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Editorial: Changes in plant–herbivore interactions across time scales: bridging paleoecology and contemporary ecology

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Editorial on the Research Topic

Changes in plant-herbivore interactions across time scales: bridging paleoecology and contemporary ecology

Plants and arthropods predominate in terrestrial ecosystems, both in biodiversity and biomass (Bar-On et al., 2018). Their trophic interactions, primarily herbivory, have profoundly shaped terrestrial ecosystems, affecting evolutionary trajectories, ecosystem structures, and responses to environmental change. The fossil record provides key insights into long-term processes and large-scale patterns of arthropod (mainly insect) herbivory stretching back to early terrestrial ecosystems, such as the Silurian (~443-419 million years ago) and Devonian (~419-359 million years ago) (Labandeira and Wappler, 2023), despite limitations from temporal and spatial gaps and the need to deduce ecological patterns based on insect morphology, community composition, and plant damage caused by herbivores. Contemporary ecology, in contrast, allows for direct real-time observation and precise measurement of variables related to herbivory, though it lacks the expansive temporal scope.

Ideally, our understanding of plant–insect interactions would integrate insights from both ancient and modern ecosystems, spanning ecological (particularly macroecological) and evolutionary patterns across geologic timescales and present-day contexts, with implications for the future. The five manuscripts in this Research Topic contain a multitude of paleoecological insights that will interest specialists in both ancient and modern ecosystems.

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Advances in paleoecology

A plurality of evidence of Paleozoic insect herbivory comes from the Permian of Texas. The frequency and richness of herbivory on Permian ferns and gymnosperms is lower than what we typically see in much younger, angiosperm-dominated deposits, but nevertheless varies considerably (Labandeira and Allen, 2007; Schachat et al., 2014). Dos Santos et al. break new ground with the first report of Permian herbivory that includes feeding event occurrences, an exceptionally finely resolved form of data (Xiao et al., 2022). Dos Santos et al. found a low proportion of herbivorized surface area, as reported by Labandeira and Allen (2007) for another Permian assemblage, but high richness of damage types, as reported by Schachat et al. (2014). Dos Santos et al. have thus expanded the known "ecospace" occupied by herbivorous insects of the Permian, enriching our understanding of this period.

Turner et al. examine plant–insect interactions following the uniquely devastating Permian/Triassic extinction. They note a particularly sparse published record of these interactions, likely due to both the extinction's impact and the scarcity of fossil remains. Various fossil floras from the Triassic of Gondwana are documented in the scientific literature but there are few mentions of insect herbivory. Does this reflect a genuine near-absence of insect herbivory after the mass extinction event, or does the scientific literature simply not mention evidence of herbivory on fossil leaves from which other types of data were collected? Turner et al.'s contribution is particularly thought-provoking for the authors' clever use of original data to evaluate these two possibilities; the authors find that evidence of herbivory indeed appears to be under-reported.

Among the "big five" mass extinctions, insect herbivory across the Triassic/Jurassic extinction is even more poorly documented than for the Permian/Triassic extinction (Steinthorsdottir et al., 2015). Xu et al. present an analysis of insect herbivory immediately before and after the Triassic/Jurassic extinction, with data from hundreds of fossil leaves. Perhaps surprisingly, the authors find similar frequencies of damage types during the latest Triassic and earliest Jurassic, despite substantial turnover in the composition of plant communities in Sichuan Basin from which the Triassic and Jurassic fossil leaves were collected. This consistency in feeding behaviors across a major mass extinction mirrors the findings of Wappler et al. (2009) from the Cretaceous/Paleogene.

Santos et al. focus on the mid-Cretaceous El Chango Lagerstätte from Mexico. Studies of herbivory as far back as the Paleozoic have, unsurprisingly, found far more feeding damage on broadleaf foliage than on small, needle-like leaves—leading to an explicit suggestion to limit comparisons of herbivory among taxa and assemblages to broadleaf foliage only (Schachat et al., 2018). This preference for broad-leaved plants is also evident in contemporary studies of insect herbivory. Despite the significant ecological and economic importance of conifers and their dominance in certain ecosystems, only 0.38% (Kozlov et al., 2015) to 1.8% (Turcotte et al., 2014) of published data on insect herbivory levels have been derived from studies on coniferous plants. Indeed, Santos et al. found that herbivores preferred broadleaf foliage at El Chango. The needle-leaved taxa at El Chango are gymnosperms and the broadleaf taxa are angiosperms, which highlights the need to account for vegetation traits, including but not limited to leaf shape, when evaluating major evolutionary transitions such as the rise of angiosperms. Similarly, in contemporary boreal forests, broadleaved woody angiosperms experienced, on average, five-fold higher herbivory than needle-leaved gymnosperm (coniferous) trees (Zvereva et al., 2020).

Boyce explores the role of nutrient constraints in herbivore adaptation, with high carbon-to-nitrogen ratios in land plants shaping invertebrate feeding strategies. This study demonstrates the benefits of integrating paleoecological and modern data: studies of fresh plant material have allowed a detailed understanding of where plants store carbon, and studies of fossils have shown that the oldest herbivores are those that can most easily avoid the highest concentrations of carbon in plant material. Whereas most studies of herbivory in the fossil record necessarily have a biomechanical focus, based on the leaf damage that an animal was physically capable of creating, Boyce's study provides a new lens through which the biochemical considerations that pervade the literature on modern herbivory can be integrated into paleontological analyses.

Missed expectations

Despite efforts to integrate contemporary and paleoecological perspectives in this Research Topic, we faced two main challenges. First, none of the scientists specializing in contemporary herbivory accepted our invitation to contribute. Second, paleontological manuscripts use different vocabulary and methodologies than those commonly used in contemporary studies, potentially making this Research Topic less accessible to ecologists focused on present-day systems.

These challenges are further exacerbated by systemic barriers. Fossil data often lack the resolution needed for direct comparisons with modern datasets, as damage on fossilized leaves cannot usually be attributed to specific taxa (Labandeira et al., 2007). The hundreds of known insect damage types provide only a coarse view of herbivore diversity compared to the vast number of extant herbivorous insect species (Bar-On et al., 2018), and many distantly related taxa can induce similar damage types (e.g., Carvalho et al., 2014), complicating comparative analyses. Moreover, while the diversity of leaf damage types has been central to paleoecological research for decades (Labandeira and Wappler, 2023), contemporary studies have largely overlooked this variable (but see Adams et al., 2011; Bachelot and Kobe, 2013). Factors influencing the composition and richness of plant damage types in modern ecosystems remain poorly understood, limiting our ability to align spatial and temporal patterns in herbivory with herbivore identities.

Future directions

Rather than chasing the dream of apples-to-apples comparisons of modern and fossil datasets, an explicitly hypothesis-driven framework can better unify these fields. Theoretical advances and the rich datasets presented in this Research Topic illustrate how our discipline can transition from a correlational approach—focused on apparent increases in herbivory during periods of climate change or extinction events—to rigorous hypothesis testing. This shift will not only make paleontological findings more compelling but also enable scientists from both fields to better predict the resilience of terrestrial food webs in the face of anthropogenic change. Bridging paleoecology and contemporary ecology in plant-herbivore studies will require continued collaboration, mutual openness, and a commitment to methodological rigor. Achieving this goal remains challenging but is essential for a more integrated understanding of plant-herbivore dynamics across temporal scales.

Author contributions

BA: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. MK: Conceptualization, Writing – review & editing. JR: Conceptualization, Writing – review & editing. SS: Conceptualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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