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Arctic archives in old wood: Dendrochronological potential of Svalbard dwarf shrubs from historical polar expeditions

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Abstract: Instrumental climate records from Svalbard are sparse and discontinuous, with most observations beginning in the 20th century, making dendroclimatological reconstructions essential for extending climate information into earlier periods. In the treeless High Arctic, dwarf shrubs constitute the only dendrochronological archive; however, existing shrub-ring chronologies from Svalbard are generally short and largely restricted to the recent past. This study assesses the dendrochronological potential of Arctic dwarf shrubs preserved in historical herbarium collections originating from early polar exploration. We analyzed herbarium specimens of *Salix polaris* Wahlenb., *S. reticulata* L., *Dryas octopetala* L., and *Empetrum hermaphroditum* Hagerup collected between 1838 and

1898 and stored in major European and North American herbaria. Using modern microanatomical preparation and ring-width measurement techniques, annual growth rings were successfully identified and measured in dried herbarium material. Based on species composition and spatial distribution, three mean ring-width chronologies were developed for southern and central Spitsbergen, extending into periods lacking instrumental climate observations. The time span of the newly developed chronologies is 1803–1928. Although sample replication remains limited and direct calibration with meteorological data is not yet possible, herbarium-based chronologies show coherent growth patterns and reveal intervals of reduced and enhanced growth consistent with independent climate proxies from ice cores, lake sediments, and early meteorological records. These results demonstrate that historical herbarium collections can substantially extend Arctic shrub dendrochronological records and provide climate-sensitive information from ice-free areas of Svalbard.

Keywords: Arctic, Spitsbergen, Little Ice Age, herbarium specimens, historical collections, growth ring widths, climate.

Introduction

The High Arctic is a unique and sensitive environment where the interaction of climate, vegetation, and human exploration has been recorded over centuries. Svalbard has experienced pronounced climatic fluctuations over the past two centuries, including periods of cooler summers during the late Little Ice Age, followed by a general warming trend in the early 20th century, but sparse and fragmentary instrumental records limit direct reconstruction of these historical temperature changes. Instrumental climate records for Svalbard are relatively short and sporadic, with continuous temperature observations beginning only in the late 19th century (Przybylak *et al.* 2016; Nordli *et al.* 2020), leaving the preceding decades, spanning the final phase of the Little Ice Age, largely undocumented. In addition to historical meteorological records, ice cores and lake sediment cores have also been developed, but these data have reduced temporal and spatial resolution.

In the treeless High Arctic environment, dendrochronological data depend on investigations of dwarf shrubs, whose woody tissues preserve annual growth increments that can be used to infer past climatic conditions. Early attempts to use dwarf shrubs for dendrochronological dating in the Arctic can be traced back to the work of Nicholas V. Polunin, who recognised the potential of woody Arctic plants to record annual growth increments. In his studies of Arctic vegetation, Polunin noted that dwarf shrubs such as *Salix* and *Dryas* form distinct annual rings despite their small size and harsh growing conditions, making them suitable for age determination and retrospective ecological analyses (Polunin 1945, 1955). Although these early observations were largely qualitative and lacked modern cross-dating techniques, they laid the conceptual foundation for the later development of Arctic shrub dendrochronology.

Recent dendrochronological records from Svalbard dwarf shrubs provide valuable climate proxies, their relatively short length limited by short plant lifespans, often spanning only several decades, limits their ability to capture longer-term climatic trends. The dendrochronological series compiled so far from Svalbard are short, e.g., *Salix polaris* Wahlenb. series spans roughly 50–70 years (Buchwał *et al.* 2013; Owczarek *et al.* 2013; Owczarek and Opała 2016; Le Moullec *et al.* 2020; Phulara *et al.* 2025). Longer records were compiled for *Salix polaris* from Bear Island (Bjørnøya), the southernmost part of the Svalbard archipelago, covering 95 years (1922–2016) (Owczarek *et al.* 2021), while a series of shoot length growth (Wintermarksepta) of *Cassiope tetragona* (L.) D. Don from Endalen in central Spitsbergen spans over 100 years (Weijers *et al.* 2010).

Historical herbarium specimens collected during early polar expeditions offer a unique opportunity to expand these records, as previously documented for Greenland (Opała-Owczarek and Owczarek 2023; Opała-Owczarek *et al.* 2025). By integrating contemporary dendrochronological materials with herbarium records, it becomes possible to situate Arctic shrub growth within a broader context of climate variations at the transition between Little Ice Age and contemporary warming. Novel approaches that combine historical exploration of Svalbard with dwarf shrubs dendrochronological methodology not only enrich our understanding of plant responses to environmental change in extreme conditions but also highlight the enduring scientific value of historical botanical collections.

The primary aim of this study is to assess the dendrochronological potential of Arctic dwarf shrubs from Svalbard preserved in historical herbarium collections originating from early polar expeditions. By integrating botanical material collected during 19th and early 20th century explorations with modern dendrochronological techniques, this work seeks to bridge the temporal gap between short shrub-ring chronologies and longer-term climate reconstructions based on ice cores, lake sediments, and historical meteorological observations. We will examine the extent to which herbarium-based dendrochronological data can extend existing shrub growth records into periods not covered by instrumental climate measurements. By placing dendrochronological analyses within the historical context of Svalbard exploration, this study also aims to highlight the under-utilised methodological value of historical herbarium collections as biological climate archives from the High Arctic.

Study area

General settings

Svalbard is a High Arctic archipelago comprising the isolated island of Bjørnøya (*ca.* 74°N) and the main island of Spitsbergen, along with neighbouring islands (*ca.* 77–81°N) (Fig. 1A). The region is largely ice-free along its western coast due to the North Atlantic Current, while extensive glaciers, permafrost, and tundra dominate the landscape. Glaciers and ice caps currently cover around 57% of the archipelago (Nuth *et al.* 2013). However, the extent of glaciation varies, with the majority of glaciers located in the eastern and northern regions. Central Spitsbergen has the least glacial coverage, with less than 18% of the area covered by ice. A characteristic feature of the landscape is long and deep fjords, mainly in the western part of Spitsbergen, wide U-shaped valleys, and high mountains with an alpine relief. According to the Köppen climate classification, Svalbard's climate is a subtype of the polar tundra climate (ET) with strong oceanic influence, but it is characterised by high regional variability. This is particularly evident in the amount of precipitation. In the central part of Spitsbergen, precipitation is very low, averaging 207.9 mm annually, while in the southern part, the average precipitation is around 500 mm, reaching a maximum of up to 805 mm (Migała *et al.* 2023). The average annual air temperature is −4.5°C, with seasonal temperatures ranging from −11.7°C in winter to 5.2°C in summer. Nevertheless, it is important to note that the air temperature in Svalbard has increased by 3–5°C over the last 40–50 years (Hanssen-Bauer *et al.* 2019). Svalbard is characterized by high terrestrial vegetation heterogeneity in relation to local climate and landscape diversity (Elvebakk 1985; Jónsdottir 2005). Despite the Svalbard archipelago's comparatively limited land area, it encompasses the three coldest zones of Arctic vegetation: A, B, and C (CAVM 2024). The dominant vegetation type on higher elevations, plateaus, and close to glaciers and ice caps is tundra, which is classified as a cryptogamic herb barren. Scattered vegetation includes herbs, lichens, mosses and liverworts. This type of vegetation is characteristic of bioclimatic zones A and B of the Arctic and is typical of cold and dry areas. Prostrate shrubs, such as *Dryas octopetala* and *Salix polaris*, which are less than 5 cm tall, dominate lower elevations and valleys, along with graminoids and forbs. Moist to dry tundra dominated by prostrate and hemiprostrate shrubs less than 15 cm tall, particularly *Cassiope tetragona*, is found within alluvial fans and is known as prostrate and hemiprostrate dwarf-shrub, lichen tundra. This type is typical of maritime, acidic environments within Subzone C (CAVM 2024). The western coast of Svalbard, especially the interiors of fjords are characterised by a relatively mild climate. The middle Arctic tundra subzone C is found in their coastal areas. The shrubs with woody stems commonly found in this zone, such as *Salix polaris*, *Salix reticulata* and *Dryas octopetala*, make it a key area for dendrochronological research in Svalbard (Opała-Owczarek *et al.* 2018; Le Moullec *et al.* 2020; Phulara *et al.* 2025). The fjords and bays were the most easily accessible areas for scientific expeditions, and the majority of the research work was carried out there.

Early polar expeditions to Spitsbergen mainly operated in fjords along the western coast, including Bellsund, Isfjorden, Billefjorden, and Hornsund. These areas offered sheltered anchorages and proximity to ice-free coastal zones, facilitating navigation and specimen collection. The concentration of early exploratory activity in these fjords resulted in the first systematically documented natural history and meteorological observations, as well as the accumulation of botanical specimens that now reside in European and North American herbaria.

Historical polar expeditions to Svalbard

Early exploration of Spitsbergen was driven by the search for the Northeast Passage, with Willem Barents' voyages (1594–1597) providing the first detailed maps and observations of the archipelago's northern coasts and sea ice conditions. Subsequent expeditions, including those led by Henry Hudson and William Parry (1819–1822), focused primarily on navigation and mapping. Parry's voyages to Bellsund and Isfjorden included meteorological and natural observations, but systematic botanical collections did not begin until later scientific expeditions. Scientific exploration and the collection of herbarium material commenced with the French Admiralty Expedition aboard *La Recherche* (1838–1840) and continued with later 19th century expeditions such as Fries (1869) and Conway (1897). These expeditions targeted ice-free fjords along the western coast, including Bellsund, Isfjorden, and Hornsund, and yielded the most herbarium sheets with specimens of Arctic shrubs (Fig. 1A). The plant material preserved during these expeditions now represents a unique historical archive, providing precisely dated specimens of Arctic vegetation.

The French Admiralty Expedition aboard the corvette *La Recherche* (1838–1840), led by naval surgeon and naturalist Joseph Paul Gaimard (1793–1858), was an international scientific enterprise to North Atlantic islands, including the Faroe Islands, Spitsbergen, and Iceland (Fig. 1B). It conducted comprehensive research in geography, geology, meteorology, botany, and zoology, with findings published in a series of reports between 1842–1843 and 1855 (Kajihara 2024). In addition to observations primarily focused on meteorology and geomagnetism (Locher 2007), the expedition collected numerous specimens, including botanical material, with *Dryas octopetala* and *Salix polaris* gathered from two sites in Spitsbergen: Magdalena Bay and Bellsound (Martins *et al.* 1842).

The 1861 Swedish expedition to Svalbard, conducted aboard the Norwegian sealing schooner *Æolus* and led by Otto Martin Torell, carried out a boat-based survey along the western coast of Spitsbergen, including the interior of fjords (Fig. 1C), and the northwestern coast of Nordaustlandet. In addition to initiating meridian arc measurements, an undertaking that remained incomplete, the expedition focused on the collection of zoological and botanical specimens, as well as on geological and astronomical observations (Chydenius 1865; Väre 2017). In 1864, a Swedish expedition to Svalbard was led by Adolf Erik Nordenskiöld under the auspices of the Royal Swedish Academy of Sciences, which appointed him commander of the schooner *Axel Thordsen* to continue the meridian arc survey initiated during earlier expeditions. The programme focused on natural history and geological investigations. The expedition aimed to extend the cartographic work begun in 1861 by mapping the southern part of the archipelago, collecting botanical and zoological specimens, and conducting preliminary determinations of latitude and longitude, comparable to earlier surveys undertaken in northern Spitsbergen (Wråkberg 2019).

The Conway Expedition of 1896 aboard the steamer *Raftsund*, led by Sir Martin Conway and supported by the Royal Geographical Society and the Royal Society, was the first expedition planned specifically to survey the interior of Spitsbergen. During the expedition J. W. Gregory and A. Garwood conducted extensive geological work and gathered collections of flora and fauna (Garwood and Gregory 1896; Gregory 1896).

The Oxford University Expedition to Spitsbergen of 1921, conducted between June and August aboard the sealing ship *Terningen*, was led by the British amateur ornithologist and zoologist Francis Charles Robert Jourdain. Originally intended as an ornithological expedition, it was later expanded to encompass a broad range of scientific activities, including geography and geology (Fraser 1922), as well as the collection of floral and faunal specimens and detailed ecological observations (Summerhayes and Elton 1923).

In addition to the expeditions described above, many herbarium specimens originate from scientific trips conducted by individual researchers. Among these, Nicholas Vladimir Polunin conducted fieldwork in Arctic regions, including Spitsbergen, in the 1930s and 1940s, collecting botanical material and documenting vegetation patterns (Polunin 1945, 1955, 1959).

Materials and Methods

Herbaria with the largest collections of specimens from historical expeditions to Svalbard were contacted: Royal Botanic Gardens, Kew (herbarium code: K), Cambridge University Herbarium (CGE), Oxford University Herbaria (OXF), Herbarium Conservatoire et Jardin botaniques de la Ville de Genève (G), the William and Lynda Steere Herbarium, New York Botanical Garden (NY) and the United States National Herbarium, Smithsonian's National Museum of Natural History (US).

Only specimens of selected species (*Salix polaris, Salix reticulata, Dryas octopetala, Empetrum hermaphroditum*) of dwarf shrubs, with the appropriate metadata were selected for the study (Fig. 1D). With permission of herbarium curators, a small section of stem was removed, and photographic documentation of the specimen made. The detailed methodology is presented by Opała-Owczarek and Owczarek (2023). In the laboratory, stem portions were sectioned and processed using a standard paraffin embedding protocol. The material was fixed in 70% ethanol, dehydrated through a graded ethanol series, and infiltrated with paraffin at 58–60°C. Embedded samples were cut using a rotary microtome and subsequently stained with Astra Blue and Safranin to enhance the contrast between lignified and non-lignified tissues (Schweingruber and Poschlod 2005; Gärtner and Schweingruber 2013). This staining combination enabled clear visualisation of annual growth ring boundaries and key wood anatomical features required for dendrochronological analysis. The resulting sections were photographed under a microscope (Leica DM1000 with magnification 40x) and stitched together using PTGui (New House Internet Services B.V. 2024) to create a composite image for each sample. We used the WinDENDRO software (Regent Instruments Inc. 2016) to measure the growth ring variability of the analysed cross-sections.

The raw growth-ring sequences were visually cross-dated by comparing characteristic ring-width patterns, including distinct narrow and wide rings. Particular attention was paid to unique growth anomalies and dendrochronological "signatures" that facilitated the alignment of overlapping sequences among sequences. The year of the most recent growth ring in each specimen was assigned based on the collection date provided on the herbarium label, allowing absolute dating of the outermost ring. Statistical analyses in COFECHA (Holmes 1983) were performed as a final step to verify the consistency of overlapping sequences, confirming the reliability of the visual cross-dating. Ring-width series were individually detrended to remove age-related growth trends. After visual assessment of different detrending methods, a horizontal line, a negative exponential function, or a spline were applied to construct mean chronologies.

Results

Taxonomic composition and dendrochronological characteristics

The analysed Spitsbergen dwarf shrubs specimens dated from the years from 1838 to 1898. Despite long-term storage, most herbarium specimens were well preserved, allowing detailed anatomical observations. Major tissue types and diagnostic cellular features were clearly identifiable, indicating sufficient anatomical quality for microscopic analysis (Fig. 3). From *ca.* 150 Svalbard herbarium specimens, 65 were selected for sampling, but only 48 were suitable for measurement of width of annual growth rings. They included the following species: *Salix polaris*, *S.reticulata*, *Dryas octopetala* and *Empetrum hermaphroditum* (Fig. 2).

The timing of collection varies from June to August. The earliest collection was *S. polaris* made on 24 June (1896; Adventdalen). The latest collection was of *D. octopetala* made on 12 August (1936; Klaas Billen Bay). Dates appearing on the herbarium specimens fall between the end of June and early August, reaching a maximum in July.

Regardless of the diameter of the stem of the dwarf shrubs, the number of annual rings varied from 7 to 34 rings in *S. polaris*, from 13 to 32 rings in *S. reticulata*, and from 7 to 100 rings in *D. octopetala*. The annual growth rate was 40–60 µm in >30-year-old specimens, with much higher values in younger shrubs (>100 µm). Based on spatial distribution and species dominance, three mean growth-ring-width chronologies were developed from individual growth curves: (1) *S. polaris* and *S. reticulata* from southern Spitsbergen (Bellsund), (2) *S. polaris* from central Spitsbergen (Adventdalen, Isfjord), and (3) *D. octopetala* from central Spitsbergen (Adventdalen, Isfjord) (Table 1, Fig. 4). Due to the limited number of specimens and/or the lack of temporal overlap, it was not possible to construct mean chronologies for Hornsund, King's Bay, Magdalenafjorden, or Bear Island.

Table 1. Statistical parameters of ring-width chronologies of Svalbard dwarf shrubs derived from herbarium specimens.

Site	Species	Time span (number of years)	Number of samples	Correlation with master chronology	Mean samples length (min/max)	Mean growth ring width in µm (SD)	Mean sensitivity
Bellsund	*Salix polaris, S.reticulata*	1803–1872 (70)	11	0.547	21 (8/36)	113 (50)	0.418
central Spitsbergen	*S.polaris*	1843–1922 (80)	19	0.513	22 (7/34)	102 (52)	0.520
central Spitsbergen	*Dryas octopetala*	1818–1928 (111)	11	0.400	33 (7/100)	96 (56)	0.445

Discussion

Dendrochronological potential of historical herbarium dwarf shrub specimens

Developed growth-ring chronologies were 70, 80, and 111 years old (Table 1). Due to the lack of temporal overlap with the existing dendrochronological records of contemporary-growing *Salix* specimens from Spitsbergen, with records starting in the 1940s, or the absence of contemporary record for the *D. octopetala*, no calibration with meteorological data was performed. However, the authors are convinced that robust dendroclimatic reconstructions are possible, once the replication of these samples is enhanced, and more specimens from the mid-20th century are collected. There is a large number of specimens from the Spitsbergen area in the world's herbaria, but only a small portion can be used in dendrochronological research due to the lack of fundamental metadata, *e.g.*, locality and collection date information, specimen size and wood preservation (Opała-Owczarek and Owczarek 2023). The herbaria investigated are famous for their historical collections of Arctic plants, but future research should also focus on more recent 20th century samples to obtain a continuous dendrochronological record. However, botanical expeditions to Spitsbergen were relatively rare in the mid-20th century, largely due to the disruptions caused by World War II and the limited post-war logistical capacity for Arctic fieldwork. High costs, challenging travel conditions, and minimal infrastructure on the islands restricted plant-collecting efforts, whilst scientific priorities during this period often focused on geological, meteorological, and zoological research.

Dwarf shrubs growth as a proxy for 19th to 20th century temperature variability on Svalbard

The annual growth rate of herbarium-based dwarf shrubs from the 19th century ranged from 40–60 µm in specimens older than 30 years, with considerably higher values observed in younger shrubs (>100 µm). In the 20th century, mean ring widths were similarly variable, averaging 50–70 µm across different parts of Svalbard (Le Moullec *et al.* 2020), 70–110 µm in relatively young *S. polaris* from central Spitsbergen (Phulara *et al.* 2025), and 100–140 µm in southern Spitsbergen (Owczarek and Opała 2016). In contrast, relatively old specimens from Bear Island exhibited a lower mean ring width of *ca.* 30 µm (Owczarek *et al.* 2021), consistent with the harsh growing conditions during the early stages of plant development in the first decades of the 20th century. However, due to different sampling strategies across the analysed collections from 19th and 20th centuries, direct comparisons are difficult.

Studies on *S. polaris* from Spitsbergen generally shows positive correlations with temperature, but recent works also indicate the importance of both precipitation and temperature, or drought stress at low elevation sites associated with rising temperatures in the second half of the twentieth century (Phulara *et al.* 2025). Decrease in the strength of positive correlation with temperature since 2005 has been accompanied by a significant increase in the importance of summer precipitation as noted on Bear Island (Owczarek *et al.* 2021). However, given the harsh climatic conditions during the last phase of the Little Ice Age, in the 19th century, temperature was certainly the most important factor influencing growth ring width.

Taking the annual growth sequences of dwarf shrubs as a proxy for temperature, we can identify particularly cold conditions in the 19th century on Svalbard, such as: first decades of 19th, 1840s, beginning of 1880s, and warm conditions centred at 1833 and 1867 (Fig. 4). Standardised values smoothed with an 11-year filter indicate similarities between species, highlighting periods of warmer conditions in 1830s, cooling in 1840s clearly visible for central Spitsbergen, and prolonged to 1860 at southern Spitsbergen, and warm conditions in subsequent decades, followed by cooling at the end of 19th and first decades of 20th century (Fig. 5). A comparison with data from ice cores (Lomonosovfonna melt index after Beaudon *et al.* 2013) and lake sediments (*Chironomidae* assemblages from Revvatnet lake sediment after Luoto *et al.* 2019) from Spitsbergen consistently indicates warming in 1830s, a marked cooling in the years 1840s, and less remarkable in 1870s to 1880s, and 1900s (Fig. 5). A partially similar cooling in the 1880s and early 20th century was described by Przybylak *et al.* (2016) based on early meteorological series from Svalbard; also Nordli *et al.* (2020) analysing the Svalbard Airport composite series indicated cold regime in 1899–1929 period.

These interpretations should be regarded as indirect inferences of past temperature variability derived from shrub growth dynamics and interpreted in the context of modern ecological studies. The identified patterns are further supported by their consistency with independent proxy records, including ice core and lake sediment data, although they remain subject to the limitations inherent in proxy-based reconstructions. It should be noted that the dendrochronological dataset presented is preliminary; however, the high inter-individual correlation and consistency with other temperature reconstructions indicate strong potential for future dendroclimatic applications in selected areas of Svalbard during the Little Ice Age. By incorporating data from such ice-free sites, future research may enable more comprehensive and spatially representative reconstructions of past climate variability in this sensitive Arctic region.

Alpine and Arctic environments share key characteristics, including shrub-dominated growth forms, similar climatic constraints, and short growing seasons (Pandey *et al.* 2025; Lu *et al.* 2025). These similarities suggest that approaches developed for Arctic dwarf shrubs may also be applicable in treeless alpine regions. In particular, the analysis of annual growth sequences from herbarium specimens offers a promising opportunity to investigate past growth responses to climate variability in alpine settings, including comparisons between present-day conditions and cooler periods such as the Little Ice Age. Although the application of dendrochronological methods to herbarium material from alpine shrubs remains limited, previous studies have demonstrated the value of herbarium collections for detecting long-term ecological and functional changes in alpine vegetation (*e.g.*, Körner *et al.* 2016; Jaroszynska *et al.* 2022). Extending such approaches to growth-ring analysis could therefore provide a novel framework for reconstructing climate–growth relationships in alpine ecosystems.

Strengths and limitations of historical expedition material

Historical collections from herbaria can be viewed as "frozen time series," preserving valuable biological and environmental information across centuries. They capture plant material at specific points in time, preserving growth patterns, physiological traits, and the environmental conditions prevailing prior to collection (Willis *et al.* 2017; Lang *et al.* 2019; Ahlstrand *et al.* 2025; Daru 2025). As such, herbaria provide unique opportunities to reconstruct past climates, track long-term ecological changes, and study species responses to environmental stressors over historical periods. Unlike contemporary monitoring, which relies on continuous sampling, herbarium specimens represent discrete, time-stamped records that complement observational datasets and help fill temporal gaps in ecological data. A key strength is that herbarium specimens collected during early polar expeditions provide unique, precisely dated material from periods long before modern field expeditions, thereby extending dendrochronological records back in time. In addition, preserved specimens allow reanalysis using modern techniques that were unavailable at the time of collection. Expanding herbarium-based research, including applications in dendrochronology (Opała-Owczarek and Owczarek 2023), may further enhance their value for studying climatic and environmental variability (Briffa 2000).

Limitations include small sample sizes, potential sampling bias toward well-developed or easily collected individuals, and frequent damage of roots or basal parts where annual rings are best preserved in dwarf shrubs. In addition, the use of naturally preserved and historically accumulated material may introduce increased biological noise, tissue deformation, and non-climatic growth variability. Ring boundaries may be difficult to identify due to shrinkage, preservation effects, or poor quality, while metadata describing site conditions and microhabitats are often incomplete. Spatial and temporal gaps further complicate the integration of herbarium-based chronologies with contemporary growth-ring series. Herbarium specimens are unevenly distributed across regions and collection years, which limits representativeness. To reduce the influence of these limitations, analyses were based on the selection of the best-preserved samples and on comparisons among multiple individuals and sites, allowing the identification of consistent growth patterns and reducing the impact of local disturbances. Although sample sizes remain limited, the coherence of signals across series and their agreement with independent records indicate that the main patterns identified are robust and climatically meaningful.

Integration with modern chronologies requires alignment and standardization to account for differences in sampling strategies, plant age, and preservation conditions. Successfully merging historical and contemporary series can, however, produce longer and more spatially representative records, enabling a more comprehensive reconstruction of Arctic climate variability. Despite the intrinsic limitations of herbarium material, including incomplete sampling information and limited replication per site, the integration of data across a broad regional flora allows the extraction of a robust, integrated signal characteristic of the environmental conditions of the studied region. Future research may expand sample coverage and further validate the developed chronologies through the inclusion of material from additional herbaria, including Norwegian collections that contain valuable specimens from Spitsbergen. The identification of younger specimens would allow the extension of chronologies into the twentieth century and facilitate their integration with instrumental records. Similar approaches could also be applied in other Arctic regions and in Alpine environments, supporting broader assessments of climate variability across cold-region ecosystems.

Conclusions

Herbarium collections, particularly those originating from early Arctic expeditions, offer a methodological advantage. They allow retrospective reconstruction of Arctic shrub growth, providing insights into past climate variability that are otherwise inaccessible. The presented research has demonstrated that it is possible to perform dendrochronological analysis of specimens dried on herbarium sheets. Even very small specimens of *Salix* and *Dryas* dwarf shrubs had clearly measurable annual rings. Through this approach, incremental chronologies were developed that extend into periods previously unavailable for study, filling critical temporal gaps in Arctic dendroclimatology. While the data presented here should be regarded as preliminary, they indicate a promising new direction for enhancing and broadening our understanding of climate change on Svalbard. Notably, these specimens originate from ice-free areas, offering a unique complement to existing data that are predominantly derived from glaciated regions. Such collections are particularly valuable in regions like Spitsbergen, where the absence of trees necessitates the use of dwarf shrubs for dendrochronological studies, providing a rare window into past environmental and climatic conditions. By integrating herbarium-based records with contemporary growth-series, future research can develop longer, more spatially representative chronologies, ultimately enabling a more comprehensive reconstruction of Arctic climate variability.

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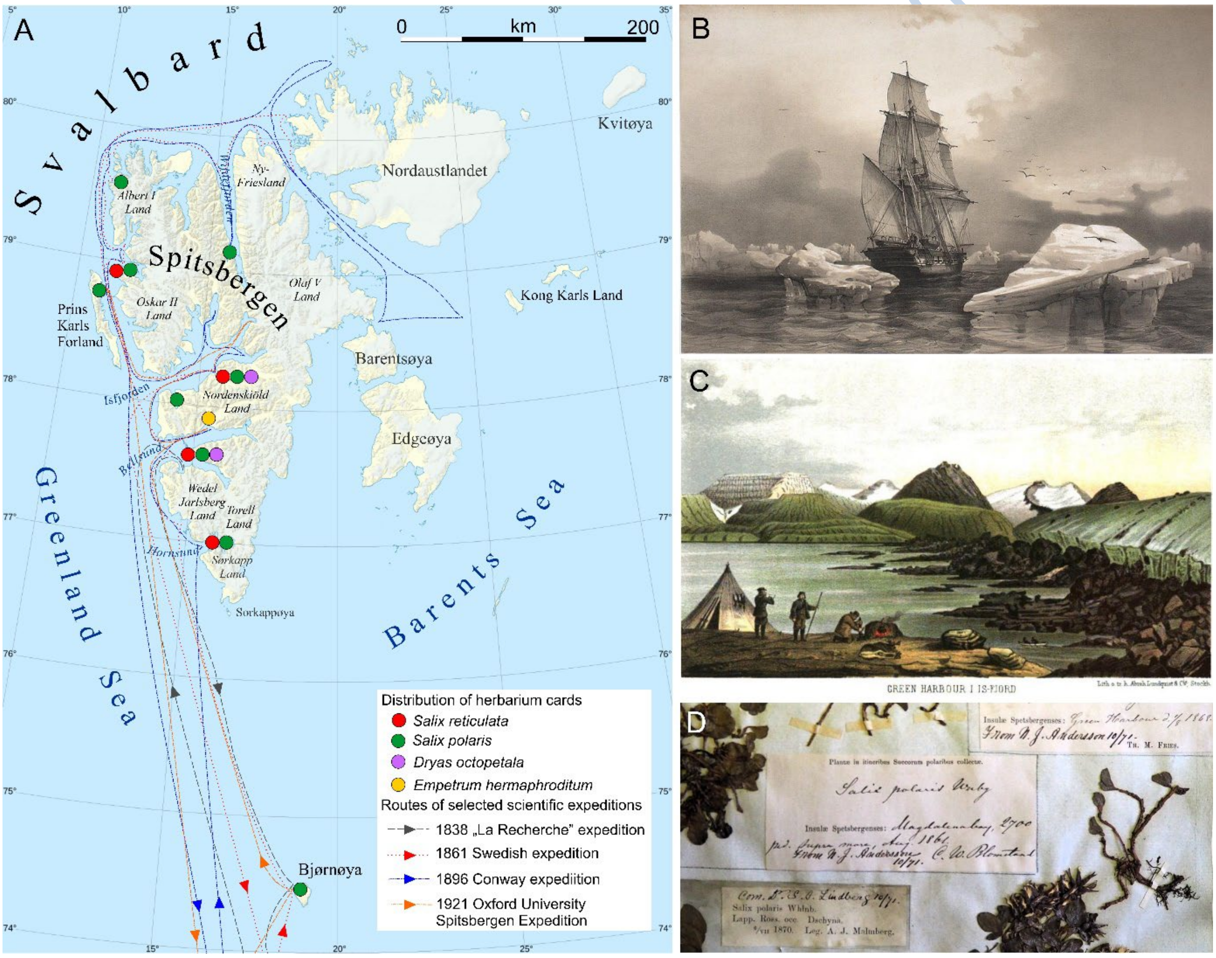

Fig. 1. (**A**) Location of sites within the Svalbard archipelago where specimens for herbaria were collected during historical research expeditions, analysed dendrochronologically in this study; the map also shows the routes of research expeditions from which the largest number of historical herbarium cards available for dendrochronological research originate, (**B**) The vessel "La Recherche" close to Bear

Island, Svalbard, August 7 1838, Auguste Étienne François Mayer (Public domain, via Wikimedia Commons), (**C**) Participants in Otto Torell's Swedish Expedition (1861) in Green Harbour, Isfjorden area (Central Spitsbergen), lithograph by A. Lundquist (Chydenius 1865) (Public Domain, Google-digitized), (**D**) Example of detailed information on the label of a herbarium card containing specimens of *Salix polaris* collected during 1861 Swedish Expedition (name of species: *Salix polaris* Wahlenb, data of collection: August 1861, place of collection: Magdalena Bay).

Fig. 2. Examples of historical herbarium cards with specimens used for dendrochronological research: (**A**) *Salix reticulata*, specimen collected in 1896 during Conway Expedition in Kongsfjorden (NW Spitsbergen), (**B**) *Salix polaris*, specimen collected in 1896 during Conway Expedition in Advent Bay (Adventfjorden, Central Spitsbergen), (**C**) *Salix polaris*, specimen collected in 1923 during the Merton College (Oxford) Expedition in Cape Petermann in Wijde Bay (Wijdefjorden, N Spitsbergen), (**D**) *Salix polaris* specimens collected during a few expeditions to the Arctic; in the upper part of the card, a specimens collected during the 1861 Swedish expedition to Spitsbergen, led by Otto Torell, in Magdalena Bay (Magdalenafjorden, NW Spitsbergen), and during the 1868 Swedish expedition to Spitsbergen, led by A.E. Nordenskiöld, in Green Harbour (Grønfjorden, Central Spitsbergen), (**E**) *Dryas octopetala*, specimens collected during the 1838 "La Recherche" Expedition in Bellsund (SW Spitsbergen).

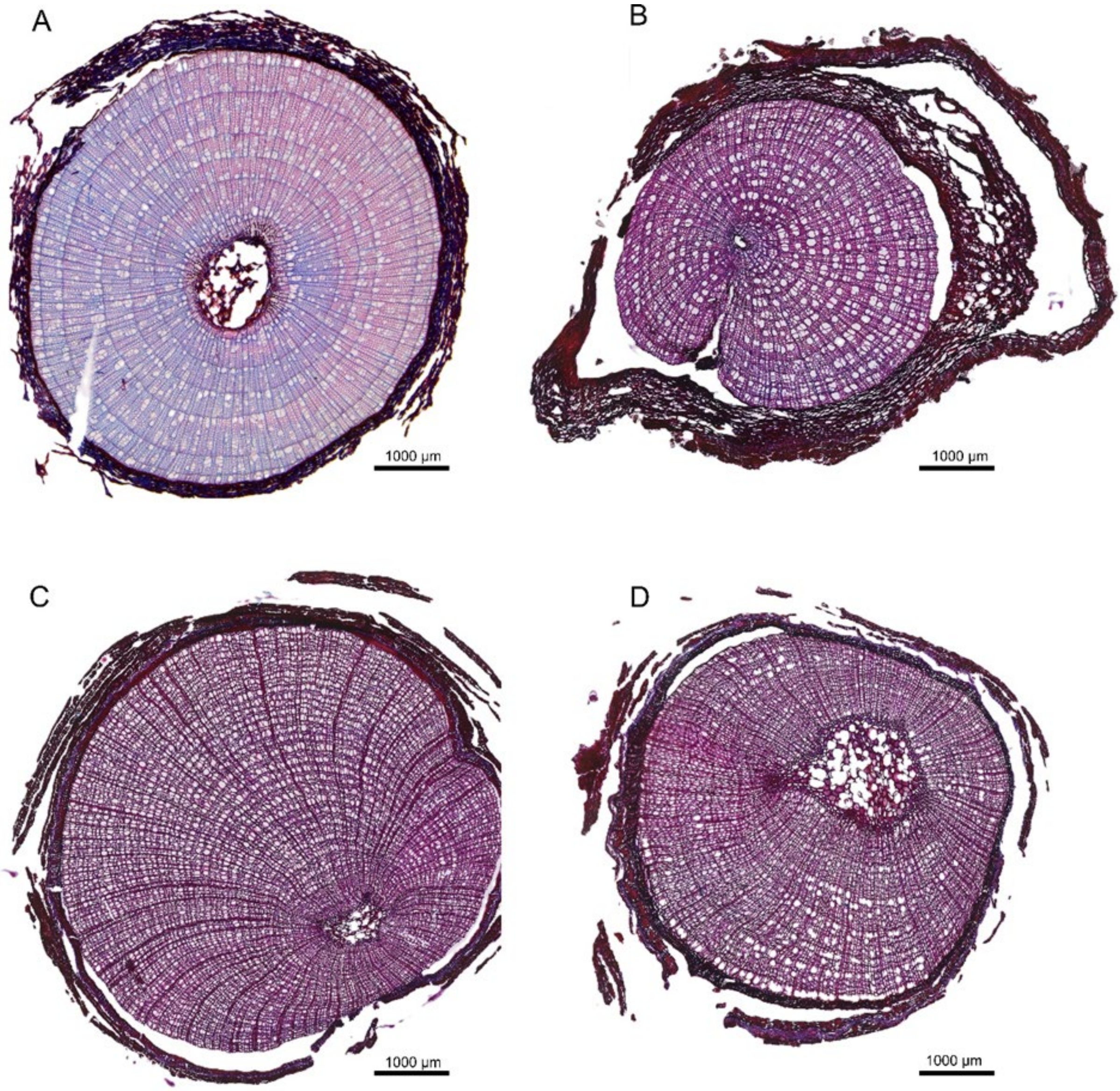

Fig. 3. Examples of cross sections of historical dwarf shrubs, (**A**) *Salix reticulata*, (**B**) *Salix polaris*, (**C** and **D**) *Dryas octopetala*; note clearly visible and countable narrow growth rings.

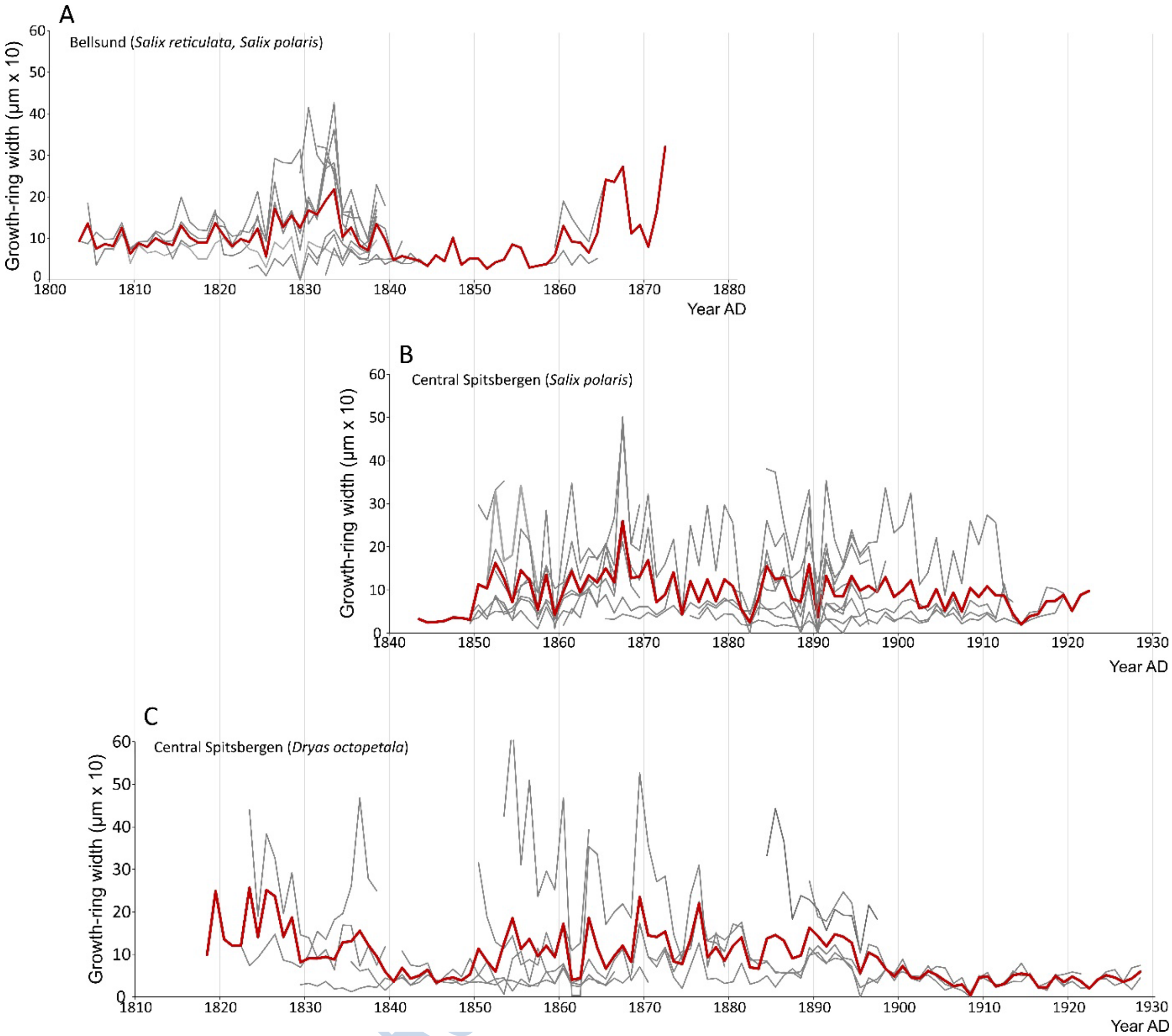

Fig. 4. Annual ring-width series of dwarf shrubs derived from herbarium specimens from Svalbard. Grey lines represent individual growth-ring-width series, while red lines show mean chronologies. Panels illustrate data from (**A**) Bellsund (*Salix polaris, Salix reticulata*), (**B**) central Spitsbergen (*Salix polaris*), (**C**) central Spitsbergen (*Dryas octopetala*).

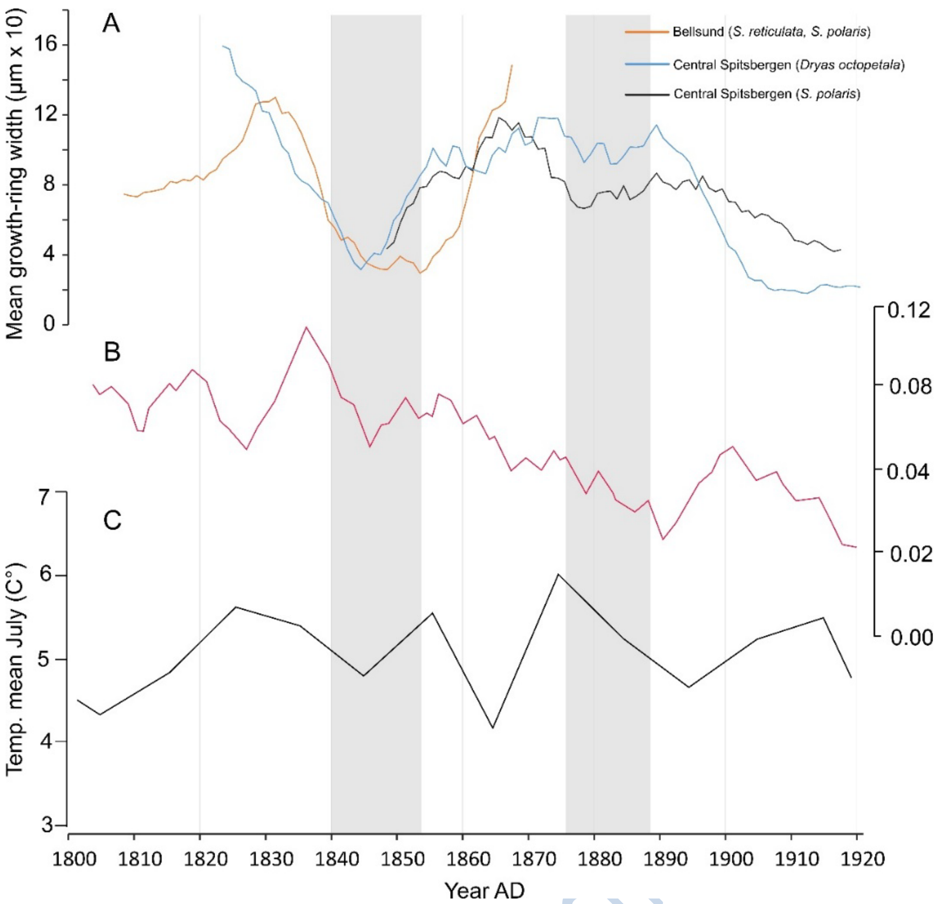

Fig. 5. Comparison of paleoclimate data for Spitsbergen covering the last phase of the Little Ice Age: (**A**) herbarium-based dwarf shrubs dendrochronological data (11-year running means), (**B**) melt index from Lomonosovfonna (10-year running average) after Beaudon *et al*. (2013), (**C**) chironomid-based mean July air temperature reconstruction derived from the Revvatnet lake sediment record after Luoto *et al.* (2017). Grey shaded areas indicate periods of reduced shrub growth corresponding to colder climatic conditions.