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Moisture record of the Upper Volga catchment between AD 1430 and 1600 supported by a δ^{13}C tree-ring chronology of archaeological pine timbers☆

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ABSTRACT

Investigations of interactions between climate change and humans suffer from the lack of climate proxies directly linked to historical or archaeological datasets that describe past environmental conditions at a particular location and time. We present a new set of pine tree-ring records (*Pinus sylvestris* L.) developed from burial timbers excavated at the historical center of Yaroslavl city, Russia. A 171-year δ^{13}C tree-ring chronology from AD 1430 to AD 1600 evidences mostly wet summers during the 15th century but exceptionally dry conditions of the 16th century at the Upper Volga catchment. According to the tree-ring record there were four major droughts ($<-1.5\sigma$) lasting from 9 to 26 years: 1501–1517, 1524–1533, 1542–1555 and 1570–1596, and major pluvials ($>+1.5\sigma$) lasting from 70 to 5 years: 1430–1500, 1518–1523, 1534–1541, and 1556–1564. We discuss a plausible contribution of these droughts to crop failures and city fires documented with historical chronicles for the Upper Volga catchment. The devastating drought regime of the 16th century corresponds to the loss of independence of the Yaroslavl principality to the Grand Duchy of Moscow and the formation of the centralized Russian State during the reign of Ivan the Terrible (1533–1584) underpinning the emergence of the Russian Empire. This study substantiates the value of archaeological timbers from the oldest Russian cities and inclusion of stable carbon isotope analysis for understanding hydroclimatic regimes across the mid latitudes of East European Plain, and their relationship to the history of Russia.

1. Introduction

In world history, societal collapse and emergence of new states and empires often coincide with rapid environmental changes triggered by climate variability, and couple with significant change in socio-economic and political settings of pre-industrial societies (e.g., Weisse and Bradley, 2001; Büntgen et al., 2011). Droughts in particular strongly connect to decline of agricultural production, food insecurity and socio-political instability (e.g., deMenocal, 2001; Varien et al., 2007). Inadequate comparability of spatial-temporal scales for historical and/or archaeological data with climate proxies challenges current advances in modeling past coupled interactions between humans and environment. Spatial and temporal variability of thermal and hydrological regimes reconstructed from seasonally-resolved tree-ring records is particularly valuable for understanding a wide scope of environmental and human responses to climate variability. However, there are a few adverse factors preventing comprehensive application of tree rings to the human-environment modeling including spatial incoherence of climatic signals in tree rings and shortness of records.

This paper aims to explore tree-ring proxies for evaluation of climate variability impact on the emergence of the centralized Russian state (post AD 1547), which takes place during the cooling transition from the Medieval Warm Epoch to the Little Ice Age in the mid latitudes of the East European Plain. The 16th century is of particular interest for historians because this was the time of great reforms of Ivan the Terrible, who transformed a medieval disintegrated state to a centralized state, and the time of consolidating political power in the hands of a new ruling clan—the Tsarist family of Romanovs (Zimin, 1960, 1986). At that time, agricultural production in the Upper Volga and Don catchments was the backbone of people's income and state wealth, and variability of moisture regimes was the most important factor impacting the fluctuations of crop productivity in the region. What can tree rings tell us about variability of moisture regimes in the areas of main Russian political and economic centers across the Upper Volga and Don catchments?

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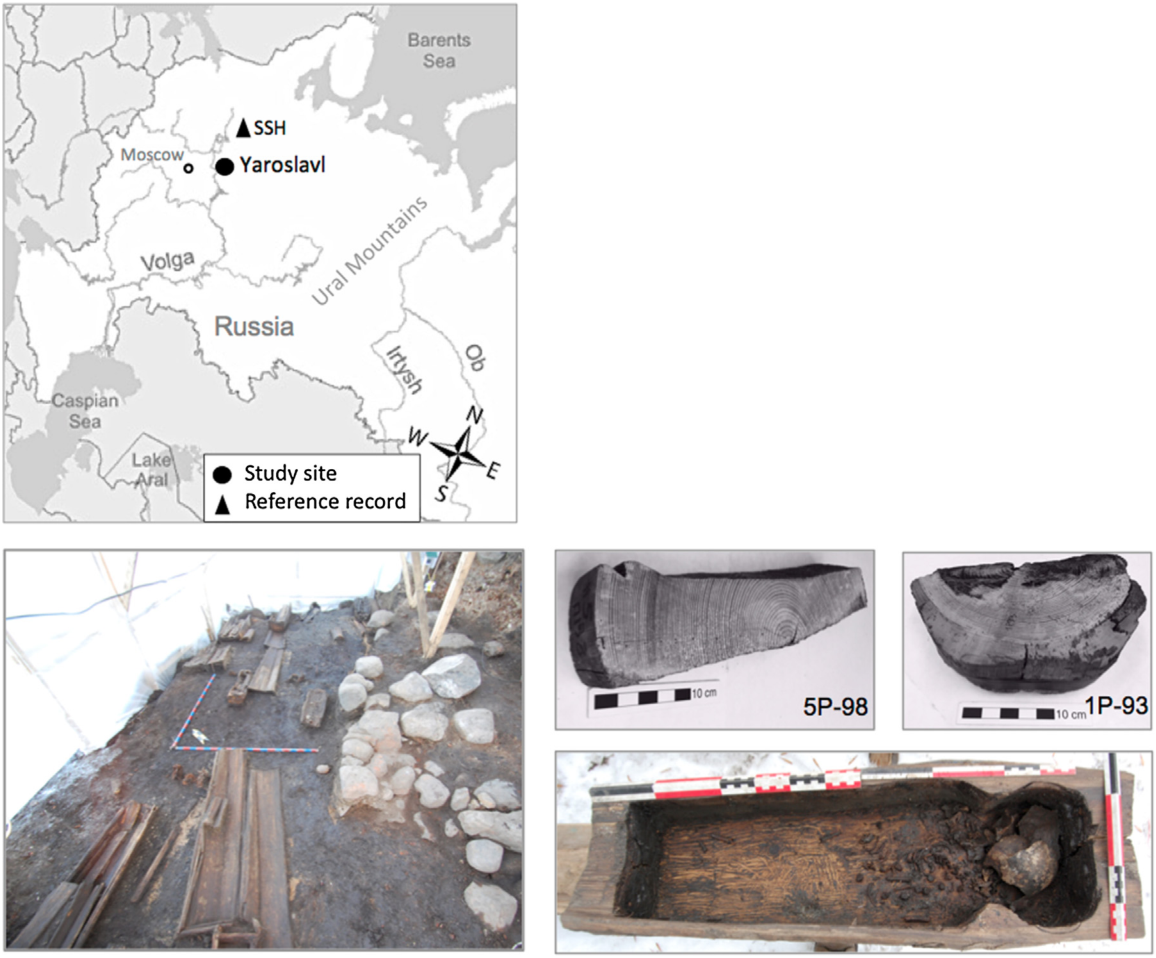

Fig. 1. Map of the European part of Russia with Yaroslavl city location. Photos show the general view of the excavated cemetery near the Church of St. John Chrysostom Nativity with coffins in situ (left) and wood specimens (right) sampled from coffins made of a pine plank (5P-98) and a pine tree-trunk (1P-93) with an example of 16th century child burial receptacle made of a single tree log.

Past climate of north and central Europe has been vigorously studied with tree-ring archives (e.g., Schweingruber and Briffa, 1996; Gagen et al., 2006; Treydte et al., 2007; Büntgen et al., 2011; McCarroll et al., 2013). On the East European Plain, tree-ring width variability of conifer trees is mostly attributed to summer temperature with stronger climatic signal in the boreal environments and weaker signal in the mid latitudes (Klimenko and Solomina, 2010; Solomina et al., 2011). Modeling precipitation signal in tree rings presents a much greater challenge, in part because of the greater spatial-temporal variability of moisture regimes involved (Pauling et al., 2006; Büntgen et al., 2010). Stable isotopes of tree rings are recognized for stronger sensitivity to moisture stress and seemingly better ability to predict moisture variability (Hartl-Meier et al., 2014). However, the climatic signature of tree-ring isotopes may be less uniform than tree-ring widths. This is illustrated in a recently-developed European network of tree-ring isotopic signals in space and time (Treydte et al., 2007), where the climatic signal of δ^{13}C and δ^{18}O tree-ring records corresponds positively to summer temperature in the north, but at mid-latitude the isotopic records correlate significantly with both summer temperature and precipitation. Spatially, the climatic signal of tree-ring δ^{13}C appears dependent on tree species/site-specific conditions. Trees alternate physiological strategies for water-use efficiency, which consequently yield a mix of climatic signals in δ^{13}C of tree rings through space (Gessler et al., 2014). Previous observations show a stronger response of δ^{13}C isotopes of pine trees to precipitation at drier sites of the mid latitudes (Gagen et al., 2004; Hartl-Meier et al., 2014). This is consistent with stable-carbon isotope fractionation models (e.g., Francey and Farquhar, 1982; Farquhar et al., 1989) that represent the ^{13}C/^{12}C ratio (δ^{13}C) of fixed carbon (and the tree rings to which it is transported) as influenced by rates of photosynthesis and leaf stomatal conductance. Consequently, low moisture conditions can induce lower stomatal conductance, reduced CO_2 concentrations in the leaves, and less discrimination by photosynthetic enzymes against ^{13}C, which resulting in higher ^{13}C/^{12}C ratios (higher δ^{13}C). This relationship is particularly strong in arid and semi-arid environments (Warren et al., 2001).

Tree-ring width reconstructions suggest with high degree of certainty that the thermal conditions of the Medieval Warm-Little Ice Age transition in the European part of Russia were cooling as in the most Europe (Klimenko and Sleptsov, 2003; McCarroll et al., 2013). Conversely, spatial and temporal variability of moisture in the East European Plain is unresolved, although it is relatively well defined for Europe (e.g., Treydte et al., 2007; Büntgen et al., 2010). This deficiency could be explained in part by the lack of a reliable network of tree-ring hydroclimatic proxies for the mid latitudes of Russia. The long-standing history of deforestation and natural vegetation change further restricts the length of tree-ring records from living trees. In this regard, stable isotopes of archaeological timbers offer an opportunity to increase coverage and temporal extent of moisture-sensitive proxies and compare with other climatic proxies. In this paper we compare historical indicators of moisture with a new δ^{13}C tree-ring record from Yaroslavl archaeological timbers originating from the southern taiga of the East