



Editorial: Frontiers and challenges in cold region dendrochronology

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Dendrochronology is a method for precisely reconstructing changes in the natural environment by analyzing growth-ring widths in woody plants. This method is commonly used in areas where forests and other tree-dominated plant communities are the primary vegetation (Schweingruber 1988). Dendrochronological data provide the most reliable and high-resolution information on climate change throughout the Holocene (Briffa 2000; Sigl *et al.* 2015). The history of dendrochronological research dates back to the 1930s, when multi-century dendrochronological chronologies were first successfully established for tree species in the southwestern United States (Douglas 1935). In Arctic and high-altitude regions in Asia described as the Third Pole, where trees are rare or absent, interest in dendrochronological research has emerged only recently, driven by advances in analytical and microscopic methods. However, it should be noted that the importance of areas near the northern and upper forest limits in reconstructing climatic conditions has already been highlighted (Jacoby 1982). A modern approach to dendrochronology requires a comprehensive methodology that integrates trees growing at the limits of their range with woody plants growing beyond these limits (Fig. 1) (Owczarek *et al.* 2024). Warming amplification over the Arctic and the Third Pole may trigger a series of environmental responses; hence, reliable climate reconstructions based on proxy data, including dendrochronological data, are particularly important for understanding global-scale changes (You *et al.* 2021).

The specific nature of dendrochronological studies of woody vegetation growing in harsh Arctic and high-mountain conditions is primarily due to the small size of the shrubs and dwarf shrubs, whose branches and woody shoots rarely exceed 1 cm in diameter. These plants produce very narrow growth rings, often less than 20 microns wide (Fig. 1A–B). Warren Wilson (1964) had already pointed out that dendrochronological analysis of Arctic dwarf shrubs could potentially provide data on past climate in Arctic regions. However, later studies, *e.g.*, by Woodcock and Bradley (1994), highlighted several analytical difficulties due to the wood anatomical irregularities. Ty-

pical anatomical features include pronounced eccentricity and uniformity of annual growth rings. Locally absent rings are also frequently observed, along with scars and other growth anomalies (Schweingruber and Poschold 2005; Owczarek 2009). These difficulties have now largely been overcome through advances in microscopy techniques, the development of specialized software, and the widespread use of serial sectioning of individual plants. However, this process is very time-consuming and requires considerable expertise (Kolischuk 1990; Gärtner and Schweingruber 2013; Myers-Smith *et al.* 2015). Analyzing these plants, which grow under extreme environmental conditions, requires an approach different from that used in dendrochronological studies of trees, as reliable environmental reconstructions depend primarily on an accurate assessment of habitat, topographical, topoclimatic, and soil conditions (Körner 2012, 2021; Phulara *et al.* 2025). Despite their small size, tundra and subalpine plants are highly sensitive to changes in the natural environment and are excellent indicators of climate change in areas with short, incomplete, or non-existent instrumental records. At present, dendrochronology in Arctic and high-altitude regions is developing rapidly, providing some of the most important findings in contemporary research into climate change and the Arctic amplification phenomenon.

Polish contribution to Arctic dendrochronology

Although research in the field of dendrochronology began in Poland as early as the 1950s (Ermich 1953), the history of Polish Arctic dendrochronology dates back only to 2007. During this time, woody shoots of the polar willow were collected from the south-western part of Spitsbergen for dendrogeomorphological studies (Owczarek 2009). It should be noted, however, that dendroarchaeological studies using driftwood on Spitsbergen began in the late 20th century (Chochorowski 1999). Dendrochronological research using tundra shrubs and dwarf shrubs is currently being carried out at three Polish institutions: University of



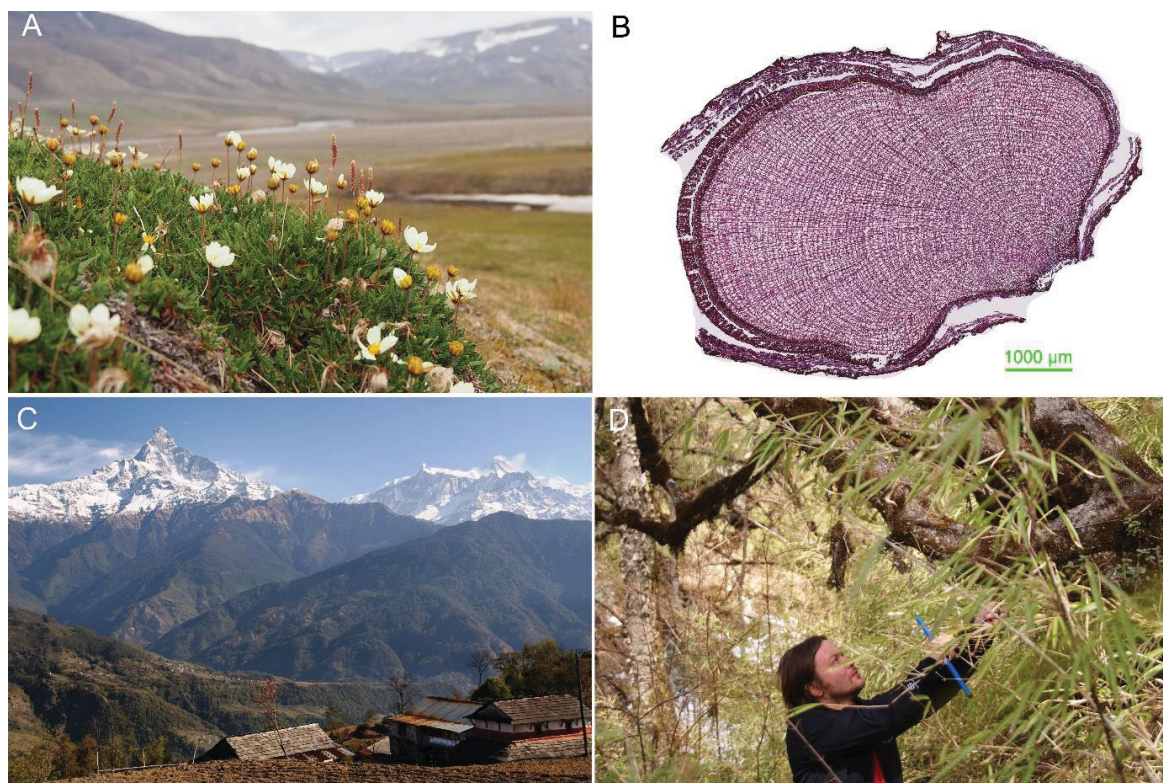


Fig. 1. The specific aspects of dendrochronological research in cold regions: (A) Dwarf shrub *Dryas octopetala* from central Spitsbergen and (B) its cross-section, note the very narrow growth rings, the eccentricity and the wedge-shaped growth rings; (C) clearly defined treeline and subalpine zone in Machhaphuchhare (6993 m a.s.l.) in Annapurna massif in the Himalayas, and (D) shrub-like plants such as *Betula* and *Rhododendron*, are the predominant species growing near the upper treeline in the Himalayas and the Sino-Tibetan Mountains.

Wrocław, University of Silesia in Katowice, and Adam Mickiewicz University in Poznań. The main areas of research cover topics in climatology, geomorphology, and ecology. Research is being conducted in both the High and Low Arctic, as well as near the northern forest boundary, using a variety of shrub and dwarf shrub species, as well as trees in the tundra-taiga ecotone. Most dendrochronological research is carried out in the Svalbard archipelago (Spitsbergen, Bear Island), which is linked to the operation of the Polish Polar Station at Hornsund and the university's polar regional stations (Fig. 2). Although Polish dendrochronological research in the Arctic only began relatively recently, it has already made a significant contribution to the global development of this scientific field. Many of these studies are pioneering and groundbreaking. Among the most significant achievements to date are the first identification of so-called “blue rings” in Arctic vegetation and the construction of the longest dendrochronological scale for the Arctic (Opała-Owczarek *et al.* 2025a, 2025b), pioneering dendroarchaeological research on Spitsbergen (Chochorowski 1999; Chochorowski and Krapięć 2017), the development of methodological principles of Arctic dendrogeomorphology (Owczarek *et al.* 2013, 2022), and research on the relationship between sea ice and the growth response of dwarf shrubs across Arctic (Buchwal *et al.* 2020). A complete list of publications in which researchers from Polish research institutions held leading authorship is presented in Table 1.

New research issues and challenges

The Arctic and the Third Pole, including the Hindu Kush-Karakoram-Himalayan-Pamir high-mountain system and the Tibetan Plateau, are currently the most promising regions for dendrochronological research. Exploring new data sources in regions north of or near the treeline may provide valuable insights into climate change and future trends across the Northern Hemisphere. This special issue comprises of four papers that address key issues relating to the development of dendrochronology in cold regions. The limited lifespan of Arctic dwarf shrubs poses a significant challenge to the reconstruction of long-term environmental changes based on annual growth rings. Previous analyses of tundra plants have been based solely on living plants, the age of which very rarely exceeds 100 years. Currently, the most significant challenge in polar dendrochronology is the search for older samples and the extension of the chronology. Opała-Owczarek *et al.* (2026a) outlines the potential for using herbarium specimens collected during past research expeditions to achieve this goal. Historical specimens collected on Spitsbergen between 1838 and 1898 and preserved in worldwide important herbaria were subjected to detailed anatomical analyses of several dwarf-shrub species. Based on species composition and spatial distribution, three mean ring-width chronologies were developed for southern and central Spitsbergen, extending into periods for which instrumental climate observations are unavailable. The newly developed chronologies span

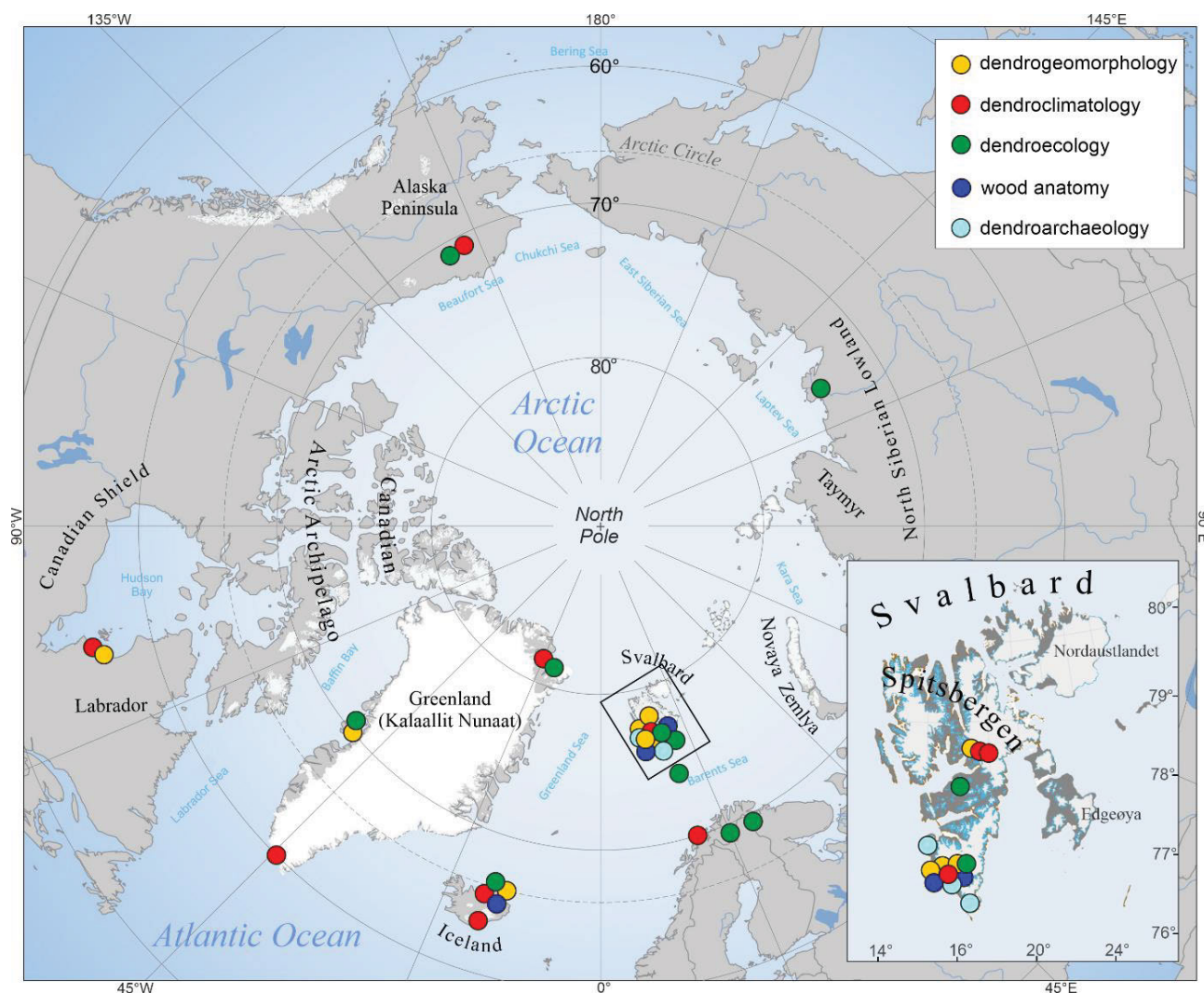


Fig. 2. Geographical distribution of Polish dendrochronological studies in the Arctic, classified by research subfields. For more details, refer also to Table 1.

the period 1803–1928 and are currently the longest chronologies available for the High Arctic.

Arctic dwarf shrubs are highly sensitive to changes in the natural environment, and their growth depends on a wide range of biotic and abiotic factors. Identifying the main factors influencing their growth remains a significant challenge. Previous studies have focused primarily on the effects of temperature or precipitation, while largely overlooking the potential impacts of pollutants on annual growth-ring structure. Opala-Owczarek *et al.* (2026b) analyzed metal contamination in samples of polar willow collected along an altitudinal transect near Longyearbyen in central Spitsbergen. Research results indicate that pollutant levels in plants growing at higher altitudes are *ca.* 2–3 times higher than in the valley, directly influencing the growth of dwarf shrubs. These observations may be associated with processes occurring within the Arctic Atmospheric Boundary Layer and with the so-called “pollutant fog deposition”. This represents the first evidence of such a phenomenon in tundra plant ecology.

The high-altitude regions of Asia, referred to as the ‘Third Pole’, are crucial to contemporary research into global climate change. Given the high climate sensitivity of species growing in these regions, high-resolution dendrochronological data from the upper treeline at elevations above 3,500 m a.s.l. are particularly valuable. It is therefore essential to identify new data sources and develop new chronologies to improve the reliability of climate reconstructions and projections of future trends. This is of particular importance, as rapid climate change is increasing the frequency and severity of natural hazards, as illustrated by the devastating flood in Nepal and Tibet on 26 August 2026, following glacier collapse and subsequent river blockage. Tiwari *et al.* (2026) assess the long-term radial growth pattern of Himalayan birch trees growing on slopes with varying aspects in the Trans-Himalayan region of central Nepal. Samples collected near the upper forest boundary indicate that this species may be valuable for climate reconstruction and for assessing regeneration dynamics, particularly in the context of ongoing climate change.

Table 1. A review of the published literature to date in the field of polar dendrochronology, categorised by sub-discipline and highlighting the research problem in which authors from a Polish research institution played a leading role.

Subfield of dendrochronology	References	Location	Species	Scientific problem
Dendro-geomorphology	Owczarek (2009); Owczarek <i>et al.</i> (2009, 2010a, 2013, 2014)	SW Spitsbergen, Svalbard	<i>Salix polaris</i> , <i>Salix reticulata</i>	reconstruction of debris flow and fluvio-glacial activity
	Buchwal <i>et al.</i> (2015)	Disko Island, W Greenland	<i>Salix glauca</i>	record of tsunami event
	Siekacz (2016)	central Spitsbergen, Svalbard	<i>Salix polaris</i>	wood anatomical features in response to solifluction processes
	Owczarek <i>et al.</i> (2020)	coast of Hudson Bay, Quebec	<i>Picea glauca</i>	reconstruction of landslide activity
	Owczarek <i>et al.</i> (2022)	NE Iceland	<i>Salix herbacea</i>	reconstruction of the rate of aeolian erosion
Dendroclimatology	Buchwal <i>et al.</i> (2013)	central Spitsbergen, Svalbard	<i>Salix polaris</i>	effect of temperature on radial growth
	Owczarek and Opała (2016)	SW Spitsbergen, Svalbard	<i>Salix polaris</i>	effect of extreme climatic events on radial growth
	Opała <i>et al.</i> (2016)	Tromsøfjord, NE Norway	<i>Betula pubescens</i>	summer temperature reconstruction
	Buchwal <i>et al.</i> (2019)	Peary Land, northern Greenland, central Spitsbergen, Svalbard	<i>Salix polaris</i> , <i>Salix arctica</i>	effect of summer temperature on radial growth
	Opała-Owczarek <i>et al.</i> (2020)	coast of Hudson Bay, Quebec	<i>Salix uva-ursi</i>	effect of extreme climatic events and temperature on radial growth
	Phulara <i>et al.</i> (2022)	NE and S Iceland	<i>Salix herbacea</i>	effect of temperature and precipitation on radial growth
	Buchwal <i>et al.</i> (2023a)	northern Alaska	<i>Betula nana</i>	effect of summer temperature on radial growth
	Opała-Owczarek and Owczarek (2023)	Arctic	<i>Salix glauca</i> , <i>Salix polaris</i> , <i>Salix herbacea</i> , <i>Salix reticulata</i> , <i>Salix arctica</i> , <i>Dryas octopetala</i>	extending chronologies using herbarium specimens
	Opała-Owczarek <i>et al.</i> (2024)	NE Iceland	<i>Dryas octopetala</i> , <i>Calluna vulgaris</i> , <i>Salix arctica</i> , <i>Salix herbacea</i> , <i>Empetrum nigrum</i> , <i>Juniperus communis nana</i> , <i>Betula nana</i>	effect of climate change on tundra plants
	Opała-Owczarek <i>et al.</i> (2025a)	N Iceland	<i>Juniperus communis</i>	summer temperature reconstruction and blue and frost rings detection
	Opała-Owczarek <i>et al.</i> (2025b)	S Greenland	<i>Juniperus communis</i>	summer temperature reconstruction and blue and frost rings detection

Table 1 - continued.

Subfield of dendrochronology	References	Location	Species	Scientific problem
Dendroecology	Opala-Owczarek <i>et al.</i> (2018)	SW Spitsbergen, Svalbard	<i>Saxifraga oppositifolia</i> , <i>Salix polaris</i>	assessment of the impact of various abiotic factors on plant growth
	Buchwal <i>et al.</i> (2020)	Arctic	<i>Different species of dwarf shrubs</i>	divergence in the growth rates of the Arctic dwarf shrubs in relation to sea ice
	Owczarek <i>et al.</i> (2021)	Bjørnøya, Svalbard	<i>Salix polaris</i>	assessment of the impact of current warming on plant growth
	Buchwal <i>et al.</i> (2023b)	Lena River Delta, Siberia	<i>Larix</i> , <i>Betula nana</i>	assessment of the impact of current warming on plant growth
	Buchwal <i>et al.</i> (2025)	northern Norway	<i>Pinus sylvestris</i> , <i>Juniperus communis</i>	analysis of blue rings as indicators of cooling from the boreal zone
	Phulara <i>et al.</i> (2025)	central Spitsbergen, Svalbard	<i>Salix polaris</i>	assessment of the impact of complex abiotic factors on plant growth
	Marsicka <i>et al.</i> (2026)	northern Norway	<i>Pinus sylvestris</i> , <i>Juniperus communis</i>	assessment of the impact of current warming on plant growth in the boreal zone
Wood anatomy	Owczarek (2010b)	SW Spitsbergen, Svalbard	<i>Salix polaris</i> , <i>Salix reticulata</i>	wood anatomical features associated with the activity of geomorphological processes
	Ślupianek <i>et al.</i> (2019)	SW Spitsbergen, Svalbard	<i>Salix polaris</i>	formation and anatomy of the derived secondary tissues
	Phulara <i>et al.</i> (2024)	NE Iceland	<i>Salix arctica</i> , <i>Salix herbacea</i>	morphometry of vessels and fibres
Dendroarchaeology	Chochorowski (1999), Chochorowski and Krapić (2017, 2018)	S and SW Spitsbergen, Svalbard	<i>Larix</i> , <i>Picea</i> , <i>Pinus</i> (drift wood)	dating of Pomor hunting stations and settlements using drift wood

The high mountains of South Asia, including the Hindu Kush, Karakoram and Himalayan ranges, are known as the 'Water Tower of Asia' because of their important role in supplying major Asian rivers (Wiltshire 2014). A proper understanding of the growth responses of trees at the upper forest limit to hydrological changes is therefore particularly important in this region for forecasting future changes. Asad *et al.* (2026) provide an overview of the dendrochronological research carried out to date in northern Pakistan, in the Karakoram and the Himalayas. They identify numerous chronologies based on different tree species, extending back more than 1,200 years. The homo-

geneity and significant correlations among these chronologies enable supra-regional dendroclimatic reconstructions that can be integrated with other datasets from the high mountains of Asia. Particular attention is given to two species occurring near the treeline: juniper and rhododendron. Given their widespread distribution, the authors emphasize the need to establish a network of research sites covering the entire region known as 'High Asia'.

In conclusion, the value of dendrochronological research conducted in the extreme environments of cold regions should be emphasized. Identifying the factors that determine local growth patterns in dwarf shrubs, shrubs,

and trees is essential for maximizing the potential of dendrochronological data for practical applications. Reliable interpretation of environmental signals requires the application of advanced research methods that extend beyond the analysis of growth-ring width to include detailed examination of the anatomical characteristics of woody plants. The papers in this special issue present a small but varied selection of research demonstrating new possibilities in research on shrubs and trees, highlighting the integrity of this research and the particular role of the Arctic and the Third Pole in climate change research. We hope that these articles will inspire further research into dendrochronology in cold regions.

Finally, Piotr Owczarek would like to express his sincere gratitude to Holger Gärtner (Swiss Federal Research Institute WSL), who drew his attention to the anatomy of shrubs 20 years ago, and to Krzysztof Migala (University of Wrocław), who was the first to introduce him to the Arctic.

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