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# Editorial: Functional Traits as Indicators of Past Environmental Changes

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**Editorial on the Research Topic**

**Functional Traits as Indicators of Past Environmental Changes**

Paleoecology uses the biological remains in lake and bog sediments to reconstruct past environmental changes and to provide a valuable historical perspective on climatic and ecosystem changes occurring in the present day. Most paleoecological reconstructions are based on the analysis of the relative abundance of sub-fossils of plant and animal remains (e.g., testate amoebae, diatoms, fossil pollen), which are regarded as a proxy for past environmental conditions. Calibration data sets can be used to infer quantitative reconstructions of past environmental variables such as water-table depth, pH, and temperature. One emerging sub-discipline in paleoecology aims to reconstruct past functional diversity patterns of plants (e.g., using pollen and plant macro-remains) and other organisms (e.g., testate amoebae, diatoms, and chironomids) through a focus on functional traits. Such an approach has been argued to offer an alternative perspective from paleoecological archives, especially for understanding how past climate changes and human impacts influenced species' functional diversity and then ecosystem functions over long timescales.

The papers in this Research Topic are based around the theme of using functional traits for better understanding past environmental changes from sediments. Across the fossil record, species may appear and disappear through environmental filtering, but certain traits might remain regardless of which species carries the trait (Lamentowicz et al., 2019). Thus, if the aim is to understand how current climate changes influence species and their functions over long-time scales, focusing on functional traits is of paramount importance for gaining insight. Such an approach will allow us to (1) build hypotheses for past and/or future patterns and processers based on different traits and (2) use the fossil record to test the strengths and weaknesses of different modeling approaches in predicting biodiversity patterns in response to current and future climate changes. The papers in this Research Topic demonstrate the potential breadth and scope of functional paleoecology, with contributions related to ecosystem ecology, forest management, peatland conservation, paleoclimatology, paleolimnology, and biogeography.

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## THE USE OF PLANT TRAITS IN UNDERSTANDING PAST VEGETATION AND ECOSYSTEM PROCESSES

Several papers published in this Research Topic evaluate the use and potential of plant traits in paleoecological studies using pollen-based proxies. For example, Blaus et al. investigate modern plant-pollen relationships from moss pollsters sampled in Estonian fens. They investigate the correlations between several modern pollen and plant diversity estimates, including taxonomic richness, functional diversity (FD), phylogenetic diversity (PD), in addition to ecological attributes such as Ellenberg indicator values (EIVs). They find that the modern relationships between pollen and plant diversity indicators are both variable and scale-dependent, and that separation of herbaceous and woody plant taxa is a useful approach if such relationships are to be applied to reconstructions. After applying their metrics to a sediment core spanning the past 9,000 years, they argue that an integration of functional diversity, phylogenetic diversity and Ellenberg Indicator Values provide new opportunities for studying the long-term patterns of community assembly which are not usually observed in traditional pollen diagrams.

Similarly, Brussel and Brewer used The Neotoma Paleoecology Database to link surface pollen samples to three functional traits (leaf area, plant height and seed mass) that reflect plant ecological strategies from the BIEN database (Enquist et al., 2016). Further, they show that continental functional diversity patterns inferred from modern pollen datasets generally match those patterns inferred from tree assemblages (Lamanna et al., 2014). Their results suggest that, despite challenges in taxonomic precision, pollen percentages can be used to infer past patterns of functional diversity change in North American Quaternary pollen sequences. Such pollen-plant trait relationships might then be used to provide explanations of evolutionary, ecological, and biodiversity dynamics that can contribute to sustainable conservations and management.

The studies above demonstrate a range of perspectives that can be introduced when paleoecological records can be viewed through the lens of plant traits. However, the review provided by Birks in this special issue introduces some important caveats. Firstly, Birks highlights the differences between ecological attributes (or ecological characteristics) and plant traits. Whilst an ecological attribute is a general feature of a taxon describing its overall ecology, a plant trait is a measurable property of an organism measured individually and which is comparable across species. But whilst a plant trait might be considered intrinsic to its genome, an attribute may not be considered a plant trait since it might be dependent on other factors (e.g., the geographic distribution of a species is dependent on historical chance events) (Birks). In his paper, Birks argues that traits and ecological attribute analyses have played a vital role for reconstructing ecological and environmental changes for the last 120 years in paleoecological studies, and that such analyses are complementary to current interest in the use of plant traits in macroecology (McGill et al., 2006). However, he suggests that the challenges related to taxonomic precision in Quaternary assemblages might limit the development of a "new" Quaternary botany based solely on plant traits.

As an alternative to estimating functional ecological changes based on a reinterpretation of palynological data, Loisel and Bunsen explored general ecosystem functional properties related to peatland trophic state. Through the analysis of 90 peat profiles from southernmost South America, they demonstrated that a synchronous, regional scale transition from fen to bog occurred 4,200 yr BP, with allogenic drivers most likely being responsible for this change. This functional critical shift appeared to be related to peatland-carbon accumulation that was much greater and stable for bogs than for a fenland ecological state. The authors built conceptual models for non-linear fen-bog transition scenarios that allow for improved understanding of the dynamics of the terrestrial carbon sink in South America.

## MICROBIAL TRAITS AS INDICATORS OF PAST ENVIRONMENTAL CONDITIONS

Protist functional traits have been used increasingly to reconstruct past environmental conditions and ecosystem functions. Many studies from the Research Topic focused on testate amoebae, which have been the focus of paleoecologists for several years. Marcisz et al. provide a review of this topic, showing the increasing potential of testate amoebae morphological traits in the exploration of past ecosystems. They describe and comment on the most common testate amoebae morphological traits when studied in the context of environmental gradients in lakes and peatlands, with examples from *Sphagnum* peatlands, fens, tropical peatlands and lacustrine habitats. The paper provides the first of its kind look at the current knowledge about testate amoebae traits as proxies of past changes in the environment e.g., climate change, deforestation, hydrological dynamics, eutrophication, dust deposition, carbon accumulation, and food web transformation. It also underlines the importance of testate amoebae as a robust proxy with well-identified functional trait potential and stresses the need for a better understanding of testate amoebae trait-environment relationships.

Given the need for a better understanding of trait-environment relationships, Macumber et al. addressed questions related to testate amoebae morphological traits variability in lakes using unprecedented geometric morphometric analyses. They explored test size and shape along a temporal gradient of eutrophication in Loch Leven, Scotland (United Kingdom) and found that decreasing test size might be related to disturbance connected with eutrophication. This contribution shows a strong agreement in the stratigraphic comparison between testate amoebae morphological traits, testate amoebae taxonomic composition and plant macrofossils in the lake sediment core. It further shows that using only the shape and test size of testate amoebae provides complimentary summaries of ecological function not captured by taxonomy. They finally suggest that such approaches might be further developed in paleoecological studies on lake ecosystems.

In another contribution, Krashevska et al. studied testate amoebae taxonomy and trait-based transfer functions. They used surface samples from the tropical peatland in Sumatra to build a data set that will be used for quantitative paleoenvironmental reconstructions. The best performance of the model with the depth to the water table (describing peatland hydrology) was obtained with five morphological traits: shell width, aperture shape, aperture invagination, shell shape, and shell compression. This work brings a novel data set from an undersampled area of the world with the potential to improve understanding of the paleohydrology of SW Asian tropical peatlands.

Comparison of four testate amoeba functional traits (mixotrophy, biovolume, aperture size, and aperture position) to C accumulation, hydrological, and vegetation changes in 12 peat profiles in Northwestern Québec, Canada is provided by Zhang et al. This study is a rare example of the study exploring multiple peat sections to compare testate amoebae functional traits with vegetation changes and carbon accumulation rates. Results show a different sensitivity of various traits to environmental changes. The authors of this paper also try to predict future peatland ecological functions and adaptation of testate amoebae communities with the different trait types. Furthermore, the contribution of mixotrophic testate amoebae as important drivers of peatland C assimilation is discussed in the perspective of the future drier peatlands.

Besides testate amoebae, two other contributions focused on microbes. Kearns et al. showed the potential of the individual trait-based analysis to explore past changes in the ocean. They explored the potential of planktonic foraminifera in the genus *Subbotina* by morphological measurements of the tests to understand trait changes through the Middle Eocene Climatic Optimum [MECO: ∼40 Myr ago (mega annum, Ma)]. They investigated functional trait changes through climatic perturbations along with the MECO. However, no relationship was found between measured traits in terms of size also concerning stable isotopes of oxygen and carbon. The authors suggest that the study could be extended to other genera, to explore changes in the deep using novel imaging techniques.

The final contribution in our Research Topic explores morphological traits of Chironomidae, another organism commonly used as a quantitative proxy in paleoecology. Remains of chironomid larvae found in lake sediments are used mainly for air temperature reconstructions. In this study, the authors identified several features in the mouthparts of larvae that might be promising indicators of the habitat changes including physicochemical conditions and vegetation. This assumption was tested using the sediment cores that were taken from a sequence that originates from a Late Medieval moat, and from a second core which covers the Late Weichselian paleochannel history. The study provides an alternative perspective on Chironomida paleoecology, suggesting that Chironomida traits provide complementary information about the local changes in the sedimentary environment.

## CONCLUSIONS AND FUTURE DIRECTIONS

The case studies and syntheses published in this Research Topic provide additional insights into the application of functional traits in paleoecological research. Whilst a taxonomic perspective has been used as the standard in paleoecology and remains as the basis of the quantitative paleoenvironmental reconstructions focused on past climate or human impact, the papers in this special issue demonstrate that the integration of trait-based approaches may lead to reconstructions of ecosystem functions that are often not possible to be explored in a taxonomic context. However, an important distinction should be made between those studies which rely on indirect estimation of traits through translation tables (e.g., Brussel and Brewer), and those studies which allow for direct measurements of phenotypic features that may be related to ecosystem functions (e.g., Macumber et al.). If morphological traits can be directly linked to the functional performance under different environmental conditions, it is possible that this may lead to more refined proxy reconstructions of different environmental parameters across different terrestrial, freshwater, and oceanic habitats. Thus, a priority for future studies, particularly in relation to morphological analyses of microorganisms is to establish better links between organismal traits and ecosystem functions.

It has also been stressed in several papers in this special issue that functional traits analysis cannot be applied alone, and it should be complementary to standard paleoecological work. Nevertheless, the papers in this Research Topic demonstrate that techniques related to functional paleoecological research are likely to continue to play an increasingly important role in contributing to our understanding of the environmental changes that have occurred when interpreting sediment records. Such an approach can provide novel proxies of the past human-related disturbances like deforestation, pollution, in addition to hydrological disturbance related to increasing drainage. Such information is also useful for studies into ecosystem management and for assessing results of restoration efforts.

## AUTHOR CONTRIBUTIONS

VJ, ML, and AS proposed the Research Topic. ML wrote the first draft. All co-authors edited the text and provided the final version of the manuscript. All authors contributed to the article and approved the submitted version.

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