*Paleobiology*

www.cambridge.org/pab

# Introduction: Fifty years of *Paleobiology*

Mark Patzkowsky[1] and Wolfgang Kiessling[2]

[1]Department of Geosciences, Pennsylvania State University, University Park, Pennsylvania 16802, U.S.A.
[2]Geozentrum Nordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, 91054 Erlangen, Germany

**Review**

**Cite this article:** Patzkowsky, M., and W. Kiessling (2025). Introduction: Fifty years of *Paleobiology*. *Paleobiology* **51**, 1–7. https://doi.org/10.1017/pab.2025.4

Received: 15 December 2024
Revised: 06 January 2025
Accepted: 16 January 2025

**Handling Editor:**
Erin Saupe

**Corresponding author:**
Mark Patzkowsky;
Email: mep12@psu.edu

*Paleobiology* was founded 50 years ago to provide an outlet for biological paleontology, with an emphasis on investigating evolutionary patterns and processes that could apply generally across the history of life. While the intellectual and financial prospects for *Paleobiology* were uncertain in the beginning (Sepkoski 2012; Valentine 2009), this 50th anniversary issue testifies to its overwhelming success. Fifty years of anything well done deserves a celebration. These moments are a time for reflection and a time for imagining future directions. With this introduction, we outline briefly the start of the journal and two landmark anniversary issues, the 10th and the 25th. No special issue can adequately survey all research themes in a field as intellectually rich as paleobiology. However, these anniversary issues offer a snapshot of research directions, and they can trace the shift and expansion of established fields and mark the emergence of new ones. We end by outlining the contributions to the 50th anniversary issue that summarize current themes and future directions for the field.

## Starting the Journal

In the decade spanning 1970 to 1980, paleontology was undergoing a revolution that had the explicit aim of infusing the discipline with biology (Sepkoski 2012). Eldredge and Gould (1972) published their classic paper on punctuated equilibria, and Stanley (1975) then expanded on this idea to suggest that selection could operate at the species level to drive long-term evolutionary trends. A group of paleontologists and biologists (Schopf, Gould, Raup, Simberloff) working at the Marine Biological Laboratory in Woods Hole in Massachusetts developed early stochastic models of clade diversity (Raup et al. 1973). Valentine (1973) published his classic book *Evolutionary Paleoecology of the Marine Biosphere*, where, among many other ideas, he laid out his vision for a dual ecological and taxonomic hierarchy, and he explained how drifting continents interacting with global climate patterns exerted a first-order control on global diversity change through time. Jack Sepkoski (1978, 1979) compiled the first comprehensive database of Phanerozoic marine diversity, which led to the "consensus" paper that showed that sampling issues aside, compilations of global Phanerozoic diversity of marine animals contained a strong biological signal (Sepkoski et al. 1981; Miller 2009).

This cadre of paleontologists and many others discussed the need for a journal to house these new ideas in biological paleontology, to broaden the intellectual reach of the discipline by bringing evolutionary biologists and ecologists into the conversation. In response to this need, Jim Valentine, who was then president-elect of the Paleontological Society, proposed to the Paleontological Society Council the creation of a new journal where biologists and paleontologists could publish on topics of mutual interest (Valentine 2009). His proposal was accepted, and the first issue of *Paleobiology* was published in 1975 as a new journal of the Paleontological Society. The champion of the new journal was Tom Schopf, who served as the first coeditor, along with Ralph Gordan Johnson, both at the University of Chicago. Topics in the first issue included papers on functional morphology, quantitative and theoretical morphology, comparative paleoecology, and evolutionary rates. These papers represent what *Paleobiology* strived to be, the leading journal of paleobiological theory and quantitative methods. Notable among these is Raup's (1975) paper wherein he named the "law of extinction" , Van Valen's law for the empirical observation that species extinction rates within taxonomic groups are approximately constant through time (Van Valen 1973).

## Tenth Anniversary Issue

The 10th anniversary issue appeared in 1985 and marked the coalescence of paleobiology into a vibrant field (Table 1). Essays covered a wide range of topics, including hierarchical scale of evolutionary processes (Gould 1985), rates of evolution (Gingerich 1985; Stanley 1985), mathematical models of cladogenesis (Raup 1985), systematics (Eldredge and Novacek 1985), biogeography (Jablonski et al. 1985), evolutionary paleoecology (Kitchell 1985), taphonomy (Behrensmeyer and Kidwell 1985), evolutionary morphology (Fisher 1985), and Precambrian paleobiology (Knoll 1985). A few common themes were woven through these contributions, pointing to areas of intense interest: macroevolution and units of selection, mass extinction as an evolutionary process, and the nature of the fossil record.



PALEOBIOLOGY A PUBLICATION OF THE Paleontological SOCIETY

CAMBRIDGE UNIVERSITY PRESS

**Table 1.** Table of contents for the 10th anniversary issue of *Paleobiology* (1985, Vol. 11)

| Authors | Titles | Pages |
|---|---|---|
| J. John Sepkoski Jr. and Peter R. Crane | Introduction | 1 |
| Stephen Jay Gould | The Paradox of the First Tier: An Agenda for Paleobiology | 2–12 |
| Steven M. Stanley | Rates of Evolution | 13–26 |
| Philip D. Gingerich | Species in the Fossil Record: Concepts, Trends, and Transitions | 27–41 |
| David M. Raup | Mathematical Models of Cladogenesis | 42–52 |
| Andrew H. Knoll | Patterns of Evolution in the Archean and Proterozoic Eons | 53–64 |
| Niles Eldredge and Michael J. Novacek | Systematics and Paleobiology | 65–74 |
| David Jablonski, Karl W. Flessa, and James W. Valentine | Biogeography and Paleobiology | 75–90 |
| Jennifer A. Kitchell | Evolutionary Paleoecology: Recent Contributions to Evolutionary Theory | 91–104 |
| Anna K. Behrensmeyer and Susan M. Kidwell | Taphonomy's Contributions to Paleobiology | 105–119 |
| Daniel C. Fisher | Evolutionary Morphology: Beyond the Analogous, the Anecdotal, and the Ad Hoc | 120–138 |

Punctuated equilibria (Gould 1985) provided a new basis for macroevolution, although the tempo and mode of evolution, and particularly the frequency of phyletic gradualism, still represented a vigorous and ongoing debate (Gingerich 1985). Punctuated equilibria stated that species had clearly identifiable beginnings and ends with little morphological change over their durations. The still-new field of cladistics added clades in addition to species as definable, temporally bounded "individuals" subject to evolutionary study (Eldredge and Novacek 1985). Thus, species selection (Stanley 1985) and similar differential sorting of monophyletic taxa might explain long-term trends in the fossil record. Raup (1985) provided a primer on the mathematical models that describe speciation and extinction in biological groups. It proved to be a foundational paper for modeling diversification and served as the basis for fossilized birth–death models (Mulvey et al. 2025).

The idea that a large bolide slammed into Earth wiping out the non-avian dinosaurs and large percentages of other species (Alvarez et al. 1980) elevated mass extinction to an important process that can redirect the trajectory of life. Mass extinctions were recognized to be "more frequent, more rapid, and more extensive … and more qualitatively different in effect" than paleontologists had thought possible (Gould 1985: p. 8). For example, the size of geographic ranges could explain differences in selectivity between background extinction and mass extinction events (Jablonski et al. 1985) and thus explain many geographic patterns of survival and diversity throughout the history of life.

One of the primary drivers of the paleobiological revolution was a rereading of the fossil record (Sepkoski 2012); that is, the fossil record is not hopelessly incomplete, but rather much of its structure is interpretable directly as a reflection of evolutionary processes (Eldredge and Gould 1972; Sepkoski et al. 1981). However, this rereading of the record did not change the fact that the fossil record is structured by stratigraphic architecture and sedimentary processes. Behrensmeyer and Kidwell (1985) explained how the biological interpretation of the fossil record relies inherently on understanding preservation processes and how they affect the biological signal of interest.

## Twenty-Fifth Anniversary Issue

The 25th anniversary issue (better known as the "Deep Time" issue) witnessed a substantial expansion of the field (Table 2). The number of contributions increased by 50% and the page count more than doubled compared with the 10th anniversary issue. The Deep Time issue was perhaps the last one that could still aim to cover the entire breadth of paleobiology as a discipline. Several themes in the 25th anniversary issue have expanded into specific subdisciplines of active research today and are reflected in the 50th anniversary issue. Fossil preservation, for example, was covered by three contributions in the Deep Time issue, one on large-scale taphonomic biases (Behrensmeyer et al. 2000), a second on the preservation of organic compounds (Briggs et al. 2000), and the third on a model-based approach to evaluate the quality of the fossil record based on sequence stratigraphic principles (Holland 2000). Holland's modeling work established the fundamental framework for current work in stratigraphic paleobiology (Holland et al. 2025). Neogene and Quaternary ecosystems and their relation to global environmental change were the subject of several contributions in the 25th anniversary issue (Alroy et al. 2000; Jackson and Johnson 2000; Jackson and Overpeck 2000; Norris 2000). These papers formed the basic road map for conservation paleobiology, which intends to align paleobiological research with conservation needs (Blois et al. 2025; Dillon and Pimiento 2025; Kiessling et al. 2025). Finally, Wagner (2000) highlighted the unique challenges of using the fossil record in phylogenetic analyses, and this laid the foundation for subsequent methodological developments in using fossil data in phylogenetic inference (Mulvey et al. 2025), which is one of the more active areas of collaborative research between paleobiologists and evolutionary biologists.

## Summary of 50th Anniversary Issue

The 14 papers in this issue (Table 3) summarize current knowledge on a wide range of topics ranging from innovations on core questions in paleobiology to application of knowledge on issues of societal relevance. In the ensuing discussion, the papers are grouped into six loose themes: space and time dynamics, intrinsic macroevolutionary processes, Earth–life interactions, ecosystem origins, morphology and phylogenetics, and data equity.

### *Space and Time Dynamics*

Paleontological data (taxa, traits, occurrences) are unique in that they are centered in both space and geologic time. These data provide essential information on long-term ecological and evolutionary processes, but also on spatial and temporal variations in preservation and so present unique challenges.

The critical need to predict the fate of species in response to current and future climate change has pressed ecologists to explore past species under different climate scenarios to understand a fuller

**Table 2.** Table of contents for the 25th anniversary issue of *Paleobiology* (2000, Vol. 26 supplement)



**Table 3.** Table of contents for the 50th anniversary issue of *Paleobiology* (2025, Vol. 51)



range of environmental controls on ecosystem structure and function. Blois et al. (2025) survey the application of environmental niche models (ENMs) to occurrences of fossil species. Using data from fossils introduces unique issues and concerns about data quality, so it is not surprising that most paleoENM studies have been based in the Quaternary, although paleoENMs have been applied to ecosystems as far back as the Ordovician (Stigall 2023). Despite these challenges, paleoENMs have been used in a variety of paleobiogeographic studies to determine range shift through time, infer spatially explicit population dynamics, and evaluate factors responsible for speciation, extinction, and niche change, as well as in conservation paleobiogeography. The authors identify incorporating traits and phylogenetics into paleoENM studies as especially fruitful future directions.

Preservation of soft tissue provides a wealth of information on components of ecosystems that are rarely preserved. For example, exceptional preservation can inform phylogenetic studies with rarely observed character traits, extend the stratigraphic ranges of poorly preserved taxa, and reveal local diversity of taxa usually not preserved. Although these deposits with exceptional preservation, or Lagerstätten, occur in all environments and throughout the geologic column, some types of preservation are restricted to specific intervals of time. Gaines and Droser (2025) explore these deposits with a focus on two modes of preservation known only from the Ediacaran and early Cambrian. Ediacaran-type preservation required early lithification of the seafloor by silica cements preserving the Ediacaran assemblages as molds. Burgess Shale–type preservation resulted from early calcite cementation of the seafloor restricting oxidation and microbial activity, thus preserving soft tissues. Early calcite cementation may have been aided by an abundance of kaolinite helping to preserve the soft tissue. The authors argue that the chemical conditions that led to this style of preservation may have also helped to drive diversification by providing nutrients to stimulate productivity and other dissolved compounds to enhance biomineralization.

Many of the frontline questions in paleobiology today, such as the causes and timing of mass extinctions and their recoveries, require knowing how to interpret stratigraphic occurrences of fossils. Stratigraphic paleobiology, the application of modern stratigraphic methods to the study of fossil occurrences, provides this knowledge, and much of the early work in this area appeared in *Paleobiology* (Jablonski 1980; Holland 1995, 2000). Holland et al. (2025) summarize the developments in this field and outline fruitful new directions. Much of the early work was done in marine systems, but studies in terrestrial deposits are just beginning and show great promise (Holland and Loughney 2021). Beyond the study of mass extinctions and recovery, stratigraphic paleobiological concepts form the basis for investigation of many other important questions such as the partitioning of diversity in regional ecosystems, the stability of ecological niches, and studies of morphological evolution. New areas where stratigraphic paleobiological approaches are expected to have impact are climate change studies, the interpretation of geochemical proxies related to biotic change, more realistic sampling models for phylogenetic analyses, and assessments of the large-scale structure of the fossil record.

## *Intrinsic Macroevolutionary Processes*

Revisiting multilevel selection in macroevolution, Simpson et al. (2025) highlight common misconceptions and provide a way forward. If the average fitness of a group is just the mean of the fitness of its constituents, there would be no place for a selection process to operate differently at different levels, nor would there be the concept of emergent fitness. The authors return to an old idea of "expansion" introduced by Van Valen (1973 and other papers). They use it to explain how expansion at one level (like colony size in bryozoans or somatic cell numbers in *Volvox* colonies) may reflect fitness independent of individual member reproduction. Defining fitness as a vector rather than a particular fixed value is a key contribution of this paper to enhancing macroevolutionary theory.

The role of competition in driving macroevolutionary trends has a long history in paleobiology (Van Valen 1973; Sepkoski 1978, 1979). Liow and Quental (2025) summarize the state of understanding for how interspecies interactions—like competition, predation, and mutualism—can drive diversification, geographic distribution shifts, and trait evolution over time. By reviewing studies of these dynamics, the authors argue that the fossil record uniquely informs long-term evolutionary impacts of such interactions, which are impossible to derive from neontological studies. However, common approaches to establish biotic interactions using the fossil record are deemed inadequate. Liow and Quental (2025) encourage cross-disciplinary approaches that combine ecological theory, paleontology, and advanced statistical methods to achieve a more holistic view of the interplay of biotic and abiotic factors that shape biodiversity and trait evolution in deep time.

Jablonski and Edie (2025) review the evolutionary consequences of mass extinctions. The authors argue that mass extinctions, while catastrophic in erasing large swaths of taxonomic diversity, often allowed functional diversity to persist. Nevertheless, mass extinctions have substantial macroevolutionary consequences. Global biodiversity will eventually rebound, but in an unprecedented new world such that "recovery" is seen as a misnomer in the context of mass extinctions. The variable postextinction fate of surviving lineages has long been a matter of intense research. Jablonski and Edie (2025) provide a succinct yet comprehensive review of suggested reasons for these possible evolutionary fates, among which what they call "fatal attractors" is perhaps the most promising. "Fatal attractor" refers to the concept that the short-term ecological benefit of some traits may starkly contrast with long-term evolutionary vulnerabilities. A better integration of near-time and deep-time fossil records is the way forward to solve this and similar issues on the variable outcomes of mass extinctions.

## *Earth–Life Interactions*

Kiessling et al. (2025) stress the potential contribution of deep-time paleontological data to understanding climate-induced impacts on the biosphere. Focusing on ancient so-called hyperthermal events, the authors emphasize the need to focus more strongly on effect sizes and uncertainties to inform conservation strategies amid the current climate and biodiversity crises. They also highlight the importance of understanding context and scale dependency in biological responses to climate changes and the interplay of warming, ocean acidification, and deoxygenation as key drivers of past extinctions. The most germane research challenges identified by Kiessling et al. (2025) are (1) the different timescales over which climate impacts are observed today and in the geologic past and (2) the time gap in observed responses between 100 and 10,000 years. Bridging these gaps is key to making deep-time paleontological data more comparable with and thus relevant for modern climate-impact research.

Using elasmobranchs (sharks, rays, and skates) as a model, Dillon and Pimiento (2025) provide a primer on how paleobiological research can align with conservation priorities. Conservation paleobiology is becoming the main applied branch of paleontology, but there are still few case studies. The authors outline four key research topics where paleobiological insights can contribute to elasmobranch conservation: (1) establishing historical baselines for elasmobranch abundances, (2) understanding the ecological roles of species, (3) identifying the threats they face, and (4) aligning research with current conservation priorities. Dillon and Pimiento argue that geohistorical records can provide critical long-term perspectives that extend beyond contemporary observations, helping to set realistic conservation targets and informing effective management strategies. One particularly relevant section refers to the use of fossil data to inform the IUCN Red List of endangered

https://doi.org/10.1017/pab.2025.4 Published online by Cambridge University Press

species by finding ecological and life-history correlates of empirical extinctions.

### *Ecosystem Origins*

Porter et al. (2025) revisit the early diversification of eukaryotes, to which nearly all preserved body fossils belong. The authors challenge the widely accepted idea that eukaryotes underwent a rapid diversification during the Tonian Period in the Neoproterozoic. They present a new analysis of Proterozoic eukaryote diversity that reveals a strong correlation between the number of eukaryote species found and the number of formations studied. Based on this, Porter et al. (2025) argue that the perceived Tonian radiation might be an artifact of increased sampling, suggesting we are still only beginning to understand the true history of early eukaryotes. The authors encourage a shift in focus toward better exploring the Proterozoic fossil record to gain a more accurate picture of eukaryotic diversification.

Mitchell and Pates (2025) take a fresh look at the Precambrian/Cambrian boundary to discuss the most plausible drivers for this key time of early animal diversification. The authors explore the diversification of animal body plans, feeding strategies, and ecological interactions over the 75 Myr period from the middle Ediacaran into the middle Cambrian. Their analysis emphasizes the increasing complexity of ecosystems, transitioning from early Ediacaran communities dominated by passive filter feeders to the Cambrian, where a more structured, niche-driven system with specialized predators, prey, and ecosystem engineers emerged. Mitchell and Pates (2025) highlight key ecological innovations such as biomineralization, bioturbation, and the emergence of complex food webs, ultimately laying the foundation for the complex biosphere we see today. An avenue of future research may be in the delay between the advent of a novelty such as predation and the establishment of complex predation-structured food webs.

When and how did life conquer land? Boyce and Nelsen (2025) synthesize information on terrestrialization across the tree of life and reveal potential cause–effect relationships in the evolution of life on land. Tackling not just plants and animals but also microbes and fungi, the authors highlight that all organisms initially inhabited the soil. Only when habitat providers such as plants provided opportunities could animals take advantage of these opportunities and evolve, for example, deeper borrowing and flight. The soil fauna has remained essentially constant since the Devonian at high taxonomic levels. Turnover and rapid radiation is only evident for those clades that made it out of their soil homes. The first step toward this extra-soil evolution was the invention of efficient herbivory, which is a major challenge because of the skewed nutrient ratios in plants. Depending on the definition of terrestrialization, the process may have been completed by the Devonian or is still ongoing if we consider pulmonate snails and brachyuran crabs. Boyce and Nelsen (2025) argue that this ongoing terrestrialization may have been facilitated by increased productivity on land partly driven by the emergence of angiosperms.

### *Morphology and Phylogenetics*

Quantifying morphology to study evolutionary trends, phylogenetic relationships, and how organisms interact with their environment has been an enduring theme of paleobiology for more than a century. Advances in this field have tended to track technological innovations, and Goswami and Clavel (2025) argue that the field is on the brink of another technological inflection point driven by the ability to rapidly create massive datasets of 3D imagery of fossils and to unleash artificial intelligence to find structure in the data. This new field of "evolutionary phenomics" promises several orders of magnitude increase in data density on hundreds of thousands of specimens for analysis. The authors summarize advances in quantifying morphology, morphospace analysis, phylogenetic comparative methods, and modeling expectations of disparity with different evolutionary models, pulling examples of their own work on mammal skull evolution (Goswami et al. 2022) and on linking morphological models with climate variables through time. These studies highlight the potential to join these methods with evolutionary phenomics.

Recent progress in building phylogenetic relationships has come from using Bayesian inference to estimate the joint posterior probability of the phylogeny, divergence times, and rates of speciation, extinction, and sampling for fossil and extinct taxa. This approach is called the fossilized birth–death (FBD; Heath et al. 2014) process, which builds on the models of cladogenesis in Raup (1985) and is most often applied to datasets that include extinct and extant taxa but can also be applied to completely extinct groups (Wright 2017; Congreve et al. 2021). Mulvey et al. (2025) review the application of FBDs over the last decade, introduce Bayesian inference used in FBDs, and explicitly discuss the unique issues presented by the fossil record. Future challenges include developing more realistic sampling models that reflect the structure of the fossil record and incorporating variable rates of morphological trait evolution. Both challenges require paleobiologists and model developers to work together to build the next generation of more realistic models.

### *Data Equity*

Access to scientific knowledge, including the data used to generate that knowledge, should be openly available for all to use and interrogate. Paleobiological data pose specific challenges to accessibility, because they take so many forms, such as physical specimens housed in collections, electronic databases compiled from published scientific literature, and increasingly, high-density 3D scans of fossil specimens. Dunne et al. (2025) summarize the issues surrounding data equity in paleobiology that include not only the preservation, curation, and access of paleobiological data, but also the ethical collection and handling of the data. Most importantly, they provide a list of recommended actions for individuals and research teams, institutions, academic publishers and journal editors, and professional societies to improve data equity in the future. Of the many issues that they mention, open access in publishing is one area where professional societies and publishers can have a big impact. It is worth noting that with this issue of *Paleobiology* and moving forward into the future, all issues will be published as fully open access. Please see the *Paleobiology* page on the Cambridge Core website for details.

## Final Thoughts

A common attribute of all contributions to this anniversary issue is that they highlight the strengths of the fossil record to address significant questions in macroevolution and evolutionary paleoecology. Many of the contributions address fundamental questions about the history of life that relied on foundational work published in *Paleobiology.* They all point to promising research directions and the need for interdisciplinary research. Indeed, a quick glance at the number of authors per article of the past anniversary issues compared with this one show that the average number of authors per article has increased over time, which reflects a trend across science but also the growing interdisciplinary nature of paleobiological research.

One new theme in several of the 50th anniversary contributions is that paleobiology is now addressing issues of societal relevance. The latest IPCC report (IPCC 2022) included insights from the deep-time fossil record, and Kiessling et al. (2025) identify research directions where the deep-time record can provide more relevant information. Paleobiological data are relevant for conservation issues but is often misaligned with specific conservation needs. Dillon and Pimiento (2025) argue that conservation paleobiologists should collaborate with other disciplines so that relevant paleobiological data can be integrated with complementary data to address specific conservation needs. Finally, policy makers and the public rely on the scientific community to provide data they can easily access and trust, and data quality and equity is an essential step in this endeavor (Dunne et al. 2025).

Although it was not possible to review all the exciting research areas in paleobiology today, the papers in this 50th anniversary issue demonstrate the vigor of the field (see also Jablonski and Shubin 2015) and point to many exciting future research directions that are sure to appear in *Paleobiology*.

**Acknowledgments.** We wish to thank the authors of the special issue papers for meeting deadlines and sharing their views of the past and future of *Paleobiology*. We also thank the following editors of *Paleobiology* (J. Crampton, K. Boyce, N. Fröbisch, E. Saupe, M. Hopkins) who supported us as special coeditors of this volume.

**Competing Interests.** The authors declare no competing interests.

## Literature Cited

**Alroy, J., P. L. Koch, and J. C. Zachos**. 2000. Global climate change and North American mammalian evolution. Pp. 259–288 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Alvarez, L. W., W. Alvarez, F. Asaro, and H. V. Michel**. 1980. Extraterrestrial cause for the Cretaceous–Tertiary extinction. *Science* **208**:1095–1108.

**Behrensmeyer, A. K., and S. M. Kidwell**. 1985. Taphonomy's contributions to paleobiology. *Paleobiology* **11**:105–119.

**Behrensmeyer, A. K., S. M. Kidwell, and R. A. Gastaldo**. 2000. Taphonomy and paleobiology. Pp. 103–147 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Blois, J. L., A. M. Bellvé, M. A. Jarzyna, E. E. Saupe, and V. J. P. Syverson**. 2025. Paleobiogeographic insights gained from ecological niche models: progress and continued challenges. *Paleobiology* **51**:8–28.

**Boyce, C. K., and M. P. Nelsen**. 2025. Terrestrialization: towards a shared framework for ecosystem evolution. *Paleobiology* **51**:174–194.

**Briggs, D. E. G., R. P. Evershed, and M. J. Lockheart**. 2000. The biomolecular paleontology of continental fossils. Pp. 169–193 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Congreve, C. R., M. E. Patzkowsky, and P. J. Wagner**. 2021. An early burst in brachiopod evolution corresponding with significant climatic shifts during the Great Ordovician Biodiversification Event. *Proceedings of the Royal Society B* **288**:20211450.

**Dillon, E. M., and C. Pimiento**. 2025. Aligning paleobiological research with conservation priorities using elasmobranchs as a model. *Paleobiology* **51**: 112–131.

**Dunne, E. M., D. Chattopadhyay, C. D. Dean, E. M. Dillon, P. L. Godoy, J. A. Smith, and N. Raja**. 2025. Data equity in paleobiology: progress, challenges, and future outlook. *Paleobiology* **51**:237–249.

**Eldredge, N., and S. J. Gould**. 1972. Punctuated equilibria: an alternative to phyletic gradualism. Pp. 82–115 *in* T. J. M. Schopf, ed. *Models in Paleobiology*. Freeman, Cooper, San Francisco.

**Eldredge, N., and M. J. Novacek**. 1985. Systematics and paleobiology. *Paleobiology* **11**:65–74.

**Fisher, D. C.** 1985. Evolutionary morphology: beyond the analogous, the anecdotal, and the ad hoc. *Paleobiology* **11**:120–138.

**Foote, M.** 2000. Origination and extinction components of taxonomic diversity: general problems. Pp. 74–102 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Gaines, R. R., and M. L. Droser**. 2025. Fossil Lagerstätten and the enigma of anactualistic fossil preservation. *Paleobiology* **51**:29–43.

**Gingerich, P. D.** 1985. Species in the fossil record: concepts, trends, and transitions. *Paleobiology* **11**:27–41.

**Goswami, A., E. Noirault, E. J. Coombs, J. Clavel, A.-C. Fabre, T. J. D. Halliday, M. Churchill**, et al. 2022. Attenuated evolution of mammals through the Cenozoic. *Science* **378**:377–383.

**Goswami, A., and J. Clavel**. 2025. Morphological evolution in a time of phenomics. *Paleobiology* **51**:195–213.

**Gould, S. J.** 1985. The paradox of the first tier: an agenda for paleobiology. *Paleobiology* **11**:2–12.

**Heath, T. A., J. P. Huelsenbeck, and T. Stadler**. 2014. The fossilized birth-death process for coherent calibration of divergence-time estimates. *Proceedings of the National Academy of Sciences USA* **111**:E2957–E2966.

**Holland, S. M.** 1995. The stratigraphic distribution of fossils. *Paleobiology* **21**: 92–109.

**Holland, S. M.** 2000. The quality of the fossil record: a sequence stratigraphic perspective. Pp. 148–168 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Holland, S. M., and K. M. Loughney**. 2021. *The stratigraphic paleobiology of nonmarine systems*. Elements of Paleontology. Cambridge University Press, Cambridge.

**Holland, S. M., M. E. Patzkowsky, and K. M. Loughney**. 2025. Stratigraphic paleobiology. *Paleobiology* **51**:44–61.

**IPCC**. 2022. *Climate change 2022: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC)*, edited by H.-O. Pörtner, D. C. Roberts, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Algería, M. Craig, S. S. L. Langdorf, V. Möller, and B. Rama. Cambridge University Press, Cambridge.

**Jablonski, D.** 1980. Apparent versus real biotic effects of transgressions and regressions. *Paleobiology* **6**:397–407.

**Jablonski, D.** 2000. Micro- and macroevolution: scale and hierarchy in evolutionary biology and paleobiology. Pp. 15–52 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Jablonski, D., and S. Edie**. 2025. Mass extinctions and their rebounds: a macroevolutionary framework. *Paleobiology* **51**:83–96.

**Jablonski, D., and N. H. Shubin**. 2015. The future of the fossil record: paleontology in the 21st century. *Proceedings of the National Academy of Sciences USA* **112**:4852–4858.

**Jablonski, D., K. W. Flessa, and J. W. Valentine**. 1985. Biogeography and paleobiology. *Paleobiology* **11**:75–90.

**Jackson, J. B. C., and K. G. Johnson**. 2000. Life in the last few million years. Pp. 221–235 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Jackson, S. T., and J. T. Overpeck**. 2000. Responses of plant populations and communities to environmental changes of the late Quaternary. Pp. 194–220 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Kiessling, W., C. Reddin, E. Dowding, D. Dimitrijević, N. Raja, and Á. Kocsis**. 2025. Marine biological responses to abrupt climate change in deep time. *Paleobiology* **51**:97–111.

**Kitchell, J. A.** 1985. Evolutionary paleoecology: recent contributions to evolutionary theory. *Paleobiology* **11**:91–104.

**Knoll, A. H.** 1985. Patterns of evolution in the Archean and Proterozoic Eons. *Paleobiology* **11**:53–64.

**Knoll, A. H., and R. K. Bambach**. 2000. Directionality in the history of life: diffusion from the left wall or repeated scaling of the right? Pp. 1–14 *in* D. H. Erwin and S. L. Wing, eds. Deep time: *Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Liow, L. H., and T. B. Quental**. 2025. Biotic interactions and their consequences for macroevolution: learning from the fossil record and beyond. *Paleobiology* **51**: 71–82

**Miller, A. I.** 2000. Conversations about Phanerozoic global diversity. Pp. 53–73 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Miller, A. I.** 2009. The consensus that changed the paleobiological world. Pp. 364–384 *in* D. Sepkoski and M. Ruse, eds. *The paleobiological revolution: essays on the growth of modern paleontology*. University of Chicago Press, Chicago.

**Mitchell, E. G., and S. Pates**. 2025. From organisms to biodiversity: the ecology of the Ediacaran/Cambrian transition. *Paleobiology* **51**:150–173.

**Mulvey, L. P. A., M. C. Nikolic, B. J. Allen, T. A. Heath, and R. C. M. Warnock**. 2025. From fossils to phylogenies: exploring the integration of paleontological data into Bayesian phylogenetic inference. *Paleobiology* **51**: 214–236.

**Niklas, K. J.** 2000. Modeling fossil plant form-function relationships: a critique. Pp. 289–304 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Norris, R. D.** 2000. Pelagic species diversity, biogeography, and evolution. Pp. 236–258 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Plotnick, R. E., and T. K. Baumiller**. 2000. Invention by evolution: functional analysis in paleobiology. Pp. 305–323 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Porter, S.**, **L. A. Riedman**, **C. R. Woltz**, **D. A. Gold, and J. B. Kellogg**. 2025. Early eukaryote diversity: a review and a reinterpretation. *Paleobiology* **51**: 132–149.

**Raup, D M.** 1975. Taxonomic survivorship curves and Van Valen's law. *Paleobiology* **1**:82–96.

**Raup, D. M.** 1985. Mathematical models of cladogenesis. *Paleobiology* **11**:42–52.

**Raup, D. M., S. J. Gould**, **T. J. M. Schopf, and D. S. Simberloff**. 1973. Stochastic models of phylogeny and the evolution of diversity. *Journal of Geology* **81**: 525–542.

**Sepkoski, D.** 2012. *Rereading the fossil record: the growth of paleobiology as an evolutionary discipline*. University of Chicago Press, Chicago.

**Sepkoski, J. J.** 1978. A kinetic model of Phanerozoic taxonomic diversity I. Analysis of marine orders. *Paleobiology* **4**:223–251.

**Sepkoski, J. J.** 1979. A kinetic model of Phanerozoic taxonomic diversity II. Early Phanerozoic families and multiple equilibria. *Paleobiology* **5**: 222–251.

**Sepkoski, J. J., R. K. Bambach**, **D. M. Raup, and J. W. Valentine**. 1981. Phanerozoic marine diversity and the fossil record. *Nature* **293**:435–437.

**Simpson, C., A. Halling, and S. Leventhal**. 2025. Levels of selection and macroevolution in organisms, colonies, and species. *Paleobiology* **51**: 62–70.

**Shubin, N. H., and C. R. Marshall**. 2000. Fossils, genes, and the origin of novelty. Pp. 324–340 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Stanley, S. M.** 1975. A theory of evolution above the species level. *Proceedings of the National Academy of Sciences USA* **72**:646–650.

**Stanley, S. M.** 1985. Rates of evolution. *Paleobiology* **11**:13–26.

**Stigall, A. L.** 2023. A review of the Late Ordovician (Katian) Richmondian Invasion of eastern Laurentia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **618**:111520.

**Valentine, J. W.** 1973. *Evolutionary paleoecology of the marine biosphere*. Prentice Hall, Englewood Cliffs, N.J.

**Valentine, J. W.** 2009. The infusion of biology into paleontological research. Pp. 365–397 *in* D. Sepkoski and M. Ruse, eds. *The paleobiological revolution: essays on the growth of modern paleontology*. University of Chicago Press, Chicago.

**Van Valen, L.** 1973. A new evolutionary law. *Evolutionary Theory* **1**:1–30.

**Wagner, P. J.** 2000. Phylogenetic analyses and the fossil record: tests and inferences, hypotheses and models. Pp. 341–371 *in* D. H. Erwin and S. L. Wing, eds. Deep time*: Paleobiology*'s perspective. Paleontological Society, Lawrence, Kans.

**Wright, D. F.** 2017. Bayesian estimation of fossil phylogenies and the evolution of early to middle Paleozoic crinoids (Echinodermata). *Journal of Paleontology* **91**:799–814.