The importance of Arctic driftwood for interdisciplinary global change research

Short Communication / Methodological note

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Abstract
The Arctic is one of the regions most sensitive to global warming, for which climate and environmental proxy archives are largely insufficient. Arctic driftwood provides a unique resource for research into the circumpolar entanglements of terrestrial, coastal and marine factors and processes – past, present, future. Here, first dendrochronological and wood anatomical insights into 639 Arctic driftwood samples are presented. Samples were collected across northern Norway (n =430) and north-western Iceland (n =209) in 2022. The overall potentials and limitations of Arctic driftwood to improve tree-ring chronologies from the boreal forest, and to reconstruct changes in sea ice extent and ocean current dynamics are discussed. Finally, the role driftwood has possibly played for Arctic settlements in the past hundreds of years is examined.

Key words: Arctic Ocean, climate change, dendrochronology, driftwood supply, sea-ice dynamics

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Introduction

The Arctic is one of the regions most affected by global warming, with an increase in annual average temperature nearly twice the global figure for several decades (Hantemirov et al. 2022, [1]). Rapid warming has had adverse consequences in the high latitudes, including increased river discharge to the Arctic Ocean, declines in the Arctic sea ice extent [2], irreversible permafrost thawing (Lenton et al. 2019), changes in the composition and cover area of Arctic vegetation that has expanded further north (Power et al. 2022), and an unprecedented occurrence of boreal wildfires (Witze 2020). Putting these changes into a long-term perspective is important to predict future changes, and to develop realistic mitigation and adaptation strategies. However, instrumental measurements and proxy records with high spatial and temporal resolution are limited in the high-northern latitudes (Gordov et al. 2013, Woelders et al. 2018).

Arctic driftwood represents a valuable natural proxy record at the interface of terrestrial, coastal and marine environments (Hellman et al. 2013, 2017; Funder et al. 2011, Hole and Macias-Fauria 2017). As a consequence of natural riverbank erosion or logging and floating activities, a huge amount of driftwood enters the Arctic Ocean from large boreal river systems (Eggertsson 1993, 1994a; Hellmann et al. 2017, Johansen 1998). Since the maximum period of buoyancy is 10–17 months for the wood of conifers and 6–10 months for the wood of broadleaved tree species, it is only prevented from sinking to the seafloor when incorporated into the sea ice (Häggblom 1982). Driftwood is then ice-rafted across the ocean before being melted out of the ice and deposited along shallow Arctic and sub-Arctic coastlines (*see* Fig. 1, 2a; Krumpen et al. 2019, Dalaiden et al. 2018, Hellmann et al. 2017). During this journey, which may last several years, many interacting factors and processes can influence the transport routes and driftwood abundance (Kolář et al. 2022). Dendrochronological and biochemical studies of Arctic driftwood may provide reliable insights into past environmental changes and human settlement patterns across the high-northern latitudes (Eggertsson 1993, 1994a; Hellmann et al. 2017, Johansen 1998, Shumilov et al. 2020, Rämä et al. 2014, Blanchette et al. 2016).

Here, we present the samples of Arctic driftwood collected by our team from northern Norway and north-western Iceland in 2022 (Fig. 1). Combined wood-anatomical and dendrochronological analyses will be applied to the recently collected driftwood (*see* Material and Methods) since precise determination of the age and origin of wood is an essential part of any further assessment (Hellmann et al. 2015).

Material and Methods

In 2022, we collected 430 driftwood samples from the Nordkyn and Varanger peninsulas in northern Norway, and 209 samples from north-western Iceland (*see* Fig. 1). The driftwood was often characterized by a very light-coloured surface (Fig. 2a; due to natural weathering), holes from shipworms *Teredinidae* (Fig. 2b; Charles et al. 2016), fungal infestation (Fig. 2c; Blanchette et al. 2016) or reaction wood. Sampling was mainly of old driftwood because the probability of successful cross-dating increases the greater the number of tree rings.

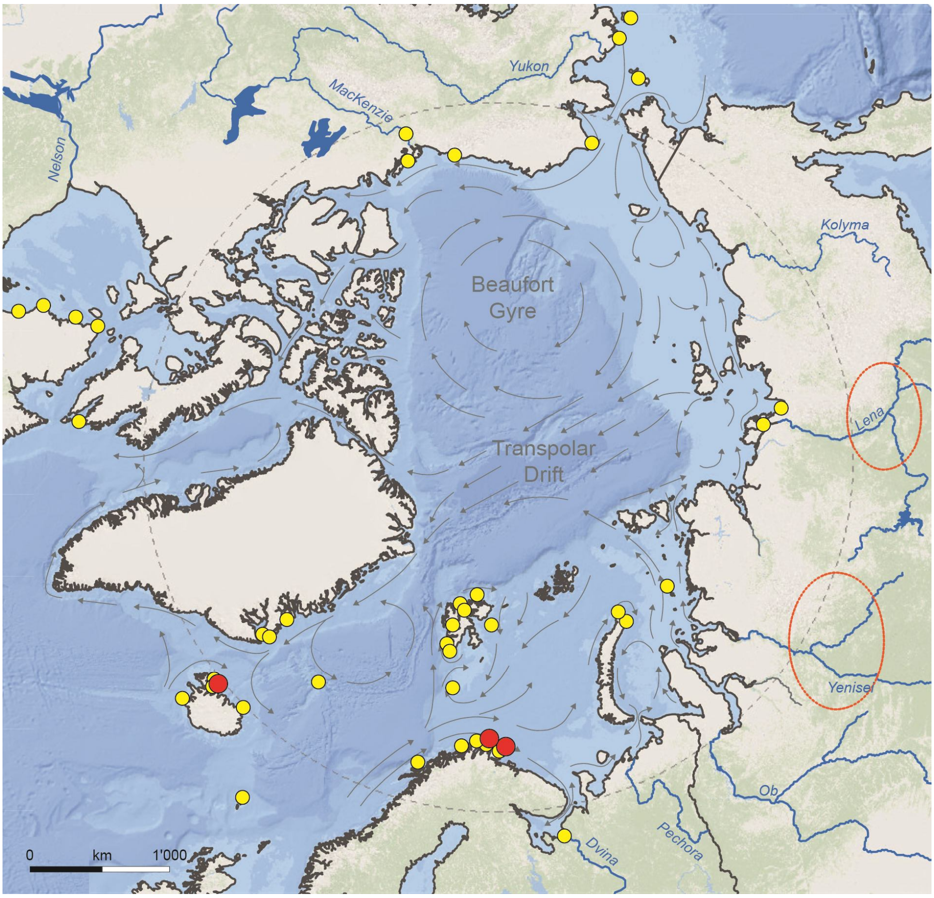

Fig. 1. Our new driftwood sampling sites from 2022 (red dots), together with the location of previous driftwood sampling sites (yellow dots), from which the age and origin of Arctic driftwood have been documented (Giddings 1940, 1952; Oswalt 1951, Stone 1958, Bartholin and Hjort 1987, Eggertsson 1993, 1994a, 1994b; Eggertsson and Laeyendecker 1995, Johansen 1998, 1999, 2001; Nash 2000, Johansen and Hytteborn 2001, Hellmann et al. 2013, 2015, 2016a, 2016b, 2017; Steelandt et al. 2015, Sander et al. 2021, Shumilov et al. 2020, Hole et al. 2021, Linderholm et al. 2021, Kolář et al. 2022). The orange ovals refer to the main boreal source regions of Arctic driftwood along the Yenisei and Lena in central and eastern Siberia.

Old driftwood was selected visually based on the number of tree rings in cross-sections, trunk size and the character of the trunk surface. Increased attention was given to twisted trunks (Fig. 2d; spiral grained), which is an indication of harsh growing conditions; such samples often contain numerous tree rings (Schweingruber 1996). Samples were taken as discs (roughly 3–5 cm thick) from the driftwood logs using a chainsaw. Disc samples provide several advantages over core samples, especially the presence of the pith, longer tree-ring series, facilitated detection of locally absent rings and a tendency to reflect slightly stronger temperature signals (Kirdyanov et al. 2018). All samples were labelled as natural (Fig. 2e) or logged (Fig. 2f) material.

Fig. 2. **(a)** Driftwood accumulated at sub-Arctic coasts includes trunks with **(b)** holes from shipworms *Teredinidae*, **(c)** fungal infestation, **(d)** twisted trunks with extremely narrow tree-ring widths, **(e)** naturally fallen trunks with a root collar, **(f)** a logged trunks with evidence of having floated in the boreal forest zone and **(g)** newly deposited/fresh trunks from which **(h)** discs of different sizes were sampled.

Natural driftwood enters the boreal rivers due to erosion processes, spring floods or storm surges and can be clearly identified by the presence of a root collar. Logged trunks have clear-cut ends and eventually acquire evidence of river rafting in the boreal forest zone. Additionally, specific note was taken when the driftwood log was recently deposited on the coast, as could be observed from the colour of the trunk and its location near the coastline (Fig. 2g).

In forthcoming study, we will carefully sand each disc sample (Fig. 2h) in several steps using sandpapers with gradually finer grit size from 80 to 1000 to facilitate the subsequent wood-anatomical and dendrochronological analyses.

The wood-anatomical identification of species at the macroscopic and microscopic level together with consideration of boreal forest composition is crucial for tracing the origin of Arctic driftwood (Hellman et al. 2013). Observation of macroscopic criteria allows wood to be classified at genus level and facilitates identification at the microscopic level. We will perform microscopic wood identification on thin transversal, radial and tangential sections cut using a razor blade or sliding microtome. We will use unstained temporary micro sections with water as the mounting medium to observe the characteristic anatomical features of a species under the light microscope (Schweingruber 1990, [3]). Microscopic observation will reveal the genus of each sample and, in some cases, possibly even the species (Hellmann et al. 2013).

We will measure tree-ring widths (TRW) on each disc sample using a measuring device with an accuracy of 0.01 mm. In most cases two radii per disc will be measured to prevent missing rings and to obtain a better average for the individual samples (Kirdyanov et al. 2018). We will cross-date the individual TRW series obtained, correct them for missing rings and average to sample-specific mean TRW series, which we will cross-date against each other. Subsequently, we will compile well-correlated sample-specific mean TRW series into floating TRW chronologies, which we will cross-date with absolutely dated species-specific reference TRW chronologies from the expected source region, mainly the Eurasian or north American boreal forest zones. If a dense network of reference TRW chronologies for the source regions is available, dendro-provenancing can be applied. We will evaluate the significantly common growth pattern of the TRW series or chronologies statistically using standard dendrochronological metrics: two t-tests (Baillie and Pilcher 1973, Hollstein 1980), Gleichläufigkeit (Eckstein and Bauch 1969) and correlation coefficient. We will confirm the statistical assessment visually, which will allow any incorrect matching or inaccurate positioning of the series to be avoided and provide an opportunity to detect missing rings.

Discussion and Conclusion

In 2022, we collected new driftwood samples from various high-northern latitudes to reveal not only tree species, age and provenance but also the physical causes and societal consequences of long-term changes in the transport and accumulation rates of Arctic driftwood (Kolář et al. 2022).

Arctic driftwood originates almost exclusively from the Eurasian boreal forest zone and reliably reflects the natural boreal species composition (Eggertsson 1993, Johansen 1998, Hellman et al. 2013, 2017). Since the source regions are at the northern distribution limit of most tree species whose growth is temperature-limited (Schweingruber 1996), tree-ring measurements of driftwood represent a reliable proxy archive of past climate conditions. The provenance of driftwood from different source regions also provides information on changes in timber logging and rafting activities in the corresponding catchments as well as in river discharge (Hellman et al. 2015).

The abundance and spatiotemporal composition of driftwood along Arctic coastlines result not only from forest species composition in the source regions and from river characteristics but are also influenced by ocean current dynamics and the sea-ice extent (Funder et al. 2011).

Arctic sea ice is crucial for the transport of driftwood logs across the ocean and their deposition on shallow and ice-free coastlines (Häggblom 1982). The increasing trend of sea-ice loss limits driftwood transport from the boreal source region to the Arctic coastlines due to the longer distance to be covered on open water (Häggblom 1982, Kolář et al. 2022). On the other hand, increasing sea-ice cover in the cold Arctic creates permanent land-fast sea ice, which blocks the landing of driftwood on the coast (Funder et al. 2011). Therefore, measurements of a large number of driftwood samples, including age and precise provenance, may provide new insights into past changes in sea-ice extent. However, many other interrelated factors of anthropogenic global warming (*e.g.* permafrost thawing, ocean warming, water salinity, greenhouse gas emission) must be considered in the transport and accumulation of driftwood (Kolář et al. 2022).

With global anthropogenic warming, less deposited driftwood along Arctic coastlines has been observed (Kolář et al. 2022). Since driftwood represents essential material for all human societies in remote treeless areas, the availability of driftwood has most likely been of key importance to inhabitants in the region and the distribution of settlements (Alix 2005, 2012, 2016; Mooney 2016, Pinta 2018). Driftwood has been widely used for construction, tools, utensils, boats, weapons and firewood (Burns et al. 2017, Mooney 2016, Alix 2005, Alix and Brewster 2004, Johansen 1999, Malmros 1994). The economic and social importance of driftwood is shown by records in the medieval Icelandic law code Grágás (Dennis et al. 2000) and by Inuits who have specific words for driftwood based on its shape, colour and texture, and hold extensive knowledge of the best places for collecting driftwood in different seasons (Steelandt et al. 2013).

Although driftwood collections have great potential for cross-disciplinary research, high number of samples from many different Arctic regions is indispensable for more sophisticated environmental research (*e.g.* Eggertsson 1993, Johansen 1998, Hellmann et al. 2017). More research into Arctic driftwood will help not only to prolong boreal reference chronologies and thus provide reliable paleoenvironmental proxy records, but also improve our understanding of environmental and social changes in the circumpolar region.

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