Quaternary Science Reviews 157 (2017) 80–97

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Vegetation of Eurasia from the last glacial maximum to present: Key biogeographic patterns

Heather Binney [a], Mary Edwards [a,*], Marc Macias-Fauria [b], Anatoly Lozhkin [c], Patricia Anderson [d], Jed O. Kaplan [e], Andrei Andreev [f], Elena Bezrukova [g], Tatiana Blyakharchuk [h], Vlasta Jankovska [i], Irina Khazina [j], Sergey Krivonogov [j,k], Konstantin Kremenetski [l], Jo Nield [a], Elena Novenko [m], Natalya Ryabogina [n], Nadia Solovieva [o,p], Kathy Willis [b,1], Valentina Zernitskaya [q]

[a] Geography and Environment, University of Southampton, Highfield, Southampton, SO17 1 BJ, UK
[b] School of Geography and the Environment, University of Oxford, South Parks Road, Oxford, OX1 3QY, UK
[c] North East Interdisciplinary Research Institute, Far East Branch, Russian Academy of Science, Magadan, 685000, Russia
[d] Quaternary Research Center, Box 351360, University of Washington, WA, 98195-1360, Seattle, USA
[e] Institute of Earth Surface Dynamics, University of Lausanne, CH-1015, Lausanne, Switzerland
[f] Institute of Geology and Mineralogy, University of Cologne, Zülpicher Str. 49a, D-50674, Cologne, Germany
[g] Vinogradov Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, 1A, Favorsky Str., Irkutsk, 664033, Russia
[h] Institute for Monitoring Climatic and Ecological Systems, Siberian Branch, Russian Academy of Sciences, Akademicheski Ave 10/3, 643055, Tomsk, Russia
[i] Institute of Botany, CAS, Zámek 1, 252 43, Průhonice, Czechia
[j] Sobolev Institute of Geology and Mineralogy SB RAS, Koptyuga Ave. 3, Novosibirsk, 630090, Russia
[k] Novosibirsk State University, Pirogova St. 2, Novosibirsk, 630090, Russia
[l] Department of Geography, University of California-Los Angeles, Los Angeles, CA, 90095-1524, USA
[m] Faculty of Geography, Lomonosov Moscow State University, Moscow, Russia
[n] Institute of Problems of Development of the North, Siberian Branch of the Russian Academy of Sciences, Russia
[o] Environmental Change Research Centre, University College London, Gower Street, London, WC1E 6BT, UK
[p] Higher Colleges of Technologies, University City, Sharjah, PO Box 7947, United Arab Emirates
[q] Institute of Natural Management, NAS of Belarus, F. Skorynu Str. 10, 220114, Minsk, Belarus

A R T I C L E I N F O

Article history:
Received 26 July 2016
Received in revised form
14 November 2016
Accepted 15 November 2016

Keywords:
Eurasia
Pollen
Biomes
Vegetation
Late Quaternary

A B S T R A C T

Continental-scale estimates of vegetation cover, including land-surface properties and biogeographic trends, reflect the response of plant species to climate change over the past millennia. These estimates can help assess the effectiveness of simulations of climate change using forward and inverse modelling approaches. With the advent of transient and contiguous time-slice palaeoclimate simulations, vegetation datasets with similar temporal qualities are desirable. We collated fossil pollen records for the period 21,000–0 cal yr BP (kyr cal BP; calibrated ages) for Europe and Asia north of 40°N, using extant databases and new data; we filtered records for adequate dating and sorted the nomenclature to conform to a consistent yet extensive taxon list. From this database we extracted pollen spectra representing 1000-year time-slices from 21 kyr cal BP to present and used the biomization approach to define the most likely vegetation biome represented. Biomes were mapped for the 22 time slices, and key plant functional types (PFTs, the constituents of the biomes) were tracked though time. An error matrix and index of topographic complexity clearly showed that the accuracy of pollen-based biome assignments (when compared with modern vegetation) was negatively correlated with topographic complexity, but modern vegetation was nevertheless effectively mapped by the pollen, despite moderate levels of misclassification for most biomes. The pattern at 21 ka is of herb-dominated biomes across the whole region. From the onset of deglaciation (17–18 kyr cal BP), some sites in Europe record forest biomes, particularly the south, and the proportion of forest biomes gradually increases with time through 14 kyr cal BP. During the same period, forest biomes and steppe or tundra biomes are intermixed across the central Asian mountains, and forest biomes occur in coastal Pacific areas. These forest biome

* Corresponding author.
E-mail address: m.e.edwards@soton.ac.uk (M. Edwards).
[1] Present address: Department of Zoology, University of Oxford, South Parks Road, Oxford, OX1 3PS, UK.

http://dx.doi.org/10.1016/j.quascirev.2016.11.022

occurrences, plus a record of dated plant macrofossils, indicate that some tree populations existed in southern and Eastern Europe and central and far-eastern Eurasia. PFT composition of the herbaceous biomes emphasises the significant contribution of diverse forbs to treeless vegetation, a feature often obscured in pollen records. An increase in moisture ca. 14 kyr cal BP is suggested by a shift to woody biomes and an increase in sites recording initialization and development of lakes and peat deposits, particularly in the European portion of the region. Deforestation of Western Europe, presumably related to agricultural expansion, is clearly visible in the most recent two millennia.

1. Introduction

Northern Eurasia (north of ca. 40°N and from 10°W to 180°E) is a large landmass with distinct gradients in climate. The last deglaciation led to dramatic changes to the Earth system, and in the North polar amplification likely enhanced regional responses to climate forcing (Serreze and Barry, 2011). The geography of Eurasia altered dramatically as the extensive shallow coastal shelves bordering the Arctic Ocean and the shallow Bering Strait region, which were subaerial for much of the last glacial-interglacial cycle, were flooded by eustatic sea-level rise. The biotic system saw major shifts in vegetation structure and composition (Andreev and Tarasov, 2013; Lozhkin and Anderson, 2013; Willerslev et al., 2014), continental-scale ecotones between forest and steppe and forest and tundra being particularly sensitive recorders of climate change (e.g., Pielke and Vidale, 1995; Thompson et al., 2004; Williams et al., 2011). Changes in the size of mammalian populations and local and global extinctions occurred (Sher, 1997; Stuart et al., 2004; Barnosky et al., 2004). There were changes in the terrestrial carbon sink, such as the development of peatlands (Smith et al., 2004), in patterns of thermokarst and permafrost degradation (Zimov et al., 2006; Walter et al., 2007) and in other nutrient cycles (McLauchlan et al., 2013). To date, the late-Quaternary changes in Eurasian vegetation have not been comprehensively summarized and mapped using palaeodata.

How well key climate changes are depicted in palaeoclimate simulations can be examined via comparison with spatio-temporal vegetation changes on a large scale. Recent climate simulations have used contiguous time-steps over long periods (i.e., independent simulations for a set of time-slices; Singarayer and Valdes, 2010), or transient runs (i.e., continuous simulation over a given time span; e.g., Liu et al., 2009). Several comparisons have been made for the last glacial maximum (LGM), 6 kyr cal BP and present (e.g., Kaplan et al., 2003; Wohlfahrt et al., 2008; Bartlein et al., 2011), and Hoogakker et al. (2016) examined snapshots of compiled environmental data through the last glacial cycle with simulated data. To be effective, this type of exercise requires suitable comparator datasets. Pollen data remain by far the most abundant and widespread source of information about late-Quaternary vegetation change. Compared with other regions, the Siberian sector is described by relatively sparse palaeodata, but more pollen data are becoming available and can be compared with information from other sources, e.g. plant macrofossils (Binney et al., 2009) or ancient DNA (Willerslev et al., 2014). Here we build on the efforts of the PAIN project (e.g., circumpolar vegetation reconstructions for 6ka and 21 ka: the Pan-Arctic INitative; Bigelow et al., 2003) plus new data synthesized in an international workshop to develop a series of pollen-based biome reconstructions from 21 to 0 kyr cal BP for Eurasia north of 40°N. We used dated pollen records from geo-archives to map vegetation biomes using the biomization algorithm of Prentice et al. (1996) modified by Bigelow et al. (2003). We present time-slice maps of biomes and describe the most prominent changes, assess uncertainty in the biome assignments, and discuss the key emergent patterns in relation to changing Quaternary climates, distribution changes of key plant taxa and the sustainability of the Eurasian megafauna. We also summarize the dynamics of major plant functional types (PFTs) as they relate to key land-cover properties.

2. Study area

The study region extends from the Iberian Peninsula to easternmost Siberia north of 40°N (Fig. 1). In our results and discussion we distinguish eastern and western sectors delineated by the 40° E meridian. West of ca. 40°E lies largely mountainous Europe; to the east are the extensive Russian and western Siberian plains. A series of broad lowlands characterize the region east of the Taimyr Peninsula into northeast Siberia. These lowlands are bordered by a series of north-south mountain complexes. The southern fringe of the study region is marked by the Mediterranean Sea in the west and central Asian mountain ranges and basins further east. Potential current natural vegetation includes temperate and mixed forests, boreal forest, temperate grassland (steppe) and alpine and arctic tundra (Fig. 2). West of 40°E in particular, extensive forested regions have been transformed by agriculture.

Considerable climatic variation is reflected in the range of modern biomes that characterize the continent (Fig. 2). A latitudinal maritime-continental gradient is evident: steppe and desert regions occupy the arid continental interior south of ~50°N, while the presence of Atlantic and Pacific Oceans in the west and east, respectively, is linked to temperate conditions and deciduous or mixed-deciduous forest cover. In Europe, the southern margins of the study region feature a Mediterranean climate and evergreen sclerophyll vegetation. Mean annual precipitation across the boreal forest zone (north of ~50°N) ranges from over 1000 mm in mountainous Scandinavia to ~200 mm in northeast Siberia; evergreen coniferous forest in the western part of the continent grades to deciduous coniferous forest in the east. Annual temperature ranges in the eastern boreal region can be > 60 °C. The northern edge of the landmass and higher elevations support tundra, with cool growing season means below 10 °C and cold winters.

During the cold, dry glacial maximum centred on 21 kyr cal BP glaciation was relatively restricted compared with earlier phases of the last glacial cycle. Ice covered Scandinavia and adjacent areas but barely affected the western and central Siberian lowlands (Svendsen et al., 2004). In northeast Siberia (here defined as lands lying east of the Verkhoyansk Range), glaciation was largely restricted to the mountains (Barr and Clark, 2012; Velichko and Faustova, 2009). Thus much of the study region remained unglaciated between the LGM and present.

Palaeoecological records of full-glacial age from across the region from the Atlantic to the Pacific have long been interpreted as representing treeless vegetation that supported a diverse grazing megafauna (Guthrie, 1990) and small bands of human hunter-