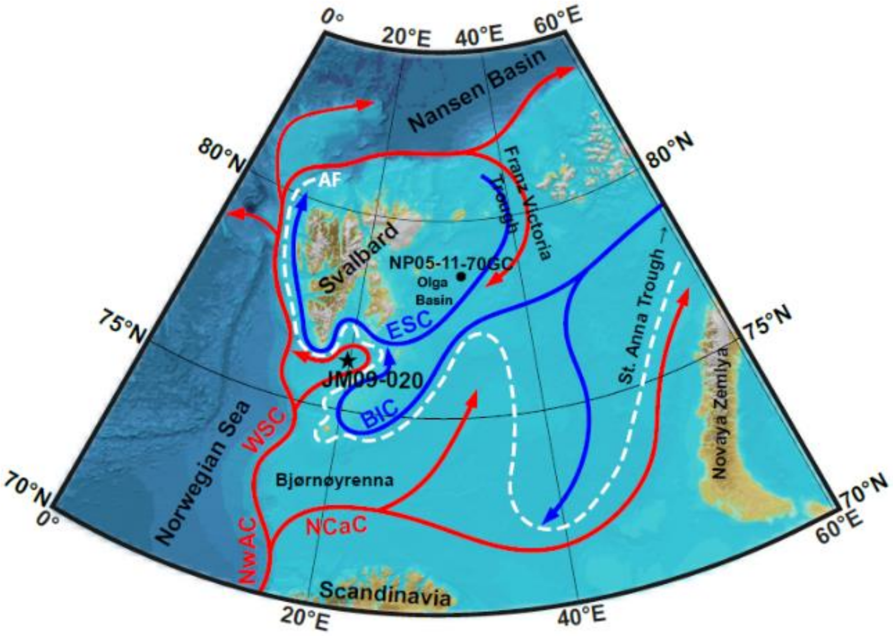

Fig. 1. Schematic map showing present-day surface water circulation in the Barents Sea. Red arrows indicate Atlantic Water, light blue arrows – Polar/Arctic Water, and white dashed line – Arctic Front (AF). The location of core JM09-020 is marked with an asterisk. The location of core NP05-11-70GC (Berben et al. 2017), also discussed in the paper, is marked with a dot. BIC – Bear Island Current, ESC – East Spitsbergen Current, NCaC – North Cape Current, NwAC – Norwegian Atlantic Current, WSC – West Spitsbergen Current.

3. RESULTS AND DISCUSSION

Our data indicate that the Storfjordrenna site remained ice-free from the Early Holocene until ~2.3 ka BP. *Echinidinium karaense*, a winter drift ice-indicative species (Telesiński et al. 2023), disappeared from the record after 8 ka BP and only reappeared at ~2.1 ka BP (Fig. 2).

A productivity peak at 2.3 ka BP suggests the proximity of the marginal ice zone, followed by a decline coinciding with increased winter ice cover. Notably, the abundance of *Operculodinium centrocarpum* s.l.—indicative of AW surface influence (Telesiński et al. 2023)

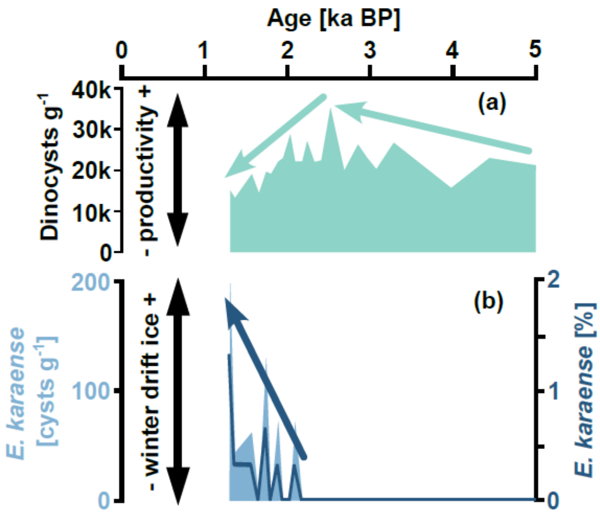

Fig. 2. Paleoceanographic proxies of Late Holocene changes in the northwestern Barents Sea from core JM09-020: (a) Dinocyst flux [cysts cm^{-2} yr^{-1}], (b) Flux [cysts cm^{-2} yr^{-1}] and relative abundance [%] of *Echinidinium karaense*.

—also peaked at this time before rapidly decreasing, signaling subsurface intrusion of AW beneath Arctic Water (ArW).

We propose that the delayed sea-ice response in the western Barents Shelf is primarily due to sustained surface influence of AW well into the Late-Holocene. The Arctic Front, typically topographically constrained, may have migrated further north and east during the Holocene Thermal Maximum, reducing the impact of cooling on local sea-ice formation. Only once AW was fully subducted below ArW did the conditions for sea-ice growth prevail.

This ~2 kyr lag between atmospheric cooling and sea-ice expansion implies a system with significant inertia, where oceanographic buffering via AW advection delays surface responses. Given the modern "Atlantification" processes resulting from enhanced northward heat transfer (Årthun et al. 2012), this has implications for the reversibility of current sea-ice loss.

4. CONCLUSIONS

Our record from Storfjordrenna provides robust evidence for a delayed sea-ice response in the northwestern Barents Shelf, occurring ~2.3–2.1 ka BP, despite Neoglacial atmospheric cooling beginning around 5 ka BP. This regional lag, likely driven by persistent AW inflow, highlights the importance of subsurface ocean dynamics in controlling Arctic cryosphere evolution.

Key takeaways:

- Paleoproxy evidence suggests a ~2 kyr delay in sea-ice re-expansion.
- Only once AW fully subducted below ArW did the conditions for sea-ice growth prevail.
- Modern warming may induce long-term loss in Arctic ice, even if global cooling resumes.

These findings underscore the challenge of reversing sea-ice decline in the Barents region and provide crucial insights into the temporal dynamics of polar climate systems.

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Inventory of Meteorological Records in the Labrador/Nunatsiavut and Southwestern Greenland Carried Out by the Moravian Brethren and their Successors Since the 18th Century

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As part of the National Science Centre research project entitled "Reconstructions of Climatic and Bioclimatic Conditions in Greenland and Labrador/Nunatsiavut ca. 1770 to 1939 from Moravian Missionary Observations (MORCLIM)", we visited numerous Moravian Church archives across Europe, including the Moravian Church House in Muswell Hill, London; the Unity Archives – Moravian Archives Herrnhut in Germany; and the Moravian Archives in Bethlehem in USA. Additionally, we consulted and checked several other archives and libraries where we suspected early instrumental meteorological data might be located for stations in southwestern Greenland and Labrador (see Fig. 1). A complete list of the archives and libraries visited is available on the project website: https://morclim.umk.pl/pages/research/.

During this preliminary archival research, we captured thousands of photographs of original handwritten manuscripts containing early instrumental meteorological data and weather notes (see Fig. 2), as well as secondary compilations of meteorological data found in 18th- and 19th-century scientific publications.

Many of these data, pertaining to air temperature, atmospheric pressure, as well as wind speed and direction, have already been transcribed, quality-controlled, and made available in the open data repository of the Centre for Climate Change Research (https://repod.icm.edu.pl/dataverse/ncu-cccr) under an open license, in accordance with the **FAIR** principles. Accordingly, the datasets by Demarée et al. (2023), Singh et al. (2023, 2024), and Chmist et al. (2024) are fully **F**indable, **A**ccessible, **I**nteroperable, and **R**eusable for further research and analysis.

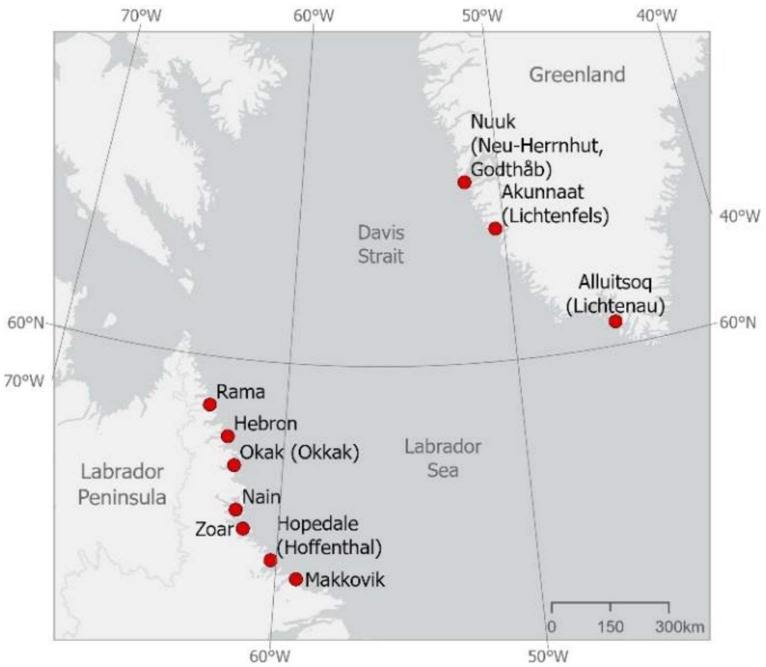

Fig. 1. Location of historical Moravian Brethren missions where meteorological measurements were carried out.

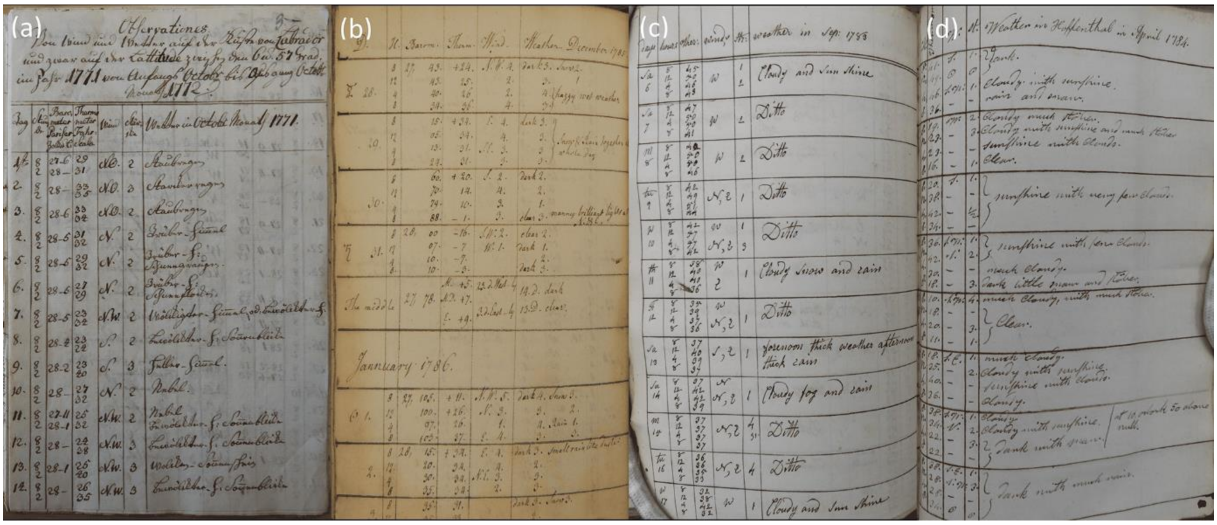

Fig. 2. Examples of manuscripts presenting meteorological observations: (a) Nain (1 October 1771 to 31 July 1786), source: Unitätsarchiv MDF.1817, the Moravian Archives in Herrnhut (Germany), data presented in the manuscript for 1 to 14 January 1771; (b) Nain (22 August 1777 to 31 July 1786), source: R.S.MA 143, The Archives of the Royal Society in London, data presented in the manuscript for 28 December 1785 to 11 January 1786; (c) Okak (1 August 1779 to 31 July 1784), source: R.S.MA 144, The Archives of the Royal Society in London, data presented in the manuscript for 6 to 17 September 1780; (d) Hopedale (1 October 1782 to 16 August 1786), source: R.S.MA 144, The Archives of the Royal Society in London, data presented in the manuscript for 25 March to 8 April 1784 (after Singh et al. 2025).

The oldest meteorological data series for southwestern Greenland and Labrador date back to the 18th century (see Fig. 3). For these series, we have detailed knowledge of their content, temporal coverage, and resolution. After the departure of the Moravian missionaries, meteorological observations in many of the aforementioned locations were continued throughout the 19th and 20th centuries by the national meteorological services of Denmark, Germany, and Canada. The data have been collected; however, they still require thorough cataloguing in terms of their content and potential use in further scientific research.

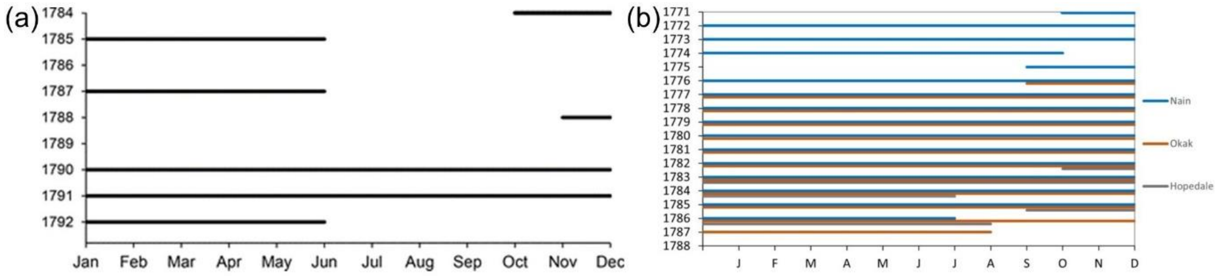

Fig. 3: (a) Coverage of air temperature data in Nuuk (previously Godthaab), 1784–1792 (after Przybylak et al. 2024) and (b) air temperature data availability for Labrador for the late 18th century (after Singh et al. 2025).

In this article, we present a detailed inventory of all archival materials collected to date containing early instrumental meteorological data for the coasts of Labrador and SW Greenland from the 18th to the beginning of the 20th century. This includes an in-depth analysis of their temporal coverage and observational gaps, the meteorological variables measured, and their resolution, as well as key metadata such as measurement methodologies, instruments used, observers, and other relevant contextual information.

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Towards "Atlantification" of the Arctic Ocean: Insights from Three Decades of Atlantic Inflow Observations

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1. INTRODUCTION

The Arctic is warming faster than the other regions on Earth due to amplification of anthropogenic climate change by sea ice loss and its impact on albedo feedbacks and heat uptake by the upper ocean. The physical environment of the Arctic Ocean is rapidly changing under ongoing warming. Not only air temperature is rising faster than average and sea ice is shrinking, thinning and its seasonal cover is lasting shorter but profound changes are also observed in the upper ocean climate and dynamics. The upper ocean heat content is rising to due advection of warmer waters from lower latitudes and increased solar warming. Warm and salty anomalies progressing from the North Atlantic into the Arctic Ocean through Fram Strait and Barents Sea result in "Atlantification" – a change toward more Atlantic conditions.

Understanding variable properties and dynamics of the Atlantic water (AW) poleward inflow is one of key prerequisites to elucidate mechanisms behind the new, warmer regime of the Arctic Ocean. As the AW progress northwards, its properties are modified by ocean-air interactions, mixing, and lateral exchanges. Vertical structure of the water column and density stratification set up the depth of winter convection and access to oceanic heat carried by the Atlantic inflow.

We present results from nearly three decades of hydrographic surveys, covering the AW inflow in the eastern Norwegian and Greenland seas, and the eastern Fram Strait up to the southern Nansen Basin. Interannual to decadal variability is analyzed with a focus on the en route modifications of AW properties in the Fram Strait Branch and varying ocean heat content. After leaving Fram Strait, the part of AW enters the Arctic Ocean along different pathways north of Svalbard. Strong ocean-sea ice interactions and lateral exchanges lead to substantial local modification of the Atlantic inflow before it continues farther eastward. Observations from year-round moorings deployed north of Svalbard since 2012 are used to describe changes in the AW vertical structure and dynamics and their links to the upstream conditions and atmospheric forcing.

2. INCREASING ROLE OF THE ATLANTIC INFLOW TO THE ARCTIC OCEAN

The spatial and temporal variability of the poleward flow of Atlantic water (AW) results in significant changes in the amount of oceanic heat delivered with the Fram Strait and Barents Sea branches to the Arctic Ocean. Understanding ocean circulation, the pathways of different Atlantic water branches, and the modification of Atlantic water properties during its northward transport is essential for estimating the impact of oceanic heat, mass, salt, and carbon transport on both local and pan-Arctic climate.

Recent studies show that the increasing temperature of Atlantic water entering the Arctic regions contributes to the retreat of the sea ice cover north of Svalbard and a rise in air temperature (e.g., Onarheim et al. 2014). Observations indicate that the oceanic heat flux significantly contributes not only to the melting of sea ice north of Svalbard (Renner et al. 2018) but may also play a crucial role in sea ice loss in the Eurasian Basin, where Atlantic water heat can more easily reach the under-ice boundary layer when ocean stratification weakens and the Atlantic water layer shoals (Polyakov et al. 2017).

Changes in Atlantic water temperature also affect the amount of oceanic heat used to melt sea ice in the regions north of Svalbard, while the resulting variations in the amount of surface freshwater from ice melt alter ocean stratification and heat fluxes toward the atmosphere and ice. Changes in the stratification of Atlantic waters entering the Arctic Ocean through Fram Strait influence the upper ocean circulation and the outflow of modified Atlantic and Arctic waters into the North Atlantic. A series of processes related to the propagation of temperature anomalies in the Arctic Ocean – especially in the Barents Sea and the Eurasian Basin – are collectively referred to as “Atlantification”, as first introduced by Polyakov et al. (2017) to highlight the role of Atlantic waters in the sea ice retreat in the European Arctic Ocean.

However, the propagation of ocean heat and freshwater anomalies is strongly modulated by regional processes and interactions that are not necessarily directly associated with the inflow of Atlantic water. As a result, the long-term warming trend of the inflowing waters is overlaid by short-term pulses of rapid temperature increase or decrease, or freshenung events, originating from both advective processes and local interactions between ocean, sea ice, and atmosphere. “Atlantification” is thus a cumulative result of long-term changes and superimposed sequences of warm/cold anomalies that modify both the total ocean heat budget and its redistribution along various Atlantic water transport branches. Changes in upper ocean stratification, driven by temperature and salinity anomalies altering the water column’s density structure, amplify ocean-ice-atmosphere interaction processes and increase heat fluxes, thereby reinforcing ongoing changes.

3. LONG-TERM OBSERVATIONS OF THE ATLANTIC INFLOW UNDER THE IOPAN MONITORING PROGRAM AREX IN 1996–2025

The Institute of Oceanology PAS (IO PAN) core activity, the long-term monitoring program AREX, is focused on multidisciplinary observations to study the long-term changes of abiotic and biotic Arctic environment. Every summer since 1987 the extensive field campaigns have been carried out in the Nordic Seas and European Arctic from the IO PAN research vessel Oceania. The main aim of the long-term AREX program is to elucidate processes responsible for changing ocean climate and marine ecosystem in the sub-Arctic and Arctic region with a special focus on the European Arctic. To achieve this goal a large-scale study area, covering the poleward flow of Atlantic water in the eastern Nordic Seas and Fram Strait, has been selected for annually repeated ship-borne measurements on a regular grid. Most of the regularly

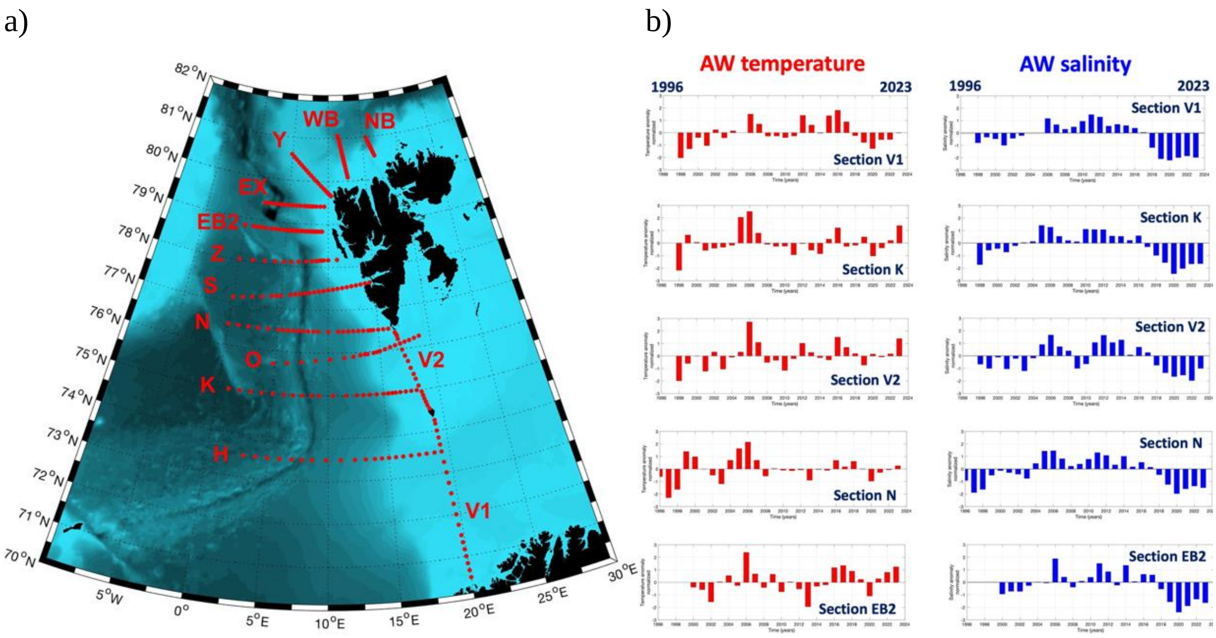

Fig. 1: (a) Regular station grid, repeated annually during the summer AREX campaigns of RV Oceania and (b) standarized anomalies of the Atlantic water temperature and salinity as measured at the main AREX sections in the Greenland Sea (section K), Barents Sea Opening (section V1), Storfjordenrenna and Sørkapp Current (section V2), the southern (section N), and northern (section EB2) Fram Strait.

repeated stations are distributed along several zonal sections, crossing the continental shelf break, and extending towards the deep basin. On the eastern side, the AREX oceanographic sections are limited by the Barents Sea shelf break and the shelf area west and north of Svalbard while to the west, the sections cross the Arctic Front, limiting the extent of Atlantic water in the Nordic Seas. The zonal sections following the Atlantic inflow from the Norwegian Sea to the northern Fram Strait allow to trace transformation of water masses originating from the North Atlantic and advected northward into the Arctic Ocean (Fig. 1).

Comparison of AW properties at the AREX main sections reveals alternating periods of warm/cold and saline/fresh anomalies (Fig. 1b). Three distinct events can be identified in the AW salinity time series: a predominance of negative anomalies from 1996 to 2003, a period of positive anomalies from 2004 to 2016, and a renewed period of strong negative salinity anomalies in Atlantic water, persisting since 2017. The time series of AW temperature anomalies show a less distinct pattern. This reflects stronger local modifications of temperature at individual sections compared to salinity, which is a more conservative tracer. Nevertheless, periods of pronounced positive temperature anomalies can be identified around 2006–2007 and again in 2016–2018. A rise in Atlantic water temperature observed since 2023 may indicate the onset of another episode of warmer water inflow from the North Atlantic. The recent increase in AW temperature, combined with the strongly negative salinity anomaly results in decreasing density of the inflowing Atlantic water and weakened stratification of the upper water column.

In our presentation we review in detail the spatial and temporal patterns of the observed AW anomalies on their way towards the Arctic Ocean and assess their impacts on the structure and variability of the Arctic Ocean Boundary Current, observed north of Svalbard with the array of oceanographic moorings.

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Glacial Influence on Micronutrient Cycling in Arctic Fjords: Seasonal and Spatial Variability in Svalbard

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1. INTRODUCTION

The Arctic coast undergoes rapid environmental changes due to glacier retreat and transition from marine-terminating to land-based (Kochtitzky et al. 2022). This transformation alters the pathways through which elements such as iron (Fe) and manganese (Mn) are transported from glaciers. These two key micronutrients, together with other trace elements like aluminum (Al), are delivered to fjords and coastal marine ecosystems from subglacial runoff and benthic processes (Herbert et al. 2020, 2021). These dramatic environmental changes can affect phytoplankton growth and marine biogeochemical processes (Wyatt et al. 2023). While previous research has emphasized the role of benthic recycling and riverine dissolved (<0.45 μm) elemental inputs, the seasonal and spatial variability of sediment-bound micronutrients, particularly in relation to glacier type and catchment geology, remains poorly understood. It is also unknown how a shift from tidewater to land-based glacier will affect micronutrient cycling and associated biogeochemical processes in the fjords (Meire et al. 2017).

With this study we aimed to determine the impact of local conditions (bedrock geology, glacier type and seasonality) on micronutrient cycling in three high Arctic fjord systems (Svalbard Archipelago).

2. METHODS

We investigated the influence of glacier type (tidewater vs. land-based), bedrock geology, and seasonal changes (spring vs. summer) on micronutrient cycling in ten fjords and associated riverine catchments in western and southern Svalbard. Sampling locations included fjords with both tidewater (TD) and land-based (LB) glaciers: 1) Trygghamna (LB) – Ymerbukta (TD), 2) Fridtjovhamna (TD) – Berzeliuselva (LB), 3) Recherchfjorden (TD) – Vestervågen (LB) – Josephbukta (LB), 4) Skoddebukta (TD) – Hansbukta (TD) – Gåshamna (LB).

Water samples were collected using Niskin bottles during summer 2022 and spring and summer 2023. For dissolved trace element concentrations, water samples were filtered (pore size 0.45 μm syringe filters) and acidified prior to analysis. Suspended particulate matter (SPM) for sequential extraction of iron species was collected on pre-weighed 0.45 μm PES (Polyethersulfone) membrane. These solids were also imaged and analyzed by scanning electron microscopy (FEI FEG Quanta 3D Dual Beam). Dissolved trace elements (Fe, Mn, Al) were quantified using high-resolution Inductively Coupled Plasma tandem Mass Spectrometry, (ICP-MS/MS, PerkinElmer NexION 5000), employing KED and DRC modes to reduce or remove interferences. Recovery of certified reference materials (NASS-5, CASS-6, and SLEW-4) was 80–120%. In all SPM samples, highly reactive iron and manganese (e.g., ferrihydrite, surface-bound Fe(II), poorly ordered Mn oxides) and more crystalline (oxy)hydroxides (e.g., aged ferrihydrite, lepidocrocite, and goethite) were extracted by ascorbic acid (FeA) and dithionite reagents (FeD), respectively (Raiswell et al. 2010; Lenstra et al. 2021).

3. RESULTS

Fjords influenced by tidewater glaciers generally exhibited higher concentrations of SPM and sediment-bound micronutrients compared to those fed by land-based glaciers. SPM levels were elevated in summer, especially in fjords with active tidewater glacier calving fronts such as Hansbukta, Ymerbukta, and Fridtjovhamna. In contrast, land-based glacier systems like Gåshamna, Josephbukta, and Berzeliuselva showed more stable and lower SPM concentrations across seasons. Intermediate values were observed in Vestervågen and Recherchfjorden, where glacial influence is present but less intense.

Sediment-bound Fe (FeD and FeA) was consistently (329 nM, 88 nM, respectively) higher than dissolved Fe (median 18 nM), with tidewater glacier systems showing significantly higher concentrations. Seasonal patterns were evident, with higher concentrations of both dissolved and particulate Fe observed in summer, likely due to increased meltwater input. Dissolved Fe showed less seasonal variation. SEM analysis showed iron oxyhydroxides on clay minerals in glacier SPM. In contrast to Fe, dissolved Mn (57 nM) was generally more abundant than sediment-bound Mn (20 nM and 6 nM for MnD and MnA, respectively) across all sites. Nevertheless, both forms of Mn showed higher concentrations in tidewater glacier fjords and during summer months, particularly in Fridtjovhamna and Recherchfjorden. Aluminum, although not a biologically essential micronutrient, was also measured due to its provenance from physical and chemical weathering on land (i.e. it is a potential geochemical tracer). Both dissolved and particulate Al were elevated in fjords influenced by tidewater glaciers and in riverine inputs such as Berzeliuselva.

4. CONCLUSIONS

Our results highlight the importance of glacier type and seasonal meltwater dynamics in controlling the availability and distribution of micronutrients in Arctic fjords (Svalbard Archipelago). Tidewater glaciers contribute more SPM and sediment-bound micronutrients than land-based glaciers, especially during summer. These findings suggest that continued glacial retreat and the transition to land-based systems may reduce the flux of bioavailable micronutrients to Arctic coastal waters as well as meltwater induced upwelling, potentially impacting marine productivity. Understanding these processes is crucial for predicting ecosystem responses to ongoing climate change in the Arctic.

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Modern Optical Tools Reveal Characteristics of Foraging Areas of Zooplanktivorous Little Auks *Alle alle* on the Western Spitsbergen Shelf

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Abstract

The Arctic environment is rapidly changing due to global warming, causing rising concern for key species of the north polar food web, especially a zooplanktivorous seabird, the little auk *Alle alle* and its prey. Energy-rich copepods, the main food source of little auks, *Calanus glacialis* and *Calanus hyperboreus*, form patches of high concentrations across the water column, which are difficult to detect via common net-sampling methods. New automatic in situ instruments provide the possibility to analyse the fine-scale distribution of *Calanus* spp. communities in relation to environmental background providing insights into little auks' foraging areas on a broader scale, focused on prey concentrations and quality.

In this study, two complementary optical methods, high resolution transects of the Laser Optical Plankton Counter (LOPC) and vertical casts of Underwater Vision Profiler (UVP6), were used to detect and examine abundance and morphology of *Calanus*-type zooplankton. Their distribution was studied accros transects and stations in two different areas of West Spitsbergen – near Hornsund and Magdalenefjorden fjords, two sites with the largest breeding aggregations of little auks in Svalbard – in the summer months of 2023 and 2024. Optical detection of particles and copepods were supplemented by environmental measurements (CTD, fluorescence, oxygen), all performed in the upper water-column layer (0–50 m depth), within a diving depth range of little auks. The abundance and transparency of particles and plankton were also compared between the two methods.

Both studied areas were exceptionally warmer in 2023 than in 2024, due to the warmer Arctic Water carried with the coastal current and less pronounced Polar Front, enabling mixing with Atlantic Water. It was also associated with increased chlorophyll *a* concentrations. Consequently, total and *Calanus*-type abundances were higher in 2023 than in 2024. Generally, abundances of particles and plankton were higher in Magdalenefjorden than in Hornsund, regardless of the study year. Atlantic Water off the Hornsund shelf had higher abundances of particles and plankton than the Arctic Water on the other side of the Polar

Front. However, distribution patterns of *Calanus*-type patches were quite specific for water masses at the Hornsund shelf. Higher concentrations of *Calanus*-type organisms were registered at deeper depths in Atlantic Water (≈ 25–50 m), compared to the Arctic Water (≈ 0–20 m). Transparency of particles and plankton showed opposed patterns across two water masses of the Polar Front. Atlantic Water was characterised by more transparent suspensions near the surface and more opaque particles registered in deeper water column layers. Whereas in Arctic Water, darker particles and plankton were observed only in surface and subsurface waters.

Environmental conditions had a significant impact on concentrations and morphology of particles and plankton. These temporal and environmental changes show that, to properly assess the quality of little auks' foraging areas, more regular and consistent monitoring is needed, with a higher number of UVP6 casts. Transparency of particles may be an interesting parameter for distinguishing those water masses and is worth further study.

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From Europe to the Arctic: Observational Evidence of Aerosol-Induced Heating Gradients and Their Role in Arctic Amplification

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Abstract

The rapid warming of the Arctic—occurring at a rate nearly four times faster than the global average—is a hallmark of climate change known as Arctic Amplification (AA, Rantanen et al. 2022). Despite extensive study, many mechanisms behind AA remain uncertain, particularly those involving long-range energy transport (Previdi et al. 2021). Among these, the role of atmospheric aerosols—specifically Light-Absorbing Aerosols (LAA) such as black carbon, brown carbon, and mineral dust—has emerged as a key but poorly understood driver (Schmale et al. 2021). While modeling studies have hypothesized that aerosol-induced heating at lower latitudes enhances poleward atmospheric energy transport (AET, Shindell and Faluvegi 2009), direct observational evidence has been lacking (Schmale et al. 2021).

This study addresses this gap by presenting novel experimental data collected during four scientific research cruises conducted between 2018 and 2022 aboard the R/V Oceania (Institute of Oceanology, Polish Academy of Sciences). The cruises covered latitudinal transects from mid-latitude Europe (Gdańsk, Poland) to the Arctic Ocean (up to 80 °N), including both summer and winter seasons. Measurements included aerosol absorption coefficients and incident solar radiation, which were used to calculate LAA-induced heating rates (HR**)** and the associated Atmospheric Power Surplus (APS)—a quantifiable metric of atmospheric energy accumulation.

Our study provides the first direct observational evidence showing how the heating effect of LAA decreases from Europe toward the Arctic. As we moved northward, we observed a clear and consistent drop in the amount of atmospheric warming caused by these aerosols. This pattern was especially visible during summer, with the strongest warming near continental Europe and a sharp decline as we approached the Arctic Ocean. In winter, the warming effect nearly disappeared in high latitudes.

This latitudinal pattern also translated into differences in how much extra energy the atmosphere retained due to LAA. Near Europe, the atmosphere gained significantly more energy compared to the Arctic, where this surplus became minimal. The difference was striking, showing that the energy accumulated in the lower atmosphere near Europe can be more than a hundred times greater than in the far North.

By applying an energy balance model, we found that this difference in energy input could help explain why the Arctic is warming more strongly than mid-latitude regions—even in places where there are no significant local emissions (Shindell and Faluvegi 2009). Our results suggest that aerosols emitted far from the Arctic, especially from mid-latitudes, can still influence Arctic warming by altering the balance of atmospheric energy and enhancing northward energy transport (Sand et al. 2013).

These findings provide valuable experimental confirmation for a theory that has so far relied mainly on modeling studies: that distant pollution sources can affect climate in remote regions like the Arctic (Navarro et al. 2016). Our work highlights the importance of considering the global impact of regional emissions and points to the need for international efforts to reduce emissions of light-absorbing aerosols, particularly black carbon, to protect the fragile Arctic climate system (Laskin et al. 2015).

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The manuscript containing the full results of this research has been submitted to Nature Communications and is presently undergoing the review process (Ferrero et al., manuscript assignment NCOMMS-24-48156-T).

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From the Baltic Sea to the Arctic: International and Interdisciplinary Research Cruise of r/v OCEANOGRAF and s/y OCEANIA

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1. INTRODUCTION

The Baltic Sea is a semi-enclosed, brackish water body that receives significantly more freshwater input from rivers and precipitation than it loses through evaporation and outflow. To balance this excess, there is a continuous surface outflow of brackish Baltic water through the Danish Straits, Kattegat, and Skagerrak. The outflowing surface water joins the Norwegian Coastal Current and flows along the coast of Norway into the Barents Sea. Additionally, the catchment area of the Baltic Sea is more than four times larger than its surface area, making it especially vulnerable to the accumulation of pollutants, originating from a densely populated and highly urbanized regions of Central and Eastern Europe (HELCOM 2010).

We hypothesized that the outflowing Baltic water carries possible pollution, relatively high load of nutrients, dissolved organic matter, and planktonic organisms from the Baltic Sea, enriching and influencing the fully saline Nordic Seas this way. To test this hypothesis, two Polish research vessels, r/v OCEANOGRAF (University of Gdańsk) and s/y OCEANIA (Institute of Oceanology PAS), followed the Baltic seawater outflow along the Scandinavian Peninsula (Fig. 1), working together in international and interdisciplinary teams. The goal of the project was to study these brackish water masses, along with their physico-chemical properties and associated biota, flowing out from the Baltic Sea towards the Arctic.

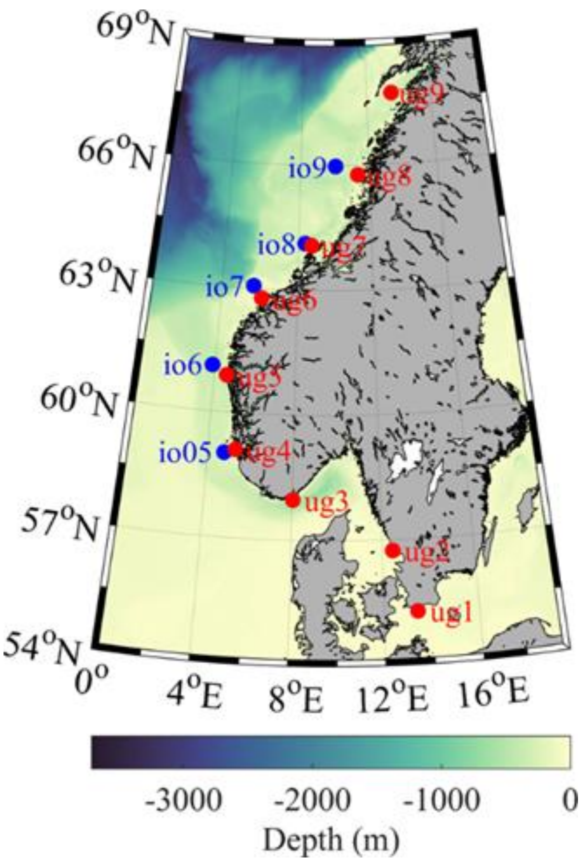

Fig. 1. The map of sampling stations by r/v OCEANOGRAF (red) and s/y OCEANIA (blue).

2. PRELIMINARY RESULTS

Twenty surface drifters launched during the cruise remained on the continental shelf, distinguishing the Norwegian Coastal Current from the offshore Norwegian Atlantic Slope Current; some ended up in the Barents Sea, confirming a northward path of Baltic seawater outflow reaching high latitudes, as predicted by the numerical Regional Arctic System Model of high horizontal resolution.

The chemical analysis of seawater revealed differences between offshore and coastal zones, and along the transect. Elevated concentrations of phosphate and nitrate in coastal waters suggest the land-based runoff, while variations in conductivity and total organic carbon reflect the mixing of waters from different origins. We observed decrease of stable carbon isotopes (δ13CPOC) values northwards and variable stable nitrogen isotopes (δ15NPOC). Results also showed the marygenic origin of chromophoric dissolved organic matter in all samples, with a sharp decrease in aromaticity northwards. Additionally, a net output of perfluoroalkyl and polyfluoroalkyl substances, a group of persistent, toxic, synthetic chemicals, from the Baltic towards the North Sea, was detected at low levels in all samples, and at higher concentrations in surface waters. The highest total mercury concentration in suspended particulate matter was measured near Bodø, while in zooplankton and phytoplankton at the Baltic Sea – North Sea section. The sea surface microlayer was enriched with heavy metals, polycyclic aromatic hydrocarbons and elemental carbon, related to the combustion of fossil fuels. The sea surface microlayer was enriched with heavy metals, polycyclic aromatic hydrocarbons and elemental carbon. On most of the stations it was directly related to the anthropogenic origin, mainly from combustion of fossil fuels (Diesel and organic burning).

Gradual decrease in chlorophyll *a* concentration in surface waters was observed northwards; and marker pigments analysis showed the occurrence of diatoms, prochlorophytes, prasinophytes, cryptophytes, chlorophytes, and cyanobacteria in varying proportions along the transect. $\Delta N_2/Ar$, a tracer for N_2 fixation, indicated similar variable trends. Consequently, we observed a shift in phytoplankton communities: from the predominance of cyanobacteria in the Baltic Sea, a bloom of diatoms in Kattegat, to dinoflagellates- and diatoms-abundant waters further north. Interestingly, in the coastal waters of the Norwegian Sea, single trichomes of poor-conditioned cyanobacteria *Nodularia spumigena* and *Aphanizomenon flos-aquae* were observed, possibly transported from the Baltic Sea. Underwater Vision Profiler revealed changes in the concentration of zooplankton and marine snow, with decreasing amounts of detritus towards the north. Additionally, hydroacoustic data, collected using split beam echosounder, demonstrated northward acoustic biomass growth, patchy horizontal distribution of biological objects, and the impact of thermohaline on their vertical distribution.

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SUDEA: Conducting Arctic Research from Outside the Arctic. Key Constraints to Sustainable Urban Development in the European Arctic

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1. INTRODUCTION

The aim of this presentation is to share the experiences and outcomes of a Polish-German research project conducted between 2020 and 2024, funded by the National Science Centre (NCN) and the German Research Foundation (DFG), which examined the challenges to sustainable urban development in the European Arctic. Carried out during the COVID-19 pandemic, the project required adaptations to qualitative research methodologies—particularly the shift of interviews and consultations to remote formats. This transformation introduced new limitations but also opened up a space for critical reflection on conducting social research "from outside" the studied region.

2. THEMATIC SCOPE OF THE STUDY

The paper will focus on two main areas:

(1) Methodological challenges of conducting social research in the Arctic without direct field presence. The discussion will include approaches to maintaining researcher–participant relationships in online environments, issues of access to local knowledge and building trust

at a distance, as well as limitations resulting from the lack of direct participation in the everyday life of Arctic communities.

(2) Findings on the implementation of sustainable development policies in Arctic cities (Wehrmann et al. 2025). Based on the analysis of interview data and municipal policy documents, the paper will present key constraints in implementing global agendas—such as the Paris Agreement, the 2030 Agenda, and the New Urban Agenda—within the local contexts of peripheral cities in the European Arctic. Particular attention is given to:

a) the impact of the multidimensional effects of climate change on urban functioning,
b) tensions related to the crisis of international cooperation in the Arctic,
c) barriers to effective local participation in planning and implementing development policies.

The presentation shares insights gained from conducting research under the challenging conditions of the pandemic and demonstrates how methodological challenges are deeply intertwined with the research topic—the dynamics of local and global processes in a region marked by high levels of uncertainty and volatility.

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Regional Security Complex in the Arctic – Transformations and Development Trends

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Abstract

Ongoing research on international relations in the Arctic allows for the assumption that since the Arctic is treated as a separate region in geographical terms, it can also be seen as a particular sub-system of international relations. The region comprises eight states that act to ensure a secure existence by pursuing their own goals and interests in the international arena. This creates a security relationships (Sadurski 2024; Exner-Pirot 2013; Hettne 2005).

The Regional Security Complexes (RSC) theory is a research framework to analyze the region's security. It clarifies international relations at the regional level, provides a picture of the security environment in the region, and enables one to see the directions of change towards securitized phenomena that change the face of the complex (Buzan and Weaver 2003; Buzan et al. 1998).

One such phenomenon is climate change, the effects of which are challenging Arctic states whose adaptation efforts are leading to transformations in international relations at the regional level (Sadurski 2022).

Another phenomenon is the full-scale war in Ukraine, which, as an extra-regional factor, influences the formation of the Arctic Regional Security Complex and its development (Sadurski 2023a).

This presentation is, inter alia, the result of research conducted within the framework of the implementation of the research project of the National Science Centre entitled "The adaptation of the regional security complex in the face of climate change: the example of the Arctic" (Sadurski 2023b) and aims at:

1) analysing the Arctic from the perspective of RSC theory;
2) show the polar region as a separately functioning system of international relations with its own security dynamics related, inter alia, to the challenges of climate change and the full-scale war in Ukraine;
3) identifying developmental trends through selected examples.

Keywords: Arctic, regional security complex, security, changes in the Arctic region.

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Adapting to the Extremes: The Role of Personality, Ego Resiliency, and Values in Polar Expeditions

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1. INTRODUCTION

Working in isolated, confined, and extreme (ICE) environments, such as Arctic and Antarctic research stations, presents numerous psychological challenges (Palinkas and Suedfeld 2021). These challenges make psychological resilience, personality traits, and personal values critical to successful adaptation. This study investigates the relationships between personality, ego resilience, and values in the context of adaptation to ICE conditions. It further explores gender, regional, duration-based, and national differences in these psychological variables, building upon previous research (e.g., Bishop et al. 2010; Kaczmarek 2019; Nicolas et al. 2019**;** Smith et al. 2017).

2. CONTEXT AND BACKGROUND

Research has consistently shown that certain psychological predispositions play a key role in how individuals cope with and adapt to stress-inducing environments (Kaczmarek 2019). Ego-resiliency, as demonstrated in studies by Kaczmarek, Sęk, and Ziarko (Kaczmarek et al. 2011), facilitates flexible adaptation, which is essential in ICE environments. Traits such as low neuroticism, high extraversion, openness to experience, and agreeableness have been associated with better adaptation in polar conditions (Bishop et al. 2010; Terlak 1982). Values are equally relevant. According to Smith et al. (2017), values such as self-direction, stimulation, universalism, and benevolence were prioritized by individuals in extreme environments. Previous studies have also indicated that cultural and gender differences might influence group dynamics and adaptation outcomes (Grant et al. 2007; Sandal et al. 2006; Strewe et al. 2019).

3. RESEARCH QUESTIONS

The following research questions were posed:

(1) Are personality traits, ego resiliency, and personal values related to adaptation to ICE environments?
(2) Are there differences between men and women in the explored psychological characteristics?
(3) Are there differences between individuals working at Arctic versus Antarctic stations in the explored psychological characteristics?
(4) Are there differences between individuals on short-term versus year-round stays in the explored psychological characteristics?
(5) Are there differences between individuals of different nationalities in the explored psychological characteristics?

4. METHODOLOGY AND RESULTS

a. Participants

The 109 individuals (35.78% women) took part in the study. Participants aged 26–77 (M = 48.84, SD = 13.91), all with professional experience in polar stations, participated. 60.55% had worked in Antarctica, 15.6% in the Arctic, and 23.85% in both. 44.95% had short-term experience, 30.28% long-term, and 24.77% both. The study involved participants of various nationalities; therefore, the questionnaires were provided in three language versions: Polish, English, and Portuguese. The Polish version was completed by 48 participants, the English version by 44, and the Portuguese version by 17. In total, 44.04% of participants identified as Polish, 26.61% as American, 15.60% as Brazilian, and 13.76% represented other nationalities.

b. Measures

The following measurements were applied in the study:

- ICE-Q (Isolated and Confined Environments Questionnaire)
- HEXACO Personality Inventory
- PVQ-40 (Portrait Values Questionnaire)
- ER-89 (Ego Resiliency Scale)

c. Results

Preliminary study outcomes are as follows:

The analyses revealed several significant associations between psychological traits and adaptation to ICE (Isolated, Confined, and Extreme) environments. Extraversion was found to be moderately positively correlated with self-rated adaptation ($\rho = 0.27$; $p = 0.038$). Further analysis of the HEXACO personality traits showed that different traits were differentially associated with various dimensions of adaptation as measured by the ICE-Q. Physical adaptation was negatively correlated with emotionality ($\rho = -0.34$; $p = 0.008$). Social adaptation was positively associated with agreeableness ($r = 0.45$; $p < 0.001$) and conscientiousness ($r = 0.31$; $p = 0.015$). Emotional adaptation showed positive associations with honesty–humility ($\rho = 0.32$; $p = 0.012$) and openness to experience ($\rho = 0.35$; $p = 0.006$). Total adaptation scores were positively correlated with agreeableness ($\rho = 0.35$; $p = 0.007$) and honesty–humility ($\rho = 0.27$; $p = 0.037$).

No significant relationship was found between ego resiliency and subjective adaptation ($\rho = 0.13$; $p = 0.318$). Interestingly, ego resiliency showed a significant negative correlation with professional adaptation ($r = -0.30$; $p = 0.021$), suggesting that higher levels of ego resilience may be associated with lower perceived professional adjustment in ICE contexts.

Subjective adaptation was significantly positively correlated with several value dimensions, including conformity ($\rho = 0.38$; $p = 0.002$), power ($\rho = 0.30$; $p = 0.019$), and universalism ($\rho = 0.26$; $p = 0.045$), with a trend-level association observed for tradition ($\rho = 0.25$; $p = 0.051$).

Associations were also found between values and specific ICE-Q dimensions. Physical adaptation was positively related to conformity ($\rho = 0.38$; $p = 0.002$), tradition ($\rho = 0.27$;

p = 0.037), and universalism (ρ = 0.27; p = 0.040). Social adaptation was significantly associated with conformity (r = 0.36; p = 0.005), tradition (r = 0.26; p = 0.042), and security (r = 0.29; p = 0.024). Emotional adaptation was positively associated with universalism (ρ = 0.37; p = 0.004), and negatively associated with power (ρ = –0.29; p = 0.026). Finally, overall adaptation was positively related to conformity (ρ = 0.35; p = 0.006).

Analyses revealed significant gender differences in certain personality traits and values. Women scored significantly higher than men on honesty–humility (M = 47.08 vs. M = 43.76; p = 0.003) and emotionality. No significant gender differences were observed in ego resiliency (U = 308.00; p = 0.347).

Regarding personal values, men reported significantly higher scores on security (p = 0.005), tradition (p = 0.004), achievement (p < 0.001), and power (p = 0.006), whereas women scored higher on universalism (p = 0.045).

When examining regional differences based on deployment location (Arctic vs. Antarctic), conscientiousness was the only personality trait that differed significantly across groups (F(2) = 6.87; p = 0.032); however, post-hoc comparisons did not yield significant pairwise differences. No significant regional differences were found in ego resiliency (F(2, 106) = 0.09; p = 0.910).

In terms of values, a significant difference emerged for security (F(2, 106) = 3.18; p = 0.045), with participants stationed exclusively in Antarctica reporting higher levels of this value dimension.

No significant differences were found in ego-resiliency levels between participants of different nationalities. However, significant cross-national differences emerged in several personal value dimensions. Brazilians scored higher in security and conformity compared to Poles and Americans. Participants of other nationalities scored lower in achievement than Americans and Brazilians. Additionally, Poles scored lower in hedonism compared to participants of other nationalities.

5. CONCLUSIONS

The findings show that personality traits and personal values significantly impact adaptation to isolated, confined, and extreme (ICE) environments. Extraversion, agreeableness, and honesty–humility were linked to better adaptation, especially in social and emotional domains. Surprisingly, ego-resiliency did not predict better adjustment and was negatively related to professional functioning. Values such as conformity, universalism, and tradition supported higher adaptation, particularly in physical and social areas. Cultural differences, like Brazilians scoring higher in security and conformity, suggest national values may shape adaptation styles. These insights may guide recruitment and training for polar missions, highlighting the importance of interpersonal traits and shared values.

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Climate Change in the Perception, Lifestyle and Political Attitudes of Arctic Inhabitants

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1. INTRODUCTION

The Arctic is a place that serves as a unique lens for observing both natural and social changes related to climate change. In this region, warming is progressing more intensely than in the rest of the planet. As glaciers and sea ice melt, the geopolitical significance of the area increases. It has become the subject of new international competition for fossil fuel resources hidden beneath the permafrost, control over new shipping routes, and political as well as military dominance in the region. These processes—both in their natural and political dimensions—directly affect the lives of the inhabitants of the Arctic Region, their sense of security, physical and emotional well-being, patterns of daily activity, and the preferred models of management for survival in the era of climate crisis. Recognizing these processes is crucial for formulating forecasts regarding social processes and changes in areas that will experience the consequences of climate change with a delay compared to the Arctic region. In turn, understanding them seems to be key in the context of designing local as well as global programs of social ecological practice, strategies for adapting to climate change, and—more broadly—an effective agenda for combating the climate crisis.

2. RESEARCH PROBLEMS AND HYPOTHESES

The aim of the speech is to answer the following research questions: 1. Do the inhabitants of the Arctic perceive the natural and social consequences of climate change? And if so, to what extent? Which of these changes are most strongly felt by them? 2. Where do Arctic residents obtain knowledge and information about climate change? 3. Does climate change affect the daily practices, activities, culture, and traditions of the indigenous peoples of the Arctic? And if so, to what extent? 4. How do Arctic inhabitants respond to adaptation and mitigation strategies proposed by politicians? Which model of climate crisis management is closest to them? Answering these questions will allow for the verification of the author's hypotheses, according to which:

H1: The perception of climate change among Arctic residents is weaker than the pace of these changes as expressed in statistical data on changes in average temperature or ice structure.

H2: Arctic inhabitants see both threats and opportunities for the development of the region and local communities in climate change.

H3: Climate change and the growing geopolitical importance of the Arctic serve as an impetus for the indigenous population towards independence, autonomy, and greater participation in decision-making processes concerning the management of natural resources or envi ronmental protection.

3. METHODS AND THE COGNITIVE POTENTIAL OF RESULTS

The research process made particular use of the aforementioned secondary analysis of available quantitative and qualitative results of public opinion research conducted among the region's inhabitants (both indigenous and migrants), as well as publicly available statistical data concerning, among other things, changes in health status, crime, addictions or suicidal behaviors among Arctic residents. Strategic documents and statements by local authorities and activists regarding the political position of the Arctic in the modern world and desired models of adaptation and counteracting climate change were also analyzed.

The results of the presented research project have enormous cognitive potential in the context of understanding the social consequences of climate change and the social responses generated by them. As already signaled, the changes occurring in the Arctic are—according to numerous experts—an indicator of global climate and environmental trends. The analysis of adaptation strategies, political attitudes, health, or educational problems of the inhabitants of the studied area constitutes a source of knowledge of universal value and may, in the long term, become an inspiration for residents of other regions of our planet.

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Arctic Fieldwork Safety: Risk Management, Training, and Indigenous Knowledge

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1. INTRODUCTION

Arctic adventure tourism is growing rapidly, increasing both the risk of accidents and the strain on local emergency preparedness systems (Hild et al. 2023). This research investigates the relationship between the competencies of outdoor leaders—including adventure guides, scientists, and field researchers—and their ability to ensure safety in the Arctic. Focusing on Iceland, Svalbard, and Greenland, it examines how training, safety practices, and risk management strategies intersect with local capacities and the evolving demands on search and rescue (SAR) systems.

This study, representing the completed PhD research on adventure guide competence in the Arctic, draws on four years of qualitative data collection, including interviews, participant observation, document analysis, and stakeholder workshops. A central focus was to examine leadership competence in relation to field-based risk management (Hild and Weiler 2024), with particular emphasis on how such competence is developed through training programs. With the increasing intensity of field operations in Greenland, the research places special emphasis on this region, presenting findings from fieldwork that explore how guides acquire safety competence during training. The study advocates for more inclusive and context-specific training frameworks that integrate Indigenous methodologies and local knowledge systems. It further calls for a collaborative, interdisciplinary approach to Arctic safety that bridges sectors such as tourism, education, and scientific research (Hild and Jóhannesson 2023).

This work contributes to the growing body of Arctic safety science by bridging the fields of outdoor adventure education, field research, and tourism studies. Through action research and stakeholder engagement, it presents safety as a shared responsibility shaped by knowledge co-creation, competence development, and context revelant practices. The study proposes practical steps toward more effective and culturally responsive risk management strategies in Arctic adventure tourism and scientific fieldwork.

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Tracking Glacier Extent and Surging on Svalbard with Sentinel-1 InSAR Coherence and Backscatter Amplitude

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1. INTRODUCTION

Svalbard's glaciers are among the most dynamic elements of the Arctic landscape, and their variable extent is a sensitive indicator of the rate of climate warming. Episodes of surging – sudden, accelerating ice flows after a period of quiescent phase – play a special role in shaping the archipelago's relief. However, effective monitoring of glacier fronts is hampered by long periods of polar night, cloud cover and poor field accessibility. The current work demonstrates that two easily derived products from Sentinel-1 radar interferometry: coherence and signal amplitude, are sufficient to capture both the long-term trends of glacier retreat and the initial phases of surging.

2. DATA AND METHODS

The analysis included a set of Sentinel-1 IW imagery from 2015–2023, covering all major Svalbard glaciers. Coherence and calibrated amplitude maps were calculated for successive time pairs, and then assembled into a regular time series. The coherence was treated as a measure of the integrity of the ice surface – a decrease in coherence indicates intense deformation, the presence of meltwater, or short-term modifications of the firn surface such as melt-refreeze events or fresh snow deposition. In turn, changes in amplitude were interpreted as the effect of seasonal ice exposure, snow deposition or deeper ice masses. Glacier boundaries were tracked by the amplitude contrast between the ice and the underlying rock or sea, while sudden drops in coherence at the kern were interpreted as an early signal of the transition of the ice into a sliding regime, typical of the pre-surging phase.

3. RESULTS

There is a clear, albeit spatially varying, trend of retreating ice fronts across the archipelago. Most of the valley and shelf glaciers show a gradual retreat, especially in the southern part of Spitsbergen, where a rise in air temperature and an increase in the proportion of rain in winter precipitation co-occur. On the other hand, several glaciers – including Tunabreen, Skobreen and Monacobreen – presented a full or partial cycle of surging during the period under study. The initial phase of the surging was manifested by several months of systematic loss of coherence in the middle reaches, followed by a sharp increase in amplitude as the young, rough ice reached the front.

The combination of coherence and amplitude makes it possible not only to distinguish glaciers conducting a systematic retreat from those preparing for surge, but also to determine the approximate timing of the arrival of the phase of rapid acceleration. The absence of the need to determine velocity fields or solve the phase of interferograms significantly simplifies the procedure and reduces the calculation effort, opening the way to quasi-permanent monitoring of range changes in Arctic conditions.

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Ice Mass Variation at Svalbard Observed by GNSS Sites Position Changes

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Abstract

In this paper we present long-term position changes of permantent GNSS sites located at Svalbard. These variations, along with crust physical properties, are utilized to infer ice mass loading changes. We found good agreement of our indirect estimation with values provided by classic glaciology. This study shows that this passive method can be easily applied for regional ice mass varaiation assesment, however with sparse GNSS network, any regional discremination is still challenging.

1. INTRODUCTION

Permanent sites of Global Navigation Satellites Systems (GNSS) usually serves as reference for terrestrial differential measurements, but they can be used for many other purposes. Using state of the art processing methods we are able to obtain daily and sub-daily position at a few millimeter accuracy at global frame. Variation in position can stem from many geophysical factors, but at Svalbad we observe dominant change in height component of 1 centimeter per year. This is mainly due to present day ice melting (PDIM) and glacial isostatic adjustment (GIA). Separating this two phenomena is challenging but possible. The rates of height changes are directly related with variation of crust loading. From this values we are able to recover regional ice mass changes. Within this work we show expanded version of previous estimates (Rajner 2018; Kierulf et al. 2022).

2. METHODS DATA AND PROCESSING

We used several permanent sites located at Svalbard at Hornsund, Ny-Alesund, Longyearbyen. This sites serves in global and European GNSS services. In this work we present for the first time very long time series from Hornsund with data not published previously. We used most advanced processing software for reliable and precise position estimates. We also used several numerical data to get the best fitting ice mass variation. These computation was done by means of Greens functions for crust deformation due to variable load.

3. RESULTS

We found very good agreement of our estimates with other studies of 15 Gt per year. We were also able to indicate periods with increased rates of ice loss. The seasonal variation was also retrieved. All of these variations are based on height changes rates. Interestingly we observed also variation in length of baselines which also can be attributed to loading variation. These horizontal component add some more information but is usually neglected.

4. CONCLUSIONS

We presented method to indirectly interfere ice mass variation from GNSS sites position variation. This method can be easily adopted, and give additional information to classic mass budget methods.

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Impact of Climate Warming on Glaciers in Central Spitsbergen, Svalbard – a 25-year Perspective

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1. INTRODUCTION

In conditions of the Arctic amplification of climate warming the most impressive landscape effect is observed in Svalbard in connection with glaciers retreat. Since the beginning of the 21st century, when GPS measurements with satisfactory precision became widely available, the number of publications appeared following the first paper on glaciers margins positions (Rachlewicz et al. 2007). The aim of the paper is to compare the results of retreat rates of glaciers and show the landscape dynamics of their marginal zones in the central part of Spitsbergen collected during the last 25 years of observations on the background of verified archive sources going back to the Little Ice Age termination.

2. RESULTS

In the cited paper the retreat of twelve glaciers near northern Billefjorden, Spitsbergen, between 2000 and 2005 was examined. Using various measurement methods, including GPS, aerial photographs, satellite imagery, and geomorphological indicators, glacier deglaciation since the Little Ice Age (LIA) climax at the end of the 19th century was presented. All glaciers have been retreating, with tidewater Nordenskiöldbreen the fastest, at an average of 35 my^{-1}, while land-terminating glaciers rates were 5 to 15 my^{-1}. The retreat rates have increased significantly in last decades of 20th century, largely due to climate warming. Factors influencing retreat include water depth at grounding line of the glacier terminating at sea, surging history, and glaciers morphology. The study generally categorized Svalbard glaciers into four types based on retreat velocities: very dynamic surging tidewater glaciers retreating 100–220 my^{-1}, other tidewater glaciers 15–70 my^{-1}, polythermal valley glaciers 10–20 my^{-1}, and small, cold based glaciers less than 10 my^{-1}. Overall, the findings highlight patterns of glacier change in response to climate and local conditions across Svalbard.

The following 20 years is exhibiting even more intensive air temperature rise and in consequence more dynamic environmental change. The inner-fiord area of central Spitsbergen is the driest part of the island and despite the rise of precipitation in warming conditions of dramatic scale, there is less of snow deposition (practically no long-term accumulation on glaciers), higher evaporation, more intensive melting, shorter period of sea-ice cover implicating higher level of heat storage, all together leading to ablation almost an order of magnitude higher than in the previously described circumstances. Some glaciers areas distinctively diminished, while some vanished completely. To complete the picture of changes in the area of glaciers coverage, in reference to Geyman et al. (2022), a larger number of archival sources in the form of rectified aerial pictures and satellite images were analyzed and earlier results were also recalculated, although major differences were found in more recent periods.

3. CONCLUSION

Retreat rates of glaciers in central Spitsbergen, possible to be traced with help of remote sources, is progressing at the scale not seen since the maximum extent during the Little Ice Age. Negative trend of glaciers mass balance and resulting decrease of their area, in some cases to total disappearance, for the first time in historical period shows a complete change of the glacial land-system.

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Exploratory Research on the Implementation of Segment Anything Model (SAM) 2 for Glacier Calving Front Detection using SAR Imagery

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1. INTRODUCTION

Accurate delineation of glacier calving fronts is essential for quantifying marine-terminating glacier retreat and understanding ice-ocean interactions. These fronts mark the dynamic boundary between glacial ice and body of water and are critical for estimating ice discharge and tracking the response of outlet glaciers to climate forcing. Synthetic Aperture Radar (SAR) amplitude imagery offers unique advantages for high-latitude glacier monitoring due to its ability to penetrate clouds and operate independently of solar illumination. However, automatic segmentation of calving fronts in SAR data remains challenging due to the presence of speckle noise, variable radar backscatter, and low contrast between surface of the glacier tongue, glacier ice mélange, and concentration of winter sea ice floes (Zhao and Ban 2025).

2. RESEARCH METHODOLOGY

In this study, we explore the feasibility of applying Segment Anything Model 2 (SAM 2), a prompt-driven, general-purpose segmentation foundation model developed by Meta AI (Geetha and Hussain 2024), to calving front delineation problem. Unlike traditional segmentation models that are trained for specific use cases, SAM 2 is designed for zero-shot and prompt-based generalization across diverse visual domains (Ma et al. 2023; Zhang et al. 2023). Its flexible architecture allows users to guide segmentation using sparse spatial prompts such as points, boxes, or masks, making it potentially valuable for scientific applications with limited training data.

We focus our investigation on major tidewater glaciers in the Svalbard archipelago, including those in Kongsfjorden, Hornsund, and Hinlopenstretet, where calving dynamics have been previously observed to vary across spatial and seasonal scales. Sentinel-1 SAR amplitude imagery is used as the primary data source. To adapt optical-model-based segmentation to radar data, we apply preprocessing techniques tailored to SAR, including multi-look speckle filtering, logarithmic scaling for dynamic range normalization, and edge-enhancing transformations. Prompts are derived from semi-automated edge detection (e.g., Sobel and Canny operators) and, in some cases, manually defined bounding boxes based on glacier outlines.

This preliminary investigation aims to assess the generalizability of SAM 2 in a new geophysical domain—cryospheric SAR analysis—and to develop a flexible workflow that can later be fine-tuned with expert annotations or paired with radar-specific models. Although model performance is not quantitatively reported here, the framework is built to support future evaluation using calving front reference datasets and metrics such as Intersection over Union (IoU), Dice similarity coefficient (also known as F1-score), and geometric accuracy.

By demonstrating the integration of a vision foundation model with SAR-specific preprocessing, this work lays the foundation for advancing automated, scalable glacier monitoring. It also contributes to the broader effort of repurposing powerful generalist models for domain-specific scientific challenges, particularly in Earth observation contexts where annotated training data are scarce.

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Grounding Line Migration at Orville Coast, Ronne Ice Shelf, West Antarctica, based on Long Interferometric Sentinel-1 Time Series

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1. INTRODUCTION

Research on ice sheets, which are a major factor in the world's climate system, has become increasingly intensive, as understanding the processes regulating their behaviour is important for assessing and predicting ongoing global climate change. One important indicator of changes in shelf glaciers is the location of the grounding line, which is defined as the line where a glacier loses contact with the bed and becomes a floating ice shelf (Weertman 1974). Determining the grounding line of an ice shelf glacier is essential for precise measurement and understanding of ice sheet mass balance and glacier dynamic (Fricker and Padman 2006).

Accurate determination of the GL position is problematic mainly due to its location beneath the glacier. Recent popular methods for monitoring the GL migration are based on remote sensing data. These data are useful because they cover extensive areas of land, and their acquisition does not require any in situ instruments. Our approach leverages Sentinel-1 synthetic aperture radar (SAR) images. The technique is based on differential interferometric synthetic aperture radar (DInSAR) (Rignot et al. 2011) and machine learning algorithms (Mohajerani et al. 2021). It allows glacier surface changes to be monitored with high resolution, even in darkness and cloudy conditions, and is thus advantageous in polar regions. The double-difference method helps minimize horizontal displacements resulting from glacier movement and expose primarily vertical displacements resulting from tidal changes (Rignot 1996). As a result, the method allows the identification of a hinge/flexure line, which is the landward limit of vertical movement. Although the flexure line is usually located slightly deeper in-land, it serves as a valid representation of the GL position (Vaughan 1994). The machine learning algorithm was adopted by Mohajerani et al. (2021) to automatically identify fringe patterns and vectorize the grounding line on images, and in effect – to significantly reduce the time needed for obtaining final results.

2. RESULTS

We employed a long time series of Sentinel-1 differential radar interferometry data from 2017 to 2021 to detect the variability in grounding line position on Orville Coast, the western region of the Ronne Ice Shelf, West Antarctica. The minimum and maximum extents of migration were identified, allowing for an estimation of the grounding zone width. In a single location, an approximate seasonality was evident, with maximum grounding line retreat typically occurring around the end of the calendar year and re-advance toward mid-year. It was then revealed that there is a high similarity in the migration extremes in different areas of the same glacier. It can be observed that they match not only in terms of timing but also in the magnitude of change. Additionally, data from separate satellite tracks showed consistency, which has also been demonstrated for the first time in the context of grounding line migration observations. It was also confirmed that the grounding zone width is several orders of magnitude larger than expected. This contradicts existing physical models, which are based on zero ice melt and a fixed grounding line position.

Irregular interactions between ice and seawater might have a significant impact on glacier evolution and projections if incorporated into physical models. The research carried out over a long period and with high frequency allowed a more detailed study of changes occurring in the grounding zone, and gave us the opportunity to detect seasonal movement in grounding line migration. We also compared it with external factors, e.g. ocean tides or topography. This might provide a better understanding of the behaviour of the ice sheet and glaciers, which are currently undergoing such rapid changes.

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Deep Seismic Investigation across the Knipovich Ridge

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1. INTRODUCTION

Mid-ocean ridges (MOR) are responsible for creating new oceanic crust. The oceanic crust, which covers approximately 60% of the Earth's surface, is formed along the MOR system. Ultraslow-spreading mid-ocean ridges can be found in both hemispheres. However, the two most extensive ultraslow-spreading systems are the Arctic Ridge system in the Northern Atlantic Ocean and the Southwest Indian Ridge (SWIR) in the Indian Ocean. The Knipovich Ridge belongs to the first one.

The KNIPSEIS OBS profile provides information on the seismic crustal structure of the Knipovich Ridge and oceanic crust in the North Atlantic. The structure of the oceanic crust generated by the ultraslow-spreading Knipovich Ridge still remains a relatively uninvestigated area compared to the other North Atlantic spreading ridges further south. The complexity of the Knipovich Ridge with its oblique ultraslow-spreading and segmentation makes this end-member of spreading ridge systems an important and interesting ridge to investigate.

This investigation presents an analysis of wide-angle reflection and refraction seismic profile acquired across the ultraslow-spreading Knipovich Ridge and oceanic crust to SE. The profile is performed in frame of the KNIPSEIS Project led by the Institute of Geophysics PAS in collaboration with University of Bergen and Hokkaido University. It was realized in 2019 to study active spreading processes and lithospheric structure of the ridge.

2. RESULTS

The Ocean Bottom Seismometer (OBS) data along a refraction/reflection profile (~280 km) crossing the Knipovich Ridge off the western Barents Sea was acquired by use of RV G.O. Sars on July 24 – August 6, 2019. The seismic energy was emitted every 200 m by an array of airguns with total volume of 80 l. To receive and record the seismic waves at the seafloor, ocean bottom seismometers were deployed at 12 positions with about 15-km spacing in 2 deployments. Seismic energy from airgun shots were obtained generally up to 50 km or even more from the OBSs. Several OBSs revealed clear arrivals beyond 100 km offset.

In general, the seismic records obtained along the KNIPSEIS profile are of good quality allowing detailed wave field analysis and crustal structure modelling to be made. The data obtained, after appropriate processing, were used for two-dimensional *P*-wave seismic modelling. A seismic velocity model of the Earth's crust along the survey profile was obtained. The high quality data recorded allowed modelling even of the layer below the Moho boundary. The model shows a relatively simple structure of the oceanic crust in the south-east direction, consisting of several parallel layers with *P*-wave velocities ranging from 1.95 km/s at the ocean floor to 7.20 km/s at the Moho boundary at a depth of about 12 km. The thickness of the sedimentary layers is up to 4 km with *P*-wave velocities of 1.95, 2.90 to 3.85 km/s. In the Knipovich Ridge area, the crust is thinner, especially for the mid- and lower crust layers. Interestingly, the greatest uplift of the Moho boundary does not occur exactly beneath the Knipovich Ridge axis, but about 30 km to the south-east, where the thickness of the crust has been determined to be only 4 km. In the transition zone between the rift zone and the older (but still young) oceanic crust, an increase in crustal thickness and an extension of the layer with a *P*-wave velocity of 6.7 km/s to a thickness of up to 5 km is determined. Along the whole profile, a layer with a *P*-wave velocity of about 7.1 km/s was found in the lower crust, possibly related to serpentinisation. *P*-wave velocities in the upper mantle were determined to be around 7.9 km/s in the Knipovich Ridge zone and 8.0 km/s beneath the oceanic crust at the south-eastern part of the profile. In the upper mantle, the existence of a seismic boundary approximately replicating the shape of the Moho boundary was also additionally observed, with a *P*-wave velocity shift of 0.1 km/s.

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Preliminary Zircon Geochronology Results from the Denman Glacier Nunataks, Bunger Hills, East Antarctica

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1. INTRODUCTION

The assembly of East Antarctica was a multistage process. Several Archean blocks became enclosed within an extensive network of Proterozoic to Lower Paleozoic mobile belts. The formation of these orogens is generally associated with amalgamation of two supercontinents – Rodinia, *ca*. 1 Ga, and Gondwana approximately 0.7–0.5 Ga. Major provinces produced by regional scale tectono-metamorphism include the Rayner Province (Enderby Land – Kemp Land – Mac Robertson Land – Princess Elizabeth Land) and Wilkes Province (Bunger Hills and terranes further east). These provinces have their counterparts in India (the Eastern Ghats) and Western Australia (the Albany-Fraser Orogen and Leeuwin Complex; Boger 2011; Fitzsimons 2000; Harley et al. 2013; Wilde and Nelson 2001).

These complicated tectonic relationships left fragments of older continental crust both inside and between mobile belts. In Antarctica, the original associations between continental blocks are largely obscured by the icecap. However, small continental fragments exist in the vicinity of Bunger Hills and the Denman Glacier (BH/DG), although their precise correlations are debated (Sheraton et al. 1992; Tucker et al. 2018). These Archean and Proterozoic basement lithologies have been variously correlated with continental blocks that surrounded Antarctica within Rodinia or Gondwana. For Australia, this includes the Yilgarn Craton (Tucker et al. 2017) and/or the Mawson Craton (Liu et al. 2018). However, correlations with terranes in India have also been proposed, which include the complex mobile belts separating cratonic areas, such as the Central Indian Tectonic Zone and/or the Eastern Ghats (Bhowmik et al. 2012). Furthermore, the Indian terranes nay have possible links with the Pinjarra Orogen, the Leeuwin Complex, and the Northampton Block in Western Australia (Wilde 1999).

Samples

For this preliminary study, four gneiss samples from the western part of Denman Glacier were selected: Possession Rock, Cape Harrisson, Delay Point, and Cape Kennedy (Fig. 1). Samples were collected by MAK during an expedition in 2021/2022: these results have not yet been published.

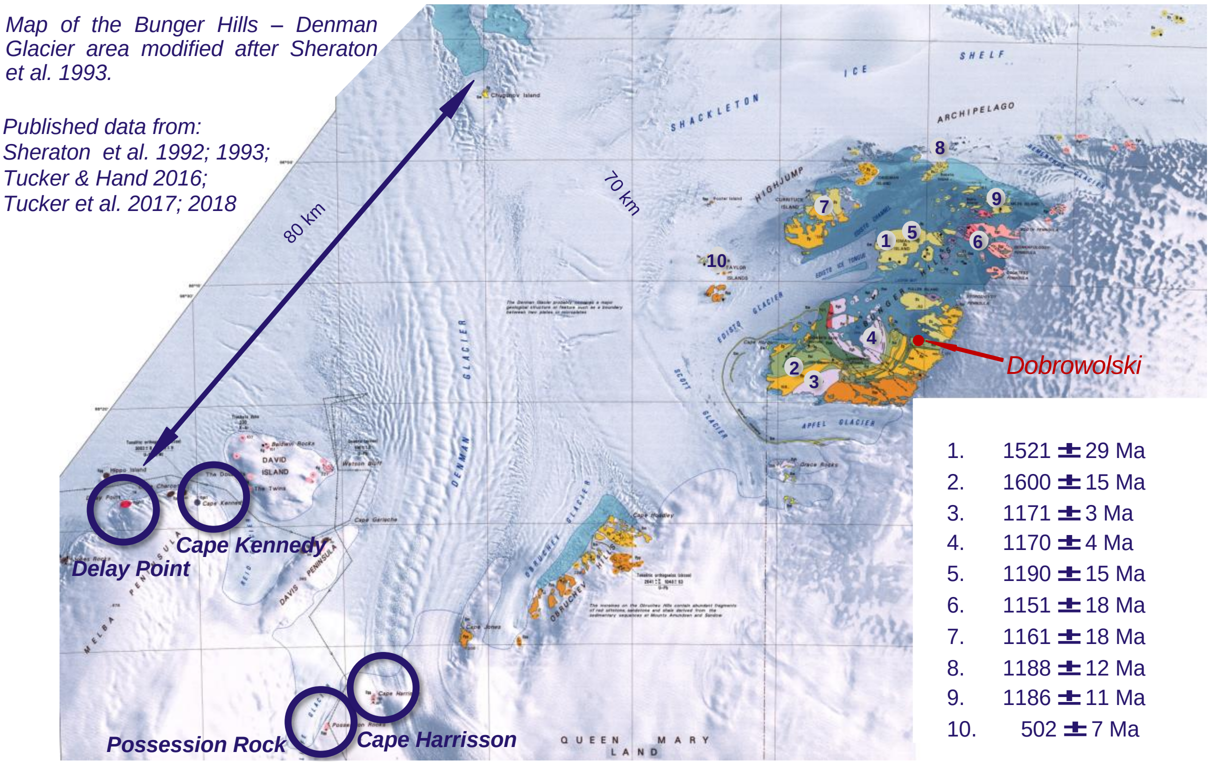

Fig. 1. Bunger Hills – Denman Glacier Map (after Sheraton et al. 1993) with sample areas in the circles.

2. RESULTS

For the U-Pb geochronology, zircon ($ZrSiO_4$) grains were separated from the samples using standard techniques in the GeoBeLa laboratory of the IG PAS in Belsk. Further, zircon grains were analysed utilizing SHRIMP (Sensitive High Resolution Ion Microprobe) at the KBSI (Korea Basic Science Institute) in Ochang. In samples from Cape Harrisson (A22103) and Cape Kennedy (A22122), grains reveal internal magmatic growth zoning in cathodoluminescence (CL) images and have U contents up to a few hundred ppm. Zircon grains from Delay Point (A22114) and Possession Rock (A22101) are black in CL images due to their very high U contents, commonly 1000–2000 ppm. Despite the high U content of the latter, geochronological data from all samples are uniform. A well-defined concordia age of 521 Ma was obtained from the most western samples (Delay Point and Cape Kennedy), whereas Possession Rock yielded an age of 553 Ma, but with a few analyses recording an age of ca. 1170 Ma. Results from Cape Harrisson do not give a concordia age and they spread from about 700–600 Ma.

3. DISCUSSION

Published geochronological data are only available for Bunger Hills, with the majority recording an age of *ca*. 1.17 Ga (Fig. 1). Tucker and Hand (2016) analysed monazite ($CePO_4$) grains from 3 samples (spots 7–9 on Fig. 1) and these data confirm the results obtained from zircon. Hence, our new results do not conform to the earlier published data, but they are in agreement with a sample from Taylor Island (spot 10 on Fig. 1). These preliminary results support paleomagnetic data by Daczko et al. (2018) and the possibility of a "cryptic" Gondwana-forming orogen. Their paleomagnetic results were interpreted as movement between Indo-Antarctica and Australo-Antarctica between *ca*. 750 Ma and *ca*. 500 Ma and implied that orogenesis reflects ocean closure of an Ediacaran-Cambrian plate boundary. Nonetheless, more complete dataset is needed to understand the paleogeographic position of Denman Glacier / Bunger Hills area during this time period.

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Termination of Whaling in South Georgia Recorded in Marine Sediments

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Polar ecosystems are environmentally sensitive and have attracted relatively little research, particularly in the Southern Hemisphere, where human presence dates back two centuries only. Initially, it was seal hunters who penetrated the sub-Antarctic seas. At the beginning of the 20th century, South Georgia, the largest sub-Antarctic island, became known as "the gateway to Antarctica". The first whaling station, Grytviken, was established there in 1904. The subsequent six decades of its operation nearly exhausted the local environment. Years after its closure, an unprecedented post-industrial recovery of both terrestrial and marine ecosystems was observed.

In late 2019, we recovered a short sediment core (Fig. 1) from the middle of King Edward Cove. This sheltered harbor is located off the former Grytviken whaling station, in a side inlet of Cumberland Bay. Using this core, we were able to reconstruct levels of contamination and biotic succession from the 1940s, when whaling was still ongoing, to the present day. We studied the geochemical composition of the sediment, as well as the concentrations of anthropogenic organic markers, foraminiferal microfossils, and sedimentary ancient DNA (Majewski et al. 2024). Three distinct phases were identified in the record. The early phase, predating c. 1970

Fig. 1. The sediment core from King Edward Cove with the brighter, upper layer representing well-oxygenated sediments that were deposited after the year 2000 (photo by Piotr Rozwalak).

and including the whaling period, was characterized by anoxic sediment, heavy metal contamination and a high presence of organic markers, as well as a lack of foraminiferal microfossils. The DNA signature was also distinct, with the zoobenthos dominated by polychaete annelids. After whaling ceased, it took only a short time for the contamination to decline and for a healthy marine ecosystem with diverse foraminifera to be established. However, recovery of the macrozoobenthos, as evidenced by the abundance of cnidarians, was delayed by several years. In the most recent period, which began around the year 2000, subbottom conditions in King Edward Cove changed again and became more oxygenated. This resulted in the foraminiferal community being dominated by calcareous taxa. Sessile cnidarians declined and were eventually overtaken by nematodes. This latest environmental change was unexpected and unlike anything observed at similar locations throughout Cumberland Bay. It appears to have been caused by frequent water mixing due to increased traffic from large cruise ships bringing visitors to the remains of the Grytviken whaling station. It seems that, after only three decades of ecosystem recovery, increased tourism is putting further pressure on the environment of King Edward Cove.

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Legacy of Coal Mining: Trace Element Contamination in Soils from Billefjord, Svalbard

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Abstract

Although trace elements naturally occur in the environment, their concentrations increase significantly as a result of anthropogenic activities such as mining and the combustion of fossil fuels. The introduction of these elements can disrupt ecosystem functioning, especially in sensitive Arctic regions. Svalbard, which has long been exploited for coal, mineral, and hydrocarbon extraction, is particularly vulnerable to such disturbances. Soils serve as long-term sinks for both local contamination and atmospheric deposition, making them effective indicators of environmental pollution. In this context, Billefjorden, and in particular Petuniabukta, where the Adam Mickiewicz Polar Station is located, serves as an ideal natural laboratory due to historical impact of intensive coal mining, especially in the area of the former Soviet mining town of Pyramiden. To assess the spatial extent and intensity of trace element contamination, soil samples were collected from three locations representing a gradient of anthropogenic pressure: Pyramiden, a heavily impacted former mining town; Elsa Valley, a site with moderate exposure; and Ebba Valley, a relatively undisturbed area. For this, concentrations of elements typically associated with mining activities —including Pb, Cd, Cu, Zn, Co, Ni, Cr, As, Sb, Te, Bi, and Mo—were analyzed using inductively coupled plasma mass spectrometry (ICP MS). Results show that in Pyramiden, concentrations of Ni, Cu, Zn, and Te were significantly higher than in Ebba Valley, while values in Elsa Valley were intermediate and did not differ significantly from either Pyramiden or Ebba. Concentrations of Pb, As, and Sb were significantly higher in Pyramiden compared to both other locations, suggesting local sources of contamination. Interestingly, Cd concentration was higher in Elsa Valley than in Ebba Valley, which may indicate transport or secondary sources of pollution. Co, Mo, and Cr showed no significant differences between locations, suggesting a geogenic origin or uniform geochemical background. It is also worth noting that despite clear signs of anthropogenic activity in the Pyramiden area, the soils in this region were partially imported from

Russia. This may imply a different geochemical background and affect local environmental conditions. These preliminary results contribute to a better understanding of pollution gradients in Arctic soils and provide valuable reference data for monitoring environmental changes in regions affected by both historical and ongoing human activity.

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Marine Macro- Meso-, Microplastics and Fungi in Polar Regions of the Northern (Longyearbyen, Svalbard) and Southern Hemisphere

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1. INTRODUCTION

Although plastic pollution is ubiquitous, and remote polar regions are no exception, relatively little is known about the presence of polymers in the Arctic and Antarctic. Additionally, basic data to perform the modelling of their transport, fate, and environmental behaviour are insufficient. Within this work, we provide information about the polymer types present in the polar environment through spectral identification of specimens from Longyearbyen (Svalbard) and the Falkland Islands. Both places were intentionally selected to compare the northern and southern hemispheres. The Arctic, being under higher anthropogenic pressure, is a perfect place to understand the long-term interaction between plastic debris and biota. In particular, fungi were selected to be studied as promising bioindicators. Thus, research on the fungisphere composition has been conducted. In contrast, the relatively little-contaminated Falkland Islands can be used as a model zone to speculate on the origin, transport, and fate of microplastics.

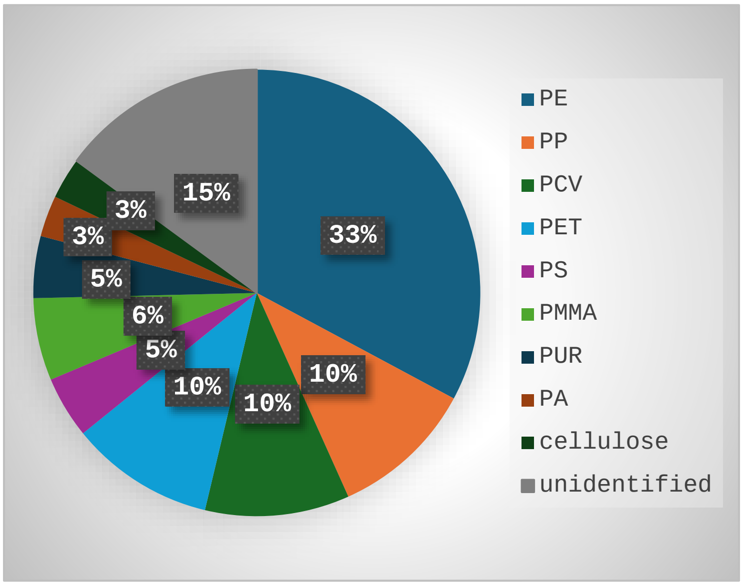
2. LOCAL MICROPLASTIC SOURCES (LONGYEARBYEN, SVALBARD)

Plastic specimens were collected at Longyearbyen beach in the summer season (2023). Several protocols were tested, with the most promising one named “local sources”. Within this approach, further study was conducted on macroplastics, around which meso- and microplastics were observed, confirming the advanced and increasing fragmentation. All samples were identified, and the most abundant types were used for the fungisphere detection.

2.1 Spectral Identification

Samples were qualitatively identified by ATR-FTIR, FTIR (in a mapping mode), and Raman spectroscopy. The main identified plastics were PE – 33%, PP, PVC, and PET – 10%, PMMA – 6%, PS and PU 5% each, PA and cellulose 3% (Fig. 1A). The percentage of unidentified polymers was 15%, mainly due to the strong deterioration or organic matter contamination (Fig. 1B).

A)



B)

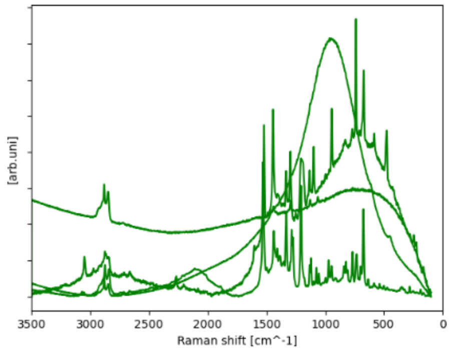


Fig. 1: A) Polymer types at Longyearbyen; B) Examples of MPs spectra at different levels of ageing and biased by self-luminescence.

2.2 Fungisphere characterization

Plastic samples were placed on three different selective culture media (with rPET, mineral oil and polystyrene as the main carbon sources) and incubated for six weeks at 22 °C. 35 strains were isolated and identified based on ITS rDNA sequencing and additional molecular markers. These strains were classified into 21 taxa. Of the 21 fungal taxa isolated, 15 have been reported in the literature as capable of degrading plastics. The identified taxa included representatives of the classes *Dothideomycetes, Hypocreales, and Leotiomycetes*, which had previously been isolated from the Svalbard plastisphere (Rüthi et al. 2023). Fungal colonies on the surface of the samples after 6 weeks of incubation are presented in Fig. 2.

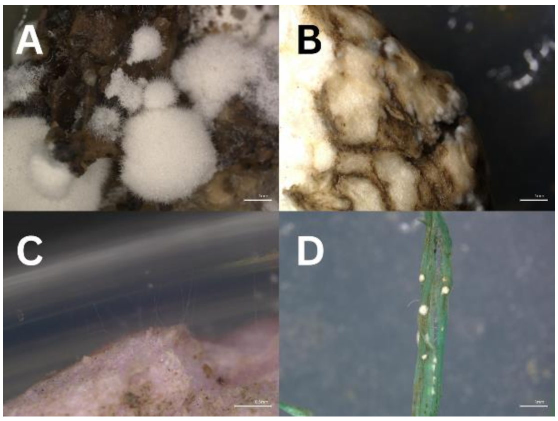


Fig. 2: A – Sample H5-H6-6, *Trichoderma* sp. colonies, scale 1 mm; B – Sample H5-H6-2, *Pleospora richtophensis* colonies, scale 1 mm; C – Sample HH8F, hyphae reaching the lid of the Petri dish, scale 0.5 mm; D – Sample HH1, Entomortierella parvispora species complex colonies, scale 1 mm.

More than 400 organisms are known for their ability to degrade plastics, including fungi (Ekanayaka et al. 2022). The ability of selected isolates to colonize polypropylene when grown on MEA (malt extract agar) was tested and confirmed for 12 out of 19 isolates. Subsequently, the ability of strains of *Alternaria alternata* and *Trichoderma* sp. to colonize polypropylene and polystyrene was examined, with these plastics serving as the main carbon source. All tested strains were capable of colonization, although differences in efficiency were observed. *Trichoderma* sp. strains showed a preference for polystyrene, while *A. alternata* preferred polypropylene. Although the experiments conducted are not sufficient to confirm the ability to degrade plastics, colonization and adhesion to the material are necessary conditions for biodegradation and represent its first stage (Oliveira et al. 2020), indicating the potential for synthetic material biodegradation by Arctic fungi.

3. TRACKING MICROPLASTIC FATE AND TRANSPORT (FALKLAND ISLANDS)

Figure 3 presents an overview of the polymer identification within different zones of the Falkland Islands. Zones under tourist anthropogenic pressure (Port Stanley during the cruising period) were compared. Obtained results suggest that the main sources of microplastic contamination are related to the ghost nets from the calamari industry brought by the plastic tide on shore (north and western parts of the archipelago), and touristic litter. Local conditions primarily influence abiotic degradation and can be precisely modelled.

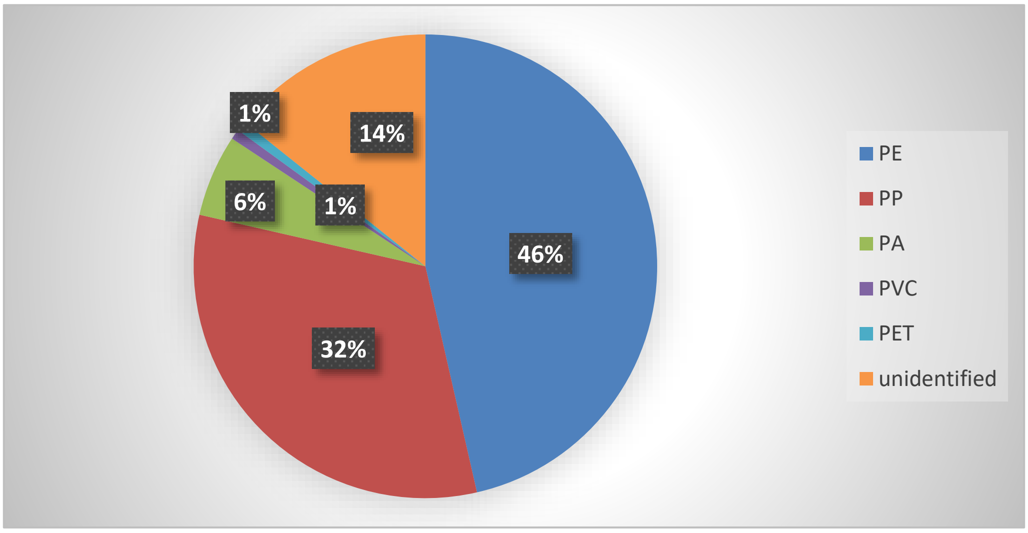


Fig. 3. The FTIR ATR test results show that the main identified plastics were PE – 46%, PP– 32%, PA – 6%, PET and PVC 1% each. The percentage of undisinfected polymers was 14%.

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Tracing the Origin of Sedimentary Organic Matter in Arctic Fjords Using Lipid Molecular Markers

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1. INTRODUCTION

The burial and long-term storage of organic matter in marine sediments play a crucial role in regulating the global carbon cycle and atmospheric CO_2 levels. Fjords, characterized by high sedimentation rates and organic carbon fluxes, are particularly significant, accounting for around 11% of the annual global marine carbon burial (Smith et al. 2015).

Despite a short productive season and limited vegetation, Svalbard fjords exhibit high area-normalized rates of organic carbon accumulation. The cycling and composition of organic matter in these Arctic fjords are influenced by seasonal changes, water mass dynamics, and various sources including autochthonous production, glacier melt, as well as river and surface runoff.

In the Arctic, both fresh organic matter from primary and secondary producers and refractory material from glacial retreat and permafrost thaw contribute to sediment composition. Ongoing rapid warming is expected to alter hydrographic conditions, organic matter sources, and long-term carbon burial in Svalbard fjords.

Various bulk proxies (e.g., C/N ratio, $\delta^{13}C$, $\delta^{15}N$) and molecular markers (e.g., alkanes, steroids, fatty acids, pigments) are commonly used to trace the sources of sedimentary organic matter in aquatic environments (Bianchi and Canuel 2011; Szymczak-Żyła and Lubecki 2022; Volkman 2006). However, in the Spitsbergen fjords, most studies have focused on bulk indicators, while data on sedimentary lipid biomarkers remain limited.

This study aimed to determine the sources of organic matter in surface sediments from four Spitsbergen fjords by analyzing lipid biomarkers, including:

(i) **n-alkanes** – hydrocarbons produced by both prokaryotic and eukaryotic organisms, may derive from bacteria, plankton, aquatic, and terrestrial plants;

(ii) **saturated cyclic hydrocarbons** (hopanes, steranes) – these compounds with thermodynamically stable configurations are indicators of the origin and maturity of source rock sediments and petroleum;
(iii) highly branched isoprenoid (**IP25**) – a proxy for the occurrence of IP25-producing sea ice diatoms;
(iv) **alkenones** – a proxy of the occurrence of alkenone-producing phytoplankton species (e.g., *Emiliania huxleyi*);
(v) **polar steroids** (sterols and stanols) – derived mainly from eukaryotic organisms, including phytoplankton, zooplankton, and vascular plants.

While previous studies have primarily relied on bulk geochemical proxies to assess organic matter origin in these fjords, our approach focuses on molecular-level evidence. We argue that lipid biomarker analysis provides detailed insights into organic matter sources in Arctic fjords and serves as a valuable baseline for reconstructing past conditions and projecting future changes under climate warming. To the best of our knowledge, no similarly comprehensive lipid biomarker-based investigation has been carried out in the studied fjords.

2. MATERIALS AND METHODS

This study investigates four fjords located between 76°N and 79°N in western Spitsbergen, Svalbard (Fig. 1). All fjords receive substantial freshwater input and are influenced by warm Atlantic Water carried by the West Spitsbergen Current. Additionally, Hornsund is affected by cold Arctic Water from the Sørkapp Current, while Adventfjorden experiences the highest anthropogenic impact due to local human activities.

This research focuses on surface sediment samples (0–5 cm layer) collected at nine locations in Spitsbergen fjords during a July–August 2017 cruise aboard R/V Oceania (IO PAS), using a Niemistö-type core sampler. Molecular markers investigated in this work were analyzed according to the procedures described by Krajewska et al. (2023).

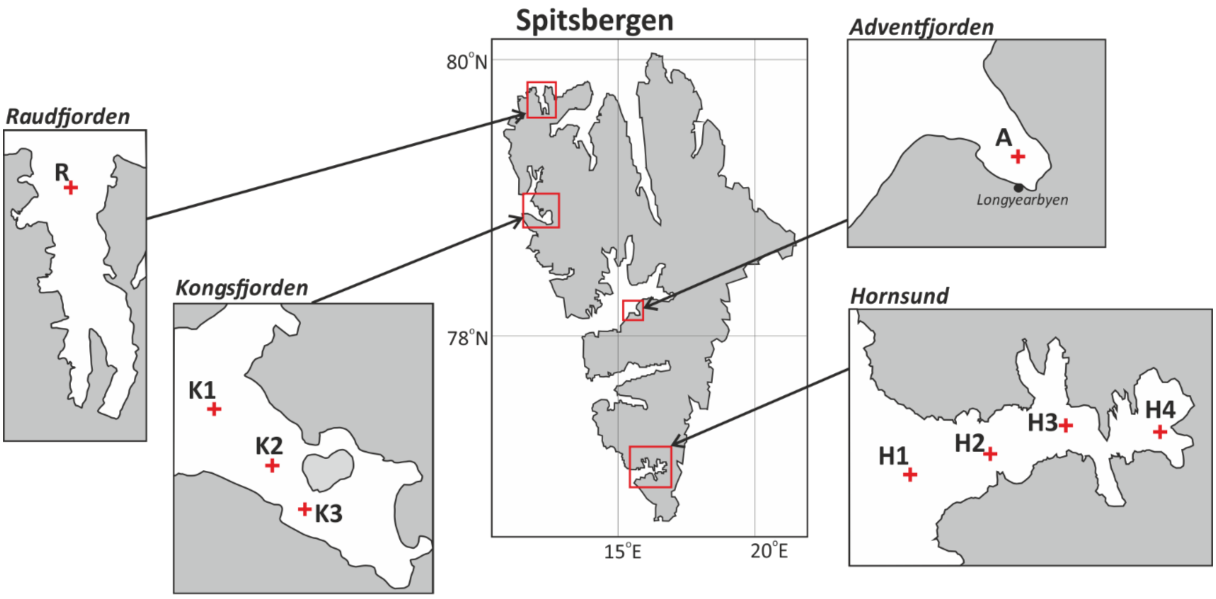

Fig. 1. Locations of sampling sites.

3. RESULTS

The concentration ranges for investigated lipid molecular markers in the studied fjords were as follows: 620–1420 μg/g TOC for n-alkanes [Σ(n-C15 – n-C39)], 8.2–101.3 μg/g TOC for hopanes, 0.56–5.1 μg/g TOC for steranes, <LOD–0.073 μg/g TOC for IP25 (highly branched

isoprenoid), 0.67–40.6 μg/g TOC for C37 alkenones, 71–546 μg/g TOC for Σ phytoplankton-derived sterols, 95–510 μg/g TOC for Σ animal-derived steroids, and 53–215 μg/g TOC for Σ land-derived steroids.

4. CONCLUSIONS

The results of this study indicate that sedimentary organic matter in the western Spitsbergen fjords originates from a variety of marine (e.g., phytoplankton, animal-derived material) and terrestrial sources (e.g., vascular plants, including Sphagnum mosses). The contribution of sea ice-associated algae to sedimentary organic matter is generally low across the studied fjords. In Hornsund, the input of organic matter from phytoplankton, zooplankton, and terrestrial plants decreases from the outer to the inner fjord.

Notable differences in phytoplankton composition were observed between the southern and northern fjords: haptophytes and cryptophytes are more abundant in the northern fjords (Kongsfjorden and Raudfjorden), while lower abundances of diatoms relative to dinoflagellates are found in northern fjords compared to fjords located farther south (Hornsund and Adventfjorden). The presence of *Emiliania huxleyi*—a species characteristic of temperate environments—in the northern fjords likely reflects strong bio-advection associated with the inflow of warm Atlantic Water.

All studied fjords show evidence of natural petrogenic inputs; however, Adventfjorden appears to be most affected by fossil organic matter, likely linked to anthropogenic emissions from nearby Longyearbyen. Although total alkane concentrations remain relatively stable along the Hornsund transect, other lipid biomarkers display clear decreasing trends, highlighting the need for further investigation into the underlying mechanisms.

This study provides comprehensive lipid biomarker-based assessment of organic matter sources in surface sediments of the western Spitsbergen fjords and contributes to a better understanding of the current state of this rapidly changing Arctic environment.

Selected data from this study have already been reported in Krajewska et al. (2023). The research is being continued with financial support from the National Science Centre, Poland (2023/49/B/ST10/03768).

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Variation in the Guano-Derived Resources for Marine Producers Below Seabird Colonies in Svalbard

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1. INTRODUCTION

Seabirds play a vital role in Arctic coastal ecosystems by delivering large quantities of organic matter and nutrients of marine origin, primarily in the form of guano, to the areas around their nesting sites. A significant proportion of these ornithogenic nutrients are absorbed by terrestrial producers, which stimulates the growth of exceptionally lush and rich tundra. However, the remainder returns to the sea through percolation, leaching and/or runoff from the ground. These nutrients are easily soluble, which increases their short-term bioavailability in coastal waters near seabird colonies, providing an important local resource for the marine food web. The greater the waves and the more open the sea, the more nutrients are dispersed in the water and lost from the area. However, the precise role and importance of seabird-derived nutrients in the marine ecosystem remains unclear.

2. MATERIALS AND METHODS

Here, we present the results of studies carried out in the marine coastal zones directly beneath bird cliffs and compared with nearby reference areas, at the south-east Bjørnøya (2022) and west Spitsbergen (Midterhuken in the Bellsund area; 2023 and 2024). We followed changes in the concentrations of resources for marine producers (ammonium, nitrate, phosphate, and silicate ions) along the distance from the cliffs (from 50 to 200 metres) and the depth (from the surface down to about 20 metres), as well as the nitrogen and carbon stable isotope ratio (δ^{15}N and $\delta^{13}C$) values in suspended particulate organic matter (POM), which serves as a proxy for ornithogenic enrichment of pelagic producers.

3. RESULTS AND DISCUSSION

We found that seabird colony inputs affected the nutrient concentrations in seawater, though the trends were not always uniform. This variability was likely due to the location of the colonies (on the cliffs facing the open sea versus those exposed to the fjord) and the timing of the sampling (before or after the spring phytoplankton bloom). Higher $\delta^{15}N$ values for POM were recorded below the bird cliffs and decreased with distance from the coast in 2022 and 2023, indicating clear ornithogenic enrichment at both location. However, in 2024, the opposite trend was observed between the seabird and reference areas, with much lower values recorded throughout compared with previous years. This suggests that other factors, such as large-scale water movement or seasonal variations related to phytoplankton blooms and nutrient turnover, may be overlapping with the impact of seabirds and must be considered when analysing trophic dynamics within the Arctic coastal zone.

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Where Does Analytical Chemistry Come From and Where Is It Going in the Polar Regions?

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Abstract

The study of the presence of chemical elements and compounds, as well as the characterization of physicochemical properties, are among the most common activities conducted in polar regions. They provide information on the functioning of polar ecosystems, their interrelationships, and their impacts. In the context of observed climate change and increasing environmental pollution, chemical analysis plays an extremely important role, providing tools for observing these processes.

Conducting chemical analysis in polar regions has its own specifics. Measurements taken directly in the field pose a huge challenge, related to the ambient temperature or logistical problems, among others. Moreover, the scope of measurements that can be performed in the field is limited, hence the need to take samples for laboratory analysis. Procedures for ensuring the representativeness of samples, their collection, protection and transportation are additional problems in polar conditions. It is also essential to ensure the reliability of the obtained data, their metrological characteristics and quality management of the research. The last but not least challenge is the need to harmonize protocols, procedures, or research methodologies used by different teams.

The report plans to present the above-mentioned problems in the light of research conducted by the authors in polar regions and cooperation with many groups conducting such research.

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The First Observation of Swarming Krill Aggregations near the Sea Bottom in Admiralty Bay (King George Island, Antarctica) Close to the Biggest Glaciers

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1. INTRODUCTION

Since the middle of the 20th century, the Southern Ocean, especially the Antarctic Peninsula, has been experiencing intense climate warming. On the west coast of the peninsula, there has been a marked increase in air and seawater temperatures, combined with a reduction in seasonal ice sea cover, the rapid retreat of glaciers and the collapse of ice shelves (Campos et al. 2013b). Observed changes not only have an impact on the physical environment, but also directly and indirectly affect marine organisms – disrupting their physiology, life cycles and thus also their feeding strategies, behaviour, and spatial distribution. Admiralty Bay – located on the northern coast of King George Island in the South Shetland – a glacially influenced coastal embayment and a key site for long-term Antarctic ecosystem monitoring is a region where intense climate change overlaps with anthropogenic pressure (Campos et al. 2013a).

Zooplankton play a key role in the trophic food webs of the Southern Ocean, with species composition and distribution shaped by environmental conditions such as melting glaciers and local water circulations (Leonor and Muxagata 2024). Antarctic krill, as a keystone species, link primary producers to higher trophic levels including seabirds and seals. Krill exhibit complex social behaviour that facilitates swarm formation and maintenance. They align their swimming direction and speed with near neighbours, enabling cohesive group movement and self-organization within swarms. Near the sea bottom, krill may aggregate to exploit localized food patches or seek refuge from predators. Several species of Euphausiacea, including the dominant *Euphausia superba* Dana, 1850 and *E. crystallorophias* Holt & Tattersall, 1906, have been recorded in the bay (Jackowska 1980; Stępnik 1982; Kittel et al. 2001). Recently the highest densities of Euphausiacea were recorded in the central part of the bay and in the outlet area, influenced by local hydrography and water mass mixing (Kittel et al. 2001). The bay's glacial meltwater input affects water column stratification and turbidity, which in turn modulate krill feeding efficiency and thus their distribution (Kittel et al. 2001).

Krill aggregations are strongly dependent on environmental factors, among them are depth or tidal speed and direction. Their density near the bottom often correlates with predator diving dynamics (Annasawmy et al. 2023). In addition, krill exhibit a variety of foraging strategies including benthic foraging (Takahashi et al. 2003). Euphausiacea can occur near the seafloor throughout the year forming aggregations at depths of 200 to 2000 meters and thus playing an important role in the transfer between benthic and pelagic communities (Schmidt et al. 2011). Krill aggregations have previously been recorded in Antarctic regions including Bransfield Strait (Annasawmy et al. 2023); on the shelf edge in the southeastern Weddell Sea (Gutt and Siegel 1994); along the Western Antarctic Peninsula (Kane et al. 2021); and on the seafloor of Marguerite Bay in the western Antarctic Peninsula (Clarke and Tyler 2008). However, no studies or direct observations of this phenomenon have been conducted so far in Admiralty Bay.

The main goal of this study was to document, for the first time, the occurrence of near-bottom krill aggregations in Admiralty Bay and to characterize their community structure. We also aimed to compare environmental conditions between two consecutive summers and to explore potential drivers.

The zooplankton samples used in this study were collected vertically (mainly from the upper 50-meters) by WP-2 plankton net (180 um mesh size) during two summers (2023 and 2024) in AB. The sampling was carried out simultaneously with CTD (equipped with fluorescence, turbidity and oxygen sensors) and Underwater Vision Profiler (UVP) measurements of particle size and morphology. A drop camera (100 frames per second with HD) – recording the whole water column from the surface to the bottom – used only in 2024 revealed the presence of krill assemblages near the seafloor at 8 stations located close to the Lange Glacier, Ecology Glacier, Domeyko Glacier and in Ezcurra Inlet. Zooplankton samples have been analysed to verify the presence of krill and to assess whether their community structure differed between the two studied years. We also aim to assess krill faecal pellets clearly recorded by drop camera in AB.

Analyses of UVP and CTD data from both studied summers together with comparison of available historical data aim to broaden our knowledge dealing with environmental conditions at stations where krill was observed. Preliminary UVP and CTD data suggest that our study covered two different years concerning the seawater temperatures and the amount of marine snow in the AB water column.

Intensive glacial meltwater influx potentially reduces the size of krill aggregations near the sea bottom due to mortality from suspended inorganic particles and shift their composition by affecting certain life stages. Thus our observation of krill near very important tidewater – Lange Glacier located on the west side of AB (with retreat rate averaging 48 m/year in recent decades) is significant because the literature indicates that in the coastal area of the Antarctic Peninsula, a reduction in sea ice area correlates with general decrease in krill abundance, leading to changes in the structure and functioning of marine food webs (e.g., Atkinson et al. 2004; Murphy et al. 2007; Hofmann et al. 2011; Campos 2013a). Despite these challenges, coastal zones near glaciers remain critical refugia for krill, particularly during periods of low offshore productivity and reduced sea ice. The interplay between physical drivers (e.g., upwelling, freshwater input), biological processes (e.g., migration, feeding), and anthropogenic pressures (e.g., fisheries) underscores the need for integrated, circumpolar monitoring networks that can capture the complexity of krill dynamics in this rapidly changing Antarctic environment.

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In the Shadow of the Atlantic: Niche Plasticity and Coexistence Strategies of Boreal-Arctic Sibling Zooplankton in the Pelagic Realm

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A b s t r a c t

The intensified inflow of warm Atlantic Water into the arctic ocean is reshaping pelagic ecosystems, making them increasingly similar to those of the North Atlantic. As a result, resident Arctic zooplankton species now commonly coexist with closely related boreal counterparts over broad regions, particularly in the European Arctic. This study explores ecological interactions between such sibling species—representing diverse taxonomic and functional groups (large calanoid copepods, amphipods, euphausiids, chaetognaths)—with a focus on their habitat use, trophic strategies, and trait plasticity.

Field data were collected during summer cruises from 2022 to 2024 aboard RV Oceania and RV Helmer Hanssen, covering six fjords across Svalbard and adjacent shelf waters. Vertical distributions and isotopic niches ($\delta^{13}C$ and $\delta^{15}N$) were analyzed to assess spatial and trophic overlap. Species identification was based on morphological criteria and confirmed with molecular tools. Selected specimens for isotopic analysis were imaged at high resolution, and body measurements were extracted using machine learning-assisted image processing.

Although sibling species often shared similar horizontal distributions, they tended to differ in their vertical occurrence within the water column, suggesting partial spatial segregation. Stable isotope data showed that trophic niches between sibling species often overlapped, but both the position and width of these niches varied depending on the functional role of the

species pair, the region, and the extent to which the species co-occurred at depth. These patterns highlight the variability in habitat use and trophic structure among boreal and Arctic zooplankton, offering insight into the complexity of Arctic pelagic systems in the context of ongoing Atlantification.

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The Coastal and Marine Ecosystem of Woodfjorden, Northern Svalbard

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A b s t r a c t

Fjords on the west and north coast of the Svalbard are currently experiencing a steadily warming mainly due to raising temperatures and increased influx of warm Atlantic waters. This warming, along with glacial retreat and associated freshwater influx, modifies fjord hydrology, stratification, and water turbidity, and thus primary production patterns, which further cascade to the whole ecosystem functioning. Woodfjorden, a long fjord north of Spitsbergen, is located at the northern edge of the West Spitsbergen Current, includes the main fjord, fed by multiple small rivers, and the two tributary fjords impacted tidewater glaciers.

We conducted a complex, multidisciplinary coastal and marine research in Woodfjorden, during r/v Oceania (IO PAS) cruise in August 2024. A wide range of physical and biogeochemical measurements were taken along the fjord axes including temperature, salinity, light penetration, dissolved oxygen, nutrients (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, DSi), pH, total alkalinity, pCO_2, phytopigments, Dissolved Organic and Inorganic Carbon in the water column, and Total Organic Carbon, grain size and phytopigments in the sediments. We measured primary

production rates (*in situ*), and assessed zooplankton, and macro- and meiobenthic community structures. *Ex-situ* experiments were performed to measure sediment respiration rate, and carbon and nutrient fluxes. Littoral zone sampling included shallow waters measurements (temperature, salinity, light penetration), algal physiology and biochemistry (*Fucus distichus*, *Saccharina latissima*), and zoobenthic studies.

Here we present the first synthesis of results from a multidisciplinary field campaign designed to help understand the consequences of ongoing environmental shifts for Woodfjorden ecosystem functioning, both in the shallow littoral zone and deep central parts of the fjord. Our findings offer new insights into the physical and biogeochemical setting of the Woodfjorden ecosystem and their influence on biological communities in shallow coastal areas and across the fjord. Together, collected datasets provide a comprehensive overview of the marine carbon cycle and ecosystem structure in this relatively understudied region of Svalbard.

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Pelago-benthic Coupling in a High Arctic Fjord

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Keywords: pelago-benthic coupling, meroplankton, settlement, experiment, Arctic ecology.

1. INTRODUCTION

Meroplankton—pelagic larvae of benthic invertebrates—plays a key role in Arctic coastal ecosystems by linking pelagic and benthic processes through dispersal and settlement (Pineda-Metz 2020). However, in shallow hard-bottom environments, factors driving this pelago-benthic coupling remain poorly understood. We investigated these processes through a year-round study in Isfjorden, Svalbard (>78 °N), combining seasonal plankton sampling with an in situ colonization experiment using settlement plates at two stations (site S and site N).

2. MATERIAL AND METHODS

The study took place in Isfjorden, the largest fjord on the western coast of Spitsbergen (Svalbard), characterized by varied hydrological conditions and underwater landscapes. Salinity in shallow zones ranges from 28 to 34 PSU, and temperatures from −1.4 to 7 °C (Nilsen et al. 2008). Inner bays are seasonally ice-covered (Nov–July), and the region experiences a 112-day polar night. Two stations were surveyed: a northern site (N) with colder, more Arctic-like conditions and greater glacier influence, and a southern site (S), warmer and less impacted by freshwater input. Environmental differences are shaped by fjord circulation, glacier proximity, and bathymetry.

Plankton samples were collected every three months using a vertically hauled WP2 net and two SCUBA diver-operated methods (horizontal net tow and suction pump). To investigate the relationship between larval supply and benthic colonization, we carried out a year-round settlement experiment using a metal frame structure equipped with two sets of triplicate plates oriented upward and downward and exchanged at three-month intervals.

3. RESULTS AND DISCUSSION

Regardless of the method, seasonality was the strongest predictor of meroplankton composition (PERMANOVA, 31.8% variation explained), with spring peaks in Polychaeta larvae and Cirripedia nauplii, summer peaks in Bivalvia veligers, Echinodermata ophioplutei, and Cirripedia cypris, and autumn peaks in Bryozoa cyphonautes. Environmental variables including temperature, chlorophyll *a*, and photoperiod, jointly explained 36.7% of variability (DistLM), supporting the view that planktotrophic larval development is an effective strategy in high-latitude taxa like Bivalvia and Cirripedia.

The southern station (S), influenced by warm Atlantic waters, showed greater productivity, while the northern station (N), affected by winter sea ice drift, exhibited higher overall meroplankton abundance. Method comparison indicated that the WP2 net was most effective for deeper sampling, but the suction pump proved valuable in shallow, kelp-dense zones where standard nets are impossible to use. Combining both methods maximized multivariate dispersion, highlighting their complementary value in shallow Arctic ecosystems.

To investigate the relationship between larval supply and benthic colonization, we carried out a year-round settlement experiment using a metal frame structure equipped with two sets of triplicate plates oriented upward and downward and exchanged at three-month intervals. The results revealed that light and temperature were the main drivers of early epibenthic colonization. These physical factors—together with depth, plate orientation, and station location—explained 46% of the variability in settlement patterns, while biotic variables, such as the presence of meroplanktonic larvae and phyto- and zooplanktonic communities, explained an additional 24% (Fig. 1).

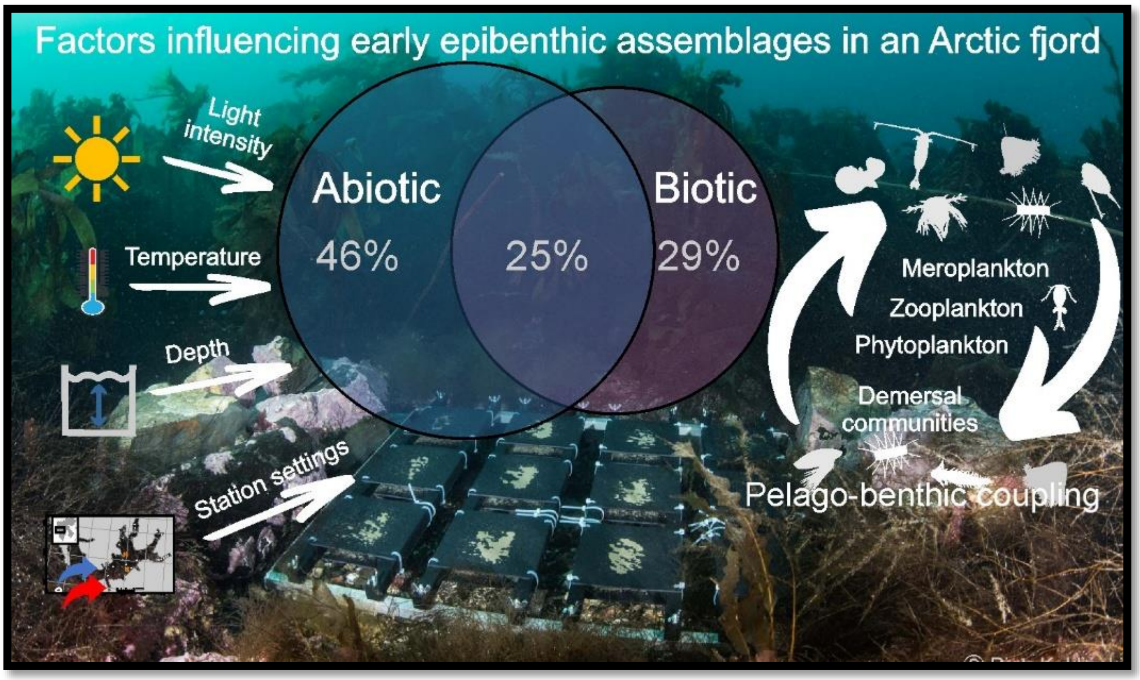

Fig. 1. Venn diagram of partition of explained variation in epiobenthic taxa composition shared between abiotic and biotic explanatory variables (modified after Ronowicz et al. 2024).

Sessile taxa displayed strong orientation-dependent settlement: coralline red algae (*Lithothamnion* sp.) dominated upward-facing plates, while polychaetes and bryozoans were more abundant on downward-facing surfaces. However, during summer, juvenile individuals of the cirriped *Semibalanus balanoides* aoutcompeted other recruits on both plate sides due to a massive larval influx triggered by phytoplankton blooms. Seasonal trends were particularly pronounced on downward-facing plates: autumn and winter were dominated by polychaetes belonging to Spirorbinae and by bryozoans; spring by *Lithothamnion* sp. and bryozoans (at station N) or Spirorbinae and bryozoans (at station S); and summer by *S. balanoides*, irrespective of site. Notably, high numbers of *Lithothamnion* sp. on upward-facing plates deployed during the polar night provide the first evidence that coralline algae at high latitudes can settle in complete darkness, suggesting that solar radiation is not a prerequisite for spore release or settlement. The connectivity between pelagic larvae and benthic recruitment was clearly visible in the seasonal sequence of cirriped life stages, and to a lesser extent in cyphonautes larvae, which may correspond to currently unidentified juvenile cheilostomatid bryozoan settling on plates.

4. CONCLUSIONS

In conclusion, this study provides novel insight into the mechanisms of pelago-benthic coupling and settlement dynamics in typically poorly explored shallow Arctic rocky habitats. Our results demonstrate that seasonality, environmental conditions, and larval dispersal patterns jointly structure meroplankton communities and influence settlement success, highlighting the complex nature of coastal habitats. These findings suggest that climate-driven changes in light and temperature regimes may alter recruitment patterns and disrupt the functioning of polar ecosystem.

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Imaging the Invisible: Insights into Morphology and Distribution of Particles and Plankton Assessed by Underwater Camera in Both Polar Regions

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1. INTRODUCTION

Recent advances in in situ underwater imaging have opened new horizons for understanding particle and plankton dynamics in marine ecosystems including polar regions. Utilizing the Underwater Vision Profiler (UVP), we conducted high-resolution investigations of particle size spectra and morphology of plankton and marine snow across both polar regions—Admiralty Bay (Antarctica), West Spitsbergen Shelf and fjords (Arctic), and several fjords along East Greenland (Arctic). This modern optical approach not only quantifies particle flux but uniquely enables the morphological classification of marine snow into distinct morphotypes, offering novel insights into their origin, biological composition, and role in the ocean's biological carbon pump.

2. RESULTS AND DISCUSSION

Our results highlight the importance of marine snow quality in regulating vertical carbon export and we demonstrate year-to-year variability in the structure of plankton–particle assemblages, particularly contrasting the summers of 2023 and 2024 in glacier-influenced coastal waters of Admiralty Bay, and summers of 2022 and 2023 in glacier-influenced Spitsbergen Fjords. Coupling UVP imaging with laser-based particle counters further refined our ability to resolve particle fields and provided new metrics to assess the food availability and quality for upper-trophic levels, including Arctic seabirds during the breeding season.

Moreover, underwater imaging allowed us to map glacial outflows and associated biological responses across East Greenland fjords, revealing how physical forcing shapes the spatial co-distribution of zooplankton and organic particles on the shelf. This integrative approach underscores the ecological and biogeochemical value of modern imaging tools and sets the stage for new perspectives in polar marine research.

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Active Layer Thermal Regime on James Ross Island, Antarctica

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1. INTRODUCTION

The active layer and permafrost are key elements of periglacial landscapes in Antarctica's ice-free regions. Variations in factors like permafrost temperature and the thickness of the active layer are valuable indicators of climate change, given their strong responsiveness to climate fluctuations (e.g. Vieira et al. 2010; Hrbáček et al. 2023). The northern part of James Ross Island, Ulu Peninsula, is probably the largest ice-free area in the Antarctic Peninsula region. Local conditions in terms of altitude, lithology, topography or vegetation abundance therefore provide favourable conditions for the soil wide range of research activities including thermal state of the active layer and topmost permafrost. In this contribution, we present the data on active layer thermal regime in the period 2006 to 2023.

2. METHODS

The monitoring network on active layer thermal regime managed by Department of Geography, Masaryk University, was initiated in 2006 when the first automatic weather stations providing also data of soil temperature up to 50 and 75 cm depth were installed. Since then, the monitoring was initiated at 12 localities (Fig. 1) containing more than 20 profiles with soil temperature monitoring between the surficial part of ground (2 cm) up to topmost part of permafrost (75 to 200 cm). The locality of the sites was selected to provide representative data for different lithologies and altitudes.

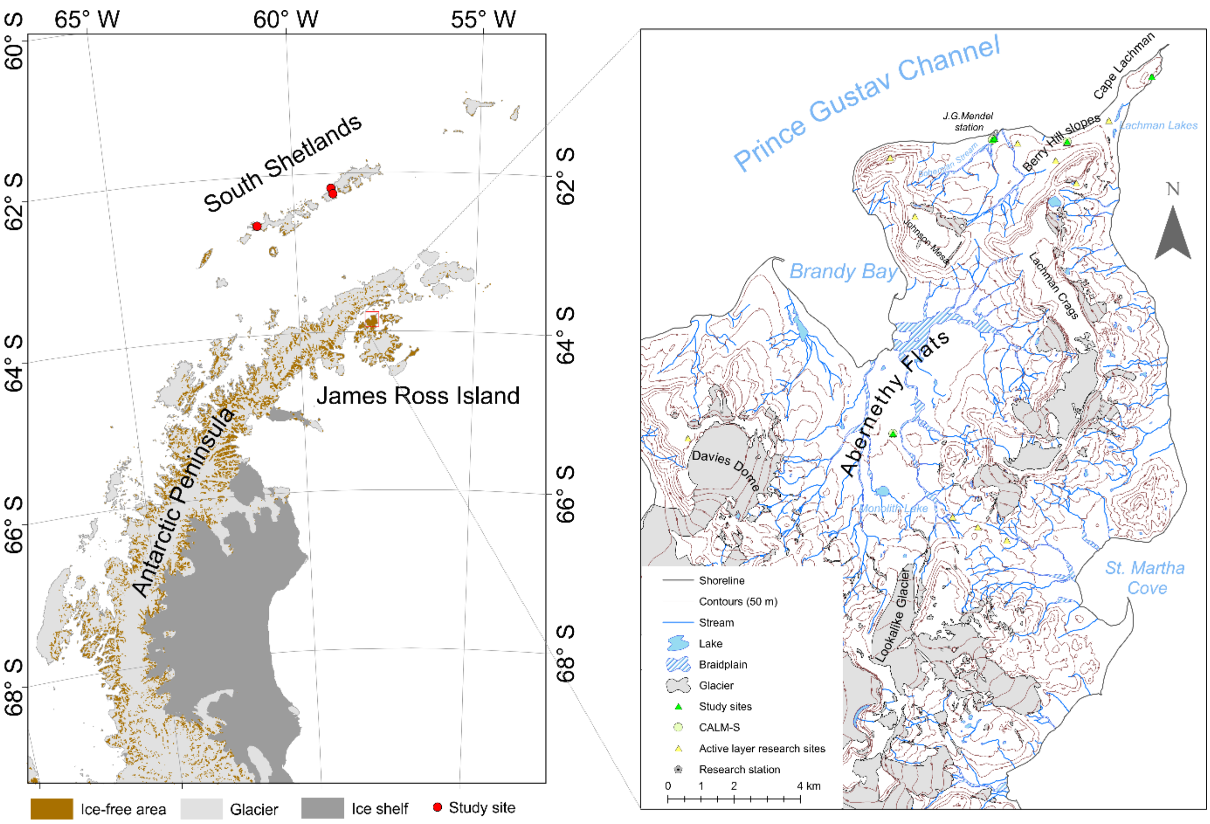

Fig. 1. Regional setting and the position of study sites on James Ross Island.

All sites have similar instrumental setting using resistance temperature detectors Pt100/8 or Pt1000/8 with an accuracy ±0.15 °C and record interval 30 minutes. In 2014, the first Circumpolar Active Layer Monitoring South (CALM-S) monitoring was initiated near to Johann Gregor Mendel Station, another two CALM-S measurements were started in 2017. To better understand active layer physical properties such as soil moisture and soil heat flux are also monitored on the selected sites. Further, the samples from selected localities were collected to set the soil texture, density, and soil thermal properties in laboratory conditions.

3. RESULTS AND CONCLUSIONS

The mean annual soil temperature on Abernethy Flats (45 m a.s.l.) providing the longest dataset available ranged from –5.7 °C to –6.0 °C at a depth 5 and 50 cm, respectively, in the period 2006 to 2023 (Fig. 2). The soil temperatures on other site of Ulu Peninsula were usually within +0.5 °C (lower elevated site) to –2.0 °C (higher elevated sites) when compared to Abernethy Flats. The study period can be divided into part of pronounced cooling by from 2006 to 2013/2014 which turned into warming continued until 2023, which was the warmest year recorded on James Ross Island. Overall, we detected warming trends of 1.81 °C/decade (5 cm, non-significant) and 1.43 °C/decade (50 cm, significant at $p < 0.1$).

Active layer thickness on James Ross Island is highly variable depending mostly on lithology and altitude. The usual annual thicknesses observed on automatic meteorological stations are between 50 and 90 cm. The maximum values > 130 cm were detected by manual probing on Circumpolar Active Layer Monitoring site near to Johann Gregor Mendel Station (CALM-S JGM). Importantly, the CALM-S JGM site very well express the importance of the lithological conditions which caused the differences in active layer thickness > 30 cm in the area of 80 to 70 m. Similarly, to ground temperature, active layer thinned before 2013/2014 (ca. 10–15 cm/decade) whereas thickening of the similar rate was observed since then.

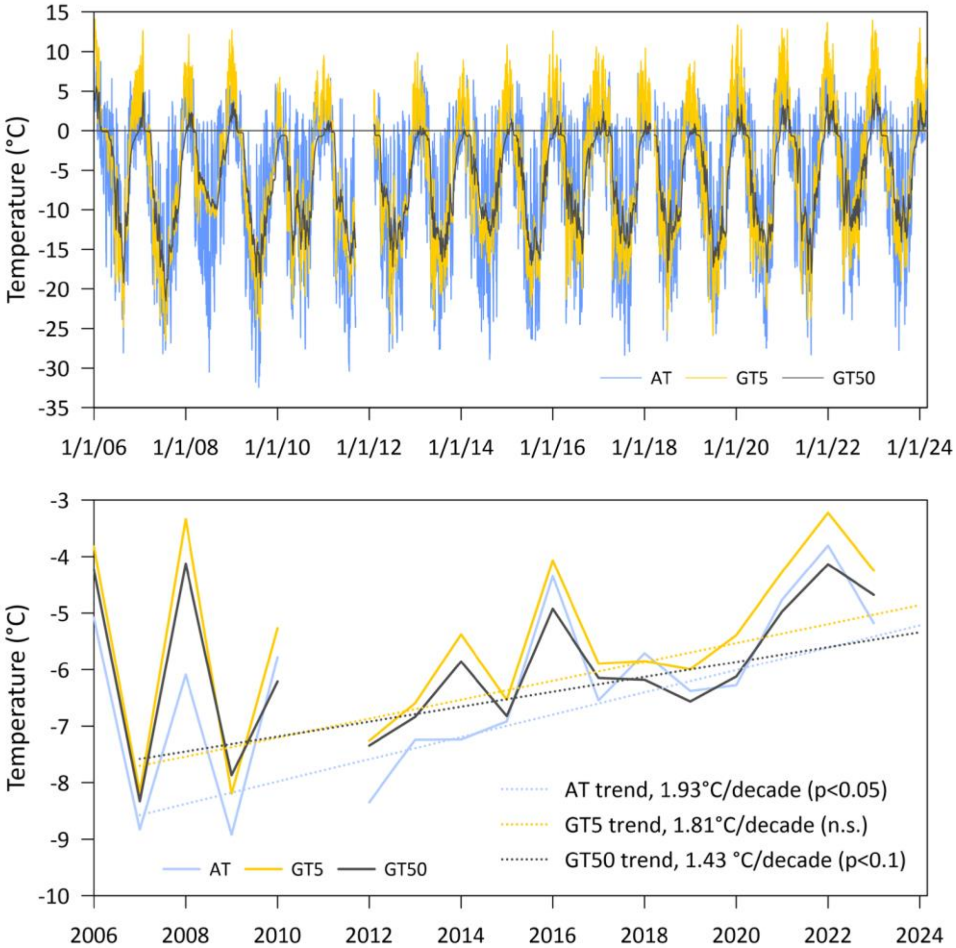

Fig. 2. Variability of mean daily (top) and mean annual (bottom) air temperature and soil temperature at a depth of 5 cm (GT5) and 50 cm (GT50).

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Thawing Off a Cliff: Organic Chemicals in Surface Waters Connected to a Degrading Yedoma Bank Outcrop (Kolyma, Siberia)

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1. INTRODUCTION

Permafrost landscape consists of a variety of frozen grounds, including the ice- and carbon-rich yedoma (occurring in Siberia, Alaska, and northern Canada), which sheds significant amounts of carbon into surface waters as a result of climate warming (Mann et al. 2022). The ice in yedoma had been formed through a variety of processes, including syngenetic ice-wedge expansion (Shur et al. 2022). Yedoma may thus contain refrozen meteoric waters of various age with various chemical traces. Permafrost has been shown to include not only a large organic matter burden, but also mercury (Fabre et al. 2024) and polycyclic aromatic compounds (PACs) of mixed origin (Muir et al. 2025; Muir and Galarneau 2021). We have demonstrated recently (Szumińska et al. 2023) that it may also be a source of other metals and metalloids released into the surrounding waters with thaw. Here, we have further investigated into the organic chemistry of various surface waters connected to and more distant from a yedoma cliff on the bank of the great Arctic river Kolyma to determine what other effects may be associated with its thaw and thermoerosion-driven input into the river.

2. MATERIALS AND METHODS

In July 2021, we collected 28 water samples from the lower Kolyma river and tributaries, two thermokarst lakes, yedoma ice and meltwater creeks (Fig. 1). PAHs were determined using GC-MS. Having analysed their concentrations of dissolved and suspended sediment fraction of PAHs and further organic compounds, we also drew paralells with the Szumińska et al. (2023) study on metals and metalloids, determined with ICP-MS and ICP-OES.

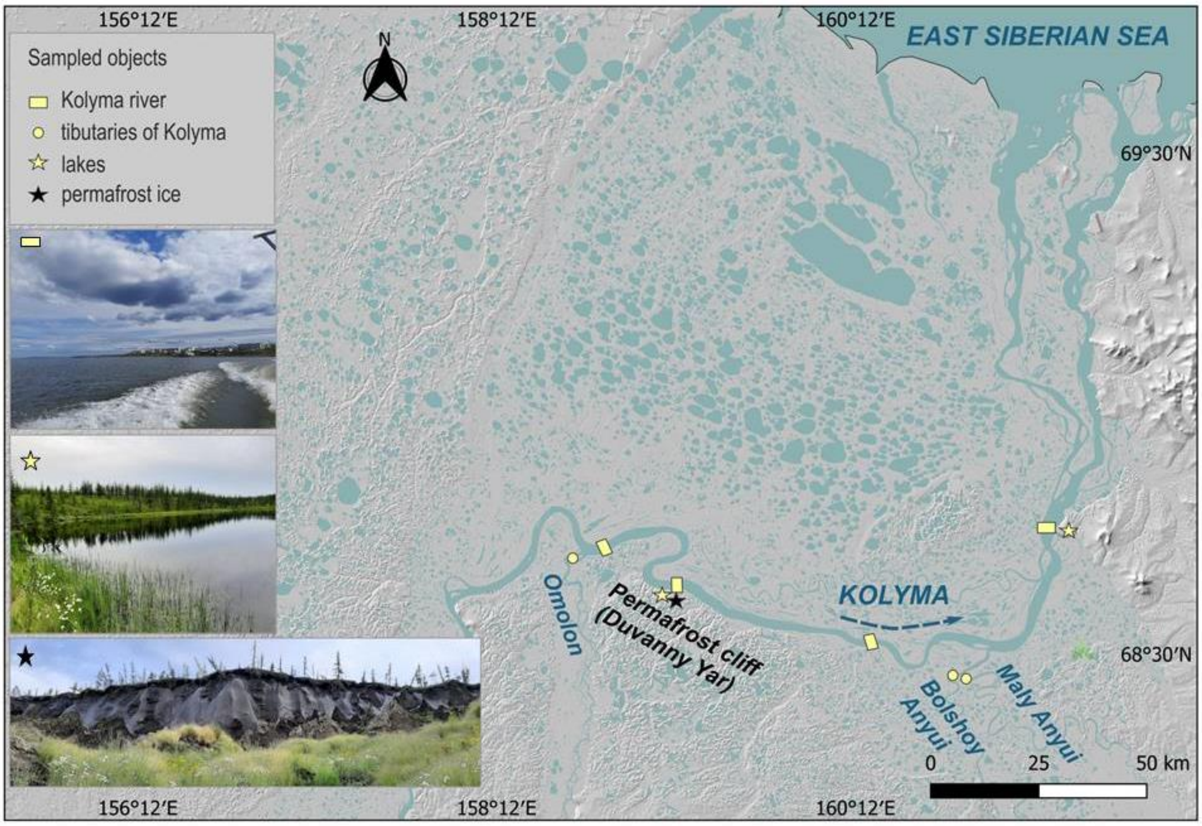

Fig. 1. Location map and example photographs of the sampled objects in the Kolyma river watershed.

3. RESULTS

PAHs concentrations in the collected samples ranged 1.12–30.2 × 10^3 ng/L, predominantly in the suspended sediment fraction. The highest concentrations pertained to two yedoma meltwater creeks and the current of Kolyma downstream of the yedoma cliff. High suspended sediment PAHs concentrations were also observed in other samples in the area, potentially connected to permafrost thaw. We explored also PAHs congener profile of the permafrost creeks and other organic compounds in these waters.

4. CONCLUSIONS

Thawing yedoma may lead to increased concentrations of various inorganic and organic chemicals in surface waters, with potential impact on downstream ecosystems. The mechanisms and dynamic of such transfers warrant further study.

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The Postglacial Lakes in the Admiralty Bay Catchment (King George Island, West Antarctica) – Morphometric and Physicochemical Characteristics

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The objective of the presented research was to gather reliable data on the bathymetry and physicochemical properties of water of lakes situated on King George Island in West Antarctica. The area that was examined in particular was the unglaciated portion of the Admiralty Bay catchment, which is situated in the central region of the island.

Since the 1950s, the climate of this region of Antarctica has been deliberately warmed (Bello et al. 2022; Dalaiden et al. 2022). For example, the annual mean surface air temperature at H. Arctowski Polish Antarctic Station for the period 1977–1999 was –1.7 °C, while for the period 2013–2021 it was –1.2 °C (Marsz and Styszyńska 2000; Plenzler et al. 2023). One consequence of the warming trend is the retreat of glaciers, with some glaciers retreating up to 1000 metres (Dziembowski and Bialik 2022). As glaciers retreat, they create new lagoons and terrain. For instance, between 1979 and 2018, land-terminating glaciers at the western shore of Admiralty Bay resulted in the formation of 2.7 km² of new terrain (Pudełko et al. 2018). The formation of lakes is a characteristic feature of the post-glacial landscape. Using satellite data, Petsch et al. (2022) found that the number of lakes at King George Island increased from 90 in 1986 to 169 in 2020. In geological terms, the glacial forefield landscape is relatively young and dynamic, meaning that the lakes may undergo changes in shape or depth, therefore it is imperative to conduct comprehensive documentation of the current state, that in the future will allow to examine the speed of environmental changes.

During the 2025 Antarctic summer, bathymetric surveys and measurements of surface water temperature, pH and specific conductivity were carried out at 46 lakes located in the Admiralty Bay catchment. The measurements were conducted using a sonic depth finder equipped with a global positioning system (GPS), installed on a small inflatable boat propelled by an oar. Water temperature, pH and specific conductivity were measured with the use of YSI 1030 probe.

The lakes that were measured during fieldworks represent variability in terms of age, water supply source, dimensions, location, and geological composition of the bedrock. The youngest, like lakes at the forefields of Baranowski, Dobrowolski, and Windy glaciers were formed during the last decade (Pudełko et al. 2018; Petsch et al. 2022; personal observation). They are situated at the terrain close to the sea level up to 220 m a.s.l. They are relatively small, with the largest being Ginger Lake and the lake in the front of Vieville glacier – according to preliminary calculations they both have an area of approx. 4.5 ha. The smallest lakes were approx. 0.01 ha. The Ginger Lake is also the deepest one – with maximum measured depth of 10 m. The range of surface water temperature was in the range from 0.3 °C to 10.2 °C. Surface water conductivity was from 17.6 to17434 μS/cm and pH was from 5.3 to 11.1. The majority of the lakes are supplied by glacial and snow meltwater, either directly or via streams that flow from the glacier. However, some are supplied only by melting snow or streams that originate from non-glaciated areas or by sea water intrusions.

The results of the research will be used to develop a scientific study aimed at analysing the variability of the hydrochemical and morphological characteristics of the lakes in Antarctica using both in situ and remote sensing methods. Moreover they may be also useful for various geomorphological and ecological studies as they provide insight into the habitat conditions within the lakes.

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Vegetation Cover as an Indicator of Active Layer Status in Maritime Antarctica: First Results from Model Plots on South Shetland Islands and Argentine Islands – Kyiv Peninsula Region

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1. INTRODUCTION

Investigating the effects of climate change on permafrost and vegetation dynamics in Antarctica is of great importance. Vegetation plays a key role in modulating soil thermal regimes and ecosystem processes under climate change in Antarctica.

Until recent, only limited results are available from distinctive Antarctic regions. In continental Antarctica, climate warming has led to an increase in the thickness of the active permafrost layer (0.3 cm/year), improved soil drainage resulting in lower moisture content, and greater diversity of vegetation–particularly lichens–in drier areas (Guglielmin et al. 2014a). The research (Guglielmin et al. 2014b) also highlights the critical role of vegetation in regulating the thermal regime of soils in continental Antarctica. Vegetation changes can affect soil temperature and the thickness of the active layer, with significant ecological consequences, particularly for carbon storage in ecosystems. A decrease in moisture in East Antarctica has caused significant shifts in the composition, distribution, and growth of local vegetation, highlighting the vulnerability of Antarctic ecosystems to climate change (Robinson et al. 2018).

These changes contrast with the maritime Antarctic, where warming is usually associated with increased moisture and a different vegetation response. In the maritime Antarctic, the thermal regime of the active layer under different vegetation types at Signy Island was analyzed (Guglielmin et al. 2008). Results showed that vegetation significantly influences permafrost thaw dynamics: areas covered with vegetation carpet of *Deschampsia antarctica* É. Desv. and *Sanionia uncinata* (Hedw.) Loeske had a shallower active layer and lower soil temperatures compared to bare ground and *Usnea aurantiacoatra* (Jacq.) Bory cover. This highlights the key role of vegetation cover structure and its thermal properties in regulating heat flow into permafrost in the maritime Antarctic. The study (Cannone and Guglielmin 2003) also emphasizes the importance of vegetation in regulating the thermal regime of the soil's active layer in the maritime Antarctic. Different vegetation types, in terms of their composition, 3-D structure and cover area, can influence soil temperature, which in turn can affect permafrost stability and the overall ecosystem. The findings also highlight the need to use the "thawing degree days" index rather than "growing days" when assessing favorable conditions for cryptogamic vegetation growth in Antarctica. The effects of climate (air temperature and solar radiation) and vegetation on ground surface temperature and active layer thickness (ALT) in three Antarctic Conservation Biogeographical Regions between 60° and 74° S was investigated (Hrbácek et al. 2020). These findings emphasize the importance of accounting for moss type and its water retention properties to accurately model ALT variation and its climate change feedbacks.

Our study investigates the composition and characteristics of vegetation, with an emphasis on cryptogamic species, across research plots to examine their relationship with variations in the active soil layer and to assess the potential impacts of climate change.

2. MODEL PLOTS

The study is conducted in two remote regions within the maritime Antarctic – the South Shetland Islands and the Argentine Islands – Kyiv Peninsula region (Fig. 1). In the South Shetland

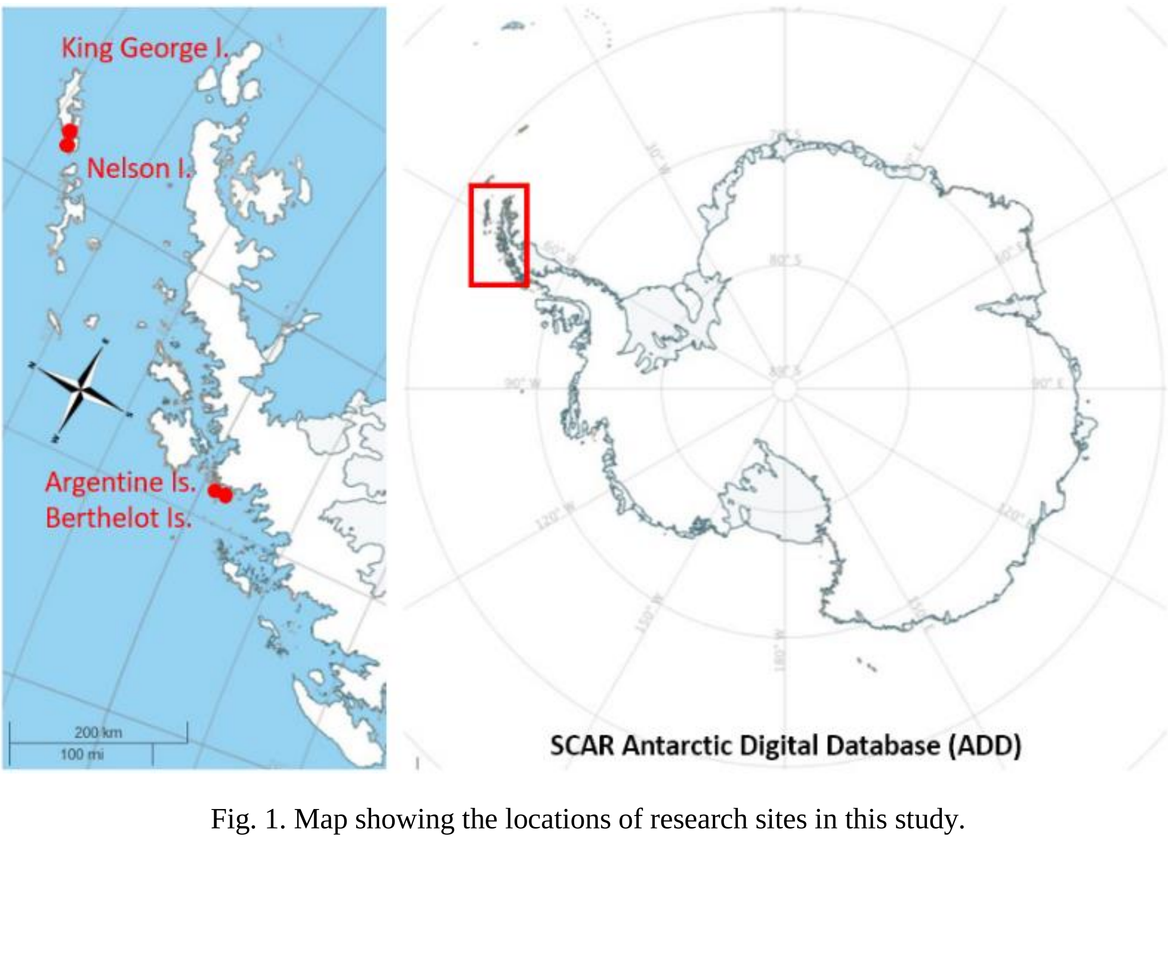

Fig. 1. Map showing the locations of research sites in this study.

Islands region, research plots have been established on Nelson Island and King George Island. On Nelson Island, in the northern part – the Stansbury Peninsula – model sites are located in various zones of the oasis. To encompass different vegetation types, contrasting biotopes caused by the differences in relief of the terrain were selected. The “Dry Hill” plot is dominated by dry Andreaea–Usnea association, with isolated patches of moss carpet sub-formation. On Fildes Peninsula of King George Island the study plot “Artigas” is dominated by dry Andreaea–Usnea association. The “Lakes” plot represents a typical area of bare soil with scattered moss patches. The “Green Valley” plot features a well-developed vegetation cover, represented by mosses with a relatively broad spectrum of diversity.

In the area of the Ukrainian Antarctic station Akademik Vernadsky, the Argentine Islands – Kyiv Peninsula region, regular monitoring sites were selected on Galindez Island (Argentine Islands) and the Berthelot Islands, a typical area of bare soil with patches of moss communities.

During the 3-year monitoring period, we developed and refined a specific measurement methodology. On the research plots, we conducted a study of the moss biodiversity with subsequent vegetation mapping within the plots. Using HydroSense II Handheld Soil Moisture Sensor (Campbell Scientific, USA) we measured moisture levels for individual vegetation fragments and bare soil. Additionally, using portable spectrometer PolyPen RP 410 UVIS (PSI, Czech Republic), we obtained the spectral characteristics of individual components of the moss communities.

3. RESULTS

The moisture in research plots ranged from 4.6 to 43.7% on dry Andreaea–Usnea association with fragments of relatively moist moss carpet sub-formation (“Dry Hill”), from 14.5 to 49% on moist moss carpet sub-formations (“Lakes”), from 11.8 to 68.7% on developed moist moss carpet formation with more dry margins with Andreaea–Usnea association (“Green Valley”), from 4.6 to 22.6% on dry Andreaea–Usnea association (“Artigas”) in South Shetland Islands, and from 10.7 to 71.5% in moss turf and moss carpet sub-formations combination (“Galindez”), from 19.3 to 56.7% wet moss carpet sub-formation (“Berthelot”) in Argentine Islands and Berthelot Islands, respectively. The lowest values were observed on bare soil plots, the highest values were measured in areas associated with rich bryophytes vegetation of moist moss carpet sub-formation. The contrast between dry Andreaea–Usnea association and wet moss carpet sub-formation registered. Within each polygon, certain fragments of moss communities dominated by specific moss species were also distinguished. These species differ in their characteristic moisture levels (including variations due to their physiological condition) and, accordingly, in their spectral characteristics.

Overall, the use of these differences provides a promising approach for identifying relationships between permafrost development, moisture levels, the composition of plant communities, and the spectral properties of individual species (and their physiological states) during large-scale monitoring using remote sensing methods. The heterogeneity of surface moisture and the associated condition of the vegetation cover that we have identified may be indicators of the dynamics of the active layer, which requires further research.

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Glacial Lakes as Forms Sensitive to Seasonal Change using the Example of a lake in the Ragnarbreen Foreland, Central Spitsbergen

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Abstract

Glacial lakes are some of the more prominent evidence of progressive, contemporary climate change. Their development is directly linked to the overgrowth of glacial water inflow over drainage, leading to accumulation in the proglacial zone. Research on Svalbard has shown that the increase in the total area of glacial lakes in this Arctic archipelago is greater than the average increase from other glaciated regions of the world – relative to the end of the Little Ice Age (Shugar et al. 2020; Wieczorek et al. 2023).

Ongoing observations of glacial lakes around the world show that they are important forms of freshwater retention that, due to their instability (dams built of unconsolidated moraine material or ice), can significantly influence the landscape shape of the runoff zone as well as the Arctic coasts themselves (Wołoszyn et al. 2022).

Ongoing observations on the glacial lakes of Svalbard indicate that an important element in understanding the mechanics controlling their evolution is to pay attention not only to long-term evolution but also to seasonal changes in this fragile Arctic landscape.

So using a UAV, we carried out flights over a lake in the Ragnarbreen foreland in central Spitsbergen. High-resolution satellite data were also used for full data compilation. The compilation of these remotely sensed data allowed us to identify sites that had evolved over the course of one year. These results were further supported by meterological data and field observations on the geomorphology of the run-off area. The main element that caught our

attention is the significant mass movements associated with the melting of dead ice located in the moraine.

Dead ice in moraines has a significant destabilising effect on these structures and ultimately on the potential for Glacial Lakes Outburst Floods. This research is intended to help better predict the geohazards associated with glacial lakes. This research was supported by the Polish National Science Centre under project GLOWS [2023/49/N/ST10/01075].

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Evaluating the Role of Hydro-climatic Drivers in Shaping Suspended Sediment Dynamics across Sub-Arctic Riverine System: A Case Study of Tana River Deltaic Estuary

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1. INTRODUCTION

The Arctic flow regimes have become vulnerable to the ongoing climate change-induced Arctic Warming, which is referred to as Arctic Amplification (Rantanen et al. 2022). Consequently, Arctic Amplification has impacted the riverine water flow, significantly affected stream networks, and critically impacted the large river deltaic estuaries. Nutrients. Across the Arctic, a 2 °C rise in air temperature can lead to a 30% increase in sediment flux, while a 20% increase in river runoff can result in a 10% increase in sediment load (Syvitski 2002). It has induced permafrost thaw across the Arctic catchments, mobilizing sediment particles and associated nutrients. Due to Arctic amplification, since 1990, Scandinavia has experienced a warming trend, primarily due to winter warming; it was unusually warm even during the 20th century's first half (Dankers 2002). Temperature rise in the Scandinavian Arctic significantly impacted the hydrological cycle as higher water vapour concentrations in the atmosphere could have led to increased precipitation, particularly from the northern mid-latitudes to the high latitudes. In addition, precipitation in Finnish Lapland has increased significantly since 1879 (Lee et al. 2000). Previous research on northern Scandinavia indicated that the rise in extreme precipitation events in recent decades reduced soil storage capacity, triggered extreme soil erosion events, and contributed to sediment availability and mobilization across flow regimes. Thus, the significance of permafrost thaw impacting hydrological processes is recognized widely (Vihma et al. 2019); however, the hydrological processes operating in Arctic River deltaic estuaries have been mainly overlooked due to the challenges and associated costs associated with assessing the water-sediment processes (Chalov et al. 2023).

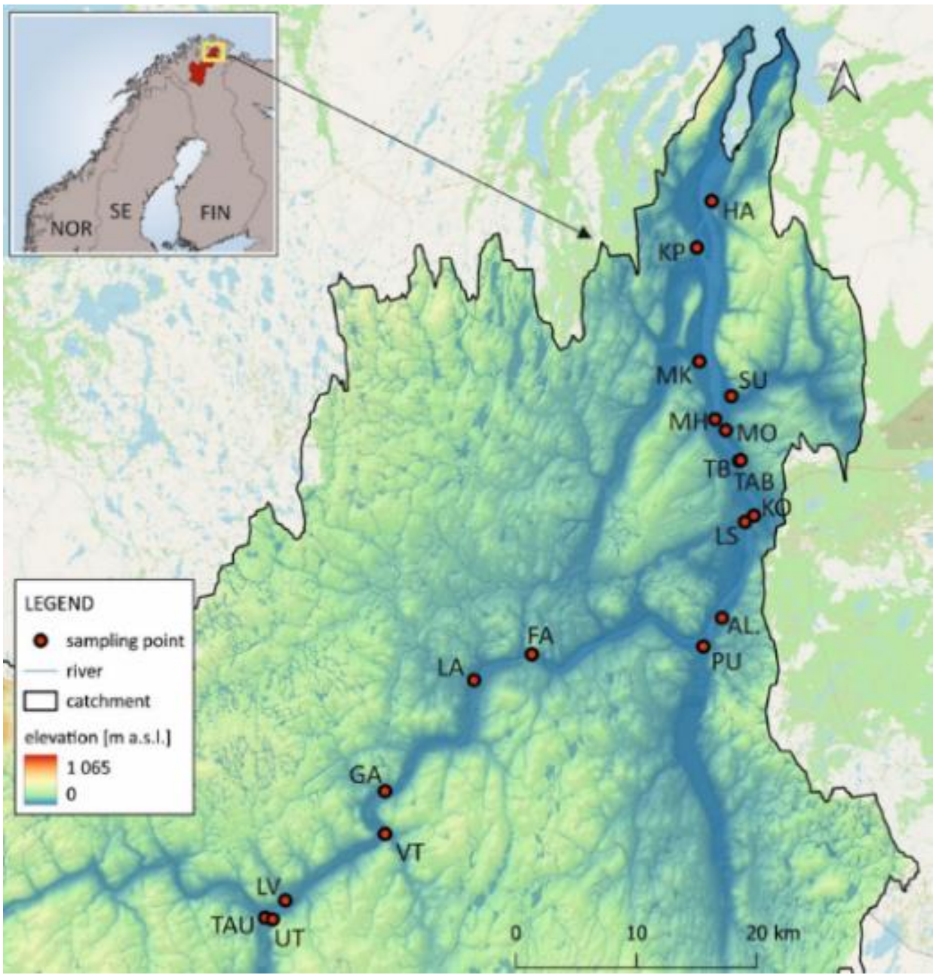

Fig. 1. Study area selected for the projected with sampling points selected for the field investigation across the Tana River estuary.

Considering the complexities of hydrological monitoring, our study is based on the Finnish-Norwegian river basin of Tana (also known as Tenojoki in Finnish), located in the circumpolar subarctic zone (between 68°N and 70°N). This study involves a meticulous investigation of the seasonal dynamics of the Suspended Sediment Concentration (SSC) across the estuarine catchment of the Tana River (Fig. 1).

2. SUMMARY OF METHODS AND RESULTS

The Tana River, being the formal boundary between Norway and Finland spanning over 338 km, is one of the largest and unexploited river deltaic estuaries of Scandinavia. The unique flow regime of Tana features low discharge (21 m^3s^{-1}) between December and mid-May when the basin is ice-covered, which can occur as early as October. Following that, the Peak discharge range (1,000–2,000 m^3s^{-1}) occurs from late May until June when the temperature is >10 °C during the spring freshet post-ice-breakup from late May to June. To begin the research approach has prioritized in-situ SSC sampling conducted across the tributaries (indicated in Fig. 1, as acronyms) of Tana's estuarine section (Utsjoki, Levessejhoka, Pulmankijarvi Kulpukanjoki, Álletjohka, Korselva, Vestjoki, Mohkkevajohka, Harrijoki, and Maskijoki) during the peak flow events after ice breakup and consequent spring freshet (end of May 2024 and 2025), alongside observations from lower flow summer conditions (e.g. in August). The field-based SSC measurements establish a baseline for comprehending the Tana flow regime's rapid response to the dominant impact of ice-breakup.

Field data depicted significantly higher SSC values during May 2024; for instance, Tana River's tributary Maskijoki exhibited SSC values ranging between 41.87–114.4 mg/L, whereas in August measurements for the same tributary recorded markedly lower SSC range of 0–5.8 mg/L (Fig. 2).

This pronounced seasonality in SSC can be directly linked with the intense spring runoff, reflecting the sharp increase in discharge patterns during the freshet flood period (as shown in Fig. 3 – Flow Hydrography of Tana).

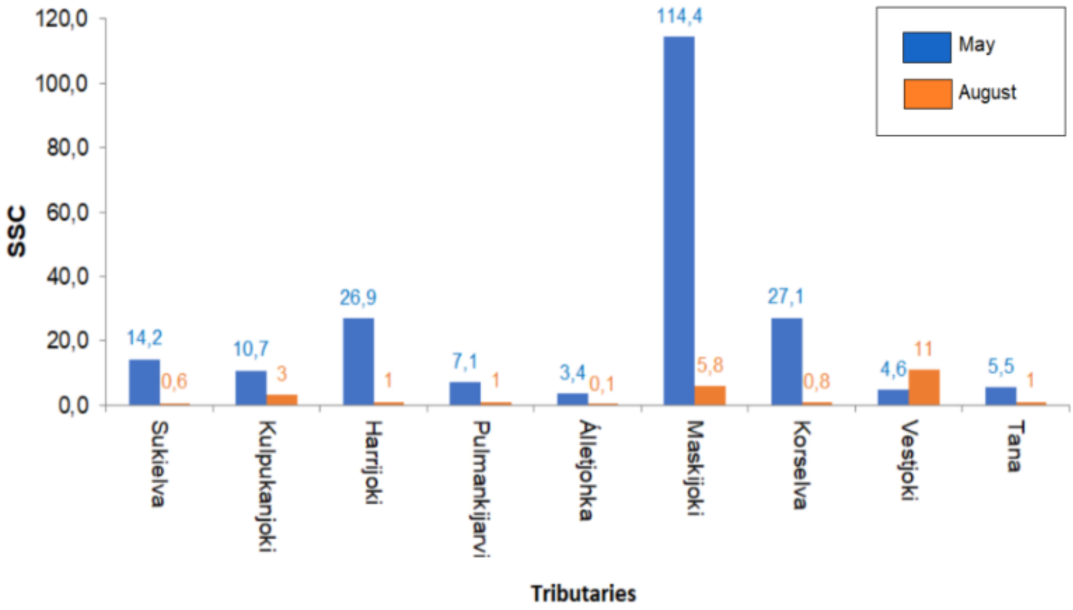

Fig. 2. Estimated SSC in 2024 via in-situ sampling undertaken across Tana and its tributaries.

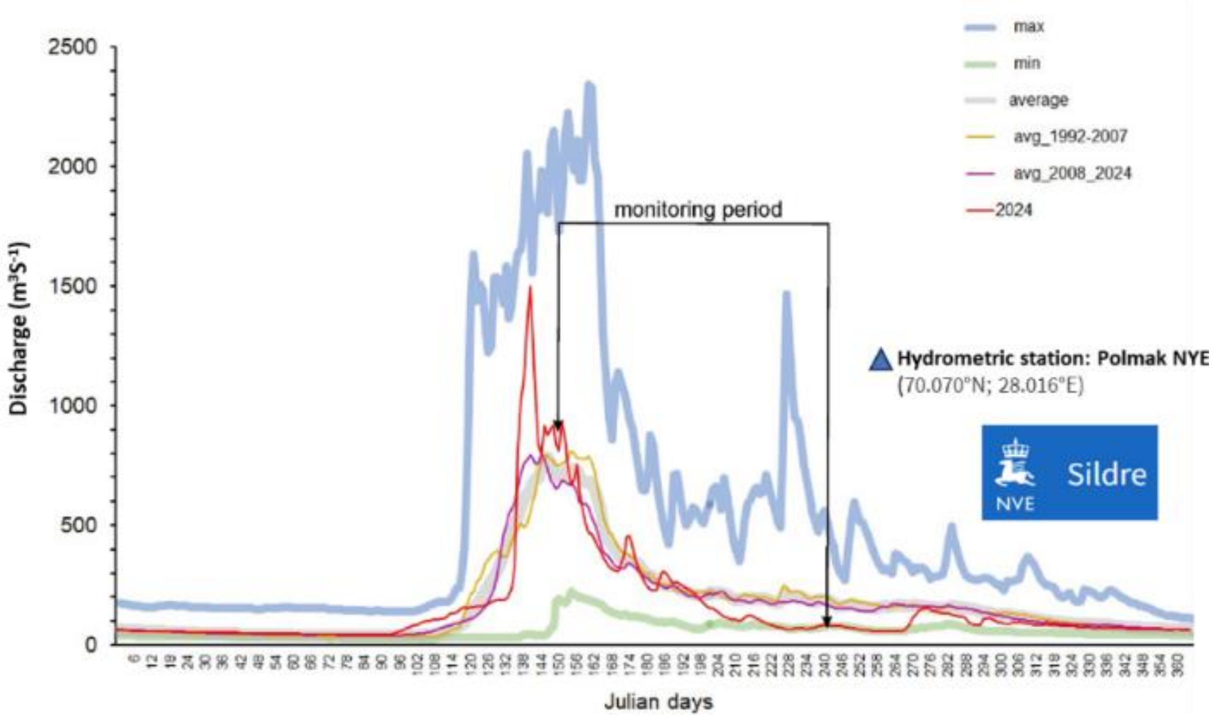

Fig. 3. Flow Hydrograph: Tana River, 1992–2024, recorded at Polmak NYE, Norway (Raw data source: https://sildre.nve.no/map).

The second part of the research involves leveraging the robust in-situ SSC dataset to develop and validate satellite data-based SSC estimations via optical remote sensing data using Sentinel-2 MSI. Therefore, this integrated approach of field data data-to-satellite data-based SSC patterns across the Tana River Estuary and its tributary network overcoming the limitations of solely point-based measurements.

3. CONCLUSIONS

Our two years monitoring covered more than 20 locations spanning a route of approximately 100 km, enabling the effective characterization of SSC patterns across the entire Tana River Estuary. Our research tends to establish that ice breakup and spring freshet are the dominant drivers influencing the duration and level of sediment flux and concentration in the Tana River Estuary, which is profoundly influencing its morpho-dynamics, channel stability, and the overall sediment budget. Our observations in May 2024 and 2025 shows that the specific climatic conditions of the Arctic, the ice cover, are an important factor modulating the flow of water and sediments between the Tana River and its tributaries. At the same time, each of the tributaries is characterized by individual features, hence the dates of the SSC peak differ.

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Special Session: Education and Science Communication: Polar Experiences: Communicating Science and Climate Change in Polar Regions

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Teaching at the Edge – Polar Experience in Tiniteqilaaq

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Abstract

This presentation delves into the lived experiences of a primary school teacher working in a remote Greenlandic settlement. The challenges and opportunities inherent in Arctic education will be highlighted through educational projects carried out at school.

Tiniteqilaaq is a traditional fishing and hunting settlement in East Greenland which about 70 inhabitants call home. It is considered remote even by Greenlandic standards. It lies about 30 km into the majestic Sermilik icefjord, on the Greenlandic mainland in beautiful surroundings. The views across the fjord with its enormous icebergs are spectacular. Local living conditions are rather spartan compared to what one is used to in a so-called “civilized” world. Drawing from my time spent living and working in Tiniteqilaaq, this presentation discusses several topics informed by firsthand personal experience.

Overview of the educational system in Greenland and insights into culturally responsive teaching practices, with emphasis on engagement with community-based educational projects, the integration of local knowledge and language into the curriculum, and the unique rhythms of school life shaped by seasonal cycles and small community dynamics.

Particular attention is given to collaborative educational projects developed with learners, including building a kayak and sledges, nature-based learning, storytelling initiatives, and interdisciplinary work that bridges traditional knowledge with formal education.

The presentation also reflects on the teacher’s role as a cultural mediator and learner, navigating linguistic diversity, community expectations, and the socio-emotional needs of children growing up in geographically and socially isolated region.

These reflections aim to contribute to broader discussions about decolonizing education, sustaining indigenous knowledge systems, and building resilient learning environments in the Arctic and other remote regions, discuss a local perspective on hunting, development of tourism and environmental changes in the form of climate change.

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"Spitsbergen Challenge" – Educational Project for Students of Technical Universities

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1. INTRODUCTION

The project aims to promote polar research and knowledge development among students at technical universities. By participating, students gain a global perspective on climate change and deepen their understanding of the mechanisms driving it. The project has two main objectives: scientific and didactic. The scientific objective is to organise an expedition to Spitsbergen, during which research is conducted to identify changes in the Arctic environment, which is undergoing rapid transformation due to anthropogenic pressure and climate change. The didactic objective is to provide students with experience in working on international and interdisciplinary scientific projects and to disseminate knowledge about climate change. The project is being implemented over three years (2022–2025), with a total of 36 students participating.

2. PREPARATIONS FOR THE EXPEDITION

To prepare for organising and participating in the Spitsbergen expedition, students took part in numerous activities aimed at improving their skills in fieldwork and laboratory research.

2.1 Science camps

3 field campaigns in Władysławowo (2022) – surface water monitoring in the Seaside Landscape Park, 7 field campaigns in Borucino (2022–2023) – monitoring of coastal waters in the Kashubian Landscape Park, 2 scientific camps in Nadbrzeże (2023–2024) – monitoring of coastal waters and bathing areas in the Vistula Lagoon, 1 scientific camp in the Beskidy Mountains (September 2022). During this five-day trek (over 65 km with a 3,000 m elevation gain), students tested their ability to live and work under conditions similar to those in summer on Spitsbergen (tent camping at around 0 °C, preparing meals from freeze-dried food). During the

trek, water samples were taken from springs, and basic environmental parameters (temperature, pH, conductivity) were measured. Training camp (2024) – focused on improving camping and orientation skills

2.2 Online role-playing game

An online role-playing game developed by the students supported expedition preparation by deepening participants' understanding of the challenges faced by polar researchers. Upon completing the game, participants are expected to: possess broad knowledge of polar regions, understand the mechanisms of climate change and the importance of mitigation, acquire skills necessary for laboratory work (microbiological and chemical), gain experience in conducting field research, develop the ability to recognise and mitigate risks in challenging field conditions

3. EXPEDITIONS

3.1 First polar expedition of Gdańsk tech students to Spitsbergen (8 participants)

The expedition in August 2023 focused on research in the Eidembukta lagoon area on the western coast of West Spitsbergen, in the Svalbard archipelago. Students organised a tent field camp and collaborated with scientists from the University of Klaipėda (Lithuania) and the Institute of Oceanology PAS (Sopot). Participants formed two teams: one conducting walking surveys to collect biological, chemical, and geological samples, and the other collecting hydrochemical and hydrological data using watercraft.

3.2 Second polar expedition of Gdańsk tech students to Spitsbergen (10 participants)

The second expedition in August 2024, held in the Kaffiøyra Plain region, The team was based at the NCU Polar Station. Students conducted hydrological and geomorphological studies and designed their own research programme focusing on the physicochemical and microbiological analysis of post-glacial lakes formed on the moraines of valley glaciers.

4. POPULARISATION OF SCIENCE

A key element of the project is the active dissemination of research outcomes. Students not only presented their work at scientific conferences but also acted as ambassadors of science during public outreach events, engaging diverse audiences and raising awareness of climate change and polar research.

5. SUMMARY

Participation in the Spitsbergen Challenge enabled students to develop essential research skills, gain experience in international teamwork, and build resilience in demanding field conditions. They improved their ability to manage risks, communicate science to diverse audiences, and translate academic knowledge into practice, preparing them for future careers in research and environmental engineering.

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Between Research and the Audience: Images, Emotions, and Narratives in Communicating Climate Change in Polar Regions

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1. INTRODUCTION

In the communication of scientific research conducted in polar regions, visual and emotional narratives, along with artistic forms of expression, are gaining increasing significance. Photography, illustration, and installation art are no longer just tools to illustrate data—they become languages of their own. By transcending the boundaries of scientific jargon, they help evoke emotional responses and remain memorable. Artistic forms open a space for empathy, sensitivity, and deep personal engagement—elements that are crucial in building public awareness and action for the climate.

Images from polar expeditions—featuring retreating glaciers, signs of human presence, or the fragile beauty of remote ecosystems—illustrate how visual storytelling can strengthen the scientific message and give it a personal, human dimension.

2. REFRAMING SCIENTIFIC COMMUNICATION THROUGH ART AND EMOTION

While scientific data and graphs are essential, they are often insufficient to inspire emotional connection or behavioral change. Visual language—especially when combined with narrative—can significantly amplify cognitive and emotional engagement. Art speaks directly to human emotions, making it a powerful tool to counter apathy, engage wider audiences, and spark dialogue beyond academia.

A notable example of this interdisciplinary approach is the initiative “The Woman Image of the Sea”, organized by the Institute of Oceanology PAS. This competition showcases women’s perspectives on the sea and climate through photography and artistic narratives. The resulting works reflect environmental phenomena through the lens of personal experience and emotion, proving that images—when grounded in scientific context—can serve as effective communication tools, fostering public engagement and resonance.

Science communication benefits from cross-sector collaboration between scientists, educators, artists, and local communities. Exhibitions, workshops, and educational initiatives based on such cooperation translate specialized knowledge into visual metaphors, emotions, and shared concerns. Long-standing initiatives like the "Sopot Science Picnic", now in its 17th year, offer excellent examples of how interactive exhibitions and online formats can broaden understanding across different age groups and backgrounds.

3. BEYOND DATA: BUILDING TRUST AND DIALOGUE

Equally important is addressing climate skepticism and misinformation, which continue to undermine scientific credibility. This presentation will also highlight the importance of trust-building through open, honest, and empathetic communication. Visual narratives, personal stories, and emotional authenticity can play a crucial role in fostering trust and making science more relatable and inclusive.

In an age of information overload, science must not only inform—it must also inspire. Integrating visual language with scientific knowledge empowers new, more inclusive models of communication that invite dialogue, empathy, and co-creation of meaning. Such approaches enhance the potential for societal mobilization in the face of climate change and highlight the responsibility of the scientific community to communicate polar knowledge in accessible and emotionally resonant ways.

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Comparison of Contemporary Bioclimatic Conditions in SW Greenland Against Conditions in the Second Half of the 18th Century

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The specificity of Greenland's geographical environment and lighting conditions (polar day and night) causes the climate system in this region to differ significantly from other areas on Earth. Polar regions experience conditions that are very harsh for human life.

The paper estimates the bioclimatic conditions in the region of the modern-day capital of Greenland (i.e., Nuuk, formerly known as Godthåb or Neu-Herrnhut) in the second half of the 18th century. Nuuk is located in the SW coastal part of Greenland. Climate conditions at that time have already been analysed in a paper by Przybylak et al. (2024).

The present analysis was based on air temperature and wind speed data from sites of meteorological observations in this area, namely Neu-Herrnhut (1 September 1767 – 22 July 1768) and Godthåb (January 1790 – June 1792). The first series is the oldest available long-term series of instrumental measurements in the Arctic. Data for the year 1767/68 were obtained from the Moravian Archives in Herrnhut (Fig. 1). Thanks to this, it was possible to present the first bioclimatic conditions for humans in this region of the Arctic. The second series of meteorological measurements covers the period from January 1784 to July 1792, but, for the first years, wind speed measurements are either lacking or of low quality. Therefore, based on available data from this period, it is possible to calculate biometeorological indices only for the period 1790–1792. Data from this period were found in The Royal Library in Copenhagen in the manuscript *Astronomiske og Meteorologisk Iagttagelser, Anstillede i Godthaab i Grønland 1782–1792* (Fig. 1).

In the study, two biometeorological indices: Wind Chill Temperature (WCT) and Predicted Clothing Insulation (Iclp) have been used (Błażejczyk and Kunert 2011). These indices were computed using the BioKlima 2.6 software program (BioKlima 2024). Wind Chill Temperature (in °C) was used to examine apparent cold and to assess the risk of frostbite to the human body in Nuuk. The risk of frostbite according to WCT is as follows: low risk (0 to –9 °C), moderate risk (–10 to –27 °C), high risk (–28 to –39 °C), very high risk (–40 to –47 °C), severe risk (–48 to –54 °C) and extreme risk (–55 °C and colder) (WCT 2013). The predicted thermal insulation of clothing allows for the determination of the thermal insulation needed in given meteorological conditions to maintain the thermal balance of the body (Błażejczyk and Kunert 2011). Iclp was calculated assuming a metabolism of 135 W m^{-2} for a person moving outdoors at 4 km h^{-1}. With reference to the value of the Iclp index (in clo), the thermal environment assessment scale proposed by Krawczyk (2000) may be used: ≤ 0.30 very warm, 0.31–0.80 warm, 0.81–1.20 neutral, 1.21–2.00 cool, 2.01–3.00 cold, 3.01–4.00 very cold, > 4.00 arctic. Calculations of bioclimatic conditions were made for the hours 2–3 pm LT. The results from the historical period from the second half of the 18th century were compared with those for the contemporary period (1991–2000).

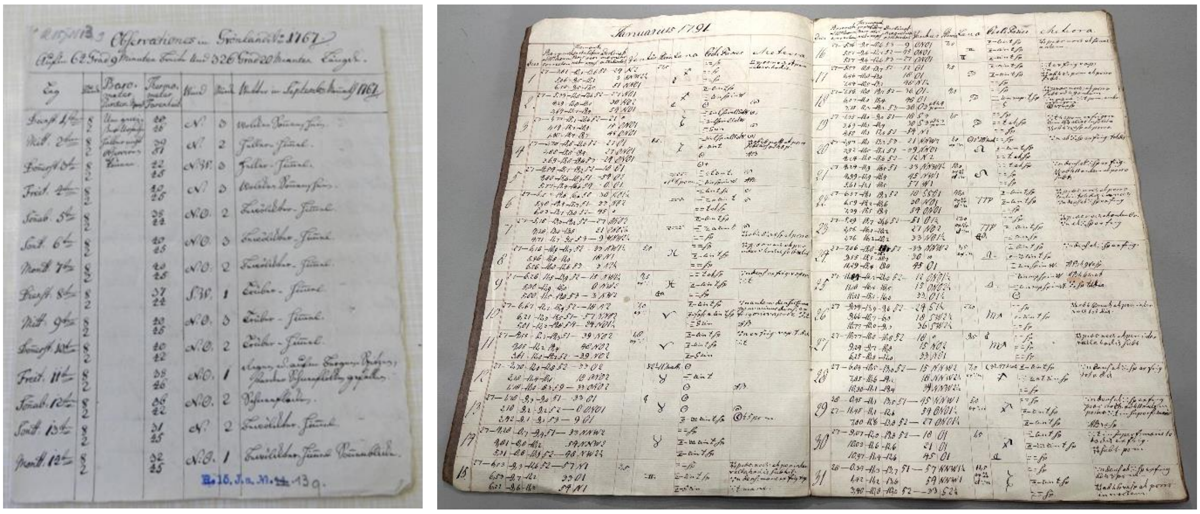

Fig. 1. Examples of manuscripts presenting meteorological observations: (photo on the left) for Neu-Herrnhut (1 September 1767 to 22 July 1768), source – MH R.15 J.a.13.9; and (photo from the right) for Godthåb (1782–1792), source – *Astronomiske og Meteorologisk Iagttagelser, Anstillede i Godthaab i Grønland 1782–1792* (Det Kgl. Bibliotek in Copenhagen; data presented in the manuscript: January 1791).

In the contemporary period, the mean monthly WCT values ranged from –11.4 ÷ –10.5 °C (moderate risk frostbite) in January–March, to 7.9÷8.8 °C (low risk frostbite) in July–August. The average historical monthly values of the WCT are in most cases between extreme values from the contemporary period. In the years 1789–1790 and 1790–1791, there was a higher risk of frostbite than the average from the contemporary period, whereas in 1767–1768 and 1791–1792 the risk of frostbite was lower. In the analysed historical period, the lowest winter values of WCT fell below –30 °C. As a result of low air temperature and high wind speed, the risk of frostbite was very high, i.e. exposed skin could freeze in 10 to 30 minutes.

In the years 1991–2020 in Nuuk, clothing with high thermal insulation properties was necessary for humans to achieve thermal comfort in motion (at metabolism = 135 W m^{-2}). In the annual course, the average monthly Iclp values ranged from 1.3 clo in July and August to 2.4 clo in February. On the other hand, a person who is motionless, i.e. standing (at metabolism = 70 W m^{-2}), needs about 5 clo on average in the winter months. Analysing the historical period in the second half of the 18th century in the years 1789–1792, a person living here required very similar thermal insulation of clothing as today. The only difference noted was that the weather in period 1767/1768 required, for a person in motion, about 0.3 clo less clothing than in the contemporary period.

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Glacial Lakes as Indicators of Environmental Change: Insights from the Kaffiøyra Plain (Svalbard, Arctic)

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Abstract

The Arctic is one of the most sensitive ecosystems on Earth, where changes in aquatic environments are closely tied to dynamic climatic processes intensified by growing global anthropogenic pressure (AMAP 2021). The Kaffiøyra Plain, located in the western part of Spitsbergen (Svalbard), is characterized by the presence of numerous glacial lakes, which constitute an important element of the local landscape and, at the same time, an excellent indicator of environmental change (Liu et al. 2024; Rizzo et al. 2025). The aim of this study was to assess the physicochemical and microbiological parameters of glacial lake waters. The data obtained were used to identify potential sources of anthropogenic pollution in the Arctic environment and to observe climate-related processes.

A total of 22 water samples were collected from glacial lakes located in the catchment areas of the Aavatsmark, Irena, Eliza, and Dahl glaciers. The physicochemical investigations included field measurements of electrolytic conductivity, pH, temperature, salinity, and dissolved oxygen concentrations using in situ methods, as well as laboratory analyses of chemical oxygen demand (COD) and concentrations of selected nitrogen and phosphorus forms (nitrites, nitrates, ammonia, total nitrogen, total phosphorus) using cuvette tests. The microbiological analyses included the determination of the total bacterial count, average cell volume, and prokaryotic biomass using epifluorescence microscopy. In addition, the samples were subjected to taxonomic diversity analysis using next-generation sequencing (NGS, Illumina) of the hypervariable V3–V4 region of the 16S rRNA gene, with data processing performed in the CLC Genomics Workbench environment.

The research conducted is part of broader efforts to monitor water quality in the Arctic and contributes to a better understanding of the functioning of glacial lakes under intensifying climate change. The obtained data highlight the importance of protecting vulnerable polar ecosystems, which are particularly exposed to rapid glacier melting and the associated hydrological transformations (Sobota et al. 2016; Sułowicz et al. 2020). At the same time, they

indicate the need for further research on microbial biodiversity, which constitutes a key component of the stability and resilience of Arctic aquatic ecosystems.

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Estimation of Seasonal and Interannual Freshwater Input to Brepollen (Svalbard)

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Abstract

The Arctic is particularly vulnerable to warming, and the environmental impacts of climate change are amplified in this region. Consequently, with the increased melting of glaciers – the largest natural reservoirs of freshwater – fjord ecosystems are likely receiving higher loads of contaminants today than in the past, which may pose a threat to the ecosystem. Here, we assess the seasonal changes in freshwater input to Brepollen, the inner part of the Hornsund fjord, a semi-enclosed glacial bay with limited water exchange. Seasonal and interannual estimations are made for two years, 2022 and 2023. The primary sources of freshwater input to the fjord include: frontal ablation of tidewater glaciers, surface melting of glaciers, meltwater runoff from unglacierized areas and precipitation over the entire basin. Frontal ablation was determined using imagery from TerraSAR-X, supplemented with Sentinel-1 satellite data. The estimations of the surface melting of glaciers were based on ablation stakes. Atmospheric precipitation and meltwater runoff from non-glacierized areas were assessed using meteorological and hydrological data collected at the Polish Polar Station Hornsund. We estimated the seasonal input of freshwater to Brepollen with 11-day resolution, and it is the first estimation with such high temporal resolution for the whole Svalbard archipelago. The study is part of the project "Quantification of Heavy Metal Discharge with Freshwater Runoff to an Arctic Fjord Ecosystem (Hornsund, Spitsbergen)", and results will allow for the estimation of the amount of heavy metals delivered to Brepollen from the land.

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Over a Decade of Changes in the Diet Composition of Little Auk Chicks – a Case Study from Hornsund between 2011 and 2024

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1. INTRODUCTION

This study presents a comprehensive analysis of the diet composition of little auk (Alle alle) chicks in Hornsund (Spitsbergen), based on 14 years (2011–2024) of regular monitoring. Little auks (LA) are the most numerous planktivorous seabirds in the European Arctic, playing a pivotal role in nutrient transfer from marine (foraging areas at sea) to terrestrial ecosystems (breeding colonies on land).

Foraging areas of LAs are situated on shelf in the Hornsund area influenced by two currents: the coastal Sørkapp Current providing cold and less saline Arctic water and the West Spitsbergen Current – transporting warmer, more saline Atlantic water (Piechura and Walczowski 2009). LA chick diet primarily consists of the fifth copepodid stage of Arctic copepod *Calanus glacialis*. However, supplementary diet components, including decapod larvae, euphausiids, and amphipods can also contribute substantially to chick diet composition (Boehnke et al. 2015). The aim of the study was to evaluate the interannual variability in LA diet in order to make predictions about future composition of their preys.

Diet samples were collected in 2011–2024, during the second week of chicks' life, in the colony at Hornsund (SW Spitsbergen; 77°00′N, 15°33′E), considered the largest breeding aggregation of LAs in Svalbard. The contents of the gular pouch of adults returning from the feeding grounds to their colony were collected, then preserved in a 4% seawater formaldehyde solution (2011–2019), (2020–2022), and recently – also by freezing (2023–2024). At least 20 samples during each summer season were collected and analysed by following the procedures described by Kwasniewski et al. (2010). All large and medium-sized calanoids were identified to the appropriate species and development stages. *Calanus finmarchicus*, *C. glacialis*, and *C. hyperboreus* copepodite stages were distinguished by the comparison of prosome length measurements in accordance to Kwasniewski et al. (2003). Additionally, prosome lengths of the first 100 individuals of *Calanus* spp. at the fifth copepodid stage (CV) were noted to obtain a consistent long term dataset. A limitation of our study could be the fact that the identification of *Calanus* spp. from the first studied year was based only on morphometry, whereas a molecular research paper by Balazy et al. (2023), based on the LA diet from years 2019–2021, revealed that 40% of *C. glacialis* from Hornsund were wrongly classified as *C. finmarchicus*.

The prevailing cold water Hornsund conditions were reflected in the species composition of the diet, especially in clear dominance of Arctic *C. glacialis* – which made up from 73% to 90% of all food items (concerning numbers) during 12 out of 14 studied seasons. Despite relatively stable diet composition mentioned above, some fluctuations were observed in year 2014, which was characterised by the high share of Atlantic counterpart of *Calanus glacialis* – *C. finmarchicus* (57% of all diet components). These fluctuations might be closely connected with recently described distinctive influx of warmer Atlantic waters to the Arctic environments in 2014 (Strzelewicz et al 2022). Furthermore, the diet from 2015 was dominated by ice-associated amphipod – *Apherusa glacialis* (94% of all diet abundance), which could be closely linked with a relatively short distance from the shore of Hornsund to drifting ice. Our long-term monitoring reveals that little auks exhibit dietary flexibility, adjusting prey selection in response to environmental variability driven by climate change. Such plasticity is crucial for their resilience in the face of shifting zooplankton communities caused by warming seawater temperatures and subsequent "Atlantification" of Arctic. In conclusion, the diet composition of little auk chicks in Hornsund between 2011 and 2024 reflects a dynamic balance between reliance on the key Arctic copepods and opportunistic inclusion of supplementary prey.

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Backwater Effects and Sediment Pulses during Ice Break-up in Permanently Connected Arctic Delta Lakes

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1. INTRODUCTION

In Arctic conditions, ice and snow cover can serve as significant sources of water supply, but also as a physical barrier to water flow within river deltas. The breakup of ice triggers hydrological pulses that play a crucial role in the exchange of water and sediment within the delta. In the late winter and early spring, the ice cover in river channels and lakes begins to crack and drift, leading to dynamic and difficult-to-predict directions and intensities of water flow. A key phenomenon during this period is the formation of ice jams and backwater effects, i.e., the reverse flow of river water caused by the obstruction of the channel by residual ice.

Lakes within deltaic plains exhibit varying degrees of hydrological connectivity with the network of distributary channels. The hydrological function and dynamics of these lakes are strongly influenced by the degree of connection to river channels. A critical moment affecting the water and sediment balance of these lakes is the period of ice breakup a dynamic yet short-lived phase that determines the direction and intensity of water and sediment exchange.

According to studies such as Dolan et al. (2024), one method for investigating the hydrological connectivity in the Arctic is the use of satellite data. These data can be used to analyze the seasonal variability in the hydrological connection between the lakes of the Mackenzie Delta and river waters. According to Lesack et al. (1998), lakes in the Mackenzie Delta can be classified according to their flooding regimes as frequently flooded, infrequently flooded or isolated. This classification is crucial for analyzing the impact of flood events and ice phenomena on water and sediment transport.

The aim of this study is to investigate frequently flooded lakes during the initial phase of the spring flood, which coincides with the period of ice breakup. The research also seeks to contribute to the development of methodologies for monitoring water and sediment exchange dynamics between lakes and the river.

2. STUDY AREA

The research was conducted in the Mackenzie Delta (specifically on the East Channel of the Mackenzie River), which is one of the largest river deltas in the Northern Hemisphere located outside the Arctic Circle. The Mackenzie Delta is a unique polygenetic region that has developed under the combined influence of fluvial hydrology, glacial and periglacial processes, and marine dynamics. Within the delta, which covers an area of 13,000 km², there are over 45,000 lakes (Marsh and Hey 1989). This study presents the results of field observations conducted at Boot Lake in Inuvik (68.35106N; 133.7108). This 23-hectare lake maintains a permanent connection with the East Channel of the Mackenzie River.

3. RESEARCH METHODS

During the field campaign conducted from May 24 to 31, 2025, water samples were collected at the inflow to the lake and at the point where the lake is hydraulically connected via a channel to the East Channel of the Mackenzie River. Water samples were taken at 12-hour intervals, and an automatic turbidity and water temperature sensor was installed at the lake's connection point with the East Channel. The sensor recorded data every 20 minutes. Collected water samples were subjected to vacuum filtration using cellulose membrane filters in laboratory conditions to determine the concentration of suspended particulate matter – expressed as SSC (Suspended Sediment Concentration) in $mg \cdot L^{-1}$.

4. RESULTS

During the field investigations, it was observed that the studied lake received several pulses of river water, indicated by a reversal of flow direction in the connecting channel, increased turbidity, and a drop in water temperature during the river water transgression. Field observations revealed that the movement of ice floes and slush obstructs and slows water flow within the river channel. When the channel cross-section becomes blocked, a temporary water level rise of 20–30 cm occurs, resulting in the flooding of the lake by river water. Over the eight-day period, several episodes of intrusions of cold, turbid river water into the lake basin were recorded, each lasting 2–3 hours. These intrusions were accompanied by intense mixing of colder river water (approximately 1.5 °C) with warmer lake water (2.5–3.5 °C). The pulses of river water caused temporary increases in lake water turbidity (from 5 to 18 NTU), with SSC ranging from 3 to approximately 80 $mg \cdot L^{-1}$. The observations clearly indicate episodic inflow of the river water into the lake occurring in the period preceding the arrival of the flood wave peak (the duration of hydrological connectivity ranged from 8 to 11 hours). At the end of the observation period, a sudden rise in the water level of the East Channel – by approximately 2 meters – was recorded, resulting in the complete and sustained inundation of the lake basin. This marked the peak of the flood wave in the Mackenzie Delta, a flash flood triggered by the release of an ice jam at the delta separation point.

5. DISCUSSION

Pulsed deliveries of riverine sediments to lakes play a significant role in their long-term geomorphological evolution and in the functioning of aquatic ecosystems. These sediments can contribute to the enrichment of bottom layers with organic and inorganic matter, as well as modulate water transparency and temperature, thereby influencing the development of phytoplankton and benthic communities.

Observations carried out in the Mackenzie River Delta, at the channel connecting one of the permanently connected lakes to the river, confirm the hypothesis that the final phase of ice cover – specifically, the processes associated with ice breakup – acts as a key mechanism initiating episodic sediment input into lakes. Such sediment delivery would not be possible to the same extent without the backwater effect caused by temporary flow restriction in the East Channel of the Mackenzie due to lingering ice.

The research also confirms that monitoring water temperature can serve as an indicator of river-lake connectivity. Accurate water temperature monitoring during spring freshet flows enables precise determination of the timing of sediment delivery from river channels to lakes. This represents a valuable complement to field observations and satellite-based analyses, which are limited by their spatial and temporal resolution.

Episodic events, such as those observed in Boot Lake in Inuvik, may contribute more significantly to the annual sediment budget than long-term processes associated with rainfall or permafrost thawing. Moreover, predicting these events is challenging, as they depend on the interaction of meteorological, hydrological, and ice-related factors occurring within a very short time window.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the conducted observations and literature analysis, the following conclusions can be drawn:

- The ice regime during the final phase of ice cover plays a crucial role in shaping sediment transport from rivers to lakes;
- The backwater effect caused by ice break-up results in episodic yet intense influxes of turbid river water into lakes;
- Lakes that are permanently connected to river channels (such as Boot Lake with the East Channel of the Mackenzie River) are particularly vulnerable to this phenomenon;
- Remote sensing and real-time monitoring are essential for effectively tracking changes in hydrological connectivity;
- Episodic sediment influxes should be incorporated into sedimentation models and Arctic delta management strategies, especially in the context of climate change.

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Unprecedented Radioactive Pollution in Spitsbergen Air during the 21st Century

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1. INTRODUCTION

Advances in nuclear science during the 20th century have led to the systematic production of a novel form of environmental contamination on a global scale. Introduced radionuclides, categorised as artificial, technogenic, man-made or anthropogenic, were previously non-existent or present in ultra-trace quantities across the Earth system. Despite the ongoing presence of the nuclear era, it should be noted that significant changes have occurred in terms of scope, objectives, and main directions over time. The initial focus on military applications has evolved significantly since then, with the development of nuclear power plants, nuclear medicine and the handling of radioactive materials in the nuclear industry being the main drivers of this change. It is clear that the ongoing revolution has brought a plethora of benefits. However, the parallel identification of new radionuclide emissions and transportation over long distances from the epicentre, with the potential to increase natural background radiation levels, has raised public awareness of the necessity to monitor and control the radiological situation routinely. These measures are required not only for critical groups, objects or areas but also to review the exposures of the population and surrounding areas. Monitoring radioactivity levels in the air is of particular importance, given that inhalation represents a significant exposure pathway.

In certain regions, there have been no air monitoring programmes dedicated to anthropogenic actinides since 2000. This is particularly evident for atmospheric radioactivity in the Arctic, where data on the level, isotopic signature or temporal variation of $^{238, 239, 240}$Pu and ^{241}Am are lacking over the 21st century. Research in this domain is still of particular interest and importance for several reasons. The artificial actinides have become a key tool in investigations of atmospheric circulations or natural "feeder" mechanisms through which previously deposited contaminants are transferred back to the air. Furthermore, research has identified $^{238, 239, 240}$Pu and ^{241}Am as the most radiotoxic elements that may be directly inhaled via aerosols or accumulated in plants and animals. It should also be noted that these radionuclides have relatively long half-lives ($^{238, 239, 240}$Pu: $T_{1/2}$ = 87.7 y, 24100 y, 6560 y, respectively, ^{241}Am: $T_{1/2}$ = 432.6 y), indicating that such pollution remains in the environment for a significant duration. In the context of potential terrorist attacks involving "dirty bombs", undeclared nuclear activity or any intentional or unintentional releases from nuclear installations, there is an imperative for the development of novel monitoring strategies. It is vital that the world's national and international nuclear safety monitoring networks incorporate routine measurements of pure beta and alpha emitters in the atmosphere.

The research project outlined in this study aimed to address the limitations in database capabilities and to enhance the understanding of the relevant processes for artificial actinides suspended in the ground-level air layers of Hornsund, SW Spitsbergen, during the years 2007–2021.

2. RESULT DESCRIPTION

While the overall levels of ^{238}Pu and $^{239+240}$Pu were consistent with recent observations from various locations, ^{241}Am levels were found to be remarkably high, with a maximum of 354 nBq/m^3 recorded in the first quarter of 2019 (Cwanek et al.2025). Further analysis of the isotopic ratios revealed a frequent enrichment of ^{238}Pu over $^{239+240}$Pu. This was inconsistent with previously documented releases. Additionally, there were single incidents of ^{237}Np in 2013, 2014, and 2018, all of which were unexpected.

A multivariate analysis incorporating data on ^{7}Be, ^{210}Pb, ^{137}Cs activity concentrations and a wide range of meteorological factors was applied to explain the behaviour of artificial actinides in the lower atmosphere. Spearman's correlation coefficients were used to establish explicit links between $^{239+240}$Pu seasonal trends and natural processes. These processes included local resuspension throughout the year and horizontal tropospheric transport of haze layers from remote areas in the first quarter. It is worth noting that analogous mechanisms were found to regulate a specific percentage of ^{238}Pu, but to a lesser extent. The maximum activity concentrations of 6.61 nBq/m^3 for ^{238}Pu and 15.51 nBq/m^3 for $^{239+240}$Pu recorded in Hornsund during the 3rd quarter of 2015 (Cwanek et al.2025), registered simultaneously at middle latitudes, could be related to random events, such as fly ash particles remobilised by wildfires of 2015 occurring, for instance, in proximity to the Chernobyl zone.

It was determined that the majority of the significantly elevated levels of ^{241}Am, ^{238}Pu, and ^{237}Np were not environmentally induced. The average annual doses associated with the exposure to the investigated alpha emitters were negligible, being about a million times smaller than the typical background radiation doses of 2.4 mSv per year. Therefore, the contamination detected did not pose a radiological threat to the Arctic environment. However, the ^{241}Am, ^{238}Pu, and ^{237}Np signals were of concern, as the circumstances of their occurrence could indicate man-made emissions, which would have been completely unnoticed by the regular monitoring of gamma emitters in Hornsund air. Trajectory simulations performed for the 1st quarter of 2019 showed the most prominent transport pathways from northern Asia and Europe via the island of Novaya Zemlya (Cwanek et al.2025). Nuclear aerosols were carried at low levels in the troposphere (below 100 metres), resulting in weak dilution and intense deposition. It should be noted that there have been no reports of radioactive discharges of man-made actinides into the atmosphere in recent decades. However, a ^{241}Am incident was identified exclusively in the urban air of central Poland during a few weeks in 2021, possibly generated by the combustion of isotopic smoke detectors. The research underlined the importance of incorporating alpha emitters into routine measurements within radiation situation control programmes.

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Case Study on Radioactive Contamination in Western Arctic Tundra

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1. INTRODUCTION

The High Arctic, a region characterised by its remote and largely inaccessible tundra terrain, was the focus of international field campaigns in 1999, 2012, and 2013. The initial expedition pertained to the freshwater systems of the Canadian Arctic, while the subsequent two projects addressed subjects concerning the tundra vegetation of the shoreline of the Western Arctic. The research material comprised lake sediments and soils, the majority of which were sourced from the Arctic Archipelago. In addition, the material included various species of lichens and mosses, which were collected from southwest Greenland, the Canadian Arctic, and Alaska. The objective of the study was to re-evaluate and supplement the existing knowledge relating to radioactivity contamination levels, trends and patterns in the terrestrial environment of the Western Arctic during the early 21st century. In order to produce a database that would facilitate such an assessment, both deposition and isotopic composition for anthropogenic radioisotopes were analysed. The primary focus was on ^{90}Sr, $^{134, 137}$Cs, $^{238, 239, 240}$Pu, and ^{241}Am. In addition to the spatial distribution, the temporal variations of pollution for lake sediments dated using ^{210}Pb dating models were also investigated.

2. RESULTS AND DISCUSSION

2.1 Level of anthropogenic radioactivity

The comparison of mean activity concentrations (± SE, 1 σ) of chosen radioisotopes was possible for lichens and mosses. The highest levels of ^{137}Cs were noted in the Arctic Archipelago and southern Greenland sites, where it reached 75 ± 42 (69°N 96°W) and 80 ± 29 Bq/kg (63°N

51°W), respectively (Cwanek et al. 2020a,b). The maximum concentrations of 39 ± 14 Bq/kg for ^{90}Sr (70°N 96°W), 4.6 ± 1.2 Bq/kg for $^{239+240}$Pu, and 1.52 ± 0.47 Bq/kg for ^{241}Am (75°N 95°W) were observed in the northern Arctic Archipelago (Cwanek et al. 2020a,b). Despite the heterogeneity of the findings across different locations, the identification of significant and pervasive geographical dependence proved to be a challenging task. The values of the Pearson's correlation coefficients (ranging from 0.34 to 0.51) indicated positive but rather low correlations between radionuclide concentrations and latitudes, especially in the case of ^{137}Cs. The observed spatial trends are likely to be attributable to the impact of the effective half-life, T_{eff}. It is evident that the deposition of anthropogenic radionuclides, which are derived from the predominant source of radioactivity on Earth – that is, atmospheric nuclear tests – has been estimated to be greater at southerly sites. However, at northern latitudes, where precipitation and temperatures are lower, biological turnover is significantly reduced, leading to a prolonged T_{eff} and, consequently, elevated levels of accumulated pollutants over time.

A further comparison of ^{137}Cs and $^{239+240}$Pu inventories (± SE, 1 σ) made for lake sediments and soils revealed the following essential quality of Canadian Arctic ecosystems. Specifically, the levels of integrated depositions of man-made radioisotopes were found to be elevated in lake sediments relative to soils from the catchment areas. For instance, the greatest values in the sediment amounted to 3488 ± 40 Bq/m^2 for ^{137}Cs and 101 ± 2 Bq/m^2 for $^{239+240}$Pu (71°N 123°W), whereas these results in soil reached only 1095 ± 22 Bq/m^2 and 37.4 ± 2.4 Bq/m^2 (71°N 123°W), respectively (Cwanek et al. 2021). The process, which was found to be the most probable cause of such differentiation, was determined to be sediment focusing. This phenomenon may occur within the lake basin, indicating the internal resuspension of matter in shallow zones by water currents, followed by transport and descent into deeper zones. Consequently, the sedimentary material present within the lake basin is generally greater in quantity than that resulting from direct atmospheric deposition. The quantitative assessment of the focusing effect of ^{137}Cs and $^{239+240}$Pu in the reservoirs under study was conducted by calculating the focusing factor, F, as the ratio of inventory in sediment and soil at a given site. As anticipated, the most effective sediment focusing occurred at the lake in the eastern Arctic Archipelago (67°N 81°W). The mean focusing factor (± SE, 1 σ) was as high as 6.36 ± 0.48 for ^{137}Cs and 6.61 ± 0.52 for $^{239+240}$Pu (Cwanek et al. 2021).

The research findings indicated the presence of ^{134}Cs traces (Cwanek et al. 2020a), which were exclusively detected in lichen samples collected at the Alaskan site (65°N 165°W). The activity concentration of ^{134}Cs averaged at 14.0 ± 2.9 Bq/kg (± SE, 1 σ; decay corrected to the day of sampling), whereas the mean of the ^{134}Cs/^{137}Cs isotopic ratio was 1.04 ± 0.14 (± SE, 1 σ; decay corrected to 2011-03-11). The latter value corresponded to the Fukushima fallout signature of 1.033 ± 0.006.

2.2 Radioactive pollution sources

The analysis of the isotopic ratios of ^{238}Pu/$^{239+240}$Pu, ^{240}Pu/^{239}Pu, ^{241}Am/$^{239+240}$Pu, $^{239+240}$Pu/^{137}Cs, and $^{239+240}$Pu/^{90}Sr was employed to deduce the primary source of contamination within the entire study area. The results were then subjected to comparison with global fallout reference levels (+SNAP 9A).

The slopes of linear trends, fitted to experimental data for lichens and mosses, amounted to 0.0318 ± 0.0013 for ^{238}Pu/$^{239+240}$Pu and 0.364 ± 0.022 for ^{241}Am/$^{239+240}$Pu, corresponding to the global fallout (+SNAP 9A) reference values of 0.025–0.04 and 0.38, respectively (decay corrected to 2013). Furthermore, the values for ^{240}Pu/^{239}Pu demonstrate consistency with the aforementioned conclusion (Cwanek et al. 2020a,b).

The findings for the Western Arctic vegetation were consistent with those established for the Canadian Arctic about the ^{238}Pu/$^{239+240}$Pu and ^{241}Am/$^{239+240}$Pu ratios for soils, as well as the

$^{238}Pu/^{239+240}Pu$ temporal variations for lake sediment (Cwanek et al. 2021) (67°N 81°W). An investigation was also conducted into the lake sediments and soils with respect to their $^{239+240}Pu/^{137}Cs$ isotopic composition. In general, for the majority of the sites, the $^{239+240}Pu/^{137}Cs$ results were found to be in rather good agreement with the global fallout signature. Deviations of $^{239+240}Pu/^{137}Cs$ in sediments towards both higher and lower values may be attributable to the migration of radionuclides downward in the cores. Such movement would provide a rationale for the presence of radiocaesium or plutonium beneath 1945 at locations 75°N 99°W and 67°N 81°W, respectively. However, a clear excess of ^{137}Cs above the global fallout, dated around the mid-1980s, was noted at site 71°N 123°W, where migration of radionuclides was not detected. It is evident that the presence of radiocaesium in the Canadian Arctic region, as a consequence of the Chernobyl accident in 1986, has had a significant impact on the lake in question (Cwanek et al. 2021).

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Not So Different – *Pseudocalanus* sp. Distribution and Diet in Arctic Fjords

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Abstract

Pseudocalanus spp. are highly abundant Arctic copepods and play a key role in zooplankton biomass and ecosystem functioning (Auel and Hagen 2002; Mumm et al. 1998). Their substantial numbers make them important secondary producers, mediating the transfer of primary production from microalgae and protists to higher trophic levels (McLaren et al. 1989; Napp et al. 2002; McLaren and Corkett 1978; Cleary et al. 2016). They are also significant contributors to carbon cycling in the Arctic (Cleary et al. 2016). Despite their ecological relevance, species-specific feeding ecology of *Pseudocalanus* remains poorly understood. This study explores the species composition and gut content of *Pseudocalanus* spp. across Arctic- and Atlantic-influenced fjords in the Svalbard archipelago. Species identification was carried out using species-specific PCR assays, and dietary analysis was performed via DNA metabarcoding of gut content. Sampling was conducted at four locations representing a hydrographic gradient in the Isfjorden system: Grønfjorden, Isfjorden Karlskronadypet, Isfjorden Adventfjorden, and Billefjorden.

Out of the identified individuals, *P. acuspes* dominated in the collected material, followed by *P. moultoni* and *P. minutus*. The metabarcoding analysis of gut contents, which included all sampled *Pseudocalanus* individuals, revealed a high dietary overlap between species, with Alveolata and Nucletmycea as the most prevalent prey groups. NMDS ordination and diversity indices (Shannon, Simpson, Pielou) indicated minor differences in prey composition and evenness, suggesting overlapping ecological niches and potential opportunistic feeding behavior across species. The study did not find significant species-specific dietary differentiation despite previous literature suggesting niche separation. Low salinity variation among sampling sites and the presence of a relatively homogenous prey community likely contributed to the observed dietary similarities.

The findings suggest that co-occurring *Pseudocalanus* species in Western Svalbard fjords utilize similar food resources, potentially due to environmental constraints rather than strong dietary specialization. Further studies incorporating prey field analysis and temporal sampling are necessary to disentangle niche dynamics in this copepod genus under ongoing climate-driven environmental shifts.

Keywords: *Pseudocalanus*, Arctic zooplankton, metabarcoding, dietary overlap, ecological niche.

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Morphometric Analysis and Classification of Isolated Pedal Phalanges of Eocene Antarctic Penguins

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1. INTRODUCTION

Penguins (Sphenisciformes) are highly specialized seabirds that exhibit a range of morphological and physiological adaptations. Within their skeletal structure, the pedal phalanges (bones of the toes) are among the elements heavily involved in both aquatic and terrestrial locomotion. As components of the feet, they enable penguins to navigate marine environments, acting functionally like the distal portion of a rudder, while also facilitating walking and tobogganing on land and ice (Williams 1995). In the fossil record of Eocene Antarctic penguins, these bones are common yet typically disarticulated, posing challenges for both taxonomic and functional interpretation (Jadwiszczak 2006). This study examines pure-shape variation in such isolated phalanges using geometric morphometrics and ordination techniques to evaluate whether consistent patterns linked to anatomical identity can be detected. By establishing a morphological baseline for early Antarctic penguins, this work contributes to understanding long-term anatomical responses to polar environmental change, offering a historical perspective relevant to current transformations in high-latitude ecosystems.

2. MATERIALS AND METHODS

The study includes 49 penguin phalanges from the Eocene (56.0–33.9 Ma) La Meseta and Submeseta formations (Seymour Island, Antarctic Peninsula), preliminarily classified based on qualitative anatomical assessment, and seven reference specimens assignable to an extant Gentoo penguin (*Pygoscelis papua*). All bones are housed at the University of Bialystok. They were 3D scanned with a structured-light scanner and post-processed in the Revo Scan 5 application. Mesh models were exported to 3D Slicer software. Each left-sided phalanx model was mirrored. All phalanges were landmarked using five open curves comprising 23 points (Fig. 1a). Landmark coordinates were analyzed in R using the *geomorph* and *uwot* packages, as well as base R *prcomp* function. The data were normalized for position, orientation, and scale using Generalized Procrustes Analysis. Allometric effects were accounted for by incorporating the log of centroid size into a size-shape PCA (Mitteroecker et al. 2013). To explore nonlinear shape variation, Uniform Manifold Approximation and Projection (UMAP; McInnes et al. 2018) was performed on 13 size-adjusted PCs, covering >90% of shape variance.

3. RESULTS

The size-shape PCA (Fig. 1b), representing a linear approach, predictably revealed that PC1 was driven by size, explaining 90.4% of total variance. The consecutive five (shape-related) principal components explained an additional 6.4%. The PC2–PC3 plane revealed well-separated clusters for phalanges II-1, IV-1, and III-3, while overlaps occurred among III-1, III-2, IV-3, and II-2. The most intriguing outlier was the sole extant III-1 specimen, far removed from its fossil counterparts. The non-linear 2D UMAP analysis (Fig. 2) revealed only two essentially

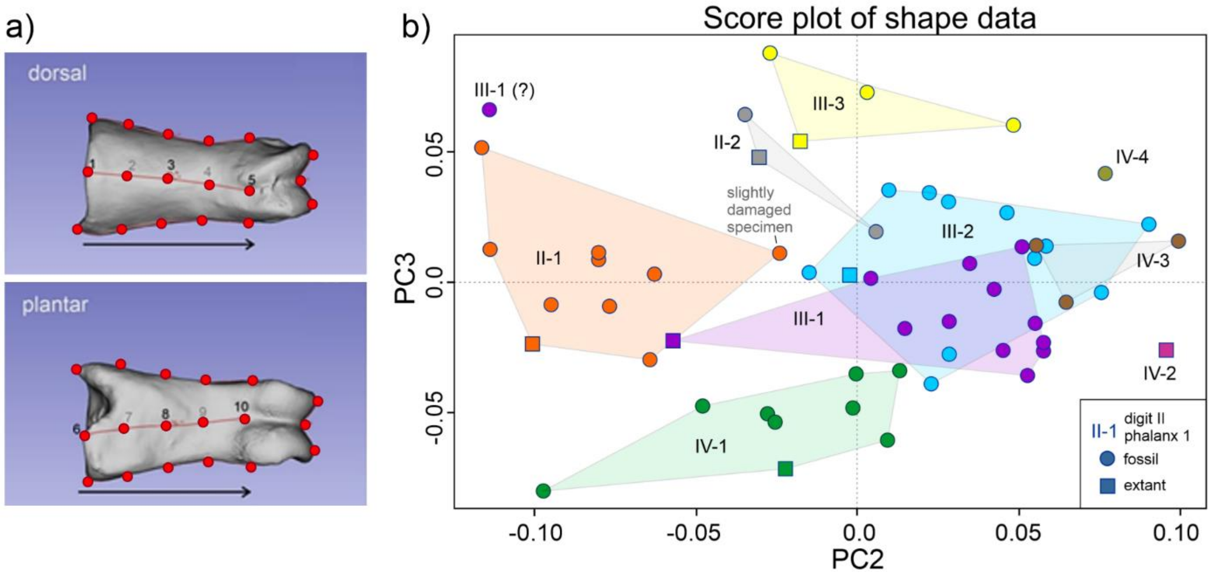

Fig. 1. Landmarking scheme (a) and score plot of shape data for PC2 and PC3 (first two size-independent components) from size-shape PCA (b). PC2–3 explained 32.3% and 13.5% of variance remaining after (size-dominated) PC1 was rooted out.

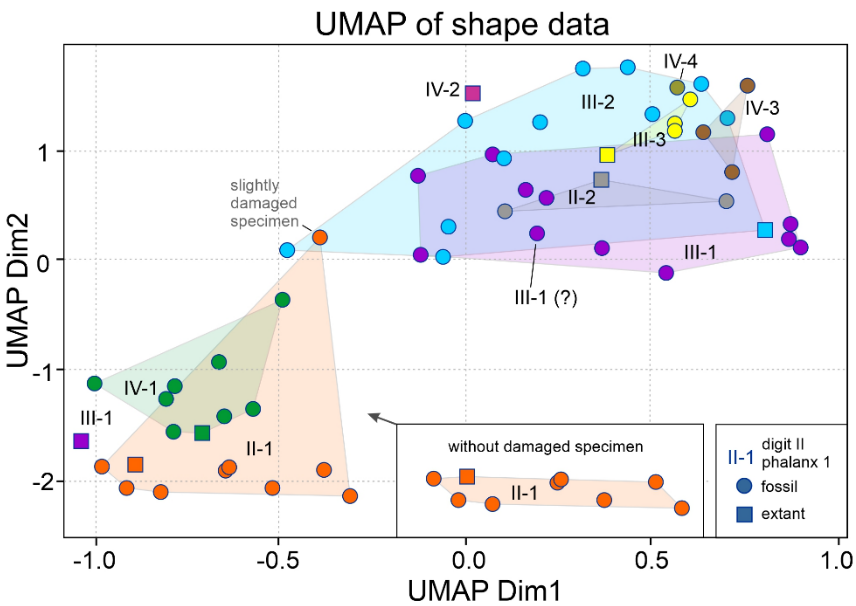

Fig. 2. Score plot of shape data (PC2–14 from size-shape PCA) projected onto the UMAP dimensions.

distinctive clusters, formed by phalanges II-1 and IV-1, and confirmed distinctiveness of modern III-1 and IV-2 observed in PCA. The 3D UMAP projection made the separation between clusters II-1 and IV-1 even more profound.

4. DATA INTERPRETATION

Results show that multivariate ordination methods can (to some degree) differentiate phalanges by anatomical position, particularly for basal-and-peripheral elements (II-1, IV-1). Apparently, these bones may undergo stronger functional constraints due to their articulation with the tarsometatarsus and their role in stabilizing the foot. Conversely, phalanges III-1 and III-2 were consistently overlapping across methods, reflecting morphological similarity likely due to their axial adjacency and position along the central axis of the foot skeleton. Such a congruity can by a by-product of the more uniform distribution of stress along this axis. Notably, the sole modern III-1 specimen was morphologically distinct, though showing a clear affinity to the II-1 cluster. The reasons for this remain unclear; however, it is likely that an evolutionary factor is involved. Since this is only a single specimen, far-reaching conclusions are not justified.

5. CONCLUSION

Multivariate shape analysis reveals that certain pedal phalanges, particularly proximal bones of digits II and IV, exhibit distinct morphological patterns amenable to classification. Central phalanges show less differentiation, likely constrained by their functional and positional homogeneity. These findings highlight the potential of landmark-based morphometrics for identifying isolated penguin phalanges and contributing to interpretations of foot function and evolutionary adaptation in early Sphenisciformes. In the context of contemporary climate-driven tipping points in polar regions, such fossil-based analyses help elucidate past adaptive pathways in Antarctic vertebrates, offering comparative insights into potential biological responses under current and future environmental stressors.

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Assessment of Anthropogenic Pollution Associated with Intensified Tourist Activity in the Longyearbyen Area (Svalbard, Arctic)

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Abstract

Climate change in the Arctic is among the most dynamic and visible worldwide. Particularly rapid warming is observed in the Svalbard archipelago, where recent years brought record-breaking temperatures, including 21.7 °C in Longyearbyen in July 2020 (Reuters 2020). Due to its geographical location and unique natural value, the region serves as a natural laboratory for monitoring global climate processes, ocean circulation, and related environmental transformations. At the same time, it is increasingly exposed to anthropogenic pressure, mainly resulting from the growing influx of tourists, which in 2023 amounted to approximately100,000 visitors (Kaltenborn et al. 2025). The dynamic expansion of tourist infrastructure and the growing popularity of recreational activities have led to noticeable changes in environmental quality.

One of the most common forms of outdoor recreation around Longyearbyen is snowmobile tourism. Approximately 2,500 snowmobiles are registered in Svalbard, a particularly high number compared with the size of the local population (Kaltenborn et al. 2025). Snowmobiles emit multiple pollutants, including nitrogen oxides, carbon monoxide, and polycyclic aromatic hydrocarbons (PAHs), which negatively affect air, water, and the snow-ice cover. Previous studies confirmed the presence of PAHs and their derivatives in air (Drotikova et al. 2020) and snow (Abramova et al. 2016) in and around Svalbard settlements, linking their occurrence to local anthropogenic sources. Soot and other light-absorbing particles deposited on snow accelerate its melting, thereby intensifying the regional warming effect (Réveillet et al. 2022). Furthermore, PAHs belong to a group of toxic and carcinogenic compounds that pose a significant threat to human health and Arctic ecosystems.

This study focuses on assessing the environmental impact of tourism, with a special emphasis on snowmobile use, in the Longyearbyen area. Chemical and microbiological methods

were applied to determine the level of contamination and to evaluate potential ecological risks. The results will provide new insights into the relationship between the intensification of tourism and the state of the natural environment in the Arctic. They may also form a basis for recommendations aimed at reducing anthropogenic pressure and supporting the protection of this highly vulnerable region.

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Inorganic Chemistry of Surface Waters in the Palsa Mires Region of Northern Finland

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1. INTRODUCTION

Climate warming in the Northern Hemisphere accelerated permafrost degradation (Streletskiy 2021), leading to physical and chemical changes in Arctic and sub-Arctic watersheds (Tananaev and Lotsari 2022; Verdonen et al. 2023). Palsa mires are a feature of sporadic and patchy permafrost landscapes in Northern Finland. We analysed inorganic chemistry (ions, metals and metalloid concentrations) of freshwater (rivers and lakes) collected from this region in the summer 2022 to detect their characteristic features.

2. MATERIALS AND METHODS

We have collected 54 water samples between Aug 17th and 25th 2022 in the Tana river watershed, from the tributaries connected to a various extent to palsa mires, and ten lakes both inside and outside of the palsa mire, for comparison. We have analysed acidified (high-purity HNO_3, Suprapur, Merck Life Science) filtrate for elemental concentrations of Be, P, S and Ti with inductively coupled plasma optical emission spectrometry (ICP-OES 9820, Shimadzu, Japan) and of Ag, Al, As, Ba, Bi, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sb, Se, Si, Sr, V and Zn with inductively coupled plasma mass spectrometry (ICP-MS 2030, Shimadzu, Japan).

3. RESULTS

The water were well buffered (pH range 5.93 – 8.23) and poor in dissolved solute (SpC 16.5 – 44.3 μS/cm). The concentrations of metals and metalloids were generally in the low range, never exceeding the drinking water guideline levels. However, the geochemical background was exceeded for some samples in the case of Ni and Zn concentrations. Multiple correlations were found between the elemental concentrations determined, and clear differences occurred between various study areas.

4. CONCLUSIONS

The hydrochemistry of palsa mire waters has showed distinct features from the surrounding waters.

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ARCTIC-O_3: Ozonation as a Wastewater Treatment Strategy for Sensitive Ecosystems: A Polish Case Study for Arctic Applications

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A b s t r a c t

The Arctic environment is one of the most vulnerable regions on Earth, facing increasing pressure from human activities such as tourism and settlement expansion. These fragile ecosystems, uniquely adapted to extreme conditions, are highly sensitive to disturbances caused by pollution. Among the most pressing challenges is the discharge of untreated wastewater into the environment, which introduces organic pollutants, nutrients, and emerging contaminants, such as antibiotics and antibiotic resistance genes (ARGs) (Khan et al. 2020; Phoon et al.2020). Addressing these challenges requires innovative, scalable, and cost-effective solutions tailored to the harsh Arctic conditions.

Polar regions, including Longyearbyen in Svalbard, are experiencing growing environmental pressure due to increasing tourism, which leads to potential ecosystem degradation and pollution from untreated wastewater. Approximately 285,000 m^3 of untreated wastewater is discharged annually into the local fjord, posing unknown ecological risks. A previous project, entitled “Influence of wastewater on the bacterioplankton community and its characteristics in Adventfjorden, Svalbard”, financed by the Research Council of Norway (Svalbard Science Forum), revealed the presence of antibiotics and ARGs in wastewater effluents. These findings highlighted the urgent need for solutions to address wastewater contamination in such fragile environments.

Building on these findings, the ARCTIC-O_3 project explores ozonation as a treatment method to reduce the environmental impact of untreated wastewater (Lim et al. 2022). It aims to evaluate the effectiveness of ozonation in removing organic, biogenic, and micropollutant contaminants, including antibiotics and ARGs, in regions where conventional biological treatment is impractical (Chu et al. 2020; Hou et al. 2019; Czech 2012; Feng et al. 2016). By addressing challenges like low temperatures and permafrost, the project seeks to offer a practical solution for protecting sensitive Arctic ecosystems.

Different ozone doses are being tested to study the effectiveness of wastewater treatment in reducing faecal contamination, removing pharmaceuticals, and affecting the presence of antibiotic resistance. Firstly, the tests are being carried out on the pilot treatment plant in Jastrzębia Góra, Poland, to optimise the ozone dosage and assess the balance between reducing pollutants and energy costs. Secondly, the chosen approach will be tested on wastewater samples from Longyearbyen to consider the actual biochemical content of the wastewater. Ultimately, this will hopefully lead to the development of an effective, economically viable wastewater treatment solution for sensitive Arctic environments.

Preliminary results of the ARCTIC-O_3 project demonstrate that a satisfactory reduction of fecal indicator bacteria (E. coli reduction of 99.9%, equivalent to a 2-log reduction) can be achieved at an ozone consumption of approximately 200 mg/L. The ozonation process can be operated through two distinct modes of action: (a) intensive ozonation which achieves the desired bacterial reduction in a shorter time by applying higher ozone concentrations, and (b) lower ozone flow which reaches the same reduction over a longer treatment period, using reduced ozone flow rates. The economic feasibility of each mode is going to be evaluated based on the ozone consumption costs and operational efficiency. The final decision is based on the integration of chemical and microbial results, ensuring the chosen method is both effective and economically viable for sensitive Arctic environments.

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Innovative Warning System for Methane Emissions in Polar Areas

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1. INTRODUCTION

The Arctic plays a critical role in the global climate system, acting as both a carbon sink and a significant source of greenhouse gas emissions, particularly methane. Methane is released from thawing permafrost, Arctic wetlands, and thermokarst lakes. These emissions may intensify under global warming, creating a feedback loop that accelerates climate change (Bartosiewicz 2020). A comprehensive understanding of this process requires robust, long-term datasets characterizing both the magnitude and variability of methane fluxes.

2. MONITORING SYSTEM DEVELOPMENT

We have developed and implemented an innovative, cost-effective early warning system for detecting methane emissions in the Arctic (Kot and Bartosiewicz 2025). The system utilizes a low-energy tunable laser sensor integrated with an Eddy Covariance (EC) instrument located on the Fuglebergslett plain near the Polish Polar Station in Hornsund, Spitsbergen. The EC tower, equipped with an IRGASON sensor, provides high-frequency measurements of gas fluxes, water vapour, and meteorological variables. This setup allows for detailed analysis of gas exchange dynamics between the surface and the atmosphere in extreme Arctic conditions.

3. FIELD IMPLEMENTATION AND DATA ANALYSIS

The system is further enhanced by remote visualization using a miniaturized methane sensor mounted on an ROV, enabling spatial and discrete methane concentration measurements in the vicinity of the EC installation. This facilitates the identification of local emission sources and the characterization of the spatiotemporal variability in fluxes. Special focus is given to thermokarst wetlands, which are emerging as key methane emitters due to organic matter decay and the release of subsurface reservoirs triggered by permafrost degradation (Bartosiewicz 2020).

4. INTEGRATION AND OUTLOOK

The integration of Eddy Covariance data with mobile ROV-based sensing offers a comprehensive monitoring solution, contributing significantly to our understanding of Arctic methane emissions and their climate feedback mechanisms.

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Following the Footsteps of the First Polish Expedition to Greenland

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Abstract

Polar regions have always been the subject of human interest. Polish researchers began to intensively explore north pole at the second half of the 19th century. After two great field-works at Spitsbergen, Poles decided to reach the largest of islands – Greenland. At the beginning of June 1937, first polish scientific expedition to Greenland set off from the seaport in Gdynia (Köhler 2017). The expedition headed to Arfersiorfik fjord (western coast of Greenland), where observations of environment most familiar to the one during Pleistocene glaciation in Poland were conducted. The Capitan of the expedition was Aleksander Kosiba, rest of the research group were scientists from Poland. One of them was Antoni Gaweł, polish geologist, whose legacy from this event enabled setting exact track of the expedition. Almost all materials collected during the expedition were untouched for almost ninety years. This poster will be focused on the expedition to Greenland in 1937 and will follow Antoni Gaweł's trail. His collection allows to show geological diversity of western coast of Greenland and will be the subject of more detailed research.

Keywords: Greenland, Arfersiorfik fjord, Antoni Gaweł, expedition, west coast.

1. EXPEDITION TO GREENLAND 1937

The Poles have a relatively long story of polar research. Exploration of north pole started in the second half of 19th century and continues to this day. First expeditions took place on Svalbard, Novaya Zemlya and Spitsbergen. In 1934 Aleksander Kosiba went to Greenland during Danish expedition (Köhler 2014). After three years he decided to set off on a venture with group of six polish scientists (Fig. 1) to west coast of Greenland. Expedition headed to Arfersiorfik fjord, where they spent almost three months. Expedition was focused on charting a map of the fjord and studies on environment with conditions most similar to those during glaciation in Pleistocene in Poland. Meteorological, glaciological, geological, geomorphological, and botanical research were conducted (Birkenmajer 2017).

Fig. 1. Photo of participants of the expedition to Greenland 1937; from left: A. Zawadzki, A. Kosiba, S. Bernardzikiewicz, A. Gaweł, R. Wilczek, S. Siedlecki, and A. Jahn (photo by A. Jahn).

2. ANTONI GAWEŁ'S LEGACY

One of the participants was Antoni Gaweł, Polish geologist who specialized in petrology and mineralogy. During expedition Gaweł conducted research on geological nature of Arfersiorfik fjord and material of moraines. Practically most of the collected materials were untouched since 1937. Thanks to the kindness of the Nature Education Centre Jagiellonian University and Archive of Science of Polish Academy of Sciences and Polish Academy of Arts and Sciences, I have possibility to work with Antoni Gaweł's legacy from the expedition. Collection includes metamorphic rocks (mainly granite–gneiss (Fig. 2) and biotite shist (Fig. 3)), mineralogical and moraines sands samples. The aim of the work will be description of hand specimens as well as thin sections of metamorphic rocks from A. Gaweł's collection. The collection and his field notebook allow both to set track of the expedition and for initial description of geology of the fjord.

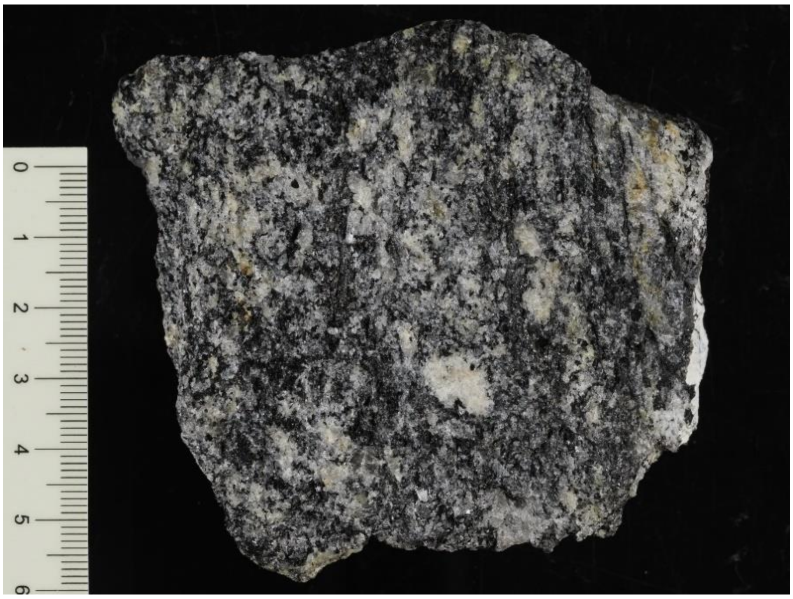

Fig. 2. Example of granite-gneiss with biotite from the collection (photo by Waldemar Obcowski).

Fig. 3. Example of biotite shist from the collection (photo by Waldemar Obcowski).

Acknowledgments. I express my gratitude to the Nature Education Centre Jagiellonian University for facilitating me A. Gaweł's collection and the Archive of Science of Polish Academy of Sciences and Polish Academy of Arts and Sciences in Cracow for making A. Gaweł's legacy available.

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Isotopic and Geochemical Signatures of Proglacial Lakes at Lions Rump (King George Island, Antarctica): Identifying Hydrological Sources and Assessing Chemical Composition in a Changing Polar Environment

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Keywords: proglacial lakes, stable isotopes, trace elements, glacial meltwater, climate change, Antarctica.

1. INTRODUCTION

Proglacial lakes in Antarctica, primarily fed by melting ice and snow, are sensitive indicators of climatic shifts and ongoing cryospheric and geochemical processes in their surroundings (Turner et al. 2005). Due to their shallow depth, limited water exchange, and geographic isolation, these systems are particularly vulnerable to contamination and hydrological imbalance (Bargagli 2008). Lions Rump headland (ASPA 151), located in the southwestern part of King

George Island, is a region of high ecological value with prominent glacial and limnological features. These isolated lakes not only record hydrological and chemical changes (Mulvaney et al. 2012) but also act as potential sites of contaminant accumulation, as previously demonstrated for periglacial systems in Admiralty Bay (Szopińska et al. 2018). This study, conducted on seventeen lakes in the area (water samples LR1–LR17), integrates the analysis of stable isotopes of hydrogen and oxygen with a broad spectrum of major and trace element concentrations to determine the origin of waters, mechanisms of recharge, and potential sources of chemical constituents.

2. METHODS

Isotopic analyses were carried out using cavity ring-down spectroscopy (CRDS, Picarro L2140-i), calibrated with international reference standards and normalized to the Vienna Standard Mean Ocean Water (VSMOW) scale (Skrzypek 2013). The $\delta^{2}H$ and $\delta^{18}O$ composition showed distinct spatial variability between lakes located near glacier termini and those situated further inland or at higher elevations. Some samples were characterized by depleted $\delta^{18}O$ and $\delta^{2}H$ values, indicative of a dominant glacial meltwater component, while others reflected mixing with snowmelt or atmospheric precipitation. Isotopic enrichment observed in a few lakes suggests the influence of evaporative processes. The $\delta^{2}H$ vs. $\delta^{18}O$ relationship and the position of samples relative to the local meteoric water line provided insight into recharge mechanisms and lake isolation levels (Gat 1996; Leng and Marshall 2004).

3. RESULTS

Chemical analyses were performed using ICP-OES and ICP-MS (Shimadzu 9820 and 2030), allowing quantification of major elements (Ca, Mg, Na, K, Fe, Si, P, S) and 22 trace elements, including Pb, Zn, Cu, As, Mn, Ni, Cr, Cd, and Se. The chemical composition of lake waters revealed clear spatial patterns related to glacier proximity, exposure to atmospheric deposition, and influence from wildlife activity. In most samples, lithogenic elements dominated, indicating strong interaction between water and bedrock through glacial erosion and mechanical weathering. Several lakes showed elevated levels of trace metals, potentially associated with ornithogenic input or long-range atmospheric deposition, a phenomenon also reported in freshwater of Admiralty Bay (Szopińska et al. 2018).

In some samples, increased concentrations of redox-sensitive metals such as Mn, Fe, and Al were found, especially in shallow, well-oxygenated basins, suggesting mobilization under oxidizing conditions. Slight enrichments of potentially toxic elements like Pb, As, and Zn were also noted but remained within typical Antarctic background levels. These findings highlight the need for continued monitoring of the seasonal dynamics and environmental thresholds of these aquatic ecosystems.

4. CONCLUSIONS

The integration of isotopic and geochemical data enabled the identification of water sources and the assessment of processes influencing solute composition. The results serve as a valuable reference point for further limnological studies in Antarctic proglacial zones and provide essential knowledge for conservation efforts in protected areas.

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Climate-induced Changes in the Subarctic River System: A Case Study on the Masjok River, Norway

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1. INTRODUCTION

The ongoing global warming and its arctic amplification (Previdi et al. 2021) might result in reduced hunting grounds and traditional food sources, degradation of drinking water, which pose challenges to food and water security for many indigenous communities (Richter-Menge 2011). Climate change is projected to significantly alter the hydrological cycle on a global and regional scale (Allan et al. 2020). Reduced snow cover and permafrost in Sub-Arctic and Arctic areas may impact drainage systems and river discharge (Bring et al. 2016). Future projections indicate a decline in the overall amplitude of yearly runoff as well as in the springtime intense snow melt runoff episodes (Javadinejad et al. 2020). River systems in the arctic and sub-arctic regions are extremely sensitive climate change sensors, and these fluvial systems are experiencing a shift in discharge and sediment load (White et al. 2007). The seasonal ice cover and suspended sediment concentration control the incoming solar radiation in the rivers and are considered two crucial factors that dictate the physical and biological state of the arctic rivers (Thellman et al. 2021). Climate change can trigger early meltdown of ice cover, resulting in high discharge and suspended sediment in the river (Burrel et al. 2023), which in turn determines the morphological evolution of river channels and coastal deltas. In arctic and subarctic rivers, ice cover and sediment dynamics regulate nutrients and biogeochemical cycles, affecting marine flora and fauna as well as water quality. Early arrival of spring and extended ice-free season could trigger erosion through the dynamic breakup of ice cover and make scour holes in the river banks.

The Masjok River (Fig. 1) is one of the major tributaries of the Tana River, with a catchment area of 568.11 km². This river is the main source of suspended sediments in the Tana River basin. Although there are ample examples of hydrological modelling (Moges et al. 2017) and sediment analysis (Wenng et al. 2021) in the Tana River, studies involving the Masjok River are relatively scarce in the literature. Therefore, our primary objective is to observe the river ice dynamics and seasonal changes in the ice cover in the Masjok River. We aim to establish statistically significant trends of important metrics such as dates of spring breakup and autumn freeze-up, total ice-covered days, ice cover, suspended sediment and discharge data, this project aims to examine the relationships between these three variables in the backdrop of climate change.

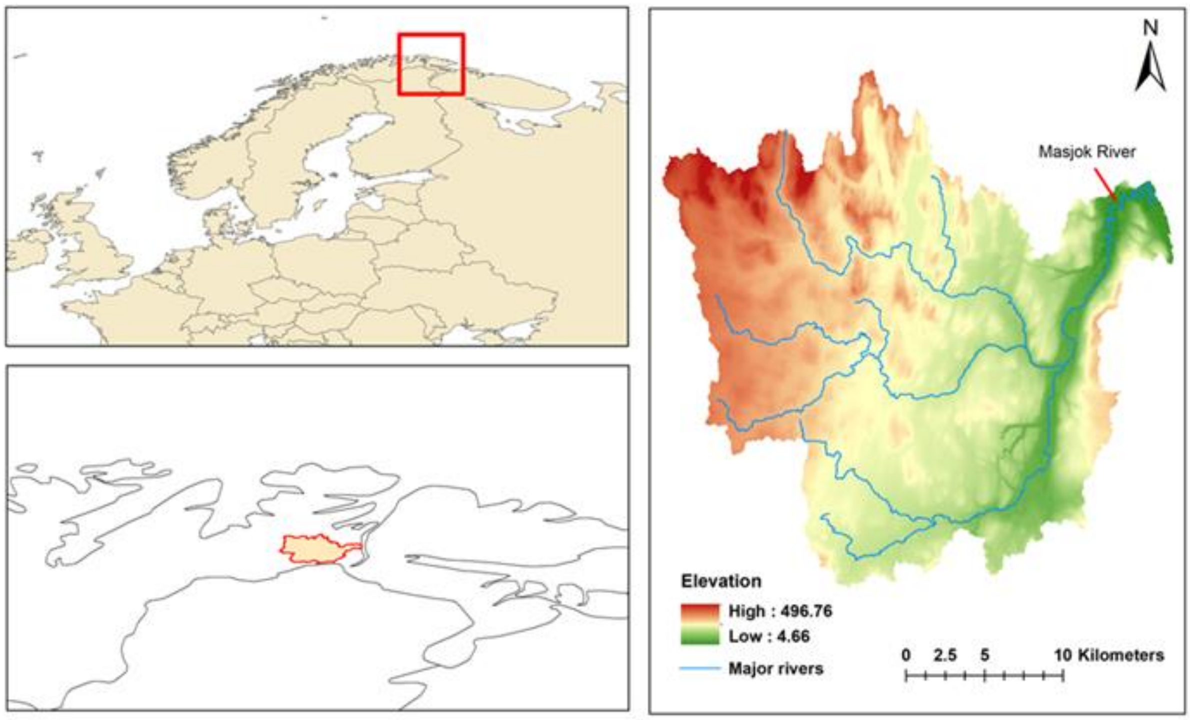

Fig. 1. Masjok River basin.

2. METHODOLOGY

The phenology of the Masjok river ice for the last 30 years was examined using Sentinel-1 C-band Synthetic Aperture Radar (SAR) data. For older periods (before 2015), in case of unavailability of Sentinel-1, Sentinel-2 MSI, and Landsat legacy datasets were consulted. Classification of river ice was based on the copolarization ratio (χ), where < 3 dB indicates open water, < –25 dB indicates thermal ice, and the values in between (from 3 dB to –25 dB) indicate consolidated ice (Mermoz et al. 2009). An extensive field campaign was performed in the lower Masjok River to collect water and sediment samples. Water samples were filtered to observe the settling velocity, and grain size analysis was performed using the laser diffraction method. Additionally, bathymetry was collected during the field visit. Time series analysis was implemented on the long-term discharge, ice cover extent and suspended sediment to find statistically significant trends. This analysis also included the Mann–Kendall test for monotonic trends and Sen's slope estimator. Then, a relationship between climatic and hydrological variables was established, which helped in understanding the physical processes in the Masjok River.

3. RESULTS

This study captured the accelerating trend of the longer ice-free days in the Masjok River and surrounding areas and their relation to increased suspended sediment concentration. Our study revealed that the ice-free days have been continuously increasing in the past 30 years. Modelling efforts in the past also predicted a similar kind of observation for the years 2070–2100, especially the TANAFLOW model by Dankers and Christensen (2005), where the snow-free season was reported to extend by 41 days based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). Moreover, the scour holes from the in-situ observation were hypothesised as the mechanical movement of dynamic ice breakup and similar observations were also reported by Eilertsen and Corner (2011) in the same area. The sediment pulse measurement provided an accurate time and process of the ice breakup in the Masjok River basin, where the observed sediment load was highest in the early spring and lowest in winter. In a recent experiment, Blåfield et al. (2024) also found similar observations at the Pulmankijoki River, another tributary of the Tana, located in the same region. The sediment load was also found to be highly seasonal, with higher concentrations of suspended sediment in autumn and winter and lower in spring and summer, which is corroborated by scenario-based modelling efforts (Lotsari et al. 2010).

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Contemporary and Fossil Distribution of Beavers in Permafrost Areas: A Literature Review

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1. INTRODUCTION

Several animal species on Earth modify the environment to suit their ecological needs, with beavers (*Castor* spp.) being among the most transformative. Research indicates that beavers (family *Castoridae*) began to appear in the late Eocene (Korth 2001) and have evolved into various species and genera across the globe until the present day (Calede 2022). They inhabit the Northern Hemisphere, which is why world literature has located beaver sites in areas currently covered by permafrost. These places indicate the presence of beavers in the past (e.g. bones, pieces of wood gnawed by beavers, sediments) and today.

The aim of this study is to identify locations in the Northern Hemisphere, in the permafrost zone, where beaver remains have been found or where beavers still dwell.

2. MATERIALS AND METHODS

The Scopus journal database was used to identify locations where beavers were described. The search involved using the terms "beaver" and "Siberia" or "beaver" and "Arctic Regions". This resulted in 20 entries for „Siberia" and 16 for the "Arctic Regions". Selected entries that referred to beavers were plotted on a permafrost map. The entries that were excluded contained only toponyms incorporating the word "beaver" or related terms, without providing any evidence of actual beaver presence.

3. RESULTS

Sixteen articles from Arctic regions were selected, each presenting contemporary research on the impact of beavers on the environment (3 articles) or fossil evidence of their presence on Ellsemere Island (3 articles). The remaining articles focused on studies of pollution, the diet of various mammals, or studies conducted in geographical units that include the word "beaver" in their name.

Twenty studies related to Siberia were identified, but not all of them concerned sites associated with the current extent of permafrost. Of the articles on beavers, three were contemporary

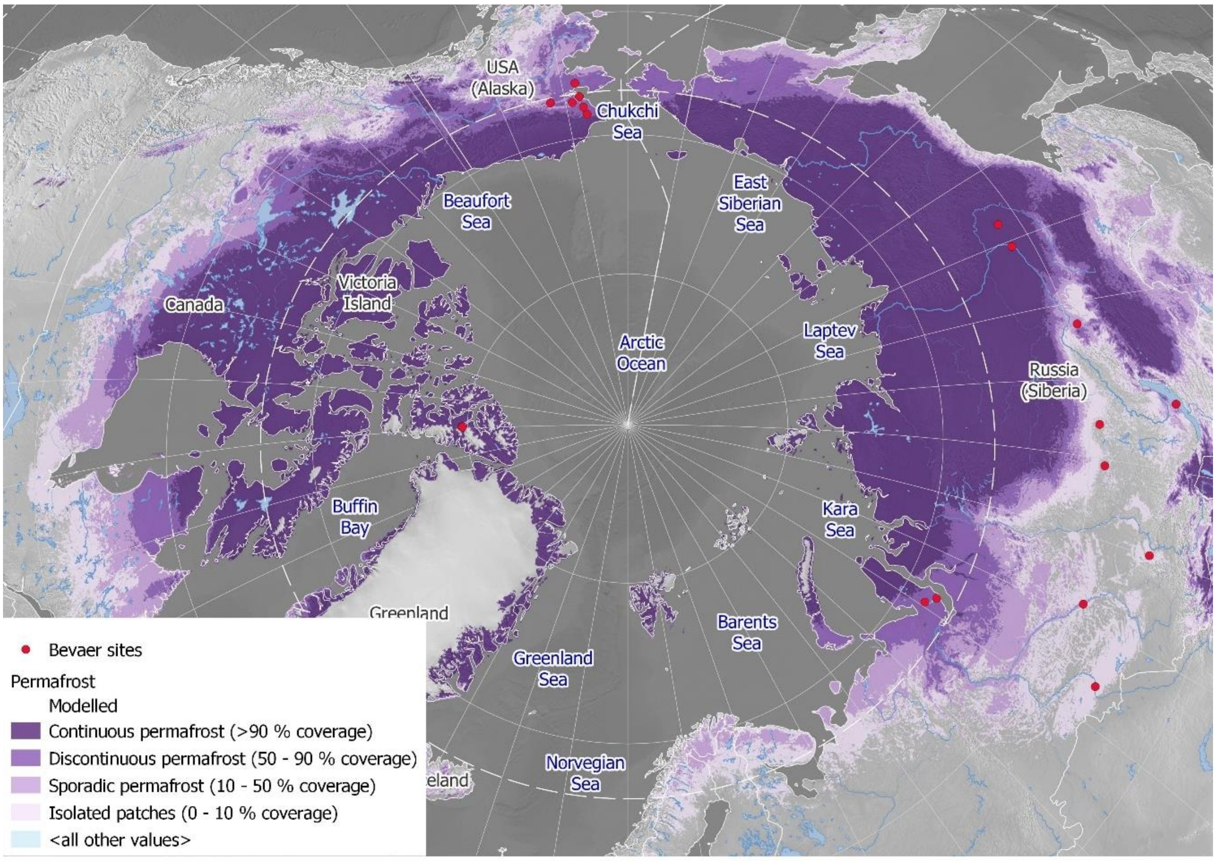

Fig. 1. Beaver sites in different permafrost zones.

research, and six described beaver skeletal remains from the Pliocene, Pleistocene, and Holocene epochs. Other studies focused on topics such as beaver hunting weapons, skin and textile analysis, beaver populations in Russia, or the sites described were located outside the permafrost range.

Contemporary studies of beaver impacts in North America focus on Alaska, while studies of past beaver impacts have been conducted only on Ellsemere Island. In Siberia, fossil evidence of beaver presence is concentrated on the Yamal Peninsula and the Lena River (Fig. 1). Research was conducted in the Novosibirsk area on the impact of beavers that have inhabited riverside areas.

The location of beaver sites indicates that beavers have inhabited or continue to inhabit various types of permafrost. These sites are located on all types of permafrost, which is an excellent factor preserving evidence of their presence, as is the case in Canada.

4. CONCLUSIONS

The presented data indicate that beavers have been changing the environment since the Pliocene (Canada). Both past and present beaver sites indicate that they chose water-related habitats (river valleys, wetlands). Contemporary observations indicate that their role in shaping permafrost areas is related to changes in water conditions, geological structure, and vegetation. Evidence of their presence is recorded in the landforms and sediments in permafrost areas. In the era of current climate change (and related permafrost loss), they may accelerate fluvial processes in river valleys in these areas.

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The Use of Remote Sensing for Studying Environmental Changes in the Area of Palsa Mires (Northern Finland)

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A b s t r a c t

The aim of the presented work is to analyze changes in the environment covered by palsa peatlands located in Northern Finland in the years 1985–2024. The research includes analysis of changes in vegetation, water relations and humidity of the area (e.g. NDVI, NDWI, NDMI index) on Landsat satellite images, using GIS tools and techniques. Based on the obtained results, it was found that the use of remote sensing methods and calculation of multispectral indices based on Landsat satellite images is a useful tool in determining changes in the palsa region environment.

1. INTRODUCTION

Permafrost peatlands host some of the southernmost lowland periglacial features in the Northern Hemisphere, marked by the presence of palsas peatland mounds with an ice core formed through freeze-thaw cycles (Seppälä 2006). In northern Finland, where they form an essential part of the tundra landscape, palsas are especially vulnerable due to their location at the permafrost margins (Gisnås et al. 2017). Their development depends on local climate conditions such as temperature, precipitation, wind, vegetation, snow depth, and soil properties (Fewster et al. 2022). Even small increases in temperature (1 °C) or precipitation (10%) can substantially reduce areas favorable for their formation (Fronzek et al. 2006). Recent warming in northern Europe along with thicker snow cover and deepening of the active layer has accelerated palsa degradation (Verdonen et al. 2023). This poses a significant threat to the stability of permafrost-dependent ecosystems.

Given the rapid climatic changes in northern Finland, there is a growing need to monitor these shifts using modern technologies. Advances in satellite imaging and open-source geospatial tools have significantly expanded its use in the study of permafrost regions during recent decades (Philipp et al. 2021). RS enables researchers to track spatial patterns and temporal changes in palsa landscapes, offering essential insights into the pace and extent of environmental changes.

2. RESEARCH AREA

The study area is located in the northern part of Finland in the sporadic permafrost zone and covers an area of approximately 402,000 km^2 (Fig. 1A). The landscape of the study area is dominated by tundra vegetation, numerous thermokarst lakes and palsa peatland (Fig. 1B).

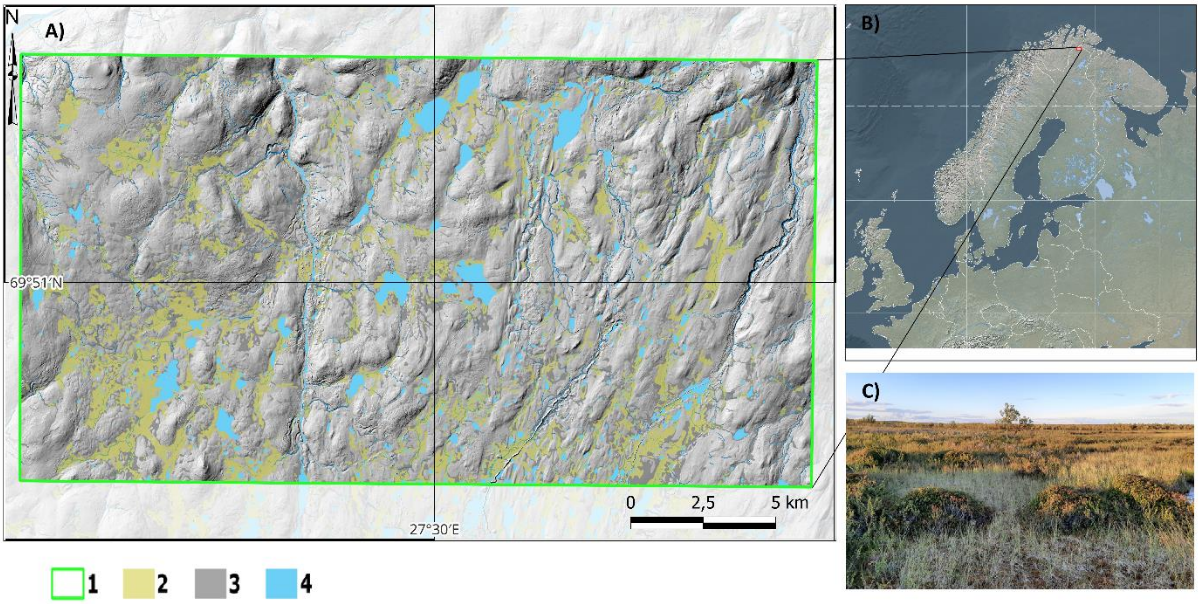

Fig. 1: A) The study area where palsa peatland occur: 1 – study area, 2 – peatlands, 3 – other wetlands, 4 – water areas; B) Location of the research area in Finland; C) View of the palsa peatland in the field (author: D. Szumińska).

3. MATERIALS AND METHODS

Satellite images from the Landsat 5/7/8/9 mission with a resolution of 30 m from 1985 to 2024, covering the vegetation period (May–September), were used. The images were made freely available by the USGS EarthExplorer (https://earthexplorer.usgs.gov/), which were then processed using QGIS 3.18.3 software. In order to identify changes in land cover and environmental conditions, selected spectral indices were calculated: NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) to assess vegetation changes, NDWI (Normalized Difference Water Index) and MNDWI (Modified NDWI) to analyze water surfaces, and NDMI (Normalized Difference Moisture Index) and SMI (Soil Moisture Index) to determine changes in vegetation and soil moisture. The analysis of the indicators allowed for the assessment of long-term environmental trends in the study area.

4. RESULTS

Analysis of Landsat satellite data from 1985 to 2024 for a selected area in northern Finland revealed a slight but consistent decline in vegetation index values (NDVI and EVI). This trend may indicate a gradual decrease in vegetation productivity or changes in vegetation structure, potentially associated with the effects of climate change, natural succession, or local disturbances in forest and peatland ecosystems. During the same period, a significant increase was observed in moisture-related indices (NDMI and SMI), suggesting improved water availability in soil and vegetation. Water indices (NDWI and MNDWI) also showed a small but steady upward trend, which may reflect an increase in the surface area of small water bodies or enhanced detectability in satellite imagery due to seasonal or hydrological changes. These shifts may have important implications for local boreal ecosystems and for the ongoing natural processes in this climatically sensitive region.

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Loneliness, Discovery, Imagination: The Poetics of Polar Experience in the Writings of Antoni Bolesław Dobrowolski

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1. INTRODUCTION

The presentation constitutes an attempt to demonstrate how Polish humanities may engage in a creative interpretation of texts situated at the intersection of science and literature, such as the journals and memoirs of polar explorers. The analysis focuses on selected passages from *Wspomnienia z Wyprawy Polarnej* by Antoni Bolesław Dobrowolski (Dobrowolski 1950) – one of the pioneers of Polish Antarctic exploration and a participant in the Belgian Antarctic Expedition (1897–1899). The objective is to reveal how, within the scientist's prose, a distinctive "poetics of the polar space" emerges, wherein cognitive endeavor is interwoven with introspection, and scientific inquiry with the work of the imagination.

2. METHODS

By juxtaposing Dobrowolski's descriptive strategies with Gernot Böhme's concept of the atmosphere of space (Böhme 1998, 2002) and Gaston Bachelard's poetics of place (Bachelard 1998a,b), it is argued that his writings can be construed not merely as documentation of meteorological and glaciological research, but also as subtle records of affective and existential attunement (Durand 1986). In Dobrowolski's account, the polar landscape is not relegated to the status of a static backdrop; rather, it becomes an active participant in the experiential field.

3. RESULTS

The encounter with such a space heightens the reflexivity of the subject – a phenomenon rendered in the poetic form of his notes, wherein landscape serves as a catalyst for contemplation and existential reflection. As Dobrowolski himself observes: "Nigdy nie patrzyłem tak śmiało w przyszłość jak teraz; nigdy nie czułem takiej równowagi"[1] – a statement which confirms that

[1] Dobrowolski, A.B. (1950), *Wspomnienia z Wyprawy Polarnej*, Prasa Wojskowa, Warszawa, 63 pp. (in Polish).

engagement with an extreme environment not only fails to diminish the sense of harmony, but may, paradoxically, intensify it. His attentiveness to sensory phenomena – the chromatic palette, the modulation of light, the depth of silence – attests to a subtle traffic between the lexicon of science and the poetic register of lived experience. Elsewhere, he remarks: "I nigdzie człowiek nie umie tak się skupić, tak milczeć, bo nigdzie chyba nie staje tak głęboko, tak naprawdę sam na sam z sobą"[2]. This passage discloses a pivotal dimension: solitude in a severe landscape is experienced not solely at the corporeal level, but as an ontological condition. The radical space of Antarctica – conceived by Dobrowolski as a world immensely alien to us, not ours and not for us ("świat ogromnie nam obcy, nie nasz i nie dla nas"[3]) – thus fosters intensified introspection and enables the formation of a particular mode of relatedness to nature, apprehended not as a passive object of cognition but as a moving co-presence.

4. CONCLUSION

The presentation is part of a broader proposition to integrate humanistic reflection into the domain of polar studies. It demonstrates that texts such as Dobrowolski's memoirs, when analyzed through the methodological lenses of the humanities, imagology, and phenomenology, permit the construal of polar space as a symbolic, epistemological, and affective territory – thereby contributing to a more profound apprehension of human experience under extreme conditions. In this sense, the humanities do not merely interpret texts concerning the Arctic; they become an integral component of its investigation.

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Toolik Lake Sediment Record as a PAHs and Other Pollution Accumulation Proxy in Permafrost Region of Alaska

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1. INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs), despite not being listed in the Stockholm Convention (2001) on persistent organic pollutants (POPs), share several characteristics with the classic POPs and are distributed in the environment worldwide. They are environmentally persistent and toxic (Jiao et al. 2009); they act as carcinogens and mutagens (International Agency for Research on Cancer 1983).

Permafrost regions have been affected by climate warming resulting in intensification of the water cycle and changes in aquatic biogeochemistry. In those regions, lake bottom sediment sequences provide knowledge on short- and long-term environmental changes, including natural, man-made (coal and oil combustion) and mixed (wildfires) sources of PAHs in environment. Furthermore, observed intense flux of selected metals (O'Donnell et al. 2024; Malcata Martins et al. 2025) into aquatic environment show possible vulnerability of freshwater to leaching and remobilization of chemical compounds accompanying permafrost thaw.

Our research objectives focus on temporal changes in polycyclic aromatic hydrocarbon (PAHs) and selected metals and metalloids and the possible influence of environmental and human activity factors on it, including the recent climate change.

2. RESEARCH AREA AND METHODS

The study was performed in the Toolik Lake (68°38'00"N, 149°36'15"W; Area = 150 ha, $depth_{max}$ = 26 m), located 20 km north of the Brooks Range in Alaska (Fig. 1). The lake is located in the continuous permafrost zone, in moraine sediments, and was formed 12000 years ago as a kettle hole. In this study, lake sediment cores were collected in September 2023 with the use of UWITEC gravity core sampler for soft bottom sediments with plexiglas pipes Ø = 90 mm, at the deepest site of the main basin fed by the inlets (T1 core), and the second small basin separate from the main part of lake (T2 core). The cores were divided in the field and 30 samples were taken from the core T1 of the total length of 0.63 m, and 33 samples from the core T2 of the total length 0.67 m. Samples were stored in the cooler in zip-lock bags during transport into laboratory in Poland.

We analysed (PAHs) concentrations in sediment extracts in dichloromethane. 16 EPA PAHs concentrations were determined with a Nexis GC-2030 gas chromatograph, coupled to a GCMS-QP2020 NX mass spectrometer (Shimadzu, Japan). Strict QA/QC procedures were followed, and recoveries of 75–84% were achieved. Organic matter (OM) content (percentage) was determined by loss-on-ignition (LOI) method at 400°C for 4 h, to avoid removing clay minerals alongside organics in the process. Concentrations of selected metals and metalloids and non-metals with inductively coupled plasma – mass spectrometry.

Fig. 1. Toolik Lake and sampling sites T1 and T2 locations (Map data ©2023 TerraMetrics, bathymetry based on Stuckey et al. (2019)).

3. RESULTS AND CONCLUSIONS

OM content was at a moderate level (median in core T1 at 17.1%, in core T2 at 24.8%) and OM variability with depth reached 5.6% and 3.7% (interquartile range, IQR) in core T1 and T2, respectively, excepting a single purely organic layer T2-21. PAHs varied along the cores, with a visible increase in core T2 and decrease in T1 toward the top. Predominant congeners at both sites were phenanthrene, naphthalene, and benzo[a]pyrene. Non-parametric coefficients of variation (IQR divided by median) were 23.7%, 46.7%, and 109.6% for naphthalene, phenanthrene, and benzo[a]pyrene in core T1, respectively, while in core T2 they reached 49.1%, 59.1%, and 41.4% for the respective compounds. Concentration increases occurred for selected metals towards the top, more noticable in T1, located in the main lake basin, which is fed by the Toolik Inlet– the largest tributary of Toolik Lake (watershed area 46.6 km^2). Simultaneously, selected elements exhibited sharp concentration peaks in the deeper sections of the cores, especially core T2. Temporal changes in PAHs, metals and metalloids concentrations reflected possible influence of environmental and human activity, including the recent climate change.

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Ecological and Biogeochemical Consequences of Changes in Sediment Supply Patterns to Tanafjord

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1. INTRODUCTION

Every sub climate change in the Arctic, including accelerated thawing of permafrost, rising air temperatures, and increasing intensity and variability of precipitation, is driving profound transformations in sediment supply dynamics to Arctic seas, including the coastal zones of the Arctic Ocean (Syvitski 2002). In northern Norway, one of the key river systems shaping the sedimentary and biogeochemical balance of coastal environments is the Tana River (Tenojoki). This river, extending over 360 km, discharges into Tanafjord—a fjord approximately 65 km long and 8–12 km wide (Dankers 2002)—whose estuary represents an important transitional zone between fluvial and sub-Arctic shelf environments. The fjord, together with the delta and estuary of the Tana River, functions as an active interface where freshwater and marine waters mix and where intense sedimentary processes occur.

Changes in sediment supply patterns, particularly with respect to fine-grained suspended sediments (SSC – Suspended Sediment Concentration), have important ecological and biogeochemical implications. These sediments act as carriers of biogenic compounds (e.g., nitrogen and phosphorus) and organic matter, thereby influencing primary productivity and the trophic structure of coastal waters. The aim of this study is to evaluate the ecological and biogeochemical consequences of changes in sediment supply to the Tanafjord estuary, with particular emphasis on the seasonal fluxes of fine-grained suspended sediments and their impact on the equilibrium of the fjord ecosystem and the sub-Arctic Barents Sea shelf.

2. METHODS

Based on the research infrastructure of the Kevo Subarctic Research Institute (University of Turku), a cyclic monitoring program of water quality is conducted in selected tributaries of the Tana River. The research program includes regular water sampling and the measurement of physicochemical and morphometric parameters in the lower reaches of the studied streams.

Collected material is subjected to detailed laboratory analyses, including determination of total suspended sediment concentration (SSC), concentrations of biogenic substances (nitrogen, phosphorus), dissolved organic matter (DOM), as well as parameters indicative of mineralization degree and eutrophication potential. These data form the basis for assessing seasonal and interannual variability in sediment and chemical loads delivered to the Tanafjord estuary and the Barents Sea shelf.

3. RESULTS

A two-year monitoring program conducted in 2024–2025 in selected catchments of the Tana River showed clear temporal variability in sediment transport. The largest suspended sediment loads occur during spring snowmelt and ice breakup, generating short-lived but intense pulses of suspended material. These episodic events lead to transient enrichment of the estuary with nutrients and a temporary increase in turbidity, which in turn affect both phytoplankton dynamics and the deposition of organic matter on the fjord floor.

The findings suggest that intensification of sediment delivery to Tanafjord—an integral component of the larger Barents Sea system—may trigger a range of adverse ecological processes. Enhanced fluxes of biogenic substances and organic matter foster eutrophication of local marine ecosystems, disrupt carbon cycling, and drive shifts in the composition of plankton communities and benthic microbiomes. At the same time, increased availability of dissolved organic matter (DOM) may stimulate seasonal phytoplankton blooms, altering energy and matter transfer within food webs and impacting biodiversity and the stability of coastal ecosystems. Such changes may exert long-lasting and cascading effects, influencing not only local but also regional biogeochemical processes across the Arctic shelf zone.

4. CONCLUSIONS

The study highlights the necessity of long-term, integrated monitoring of sediment and biogenic matter transport. It is recommended that both field-based approaches (e.g., flow measurements, suspended sediment sampling, chemical analyses) and remote sensing tools (e.g., Sentinel-2, Landsat, MODIS data) be employed to capture process dynamics across multiple temporal and spatial scales. A deeper understanding of these phenomena is essential for assessing the impacts of climate change on Arctic coastal ecosystems and for developing future strategies for their protection and sustainable management.

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Argo Floats in the Arctic

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1. INTRODUCTION

The ocean's role in the climate system is fundamental. By accumulating and transporting heat, it shapes our climate and further mitigates the effects of anthropogenic changes occurring in the environment. The role of the Arctic, including the ocean and its ice cover, is even more critical in climate processes. These regions lie at a key location where the thermohaline circulation reverses and deep waters formation occurs. Therefore Arctic is the most sensitive to ongoing changes. Therefore, there is the need for increasingly precise and comprehensive monitoring of changes in the Arctic hydrosphere and cryosphere. This is a challenging task, as these regions are difficult to access, especially in winter. Hence the increasing role of autonomous devices capable of collecting data year-round.

2. THE ARGO NETWORK

Argo floats have revolutionized global oceanographic research. The Argo float is a relatively simple device: a metal cylinder about 2 meters tall and several centimetres in diameter, containing batteries, electronics, and a hydraulic system, with sensors and a satellite antenna on top. In the core version, it includes sensors for conductivity, temperature, and pressure. The float has no propulsion and drifts with ocean currents. Vertical movement is forced by changing the volume of an external bladder located at the bottom of the float. Pumping oil from inside the hull into the bladder increases the float's volume and causes it to ascend; retracting the oil from bladder causes it to sink slowly. Based on these devices, the ARGO network was established in the early 21st century. Today, it is the only global ocean observing system providing near-real time water column data – up to 12 hours after measurements. Around 4000 floats operate continuously, covering all oceans and marginal seas. All Argo data are free and available in CORIOLIS database.

A typical float cycle includes:

(1) descent from the surface to the parking depth;
(2) drift at the parking depth, usually 1000 m;
(3) descent to profiling depth (2000 m);

(4) slow ascent and profiling of the water column;
(5) surface measurements and satellite data transmission.

In the deep ocean, a full cycle typically lasts 10 days.

3. ARGO-POLAND IN THE ARCTIC

3.1 Oceanic floats

Poland has participated in the European Research Infrastructure Consortium Euro-Argo ERIC since 2009. In 2023, the Argo-Poland consortium was established, comprising the Institute of Oceanology PAS (IO PAS) as the leader, the Institute of Geophysics PAS (IG PAS), and the Polish Naval Academy. Since 2009, IO PAS has deployed 31 floats in the Arctic. Each year, 2–3 Argo floats are deployed from the r/v OCEANIA. The long-term experience gained during AREX expeditions, particularly the understanding of Arctic current systems, has allowed for the development of a regular deployment scheme. Floats are deployed along 75 °N latitude, one in the eastern branch of the West Spitsbergen Current, the other in its western branch. The float deployed in the eastern branch usually crosses the Fram Strait quickly, where it is carried by the Svalbard Current under the sea ice and drifts along the northern slope of Svalbard with Atlantic Water. The float in the western branch tends to operate longer: it typically recirculates westward, joins the East Greenland Current, and flows south. Such floats may operate for up to 7–8 years.

However, floats entering the Arctic Ocean are not always immediately lost. In many cases, it has been possible to recover data collected while drifting under the ice. A float entering in autumn under the ice in Fram Strait may resurface next summer near Franz Josef Land. In some cases, floats submerge again under the ice and later resurface and continue transmitting data. For example, float WMO3902114 operated for 4 years, passed Severnaya Zemlya and reached the Laptev Sea.

Due to the lack of satellite positioning, under-ice trajectories are interpolated during preliminary processing at the ARGO data centre. The RAFOS acoustic positioning system is currently not operational in the Arctic. At IO PAS, we estimate the float's position using bathymetric data (Fig. 1).

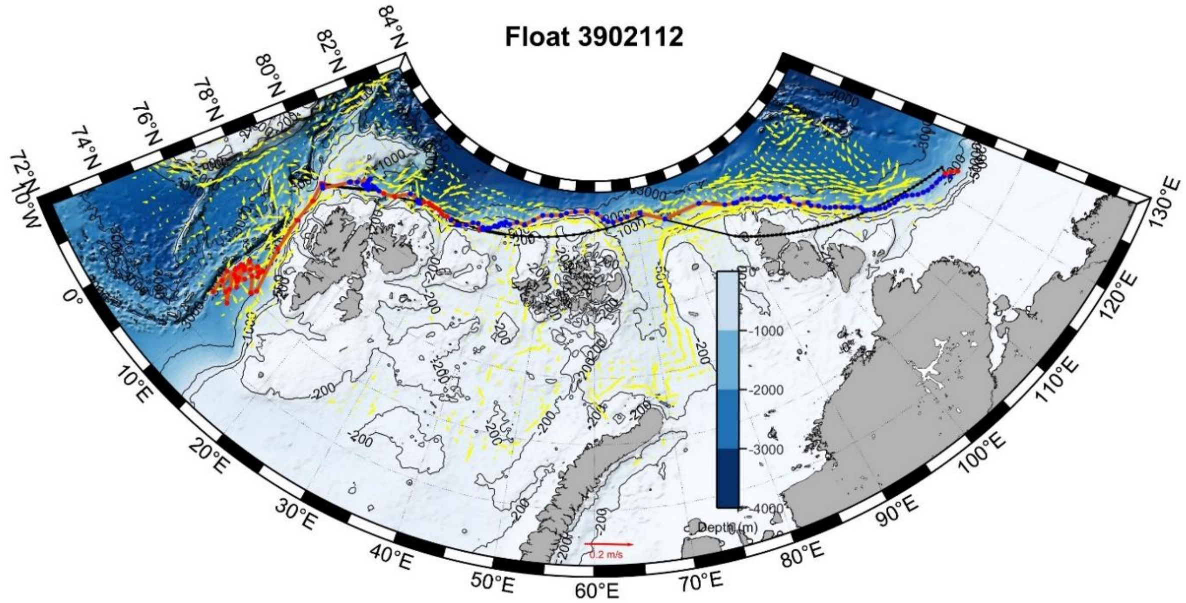

Fig. 1. Trajectory of float WMO9302112. Black line – trajectory estimated by CORIOLIS; red line – trajectory calculated using the described method; red points – known GPS positions; blue points – calculated positions. Currents at a depth of 200 m from the COPERNICUS service are indicated.

After crossing the Fram Strait, floats drift along the continental slope, and profile depths rarely exceed 2000 m, making location estimation easier. The method involves comparing the maximum depth reached during descent with regional bathymetry. In the first step, the CORIOLIS-estimated position is used to find matching depths and derive coordinates (Lat1, Lon1), considering the float's likely drift direction. In the second step, the trajectory is smoothed and the process repeated. Even when float positions are not precise, profile data allow the tracking of Atlantic Water changes during eastward advection. Of particular importance is heat content: heat exchange with surrounding waters plays a key role in Arctic Sea ice melt. These data are compared with results from moorings and research cruises, including those from r/v OCEANIA. Thus, Argo is becoming an increasingly important part of the integrated Arctic Ocean observation system.

3.2 Fjords floats

The Argo's successes in the Baltic Sea inspired us to test them in the Arctic fjords. In 2023, IO PAS and IG PAS conducted the first Argo float deployments in Hornsund. Both free-drifting and bottom-anchored floats were tested. In 2024, the focus shifted to acquiring a time series from the anchored float. It is a non-standard procedure, as Argo floats are designed to drift. However, in restricted basins, this can be beneficial. IO PAS was the first to successfully apply this technique in the Baltic Sea (Merchel et al. 2025). The experiment in Hornsund also succeeded: a 13-day time series was recorded, with 4-hourly profiles from surface to seafloor. Even this short series provided valuable insights into water column transformation near a glacier front (Fig. 2). In 2025, measurements continue in Hornsund near Hans Glacier.

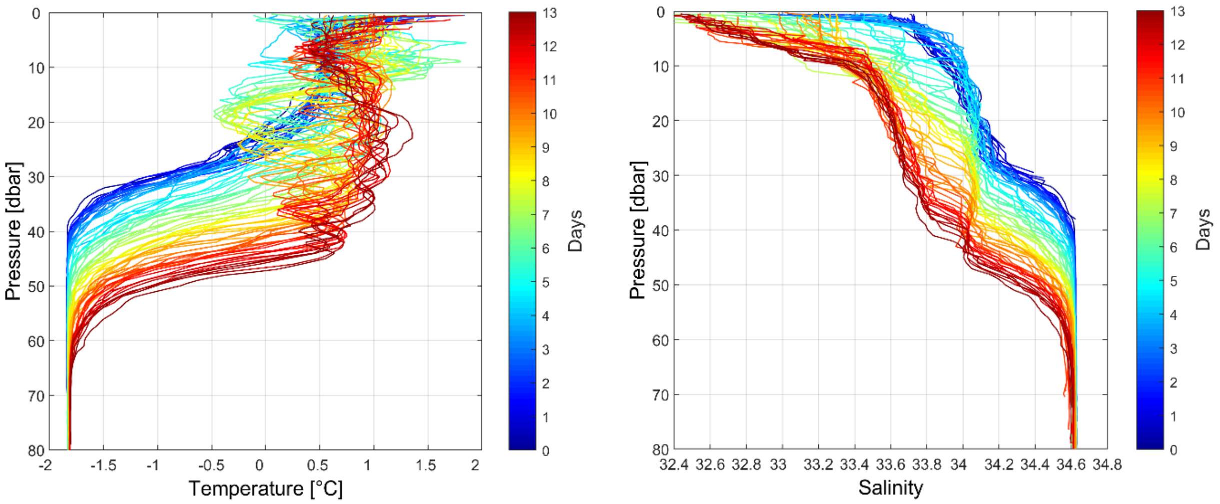

Fig. 2. Time series of temperature and salinity profiles in the region of Hans Glacier.

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Underwater Imaging of Marine Snow in Admiralty Bay

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1. INTRODUCTION

Marine snow morphology and distribution has been already investigated in Arctic region using underwater imaging, but this research is the first one focusing on Antarctic region. The main source of marine particles and their aggregates are the glacier meltwaters, decaying phytoplankton and the by-products of their consumers. Therefore, the knowledge about marine snow composition and morphology may constitute an important new indicator of the processes occurring in the coastal waters. Research objective was to characterize marine snow composition and concentrations, as well as to estimate driven by it carbon export flux in order to broaden our understanding how they change across various glacial bays at a time of climate change. Moreover, we aimed to compare Arctic and Antarctic marine snow to check if their origin deduced by morphology is similar.

2. METHODS

Field campaigns took place in the summers of 2023 and 2024 in Admiralty Bay, the largest bay of King George Island, South Shetland Islands. Imaging using underwater camera UVP6, supplemented by CTD profiles, was conducted at stations representing various horizontal gradients across various branches of the bay.

3. RESULTS AND DISCUSSION

Our results show that these two years varied environmentally, year 2023 was warmer, with higher chlorophyll-a fluorescence and fresher than 2024, which might have influenced the observed differences in marine snow composition and concentration between years. Furthermore, 2023 was a year of higher concentrations of marine snow and greater differentiation in relative roles in morphotypes. Even small differences in distance from the glacier as well as differences in timing of imaging showed changes in composition and concentration of particles, but with no consistent pattern. Vertically, higher concentrations of marine snow were near surface and decreased with depth. Comparison of data from Antarctic with data collected in the Arctic glacial bays showed that in general, there were similarities in marine snow morphology in these two distant regions, meaning they mostly shared the range of various morphological traits. However, particles from Antarctic have larger scale of variability in most traits.

This research gives highly valuable information about marine snow morphology and concentration in Antarctic region, next step is to connect this data with information about phyto- and zooplankton variability in Admiralty Bay to provide a broader picture of pelagic functioning in this vulnerable region.

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Variability of Organic Carbon and Nitrogen Concentrations in the Snow Cover of a Non-glaciated Catchment in Svalbard

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1. INTRODUCTION

Arctic catchments are particularly sensitive to ongoing climate change. On Svalbard, a clear upward trend in average air temperature has been observed – reaching up to six times the global average (Migała et al. 2023). Climate warming leads to changes in the carbon and nitrogen cycles, which, as a result of cryosphere melting, may be released into surface waters (Francis et al. 2023; Gao et al. 2024; Lehmann-Konera et al. 2018).

The primary objective of this study was to examine the spatial variability of total organic carbon (TOC) and total nitrogen (TN) concentrations within the non-glaciated Fuglebekken catchment, located in close proximity to the Polish Polar Station in Hornsund (Svalbard). The study provided insight into the less well-known aspects of the cycling of TOC and TN in the environment.

2. MATERIALS AND METODHS

Snow samples were collected from the small Fuglebekken catchment, covering an area of 1.27 km^2. Samples of the surface snow cover and the entire snow profile were analyzed for TOC and TN and collected in a manner that allowed for the illustration of spatial variability in relation to snow cover depth, altitude above sea level, anthropogenic influence and the colony of the little auk (Alle alle), that nests in the spring on the mountain slopes in the northern part of the catchment (Fig. 1).

Concentrations of TOC and TN were determined using a Shimadzu TOC-L analyzer, equipped with a TNM-L module. TOC analyses were carried out based on high-temperature (680 °C) combustion with catalytic oxidation to CO_2 using a platinum catalyst and non-disper-

Fig. 1. Geographical distribution of sampling points within the Fuglebekken catchment area.

sive infrared detection, while TN analyses were performed by catalytic thermal decomposition (720 °C), with chemiluminescence detection. The results were analyzed in terms of spatial variability using QGIS software. Statistical significance of linear trends was tested in TIBCO Statistica^{TM} software.

3. RESULTS

The highest concentrations of TOC and TN were recorded in the nesting area of the little auk colony, with maximum values of 12.1 mg/L (TOC) and 13.0 mg/L (TN). In contrast, concentrations in areas more distant from the colony did not exceed 0.3 mg/L (TOC) and 0.25 mg/L (TN). A statistically significant ($p < 0.05$) correlation was observed between concentration levels and the distance to the bird colony (TOC: Spearman rho = –0.40, TN: Spearman rho = –0.48). For the top 5 cm of snow on 8 May, and elevation above sea level, the correlation was particularly strong for TOC (Pearson $r = 0.97$, $p = 0.001$).

A spatial analysis of inorganic nitrogen (IN), ammonium nitrogen ($N–NH_4^+$) and nitrate nitrogen ($N–NO_3^-$) concentrations was also conducted, considering the influence of biological activity and elevation. They revealed similar patterns, with the highest concentrations observed in the area influenced by the bird colony.

4. SUMMARY

The most prominent feature of the spatial variation was the high concentrations of total organic carbon and nitrogen observed in the samples collected from the nesting area of the little auk colony, which exerted the most pronounced impact on the concentration of these elements in the snow cover. An increase in concentrations with altitude (in the case of fresh snow) was also observed.

5. CONCLUSIONS

The study demonstrates that the presence and activity of biological factors can have significant impact on the snow chemistry and represent an important source of chemical compounds potentially released into surface waters, an important issue in the context of ongoing climate change and changing nutrient cycles.

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