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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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