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Editorial: Past interactions between climate, land use, and vegetation

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Editorial on the Research Topic
Past interactions between climate, land use, and vegetation

Introduction

Climate and land use changes and their respective impact on vegetation composition, plant abundance, plant diversity and biodiversity in general is a challenging topic. For evaluating the current status of climate-land use-vegetation relationships, a baseline is needed. For this purpose, paleoecology, paleoclimatology, history and archaeology should be combined. However, combining data from various disciplines is not straightforward due to differences in the meaning of the data and their spatial and temporal resolutions.

To explore the past interactions between vegetation, climate and land use, Reitalu et al. (2013), Marquer et al. (2017) and Kuosmanen et al. (2018) used statistical approaches (variation partitioning and redundancy analysis) to combine pollen-based vegetation estimates, land use data (anthropogenic land cover scenarios, population density estimates and fire) and climate (climate simulations). These studies underline a potential tipping point related to the human impact on ecosystems around 4,500–4,000 years ago resulting from the spread of agriculture and the rise in human population size. However, the climate influence increased again over the last millennium due to late-Holocene climate shifts and specific climate events that are likely to have influenced both vegetation and land use.

In order to better understand these trends, more studies are needed, in particular by using a large variety of land use and climate variables based on proxies (Figure 1). Many variables based on empirical data (e.g., chironomids and historical information) are unlikely to cover a large spatial scale. In contrast, temperature, drought, and precipitation estimates inferred from tree-ring chronologies are available for regional to sub-continental scales (e.g., Cook et al., 2015; Büntgen et al., 2016; Esper et al., 2016; Ljungqvist et al., 2020; Tegel et al., 2020), although they mostly cover only the last millennium. Dendrochronological studies further provide information about historical land use (e.g., forest management) and tree-growth responses to climate changes. There is, therefore, a great potential for combining tree-ring proxies with pollen-based vegetation data to quantify the effects of climate and land use on vegetation.

Regarding land-use related estimates at regional scales, the main data so far available are model-derived anthropogenic land-cover change scenarios (ALCCs) that are based on estimates of per capita land use and past population density (Kaplan et al., 2011; Klein Goldewijk et al., 2017). Current efforts exist to collect and format past land-use data at regional scale based on archaeological and historical information (Morrison et al., 2021). However, these products are not yet available.

The aim of the present Research Topic was to bring together scientists working with pollen and/or tree rings, and provide an avenue for vegetation/climate/land use-related studies. This Research Topic is a collection of 21 articles, including primary research articles, perspectives, brief research reports, and reviews that address fundamental questions and provide additional insights into the past interactions between vegetation, climate and land use.

Pollen-based vegetation estimates

Pollen is the major biological proxy to assess past vegetation changes. Plant compositional change and diversity indices derived from pollen data are important estimates to understand how much an ecosystem or a specific vegetation type has changed through time. As an example, Zhang et al. used a Holocene pollen record from the Qingling Mountains (Central-East China) to estimate biome changes and past plant diversity indices. Their results show that climate was the main driver of vegetation composition and diversity during most of the Holocene. It is from ca. 3,000 years ago that human activities potentially started to influence vegetation compositional changes in the region.

Pollen-based land cover modeling (e.g., the Landscape Reconstruction Algorithm, LRA; Sugita, 2007a,b) is a key approach to transform pollen data into land cover reconstructions (e.g., Gaillard et al., 2010; Marquer et al., 2014, 2017, 2020; Trondman et al., 2015; Githumbi et al., 2022), which provide information on plant abundance at a known spatial and temporal scale for comparison with other proxies. Githumbi et al. presented the first continuous whole-Holocene time series of spatially complete maps of past plant cover for Europe as a result of pollen-based land cover modeling. These maps show the major Holocene trends in land cover change from the naturally open vegetation of the early-Holocene, to the mid-Holocene abundance of forests, and finally the late-Holocene human-induced deforestation. At more local scale, Hjelle et al. applied the LRA modeling to assess the vegetation-land use interactions over the last 2,400 years in coastal Norway, and compared the modeling outcomes with shoreline reconstruction and settlement intensity as measured with radiocarbon dates from archaeological sites. They identified a mosaic landscape containing infields and outfields from 2,400 years ago, settlement recession from 350 CE resulting in reforestation, and a new expansion of outfield pastures from 900 CE onwards. This study further underlines the need of studying environmental changes at a local scale, which is directly used and perceived by the inhabitants.

It is important to note that the pollen modeling schemes are dependent on the Relative Pollen Productivity estimates (RPP) used as input parameters. The RPPs present a large range of values depending on the region where they have been obtained (e.g., Broström et al., 2008; Mazier et al., 2012; Wieczorek and Herzschuh, 2020). There are still some unknowns regarding the calculation of RPPs, and several studies are in progress to better understand/estimate these parameters. As an example, Bunting and Farrell found that the RPP calculation can be affected by local differences between locations and habitats in heathlands. It is noteworthy that RPP studies have been largely developed in the northern Hemisphere, particularly in Europe and China. However, these studies are still in progress in the southern Hemisphere and the tropics (Gaillard et al., 2021), where they are needed to increase our understanding of environmental changes, as it has been reported by Piraquive-Bermúdez and Behling.

Pollen data can also be used to assess past climate information. For this purpose, Li et al. have developed a machine learning modeling scheme to reconstruct the history of permafrost. This study demonstrated that the reduction of permafrost in northern Asia during the early-Holocene led to the spread of coniferous trees, and might have decelerated the enhancement of the East Asian summer monsoon by altering hydrological processes and albedo.

Tree rings from historical and archaeological wood

Tree-ring widths of historical and archaeological wood provide information about paleoclimate and forest history in relations to past human societies and climate change. Muigg and Tegel discussed the importance of multidisciplinary

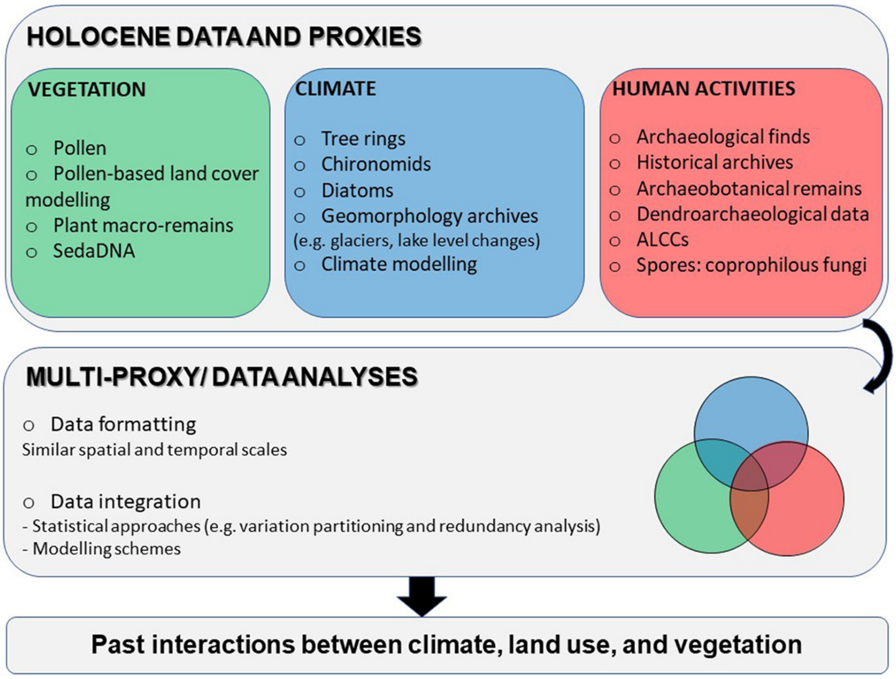

FIGURE 1
Conceptual diagram showing the potential of multi-proxy/data analyses to assess past interactions between climate, land use, and vegetation (ALCCs, model-derived anthropogenic land-cover change scenarios). Note that single proxies can simultaneously provide information for more than one category, e.g., tree rings can be used to infer past vegetation, climate variability and forest management practices or pollen data can be used to infer past climate and land use. However, for data integration one should use independent variables to avoid circular reasoning, therefore, we do not duplicate the use of proxies/data in this figure. This can be adjusted depending on the study case.

studies to get insights into forest history by connecting history and archaeology with paleoclimatology and paleoecology. Tegel et al. presented the potential of dendroarchaeology in Europe by providing an overview of the sources, methods, and concepts of the discipline, which show that several tree-ring chronologies covering most of the Holocene are available from wooden archaeological and historical samples. Dendroarchaeology provides critical information about forests, its products for human use (e.g., fuel, material for tools, weapons, and construction), and about climatic changes. Dufraisse et al. investigated the limits and potential of dendro-anthracology and anthraco-isotopy (based on charcoal from archaeological sites that reflect human activities and forest exploitation) to assess past forest managements and climate.

Multiproxy databases are important tools to assess the interactions between factors of environmental and human-related changes, specifically to study cascading events such as the causes (e.g., climate change) and consequences (e.g., vegetation or societal changes). Many tree-ring data have been made available through the International Tree-Ring Data Bank (ITRDB), however, a large amount are not yet publicly shared since they are only found in local or regional journals (i.e., in non-English speaking countries) or remained unpublished as presented by Solomina and Matskovsky for European Russia. This issue is a common problem for all databases and across disciplines such as for the pollen databases [i.e., the European Pollen Database (EPD), Neotoma and PANGAEA].

The use of large tree-ring datasets can further provide information about the regional patterns of historical building activity, as found by Ljungqvist et al., who based their study on dendrochronological felling dates from historical construction timber collected across Europe that dated from 1,250 to 1,699 CE. This study shows that building activity can be used as an indicator of settlement history and demographic development, i.e. the building boom in northeastern Germany during the 13th century and the cessation of building activity during the Thirty Years' War (1,618–1,648 CE). Seim et al. found similar trends when investigating the role of spruce in historical woodlands in southern Central Europe by comparing felling dates of spruce timbers from historical buildings and pollen-based land cover estimates. This study is the first one to combine tree rings and pollen-based land cover modeling data at similar temporal and spatial scales to answer specific research questions, which were raised by Edvardsson et al., who explored how to combine dendrochronological data and paleoecological records.

Roy et al. reviewed the climate records available for the last 2,000 years based on tree rings but also on fluvio-lacustrine sediment deposits and speleothem archives in South

Asia to explore the vegetation response to late-Holocene climatic changes. This study shows how the Indian summer monsoon dynamics might influence vegetation patterns in the Himalayan region.

It is important to note that the reliability of analyzing tree-ring widths for paleoclimate studies can be potentially influenced by historical forest management practices, mainly because the past growing conditions of the trees are largely unknown. Skiadaresis et al. found that the tree growth patterns resulting from management practices can affect paleoclimate reconstructions, however, the use of random regional samples can reduce these uncertainties. Regarding the climate influence on tree growth, Zheng et al. assessed how climate affects the wood production at cellular level in subtropical regions by monitoring the cambial activity. Their studies show the impact of yearly drought stress on wood production. Furthermore, Bing et al. explored the climate response of total ring width, earlywood width, and latewood width in the Southeastern Tibetan Plateau, and Stangler et al. studied the responses of Norway spruce, silver fir and Douglas fir to drought along elevational gradients in Southwestern Germany. Zunde demonstrated the challenge of dendrochronological dating and of interpreting growth patterns in environments, that are affected by geomorphological processes (e.g., on coastal bluffs).

Sedimentary ancient DNA (sedaDNA)

The sedaDNA extracted from lake sediments is a proxy increasingly used in multiproxy palaeoecological studies. Its techniques have been recently developed following the emergence of the DNA meta-barcoding approach (Parducci et al., 2017). As a critical tool, sedaDNA complements the vegetation information obtained from pollen data (e.g., Giguet-Covex et al., 2014), especially in terms of taxonomic resolution of most herbaceous families, as well as agricultural and pastoral activities. SedaDNA not only provides information about plant diversity but even into past livestock farming, i.e., the composition of past domestic herds that cannot be assessed by analyzing spores of coprophilous fungi observed in the pollen samples.

Regarding the plant diversity aspect, Courtin et al. studied the relationships between climate, plant species composition, and plant species richness during the last ca. 35,000 years in south eastern Yakutia (Siberia). For this purpose, they combined pollen and sedaDNA records from a sediment core collected from Lake Bolshoe Toko. Pollen data were used to assess the past vegetation trends and sedaDNA meta-barcoding data to investigate changes in plant richness. Both proxies show similar patterns. The sedaDNA data provide additional information to complement pollen data, e.g., the Late Pleistocene steppe-tundra vegetation was characterized by a higher plant diversity than the Holocene forest, which might result from the role of the Late Pleistocene megaherbivores.

Considering agricultural and pastoral activities, Messager et al. combined pollen data and coprophilous fungal spores with plant and mammal DNA analyses to assess the past vegetation-land use interactions in the western edge of the European Alps (Savoie, France) over the last two millennia. This work revealed an alternance of phases of regional deforestation and afforestation resulting from farming activities. Plant sedaDNA provided information about the plants cultivated in fields, orchards and vegetable gardens over the past centuries. This study underlined the need to further explore the spatial extent of the plant sedaDNA signals and the source area of pollen in order to compare both proxies at the same spatial scale.

Conclusion

This Research Topic highlights the potential of integrative approaches that combine paleoecology, paleoclimatology, history and archaeology, and underlines the various aspects of the past interactions between vegetation, climate and land use. One of the main challenges is still to bring different disciplines and research communities together to get temporally and spatially comparable data. For example, it would be important to use the full potential of large archaeological datasets already available (e.g., https://www.p3k14c.org/; Bird et al., 2022) that make it possible to study the intensity of human settlement across large geographical and temporal scales. Furthermore, this Research Topic opened new questions and provided new tools, approaches and data for future studies.

Author contributions

LM wrote the first editorial draft. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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