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Cruising an archive: On the palaeoclimatic value of the Lena Delta

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Abstract

Today, there are only a handful of millennial-long and annually resolved tree-ring chronologies in existence. Explicit gaps in the global distribution of these regional chronologies together with an overall declining sample size back in time compel a community-wide challenge to discover new tree ring–based climate proxy records. Here, we present evidence for a yet unexplored palaeoenvironmental archive, define allied research tasks and emphasize probable hurdles within and beyond academia, in pursuit of answering this challenge.

Keywords

Arctic driftwood, dendroclimatology, eastern Siberia, high-resolution palaeoclimatology, proxy archives, subfossil wood

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Draining approximately 2,500,000 km^2, an area almost as large as Central Europe, the 4500-km-long Lena River in eastern Siberia meanders through one of the Earth's largest hydrological catchments (Holmes et al., 2012; Hubberten et al., 2003). From its headwater in the Baikal Mountain Ridge ~1600 m a.s.l. (~58°N and 108°E), the stream crosses the boreal forest zone, the taiga and parts of the tundra after forming a gigantic delta system between ~72°N and 74°N (Walker, 1998), the greatest in the world. Summer time flow velocity of the Lower Lena is 2–2.5 m/s (www.arcticgreatrivers.org).

In addition to the enormous quantity of freshwater discharge (588 km^3) and an unprecedented amount of dissolved organic carbon (DOC; 5700 × 10^9 g) delivered to the Arctic Laptev Sea every year (Holmes et al., 2012), the widespread Lena watershed (2.5 × 10^6 km^2; ~14% of the pan-Arctic watershed) is a rich source for Arctic driftwood (Funder et al., 2011; Hellmann et al., 2013) – an hitherto unknown quantity of undissolved organic matter. The total volume of in situ driftwood, the species composition of this wood and the convoluted transport mechanisms and erosional processes involved with its deposition are poorly understood.

With ~35,000 km^2, >1500 islands and an average elevation of 0–10 m a.s.l. (Are and Reimnitz, 2000), the Lena Delta constitutes a unique sink for boreal forest trees well beyond their northern distribution limit of growth. A complex mixture of recent, dry-dead and subfossil wood, ranging from small branches to big trees, often side-by-side with mammoth (*Mammuthus primigenius*) macrofossils (DC Fisher, personal communication, 24 August 2013, Yakutsk), has been ultimately deposited after its waterway journey. The heterogeneous driftwood assemblage within the first terrace of the delta floodplain apparently covers most of the Holocene (Schirrmeister et al., 2002, 2011), during which low annual organic productivity rates associated with overall slow biogeochemical cycles and processes yielded rather moderate sediment layers of organic detritus. Endless shorelines and abundant erosion slopes provide fascinating insight into a remarkably well-preserved tree-ring archive (Figure 1).

These conditions, however, will likely be affected by increasing river discharge and permafrost thawing (Holmes et al., 2012; Peterson et al., 2002, 2006), as well as decreasing sea ice extent (Kinnard et al., 2011), a serious potential consequence of predicted climate change (Intergovernmental Panel on Climate Change (IPCC), 2007). Hence, the motivation and opportunity to recover this material for palaeoclimatic studies has never been timelier, especially for the high-northern latitudes in eastern Siberia where reliable proxy records are scarce (Figure 2; Kaufman et al., 2009; Koc et al., 2008; Past Global Changes (PAGES) 2k Consortium, 2013). Especially when focussing on absolutely dated and annually resolved pan-Arctic archives that continuously cover the last millennium and may even extend further back in time, only two tree ring–based summer temperature reconstructions have been developed so far for central Siberia (Figure 2). No such evidence, however, exists for eastern Siberia. Circumpolar activities associated with palaeoresearch north of 60°N latitude, which includes Greenland, Iceland and Alaska as well as parts of Canada, together with the massive Eurasian boreal forest, are ideally clustered under the interdisciplinary umbrella of PAGES

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Figure 1. Example of different driftwood specimens (fresh floating, dry-dead deposited and subfossil buried, with and without root collar) deposited near or within a 5-m-thick sandy erosion slope that is typical for the Lena Delta (see insets for a circumpolar >50°N as well as delta-specific orientation with the yellow star referring to the study site). The picture was taken 10 August 2013 near the Samoylov Research Station at around 72°25′N and 126°25′E (photo by W Tegel), an area representative for the most active part of the delta formed during the past ~9000 years.

(www.pages-igbp.org/workinggroups/arctic2k/). Moreover, the advent of somewhat affordable isotopic and genetic technologies now offers an unparalleled opportunity to describe not only palaeoenvironmental factors but also the age and provenance of this ancient, frozen archive.

Both quality and quantity (i.e. wood content as well as number of rings, and samples per species) of the buried and often even ice-covered subfossil remains are remarkable. All driftwoods originate from continuous and discontinuous permafrost in the Yakutian boreal forest, either from sites along the Lena itself or from woodland near the main tributaries Viyim, Olekma, Aldan and Vilyui. A substantial fraction of the material is therefore expected to be highly temperature sensitive (Esper et al., 2010). Interannual- to centennial-long variation in annual growth is reported to reflect changes in summer temperature that occurs during a rather short vegetation period between June and August (Kirdyanov et al., 2003), when photosynthetic metabolism likely prolongs from day to 'night' time. Driftwood from Yakutia mainly comprises slow growing larches (*Larix* spp.), which are characterized by small stem diameters, narrow rings and the existence of a root collar. The percentage of logged timber is expected to be relatively low in comparison to other rivers, such as the central Siberian Yenisei (Hellmann et al., 2013), where

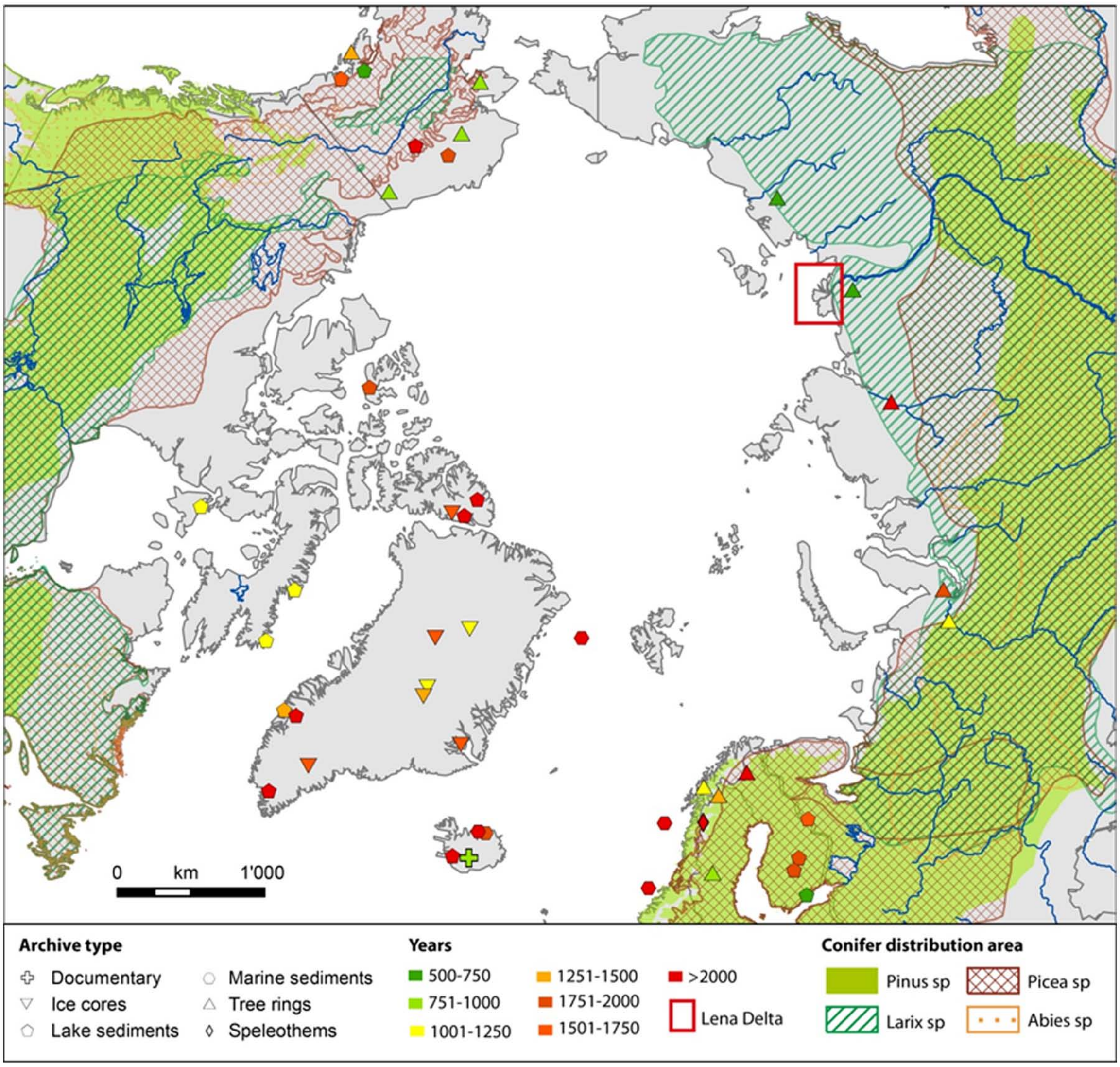

Figure 2. Locations of palaeoclimatic temperature proxy records in the high-northern latitudes and Arctic as compiled by the PAGES 2k Consortium (2013), and superimposed on the boreal forest composition and the large river systems after Hellmann et al. (2013). The map is a North Pole Lambert Azimuthal Equal Area projection, and the different symbols and colours refer to different proxy archive types and record lengths, respectively. The red square, comparable to Figure 1, highlights the Lena Delta in northeastern Siberia (this study).
PAGES: Past Global Changes.

many more trees are harvested, floated and thus (more easily) enter the Arctic Ocean. It should also be noted in this context that the Lena watershed is inhabited by only 0.4 people/km^2, compared with 3.0 people/km^2 purportedly living in the Yenisei catchment (Holmes et al., 2012). In addition, the Yenisei River forms no blocking delta.

Based on material recovered during the 2013 Swiss–German–Russian Lena-Expedition, including a first-pass screening of the samples, we have prioritized 11 interrelated research avenues: (1) develop well-replicated and continuous ring-width chronologies from living, dry-dead and subfossil trees, spanning the past millennia; (2) utilize these absolutely dated and annually resolved records, supplemented by several ^{14}C dates, to trace possible flooding events and the origin of Arctic driftwood; (3) explore tree-growth responses to climate forcing factors via calibration against instrumental measurements; (4) perform measurements of wood anatomy, density, isotopy and chemistry, as well as of ancient DNA or other microbial elements, for selected tree-ring subsets; (5) reconstruct long-term summer temperature variability and forest fire frequency – the main disturbance and principal recruitment factor within the boreal zone; (6) evaluate the new dendro-based high-resolution climate history against independent evidence from lower resolution, Holocene-length, Arctic archives by means of multi-proxy approaches; (7) employ historical dendro dates to refine sediment layer and peat bog dating and to enhance knowledge on the temporal dynamics of Arctic fluvial processes; (8) assess the putative driftwood contribution to terrigenous organic matter fluxes from terrestrial to marine ecosystems and implement corresponding refinements of carbon cycles and budgets in regional to global biogeochemical sink–source model trials; (9) amplify cross-disciplinary impetus at the interface of circumpolar terrestrial, aquatic and marine endeavours that may range from single PhD projects to global network initiatives; (10) coordinate and share research, data and infrastructure more efficiently (Hubberten et al., 2003), aiming towards a direct scientific nexus and an indirect fundraising success; (11) grasp the palaeoclimatic potential of others, although much smaller pan-Arctic delta systems, such as the Canadian Mackenzie and the eastern Russian Yana in light of 1–10. The herein spotlighted subjects seem particularly important in light of the geographical gap in current palaeoclimatic networks: Northern Hemisphere and even global temperature reconstructions will decidedly benefit from novel proxy records that represent northeastern Siberia and the Common Era (Ljungqvist et al., 2012; PAGES 2k Consortium, 2013; Shi et al., 2013), with the expected tree-ring chronology further facilitating to trace the origin of Arctic driftwood (Hellmann et al., 2013).

The ample research needs and subsequent scientific challenges, however, appear as marginal tasks when compared to the organizational and fiscal obstacles the Russian academia is currently facing (Gelfand, 2013; Razin and Vassetzky, 2013). Although institutional inertia and logistical volatility regrettably continue to hamper straightforward research activity in Russia today (Gelfand, 2011; Schiermeier, 2011), personal curiosity should be resilient enough to foster international collaborations and generate new science across disciplinary and national boundaries.

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References

Are F and Reimnitz E (2000) An overview of the Lena River Delta setting: Geology, tectonics, geomorphology, and hydrology. *Journal of Coastal Research* 16: 1083–1093.

Esper J, Frank D, Büntgen U et al. (2010) Trends and uncertainties in Siberian indicators of 20th century warming. *Global Change Biology* 16: 386–398.

Funder S, Goosse H, Jepsen H et al. (2011) A 10,000-year record of Arctic Ocean sea-ice variability – View from the beach. *Science* 333: 747–750.

Gelfand M (2011) Rid Russian science of corruption. *Nature* 478: 324.

Gelfand M (2013) What is to be done about Russian science. *Nature* 500: 379.

Hellmann L, Tegel W, Eggertsson Ó et al. (2013) Tracing the origin of Arctic driftwood. *Journal of Geophysical Research: Biogeosciences* 118: 68–76.

Holmes RM, McClelland JW, Peterson BJ et al. (2012) Seasonal and annual fluxes of nutrients and organic matter from large rivers to the Arctic Ocean and surrounding seas. *Estuaries and Coasts* 35: 369–382.

Hubberten H-W, Wagner D, Pfeiffer E-M et al. (2003) The Russian-German research station Samoylov, Lena Delta – A key site for polar research in the Siberian Arctic. *Polarforschung* 73: 111–116.

Intergovernmental Panel on Climate Change (IPCC) (2007) *Climate Change 2007: The Physical Science Basis*. Cambridge; New York: Cambridge University Press.

Kaufman DS, Schneider DP and McKay NP (2009) Recent warming reverses long-term Arctic cooling. *Science* 325: 1236–1239.

Kinnard C, Zdanowicz CM, Fisher DA et al. (2011) Reconstructed changes in Arctic sea ice over the past 1450 years. *Nature* 479: 509–512.

Kirdyanov A, Hughes M, Vaganov E et al. (2003) The importance of early summer temperature and date of snow melt for tree growth in the Siberian Subarctic. *Trees* 17: 61–69.

Koc N, Francis P, Ammann C et al. (2008) Generating and synthesizing paleoclimatic data to assess Arctic climate change: PAGES working group meeting: Arctic climate during the last 2 millennia. Boulder, Colorado, 8 March 2008. *Eos* 89: 244.

Ljungqvist FC, Krusic PJ, Brattström G et al. (2012) Northern Hemisphere temperature patterns in the last 12 centuries. *Climate of the Past* 8: 227–249.

Past Global Changes (PAGES) 2k Consortium (2013) Continental-scale temperature variability during the past two millennia. *Nature Geoscience* 6: 339–346.

Peterson BJ, Holmes RM, McClelland JW et al. (2002) Increasing river discharge to the Arctic Ocean. *Science* 298: 2171–2173.

Peterson BJ, McClelland J and Curry R (2006) Trajectory shifts in the Arctic and subarctic freshwater cycle. *Science* 313: 1061–1066.

Razin SV and Vassetzky YS (2013) Russian science: Academy reform needs a reality check. *Nature* 499: 284.

Schiermeier Q (2011) Russia revitalizes science. *Nature* 473: 428–429.

Schirrmeister L, Grosse G, Schnelle M et al. (2011) Late Quaternary paleoenvironmental records from the western Lena

Delta, Arctic Siberia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 299: 175–196.
Schirrmeister L, Siegert C, Kunitzky VV et al. (2002) Late Quaternary ice-rich permafrost sequences as a paleoenvironmental archive for the Laptev Sea Region in northern Siberia. *International Journal of Earth Sciences* 91: 154–167.
Shi F, Yang B, Mairesse A et al. (2013) Northern Hemisphere temperature reconstruction during the last millennium using multiple annual proxies. *Climate Research* 56: 231–244.
Walker HJ (1998) Arctic deltas. *Journal of Coastal Research* 14: 719–738.