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Title: The spatial structure of Phanerozoic marine animal diversity

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Abstract: The “global” fossil record of marine animals has fuelled long-standing debates about diversity change through time, and its drivers. However, the fossil record is not truly global: it varies considerably in geographic scope and in sampling of environments among intervals. We address this using a spatially-explicit approach to quantify regional-scale diversity through the Phanerozoic. Among-region variation in diversity is comparable to variation through time, and much of this is explained by environmental factors, particularly the extent of reefs. In contrast, influential hypotheses of diversity change through time, including sustained long-term increases, have little explanatory power. Modelling the spatial structure of the fossil record transforms interpretations of Phanerozoic diversity patterns and their macroevolutionary explanations. This necessitates a refocus of deep-time diversification studies.

One Sentence Summary: Phanerozoic marine diversity shows weak time effects.

Main Text:

The fossil record of Phanerozoic marine biodiversity has long been a model system for understanding animal diversification through deep time (*1-6*). Numerous hypotheses have been proposed to explain these patterns. Some invoke long-term environmental change (*7-9*) or tectonic drivers (*10*), while others emphasize time-dependent processes, ranging from unconstrained, exponential diversification (*3*, *11*) to diversity-dependent diversification constrained by biotic interactions (*2*, *5*, *12*). Inferred diversity patterns may also reflect fossil record structure, including geological factors such as rock amount (*13*) and lithification trends (*4*), or research practices, such as sampling variation resulting from research interest or taxonomic culture (*4*, *5*). However, there is little consensus about the relative importance of the many factors invoked by these hypotheses (*3-5*, *7*, *10*, *13*, *14*).

We argue that the spatial structure of the fossil record is one of the most influential factors affecting interpretations of diversity dynamics in deep time. Previous studies have acknowledged this problem but have not explicitly corrected for it (*4*, *6*). The “global” fossil record, as currently documented, is not truly global (*4*, *15-17*). There is substantial variation through geological time in the numbers, sizes, and locations of spatial regions from which fossils have been reported. Therefore, nominally “global” diversity estimates among intervals of geological time derive from different points on their respective species-area curves, introducing a confounding source of variation. Controlling for sampling intensity alone does not address this (*18*). Indeed, 50–60% of the changes in “global” sampling-standardized genus richness can be explained simply by changes in the geographic spread of fossil localities (Fig. 1C, E). This correlation is unlikely to be driven by changes in habitable area, because changes in shallow-marine sediment extent are not correlated with either "global" fossil taxon counts or the spatial extent of the global fossil record (Figs 1E, F and S1; data sources for environmental covariates are listed in Table S1). Moreover, diversity levels are controlled by factors that have non-random spatial distributions [e.g., latitude and environment (*19*)], but most studies of diversity drivers through time have not explicitly accounted for the spatial distributions of important environmental factors such as the development of reefs (*20*) or epeiric seaways (*9*).

We present a new, spatially-explicit framework to estimate regional-scale diversity patterns through the Phanerozoic, and their relationship to time and environment. We standardized the geographic scale of analysis by drawing sets of fossil localities representing regions of near-uniform spatial extent at multiple different spatial scales. We then conducted spatiotemporally-explicit tests of the influence on inferred diversity of time-dependent processes, local environmental factors, rock record/sampling variables, and research practices. We analyzed fossil occurrence data from the Paleobiology Database (*21*) comprising 396,815 occurrences of 22,855 marine animal genera. Our spatial subsampling algorithm identifies all nested sets of adjacent fossil localities using their paleocoordinates (*22*). From this, we extracted regions with minimum-spanning tree (MST) lengths (*6*) of approximately 1500 km, 2000 km, 2500 km, 3000 km and 3500 km. We estimated genus richness for each spatial region using shareholder quorum subsampling (SQS) (*5*), and additional information such as spatial statistics (e.g., counts of occupied grid-cells) and local environmental parameters (*22*).

Spatially-standardized diversity estimates reveal considerable variation across the globe within each time interval (Fig. 2), which is masked in global diversity curves. Indeed, we find that diversity varies at least as much across spatial regions within intervals as through time (Fig. S2). Our spatial standardization procedure greatly diminishes a Permian peak in diversity that was present in global curves, and which resulted from the broad spatial extent of Permian fossil localities in the Paleobiology Database (Figs 1A, S3, S4). Furthermore, the sustained Mesozoic–Cenozoic global increase in diversity, a seminal feature of global diversity curves (*2*, *23-25*), is transformed into a much more modest, stepwise increase across the Cretaceous/Paleogene (K/Pg) boundary (Figs 2, S5). In agreement with existing sampling-standardized global curves [e.g. (*5*, *6*, *24*)], however, regional diversity is on average higher in the Ordovician–Devonian and Cenozoic and lower in the mid-Paleozoic and early Mesozoic.

Low paleolatitudes (±0–30°) are best-represented during the Paleozoic, while mid paleolatitudes (±30–60°) are better represented during the Mesozoic–Cenozoic, partly due to continental drift (fossil-record sampling is most intense in North America and Europe, and landmasses on average migrated northward over this interval). Low-paleolatitude diversity in the Paleozoic is similar to that of the Neogene (Fig. 2). Mid-paleolatitude diversity is lower than average in the Permian, and higher than average in the Cenozoic. High paleolatitudes (±60–90°) are only informative for a handful of Paleozoic bins, and consistently have low diversity. Results vary only slightly across different spatial standardization criteria (*22*) (Fig. 2).

Major groups of marine invertebrates show pronounced variation in diversity through the Phanerozoic (Fig. 3), showing patterns that generally mirror their respective global curves: bivalves show a pattern of sustained increase through the Phanerozoic (*5*, *26*), but with increasing variance among spatial regions through time. Brachiopods show a very different pattern to bivalves (*5*), with clear evidence of a marked decrease in average diversity across the Permian/Triassic (P/T) boundary. Cephalopods, by contrast, show evidence of higher diversity in the immediate aftermath of the P/T, consistent with global patterns within ammonoids (*27*). Gastropod diversity remained relatively stable across the Paleozoic–Mesozoic, but experienced a sharp fourfold increase in diversity across the K/Pg [cf. a latest Cretaceous increase in global curves (*5*)]; this appears to be the main driver of the modest stepwise increase across the K/Pg within marine animals as a whole.

We used linear mixed-effects models to assess the roles of select environmental, sampling and biotic drivers of diversity change through time and space, evaluated using Akaike's information criterion and model averaging (*22*). We modelled temporal autocorrelation using a continuous-time first order autoregressive correlation structure (*22*). Exploratory analyses suggested that explanations for diversity change through time may differ between low and mid paleolatitudes, which were therefore modeled separately. Insufficient data were available for high paleolatitudes. Our explanatory variables comprise several broad categories (Table S1), including local environmental variables, shallow-marine sediment extent, temporal variables (including exponential diversification through time (*3*, *14*), and categorical variables describing equilibrial diversification phases (*2*) and short-term post-extinction decreases), and variables related to research activity (including sampling variables and modern continental region identity). Modern continental region identity was specified as a random effect to control for geographic variation in research practices (e.g., taxonomic "splitters" vs "lumpers"), and to permit us to model time series autocorrelation (*22*).

The model selection procedure is relatively more decisive for mid than for low paleolatitudes, with fewer models in the confidence set (models receiving an evidence ratio of ≤8; Fig. S6; Tables S2 and S3), and higher average goodness of fit (Table S4). Models incorporating a subset of our explanatory variables receive strongest support for most spatial extents (Table S3). Elevated mid-paleolatitude diversity is robustly associated with the proportion of reefal localities and with counts of references associated with spatial regions (reflecting either research/literature interest, high diversity driving high reference counts, or both; Figs S7, S5); Figs 4 and S8). There is also evidence that shallow marine sediment extent is positively associated with diversity (Fig. 4). Marginal coefficients of modern continental region show that Europe has higher diversity than other regions, perhaps due to variation in research or taxonomic practices (Fig. S9). At low paleolatitudes, shallow marine sediment extent, lithology counts and reference counts are important at many spatial scales (Figs 4 and S8). Overall, however, at low latitudes no single combination of explanatory variables is consistently important across all scales (Table S2). An alternate set of model comparisons including continental fragmentation index (*10*) does not recover a significant role for that variable (see Supplementary Materials: Sensitivity Analyses).

Shallow marine sediment extent, a proxy for global variation in shallow marine habitat area (*28*), is positively related to the diversity of regional-scale assemblages (Fig. 4). This is consistent with the hypothesis that some changes in marine diversity were driven by factors associated with sea level, potentially via species-area effects (*7*, *9*). We also recover strong evidence that reefs are loci of high diversity (Fig. 4). This mirrors the present-day pattern in which reefs are biodiversity hotspots, hosting a disproportionate fraction of marine species (*29*). Therefore, both flooding of continental interiors and expansion and contraction of reefs are likely to drive changes in true global diversity.

Only one temporal variable is included consistently in the best-ranked models explaining marine animal diversity: a parameter differentiating pre-Cenozoic intervals from the Cenozoic (especially at mid-latitudes; Figs 4 and S8); Tables S3–S2). This indicates on average approximately two-fold greater diversity during the Cenozoic compared to earlier intervals (Fig. S10).

No explanatory power can be attributed to the passage of continuous time (age in Ma). Model-averaged parameter estimates for the coefficient of time, which represents the net long-term diversification rate, are not significantly different from zero at either mid (-0.000994–0.000891) or low (-0.000493–0.00246) paleolatitudes at any spatial scale (Fig. 4), indicating lack of support for the hypothesis of sustained exponential background diversification (*3*, *14*). Regressions of diversity solely as a function of time within individual pre-Cenozoic and Cenozoic diversification phases are also non-significant (Fig. S11). Furthermore, we do not find evidence for low diversity immediately following mass extinction events at the timescale of our analysis (bin durations averaging 11 Ma), suggesting that recovery of regional diversity has generally been rapid.

In contrast to the lack of secular temporal trends in Phanerozoic marine animals, individual groups show marked variation in diversity through time (Fig. 3). Ecological limits imposed by finite resources such as energy and space (*30*) provide one intuitive explanation for why highly dynamic patterns within individual groups sum to produce highly constrained net diversity in marine animals throughout the Phanerozoic (excepting a stepwise increase in the early Cenozoic). Zero-sum dynamics could result from direct biotic competition between specific groups or more diffuse competition among multiple clades (*26*), but could also arise via chance.

Patterns of global diversity through time have been the focus of seminal studies in paleobiology, and their implications for macroevolutionary theory have long been debated (*2*-*5*, *11*, *14*, *24*, *25*). Our spatially-explicit analysis provides a different conception, in which variation in regional diversity is partitioned between time- and environment-dependent explanations. Diversity varies by several orders of magnitude among marine environments on Earth today (*19*), and we find it has done so for much of the Phanerozoic. In contrast, we find little evidence for sustained increases in diversity through time. We also cast doubt on the prospect of directly estimating variation in true global diversity. These observations urge scrutiny of the focus on time and time-varying global climate and Earth system parameters in "global" fossil record studies [e.g. (*2*, *7*, *8*, *10*)], although the importance of local environment as a driver of regional diversity indicates that variation in summed global diversity might ultimately result from shifts in Earth's climate and tectonic state. By unmasking the spatial component of variation in diversity – hitherto obscured by global curves – our approach raises new and exciting possibilities for the fossil record to shed light on the historic drivers of biological diversity on Earth.

References and Notes:

1. D. M. Raup, J. J. Sepkoski Jr, Mass extinctions in the marine fossil record. *Science*. **215**, 1501–1503 (1982).
2. J. J. Sepkoski Jr, A kinetic model of Phanerozoic taxonomic diversity. III. Post-Paleozoic families and mass extinctions. *Paleobiology*. **10**, 246–267 (1984).

3. M. J. Benton, B. C. Emerson, How did life become so diverse? The dynamics of diversification according to the fossil record and molecular phylogenetics. *Palaeontology*. **50**, 23–40 (2007).

4. J. Alroy *et al.*, Phanerozoic trends in the global diversity of marine invertebrates. *Science*. **321**, 97–100 (2008).

5. J. Alroy, The shifting balance of diversity among major marine animal groups. *Science*. **329**, 1191–1194 (2010).

6. J. Alroy, Geographical, environmental and intrinsic biotic controls on Phanerozoic marine diversification. *Palaeontology*. **53**, 1211–1235 (2010).

7. B. Hannisdal, S. E. Peters, Phanerozoic Earth System evolution and marine biodiversity. *Science*. **334**, 1121–1124 (2011).

8. P. J. Mayhew, M. A. Bell, T. G. Benton, A. J. McGowan, Biodiversity tracks temperature over time. *PNAS*. **109**, 15141–15145 (2012).

9. S. E. Peters, The problem with the Paleozoic. *Paleobiology*. **33**, 165–181 (2007).

10. A. Zaffos, S. Finnegan, S. E. Peters, Plate tectonic regulation of global marine animal diversity. *PNAS*. **114**, 5653–5658 (2017).

11. J. W. Valentine, Patterns of taxonomic and ecological structure of the shelf benthos during Phanerozoic time. *Palaeontology*. **12**, 684–709 (1969).

12. J. Alroy, Dynamics of origination and extinction in the marine fossil record. *PNAS*. **105 Suppl 1**, 11536–11542 (2008).

13. A. B. Smith, A. J. McGowan, The shape of the Phanerozoic marine palaeodiversity curve: how much can be predicted from the sedimentary rock record of western Europe? *Palaeontology*. **50**, 765–774 (2007).

14. S. M. Stanley, An Analysis of the History of Marine Animal Diversity. *Paleobiology*. **33**, 1–55 (2007).

15. G. J. Vermeij, L. R. Leighton, Does global diversity mean anything? *Paleobiology*. **29**, 3–7 (2003).

16. A. J. McGowan, A. B. Smith, Are global Phanerozoic marine diversity curves truly global? A study of the relationship between regional rock records and global Phanerozoic marine diversity. *Paleobiology*. **34**, 80–103 (2008).

17. D. A. Vilhena, A. B. Smith, Spatial Bias in the Marine Fossil Record. *PLoS ONE*. **8**, e74470 (2013).

18. R. A. Close, S. W. Evers, J. Alroy, R. J. Butler, How should we estimate diversity in the fossil record? Testing richness estimators using sampling-standardised discovery curves. *Methods in Ecology and Evolution*. **28**, 1023–15 (2018).

19. A. G. Fischer, Latitudinal Variations in Organic Diversity. *Evolution*. **14**, 64 (1960).

20. W. Kiessling, C. Simpson, M. Foote, Reefs as cradles of evolution and sources of biodiversity in the Phanerozoic. *Science*. **327**, 196–198 (2010).

21. The Paleobiology Database, (available at http://paleobiodb.org).

22. For further details, see Supplementary Information.

23. M. E. Patzkowsky, Origin and Evolution of Regional Biotas: A Deep-Time Perspective. *Annu Rev Earth Pl Sc*. **45**, 471–495 (2017).

24. A. M. Bush, R. K. Bambach, Sustained Mesozoic–Cenozoic diversification of marine Metazoa: A consistent signal from the fossil record. *Geology*, G37162.1 (2015).

25. A. M. Bush, G. Hunt, R. K. Bambach, Sex and the shifting biodiversity dynamics of marine animals in deep time. *PNAS*. **113**, 14073–14078 (2016).

26. A. I. Miller, J. J. Sepkoski Jr, Modeling bivalve diversification: the effect of interaction on a macroevolutionary system. *Paleobiology*. **14**, 364–369 (1988).

27. A. Brayard *et al.*, Good genes and good luck: ammonoid diversity and the end-Permian mass extinction. *Science*. **325**, 1118–1121 (2009).

28. S. E. Peters, J. M. Husson, Sediment cycling on continental and oceanic crust. *Geology*. **45**, 323–326 (2017).

29. M. L. Reaka-Kudla, in *Biodiversity II*, M. L. Reaka-Kudla, D. E. Wilson, E. O. Wilson, Eds. (Washington, DC, 1997), pp. 83–108.

30. D. L. Rabosky, A. H. Hurlbert, Species richness at continental scales is dominated by ecological limits. *Am. Nat.* **185**, 572–583 (2015).

31. S. E. Peters, M. McClennen, The Paleobiology Database application programming interface. *Paleobiology*, 1–7 (2015).

32. R. B. J. Benson *et al.*, Near-stasis in the long-term diversification of Mesozoic tetrapods. *PLoS Biol.* **14**, e1002359 (2016).

33. A. J. Lagomarcino, A. I. Miller, The Relationship between Genus Richness and Geographic Area in Late Cretaceous Marine Biotas: Epicontinental Sea versus Open-Ocean-Facing Settings. *PLoS ONE*. **7**, e40472 (2012).

34. R. Barnes, dggridR: Discrete Global Grids for R. R package version 0.1.12., (available at https://github.com/r-barnes/dggridR/).

35. T. C. Hsieh, K. H. Ma, A. Chao, iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods in Ecology and Evolution*, 1–6 (2016).

36. I. J. Good, The population frequencies of species and the estimation of population parameters. *Biometrika*. **40**, 237–264 (1953).

37. J. Alroy, Effects of habitat disturbance on tropical forest biodiversity. *PNAS*. **16**, 201611855–16 (2017).

38. R. A. Close, R. B. J. Benson, P. Upchurch, R. J. Butler, Controlling for the species-area effect supports constrained long-term Mesozoic terrestrial vertebrate diversification. *Nat. Commun.* **8**, 15381 (2017).

39. C. R. Scotese, N. Wright, PALEOMAP Paleodigital Elevation Models (PaleoDEMS) for the Phanerozoic. *https://www.earthbyte.org* (2018), (available at https://www.earthbyte.org/webdav/ftp/Data_Collections/Scotese_Wright_2018_PaleoDEM/Scotese_Wright2018_PALEOMAP_PaleoDEMs.pdf).

40. P. A. Allison, D. E. G. Briggs, Paleolatitudinal Sampling Bias, Phanerozoic Species-Diversity, and the End-Permian Extinction. *Geology*. **21**, 65–68 (1993).

41. P. D. Mannion, P. Upchurch, R. B. J. Benson, A. Goswami, The latitudinal biodiversity gradient through deep time. *Trends Ecol. Evol.* **29**, 42–50 (2014).

42. W. Kiessling, Geologic and Biologic Controls on the Evolution of Reefs. *Annu Rev Ecol Evol S*. **40**, 173–192 (2009).

43. S. E. Peters, M. Foote, Biodiversity in the Phanerozoic: a reinterpretation. *Paleobiology*. **27**, 583–601 (2001).

44. S. E. Peters, Environmental determinants of extinction selectivity in the fossil record. *Nature*. **454**, 626–629 (2008).

45. S. E. Peters, Geologic constraints on the macroevolutionary history of marine animals. *PNAS*. **102**, 12326–12331 (2005).

46. S. E. Peters, N. A. Heim, The geological completeness of paleontological sampling in North America. *Paleobiology*. **36**, 61–79 (2010).

47. N. A. Heim, S. E. Peters, Covariation in macrostratigraphic and macroevolutionary patterns in the marine record of North America. *Geo. Society Am. Bull.* **123**, 620–630 (2011).

48. S. E. Peters, N. A. Heim, Macrostratigraphy and macroevolution in marine environments: testing the common-cause hypothesis. *Geol. Soc. London Spec. Publ.* **358**, 95–104 (2011).

49. A. B. Ronov, V. E. Khain, A. N. Balukhovsky, K. B. Seslavinsky, Quantitative analysis of Phanerozoic sedimentation. *Sedimentary Geology*. **25**, 311–325 (1980).

50. M. J. Benton, Diversification and extinction in the history of life. *Science*. **268**, 52–58 (1995).

51. J. J. Wiens, The causes of species richness patterns across space, time, and clades and the role of "ecological limits." *Q. Rev. Biol.* **86**, 75–96 (2011).

52. J. J. Wiens, *Ecology*, in press, doi:10.1111/ele.12503.

53. L. J. Harmon, S. Harrison, Species diversity is dynamic and unbounded at local and continental scales. *Am. Nat.* **185**, 584–593 (2015).

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

55. D. L. Rabosky, Diversity-dependence, ecological speciation, and the role of competition in macroevolution. *Annu Rev Ecol Evol S*. **44**, 481–502 (2013).

56. H. V. Cornell, J. H. Lawton, Species Interactions, Local and Regional Processes, and Limits to the Richness of Ecological Communities: A Theoretical Perspective. *J Anim Ecol*. **61**, 1 (1992).

57. L. H. Liow, T. Reitan, P. G. Harnik, Ecological interactions on macroevolutionary time scales: clams and brachiopods are more than ships that pass in the night. *Ecology*. **18**, 1030–1039 (2015).

58. J. Alroy, Limits to species richness in terrestrial communities. *Ecology*. **53**, 1211–9 (2018).

59. D. M. Raup, Taxonomic Diversity during the Phanerozoic. *Science*. **177**, 1065–1071 (1972).

60. J. Alroy, Accurate and precise estimates of origination and extinction rates. *Paleobiology*. **40**, 374–397 (2014).

61. K. P. Burnham, D. R. Anderson, D. F. Anderson, *Model selection and multimodel inference: a practical information-theoretic approach* (Springer Verlag, 2002).

62. B. S. Cade, Model averaging and muddled multimodel inferences. *Ecology*. **96**, 2370–2382 (2015).

63. A. Gelman, Scaling regression inputs by dividing by two standard deviations. *Statist. Med.* **27**, 2865–2873 (2008).

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Author contributions: RAC, RBJB and RJB conceived the study. MTC contributed to the data set. RAC designed and conducted the analyses, and made the figures. RAC and RBJB wrote the manuscript. All authors provided critical feedback on the text.

Competing interests: The authors declare no competing interests.

Data and materials availability: The fossil occurrence data used in this study were downloaded from the Paleobiology Database (paleobiodb.org) and have been archived, together with all analysis scripts, on Dryad [address to be added upon acceptance for publication].

Supplementary Materials:

Materials and Methods

Figures S1-S19

Tables S1-S8

References (*30-63*)

Main Text Figures

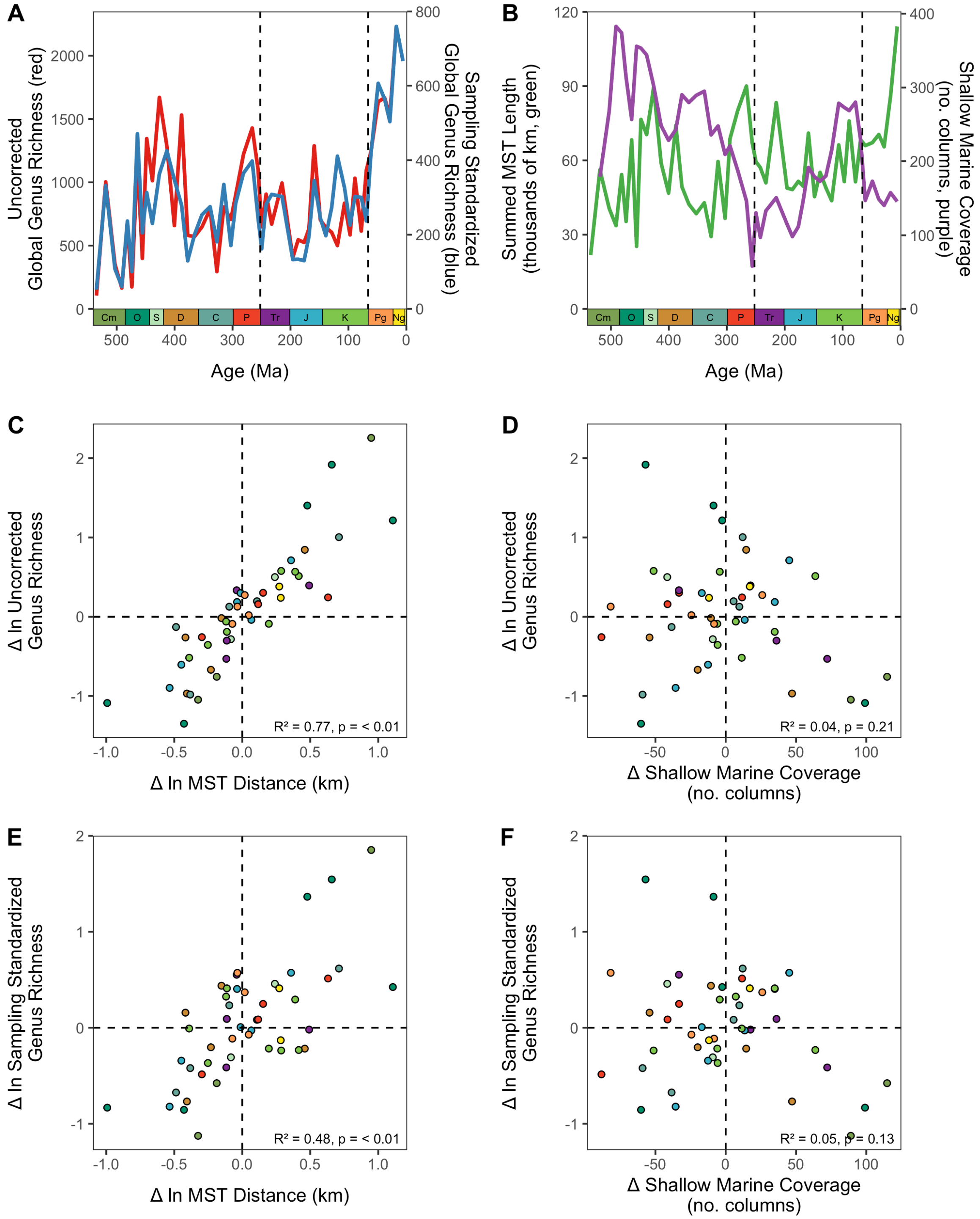

Fig. 1. Correlations between changes in Phanerozoic marine animal diversity (Eumetazoa excluding Tetrapoda) and changes in spatial sampling and habitable area. (A) Uncorrected and sampling standardized (SQS (*5*), quorum = 0.7) "global" genus richness per bin. (B) Spatial sampling (summed minimum-spanning tree [MST] length in km) and habitable area (shallow marine coverage; no. columns). (C) Relationship between spatial sampling and uncorrected

genus richness per interval. (D) Relationship between habitable area (shallow marine coverage, no. columns) and uncorrected genus richness per interval. (E) Relationship between spatial sampling and sampling-standardized (SQS, quorum = 0.7) genus richness per interval. (F) Relationship between habitable area (shallow marine coverage, no. columns) and sampling-standardized (SQS, quorum = 0.7) genus richness per interval. All variables are first-differenced. R2 and p-values derive from linear model fits. For information about variables, see Table S1. Colors of points in panels C–F match colors of geological periods in panels A and B.

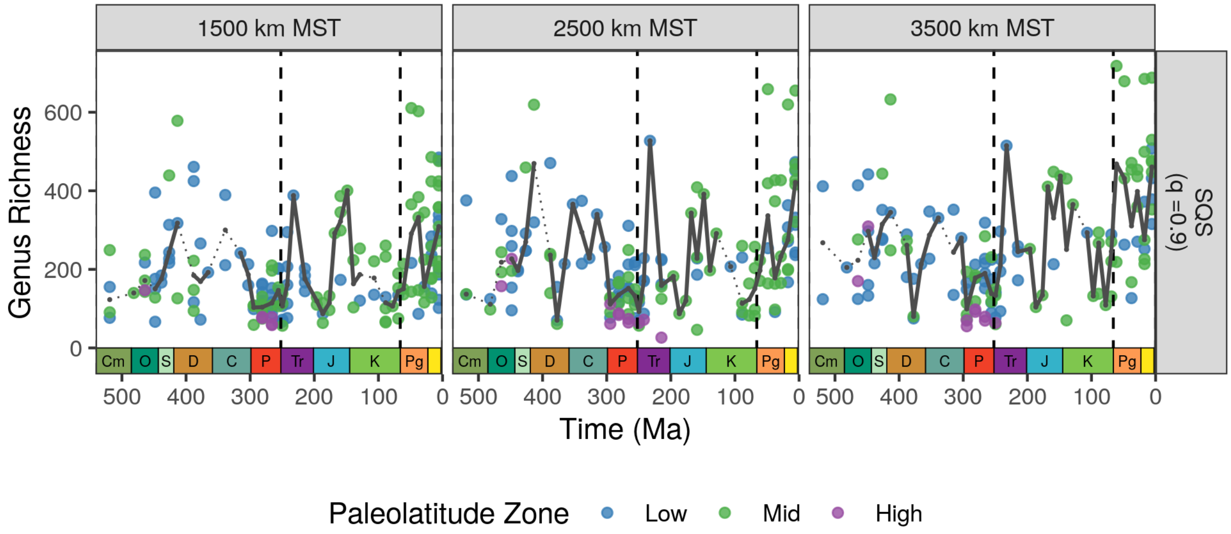

Fig. 2. Spatially-standardized diversity patterns for 1500 km, 2500 km and 3500 km MST lengths. Genus richness estimated using SQS (*5*) (quorum = 0.9). Black lines/points indicate bin-level medians.

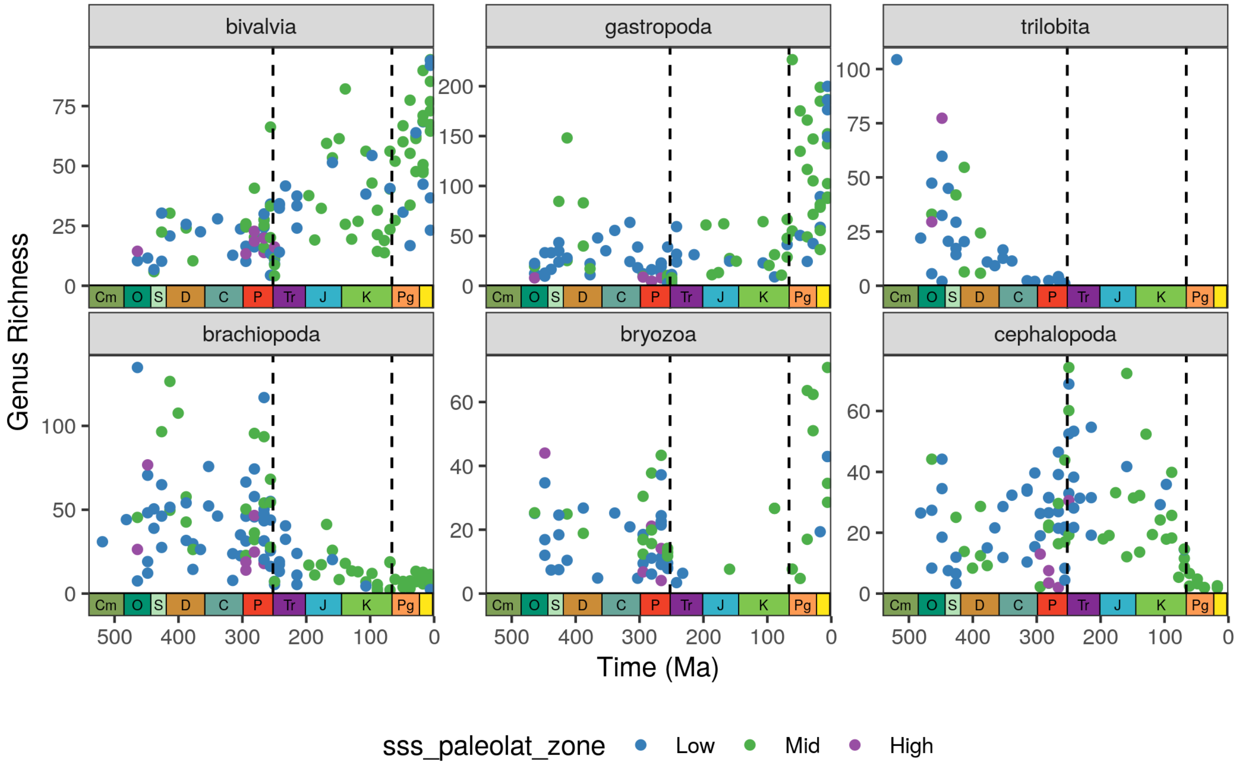

Fig. 3. Spatially-standardized genus richness patterns for selected groups of marine invertebrates at 2000 km MST length. Richness estimated using SQS (*5*) (quorum = 0.8) .

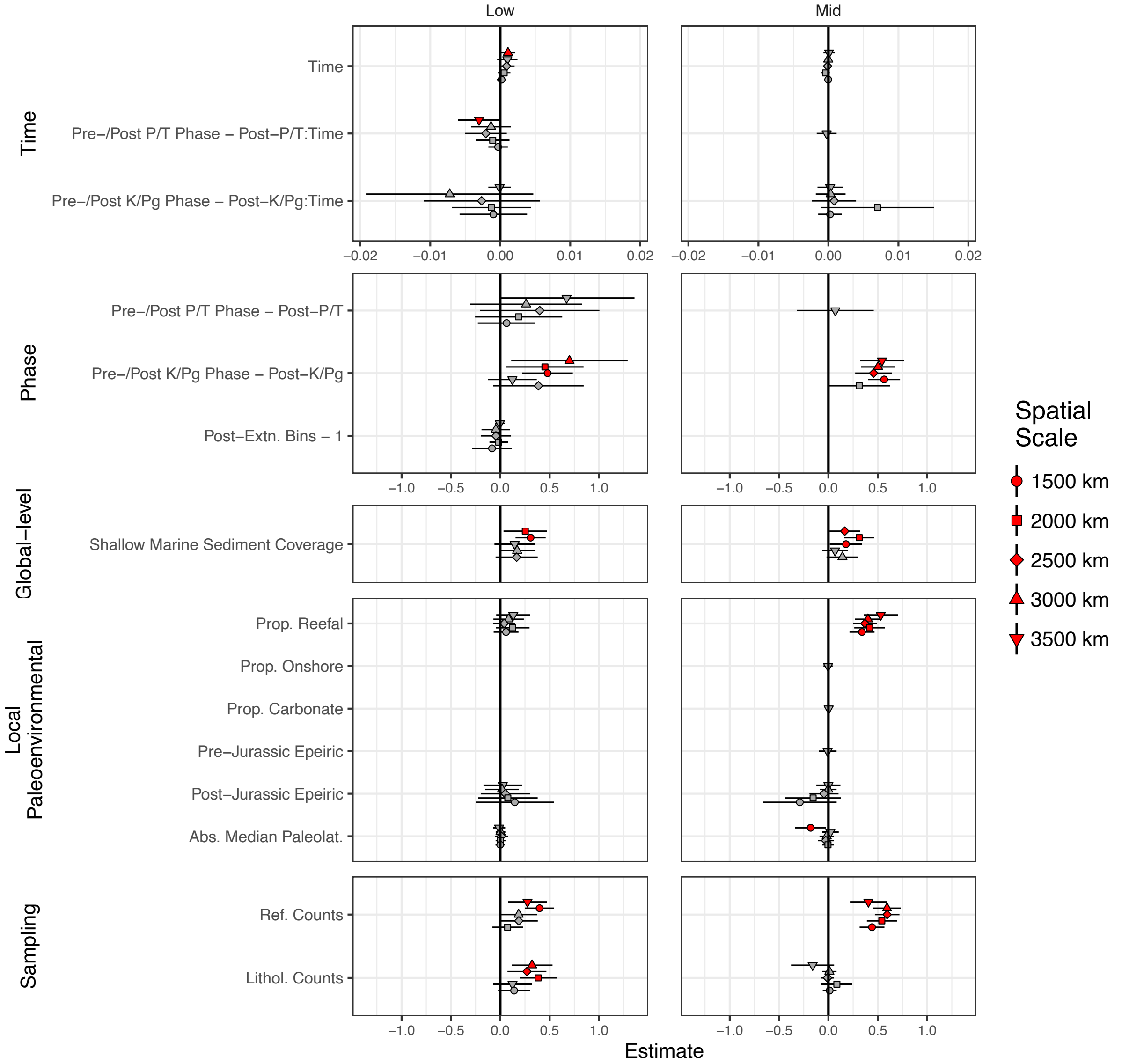

Fig. 4. Model-averaged parameter estimates for coefficients at low and mid paleolatitudes. Models were fitted to spatially-standardized diversity estimates using SQS (quorum = 0.9). See Table S1 for descriptions of explanatory variables. Red points signify estimates that do not overlap with zero; grey points indicate points that do. 5

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Supplementary Materials for

The spatial structure of Phanerozoic marine animal diversity

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Materials and Methods

Fossil occurrence data downloads

Our focal analyses were conducted on Eumetazoa excluding Tetrapoda. We used the Paleobiology Database URL API (*31*) to download fossil occurrence data. All fields were included for marine Eumetazoa excluding Chordata, Chordata excluding Tetrapoda, and Tetrapoda (see supplementary analysis code for URLs used). We restricted downloads to marine environments using the URL API command “envtype=marine”. We also downloaded lists of occurrences (using minimal fields) for marine Bivalvia, Gastropoda, Anthozoa, Trilobita, Brachiopoda, Bryozoa, Crinoidea, Echinoidea, Graptolithina, Conodonta, Cephalopoda and Decapoda. We used the occurrence_no variable in these downloads to filter the main occurrence-data downloads when analyzing specific clades (all occurrences of a taxonomic grouping can be identified using the set of occurrence_nos).

Analyses were conducted at genus level. We restricted occurrences to those that had been identified with certainty to at least genus-level using “idqual=genus_certain” (this is equivalent to excluding occurrences with “aff.”, “ex. gr.”, “sensu lato”, “informal”, question marks or quotation marks). We retained only the latest identification of each occurrence using “idtype=latest”, and we restricted occurrences to valid taxa only using “taxon_status=valid”. We also excluded form taxa and ichnotaxa using “pres=regular”.

Fossil occurrence data cleaning

In line with previous studies of Phanerozoic marine animal diversity [e.g. (*4*, *5*)], occurrences with soft-tissue or original aragonite preservation were excluded. Following Bush and Bambach (*24*), we also excluded occurrences that were replaced with silica. However, results were similar even when not excluding occurrences preserving original aragonite, those replaced with silica, or those coming from unlithified or poorly-lithified-and-sieved deposits (see Supplementary Materials: Sensitivity Analyses). We excluded collections for which geographic scale was designated as basin-level, or stratigraphic scale was designated as group-level. Occurrences lacking paleocoordinates were dropped. Terrestrial and freshwater taxa were excluded using lists of names from Bush and Bambach (*25*). To retain marine tetrapods while excluding non-marine tetrapod taxa, we used lists of names for marine tetrapods for the Mesozoic–Ypresian from Benson et al. (*32*) and for the whole Phanerozoic from Bush and Bambach (*24*), in addition to occurrence numbers obtained from Paleobiology Database downloads for the clades Pinnipedimorpha, Cetacea, Sirenia, Sauropterygia, Ichthyosauromorpha, Mosasauria and Thalattosuchia . Composite time bins with approximately equal temporal durations of ~ 11 myr were created by lumping stage-length intervals, following (*5*). Occurrences were assigned to time bins if their minimum and maximum ages fell entirely within a bin. There were 665,368 occurrences before cleaning, and 396,815 occurrences after cleaning.

Identifying subsampled spatial regions

To standardize the spatial extent from which fossil localities were analyzed, we first identified all nested sets of adjacent spatial points using an algorithm modelled on that of Lagomarcino and Miller (*33*). The algorithm recovers all nested subsets of directly-adjacent spatial points (i.e., points that are closest to each other). The advantages of the spatial subsampling algorithm used here are twofold. Firstly, all spatial regions can be initially found, and an arbitrary and extensible set of statistics and metadata later computed for them. Secondly, spatial regions can be rapidly filtered according to any arbitrary set of criteria, simultaneously standardizing based on a number of variables.

This algorithm works by 1) selecting a spatial point as a starting location; 2) identifying the closest spatial point; 3) saving these two points as a spatial region; 3) identifying the closest point to those two points; 4) saving this set as a spatial region, and 5) continuing this procedure until all spatial points (below a ceiling of 10,000 km maximum great circle distance) have been added. The procedure is then repeated for every possible starting location, and duplicate spatial regions (i.e., those comprising identical sets of spatial points) are discarded. We have implemented this algorithm in our R function findAllNestedSpatialSubsamples() {Dryad citation}.

To reduce the total number of spatial regions – and thus computation time – to a more manageable size, localities were binned within equally-spaced and equal-area hexagonal/pentagonal grid-cells with spacings (i.e., the distance from the center of one grid cell to the next) of 100 km using the R package dggridR (*34*). Those binned grid cells were used as the spatial points in the spatial subsampling algorithm described above.

We computed spatial regions using fossil localities for the most inclusive taxon set (Eumetazoa) which, broadly speaking, reflects sampling opportunities for marine taxa as a whole. For individual taxonomic groups (e.g. bivalves, brachiopods) it could be harder to distinguish spatial bias from evolutionary radiations and declines entailing expansions or contractions of their geographic distributions. For this reason, spatially-standardized diversity estimates for individual taxonomic groups were also made using spatial regions standardized using all marine animal records (i.e., all spatially-standardized diversity for all taxon sets were based on the same set of subsampled spatial regions).

See section "Spatial standardization criteria" (below) for details of how the regions recovered by this algorithm were filtered to standardize the spatial extent of fossil locality sampling at a range of spatial scales.

Variables computed for subsampled spatial regions

Richness

We estimated richness within these spatial regions using shareholder quorum subsampling [SQS (*5*)]. SQS ensures that estimates are based on samples with comparable levels of sample completeness (i.e., the method estimates the number of species found on average within a fixed fraction of individuals from the underlying population, a biologically meaningful measure of diversity). SQS richness was estimated using analytical solutions via the R package iNEXT (*35*), which allows coverage-standardized richness estimates (rarefying by collection) using both interpolation and extrapolation approaches (the latter based on the Chao extrapolator). Diversity was estimated at quorum values (i.e., sample coverage levels) of 0.7, 0.8 and 0.9, but we focus on a quorum of 0.9, which maximizes sample coverage while retaining high availability of spatial regions that meet the target quorum. Extrapolated estimates were discarded if the extrapolated sample size was more than twice that of the reference sample size (*35*). To reduce the sensitivity of SQS to variability in evenness (*18*), we excluded the dominant taxon when estimating diversity, following ref (*5*). We also computed uncorrected (=raw, or face-value) counts of genera, along with two measures of sample completeness [Good's *u* (*36*) and the multiton ratio (*37*)].

Spatial metrics

Spatial metrics include minimum spanning-tree (MST) lengths in km [our focal measure of spatial extent/paleogeographic spread (*6*, *38*)]; occupied grid-cells at a range of sizes [100 km, 200 km, 500 km, 1000 km, 2000 km and 5000 km spacings, calculated using dggridR (*34*)]; "geopacking" (counts of grid-cells per km of MST length); and paleolatitudinal/paleolongitudinal medians and ranges. Each spatial region was also assigned to low, mid or high paleolatitudinal zones based on its median paleolatitude, and to a modern continental region (regions defined in Table S5).

Sampling metrics

Additional sampling variables include counts of occurrences, collections (i.e., fossil localities that have yielded fossil occurrences), distinct lithologies, distinct environmental types, countries and references (i.e., publications that have described the fossil occurrences entered into the Paleobiology Database, defined using the occurrence.reference_no field). These variables were all calculated using fields in the Paleobiology Database downloads.

Local environmental variables

Local environmental variables include proportions of collections with carbonate lithologies [relative to siliciclastic lithologies, following ref (*6*)]; proportions of collections representing reefal paleoenvironments [based on tallies of reefal/non-reefal environments in the environment field of the Paleobiology Database occurrence downloads, following ref (*6*)]; and proportions of collections representing onshore paleoenvironments [based on tallies of onshore vs offshore environments, again following ref (*6*)]. These variables were all calculated exclusively using fields in the Paleobiology Database occurrence downloads. Spatial regions were also designated as representing either epeiric or open-ocean facing environments. Epeiric seas were distinguished from open-ocean-facing environments using the distance to the nearest continental margin (≥700 km). Water depths were calculated using the PALEOMAP Paleodigital Elevation Models (PaleoDEMS) from Scotese and Wright (*39*).

Spatial standardization criteria

Our focal results are based on spatial regions that simultaneously satisfy all of the following requirements: 1) a spatial extent of 1500, 2000, 2500, 3000 and 3500 km MST distance ±10%; 2) a minimum-spanning tree for which the longest branch is less than half of the desired MST length (i.e., the region does not represent two widely-separated clusters of localities with no sampling in-between); 3) at least five occupied grid cells (100 km spacings) per thousand km of MST length, ensuring a minimum level of spatial coverage within each spatial region; 4) at least 15 references per thousand km of MST length, ensuring a minimum level of research effort for each spatial region; 5) at least 20 collections; and 6) a multiton ratio of at least 0.2, ensuring a minimum level of sample completeness. Changing the extent at which spatial sampling is standardized does not substantially change key results.

Spatial clustering procedure

Because our spatial subsampling algorithm recovers all possible nested subsets of directly-adjacent spatial points, many samples will be very similar, perhaps differing by the inclusion or exclusion of only a single spatial point. Including diversity estimates for every spatial region in visualizations and statistical analyses would be problematic due to variable levels of autocorrelation or pseudo-independence between spatial regions. To address this issue, we applied a clustering algorithm to find spatial regions that overlapped substantially in the identities of the collections they contained. For spatial regions that met the current standardization criteria, we 1) calculated a variance-covariance matrix reflecting counts of spatial points shared between spatial regions; 2) severed connections between samples overlapping by less than four spatial points (i.e., changed counts of shared collections to zero; results differ little when spatial regions are clustered together when they share 25% of their spatial points; see "Sensitivity Analyses", below); and then 3) each overlapping set of spatial regions was designated as a distinct spatial cluster (Fig. S12).

All variables that were computed for individual spatial regions (see above) were summarized by spatial cluster, by computing medians and interquartile ranges. Each cluster was designated with the predominant paleolatitudinal zone (low/paleotropical = 0º–30º paleolatitude, mid/paleotemperate = 30º–60º paleolatitude and high = 60º–90º paleolatitude), and the predominant modern continental region.

"Global" analyses

For the "global" dataset, we used iNEXT (*35*) to compute coverage-standardized genus richness, as for subsampled spatial regions (above). We also calculated global, per-bin counts of raw genera (sampled-in-bin and range-through), MST lengths (km), and occupied equal-area grid-cells (global, and broken down by paleolatitudinal zone, hemisphere and continental region), in line with procedures used on subsampled spatial regions (above).

Statistical model comparisons

We performed a set of statistical model comparisons to evaluate some prominent potential drivers of regional-scale marine animal diversity through the Phanerozoic. The full list of explanatory variables included in our model comparisons is given in Table S1. Explanatory variables can be grouped into several broad categories:

Local environmental variables

These vary in both time and space and can be characterized for individual spatial regions. They include absolute median paleolatitude of spatial regions, which is an important proxy for other environmental factors (*4*, *40*, *41*), and proportions of localities derived from reefal versus non-reefal (*6*, *20*, *42*), carbonate versus siliciclastic (*6*, *9*, *43*, *44*), onshore versus offshore (*6*, *9*), and epeiric versus open-ocean facing environments (*44*).

Global indices

These vary in time only. This category only includes shallow marine sediment extent, calculated using the Macrostrat database by Peters and Husson (*28*) (comprising counts of Macrostrat columns with strata of a given age). We use this variable as a proxy for shallow marine habitable area. This variable also provides a test of the common-cause hypothesis, which states that variation in the extent of continental flooding is an important control on both the diversity of marine animals and the extent of the rock record (*13*, *45-48*). The estimate of shallow marine sediment extent derived from Macrostrat (generated using North American and Caribbean data) strongly covaries with the classic estimates of Ronov et al. (*49*) but has considerably finer temporal resolution.

Time-dependent changes in richness, independent of space or environment

These include the passage of time itself, diversification phases, and the occurrence of mass extinction events. The relationship between diversity and time (median ages of each time bin in Ma) tests the importance of expansionist accumulation of lineages (*3*, *50-53*). The coefficient of time in this relationship can represents the net long-term diversification rate (*54*). In contrast, diversification phase variables test the existence of protracted phases of equilibrial diversity dynamics, with most variation in diversity occurring between rather than within phases (*2*, *30*, *55*). Biotic factors hypothesized to produce equilibrial diversity dynamics include community-level interactions between species such as competition (*56-58*), or processes operating at a wider range of scales, such as diversity dependence, the appearance of evolutionary key innovations that enable exploitation of novel ecospace, or mass extinctions, which may reset diversity equilibria (*30*). We compared the fit of multiple diversification phase regimes (including phases separated by the P/T and K/Pg boundaries). Mass extinctions, meanwhile, could reduce diversity on timescales up to 10 million years (the approximate size of time bins used in our analyses). To test this, we constructed a categorical variable for which bins immediately after mass extinctions were scored as 1 and all other bins were scored as 0).

Additional sampling or research biases

Sampling or research bias variables include sampling intensity and publication/literature biases resulting from the non-random focus of researchers on different geographic regions, paleoenvironments or taxonomic groups [including monographic effects (*6*, *59*, *60*) and inflation of singleton counts (*5*, *6*, *18*, *60*)], and varying cultural practices between groups of taxonomists [e.g. "lumpers" vs "splitters" (*59*)]. These biases are difficult to capture adequately, but can be modelled by including modern-day continental region identity as a proxy for scientific/cultural spheres or differing approaches to and maturity of paleontological taxonomy. In our linear mixed-effects models (see below), we specify modern continental region identity as a random effect predominantly because it enabled us to model serial correlation using an autoregressive structure. However, variance in diversity due to research practices can also be regarded as a confounding source of variation, rather than one we wish to directly estimate using fixed effects. In addition to modern continental region identity and reference counts, this category also includes counts of different lithologies or environmental types in each spatial region, calculated using fields in the Paleobiology Database occurrence downloads. Because lithological and environmental diversity are highly collinear, we only included counts of lithologies.

Model fits

The full set of model formulae (see Table S6) was assembled by: 1) using every variable separately as an individual predictor; 2) using all individual variable categories that were defined above (e.g., only local paleoenvironmental variables); and 3) using all possible combinations of these variable categories (e.g., local paleoenvironmental variables + sampling variables). We also constructed post-hoc formulae for each paleolatitudinal zone that only included variables found to be important by model-averaging. Models containing all less-inclusive combinations of these important variables were also run.

To each of these base formulae, we added time, diversification phase (a categorical variable demarcating intervals of time, within which the slope and/or intercepts of the linear model are allowed to vary independently) as a covariate or interaction term with time, and absolute median paleolatitude. To achieve normality, count data (e.g., diversity, counts of references and lithologies) were log-transformed prior to analysis, while proportion data (proportion of onshore/offshore, carbonate/siliciclastic and reefal/not reefal) were transformed using the arcsine of the square or cube roots. Approximately 750 distinct models were fitted to each dataset (i.e., each unique combination of SQS quorum level, spatial scale and paleolatitudinal zone).

We fitted linear mixed-effects models to these formulae using maximum likelihood, via the function lme() in the R package nlme. To address potential issues with modelling relationships between time series, we used a continuous-time first-order autoregressive (corCAR1) correlation structure (a continuous-time autoregressive correlation structure was used specifically because it permits time points with missing data). Because our spatially-explicit data do not represent continuous, unbroken univariate time series, we aggregated the data by modern-day continental region identity and modelled this variable as a random effect, permitting only the intercept to vary. The approach we adopt here does not have the ability to detect any lagged biotic responses to shifting environmental conditions that might exist, and future studies may wish to attempt to address this issue using alternate methods.

Multimodel inference and model averaging

Because Akaike weights for our model comparisons do not tend to conclusively support a single model for each combination of SQS quorum level, spatial scale and paleolatitudinal zone (i.e., the top-ranked models do not have Akaike weights >0.9), we used multimodel inference and model averaging (*61*) to infer Akaike-weighted parameter estimates, via the functions model.sel() and model.avg() in the R package MuMIn. Model-averaged parameter estimates for fixed-effect coefficients were calculated from models with an evidence ratio of ≤16. Evidence ratios indicate the strength of evidence favoring the best-ranked model over each subsequent model, and are equal to the Akaike weight of the best model divided by each lower ranked model

(*61*). To address issues with multicollinearity among explanatory variables, which may affect the scale and sign of model-averaged parameter estimates when interactions are present (*62*), we (1) mean-centered and rescaled all continuous variables by dividing them by twice the standard deviation (*63*) (after transforming to achieve normality, if necessary), and (2) used sum-to-zero contrasts for all non-binary categorical predictors. These procedures ensure that regression coefficients are on the same scale as binary categorical variables (http://atyre2.github.io/2016/09/03/sum-to-zero-contrasts.html; https://statmodeling.stat.columbia.edu/2009/07/11/when_to_standar/). The only variable that was not scaled or mean-centered was time, in order to allow interpretation of the coefficient in terms of the net per-lineage rate of background diversification.

Sensitivity analyses

We ran a set of alternative analyses to test the sensitivity of our results to the choices we made for data cleaning and spatial clustering. These comprise analyses 1) retaining silicified occurrences; 2) retaining original aragonite; 3) a minimal cleaning protocol that retained original aragonite, silicified occurrences, unlithified and poorly-lithified-and-sieved sediments; and 4) a version of our focal analysis that used alternate spatial clustering settings (spatial regions were clustered together if they shared >25% of the same underlying spatial points, rather than four spatial points).

The results of these sensitivity analyses (see Figs S13, S14 and S15) are not substantially different from our focal results, suggesting that our core findings are robust.

We also present an alternate version of the statistical model comparisons analysis. These model comparisons differ from the focal set only by including one additional global-level variable, the continental fragmentation index (supercontinent index) of Zaffos et al. (*10*). This variable quantifies the degree of aggregation or fragmentation of the continents through the Phanerozoic, and is thus low when supercontinents dominate, and high when continents are fragmented. The results of this alternate set of statistical model comparisons do not support a significant role for supercontinent index in explaining patterns of regional-scale marine diversity (Figs S16, S17, S18 and S19, and Tables S7 and S8). Akaike weights for models including supercontinent index were sufficiently high to be included in model-averaged parameter estimates at low paleolatitudes only, and even then estimates strongly overlap with zero, suggesting no significant effect. It is likely that changes in continental fragmentation primarily influence marine biodiversity at larger spatial scales than those examined here, through changes in global faunal provinciality, and total habitable area associated with creation and destruction of coastlines. We have shown that it is not currently possible to directly estimate true global diversity. However, future studies may wish to directly quantify the effects that continental fragmentation and changes in the true distribution of shelf area (and associated shifts in environments) have on marine diversity across multiple spatial scales, and on patterns of faunal provinciality.

Supplementary Figures

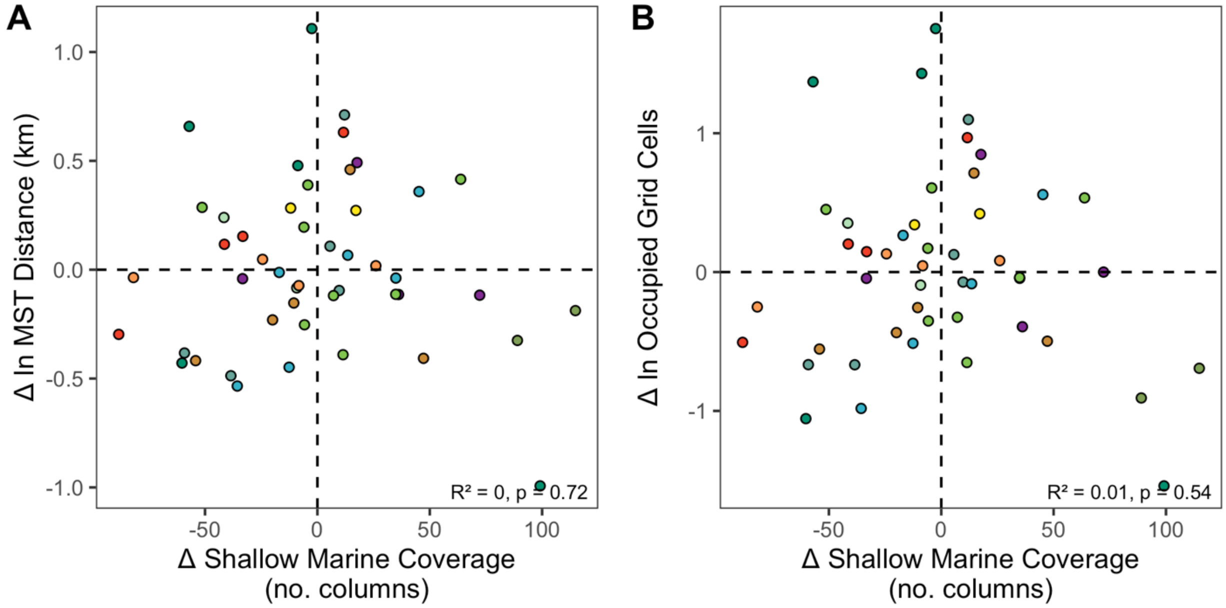

Fig. S1. Bivariate relationships between habitable area and the spatial extent of the "global" fossil record. (A) log-transformed summed MST distance (km). (B) log-transformed counts of occupied grid cells (500 km spacings). Habitable area represented by shallow-marine sediment coverage, derived from Macrostrat [counts of columns (*28*)].

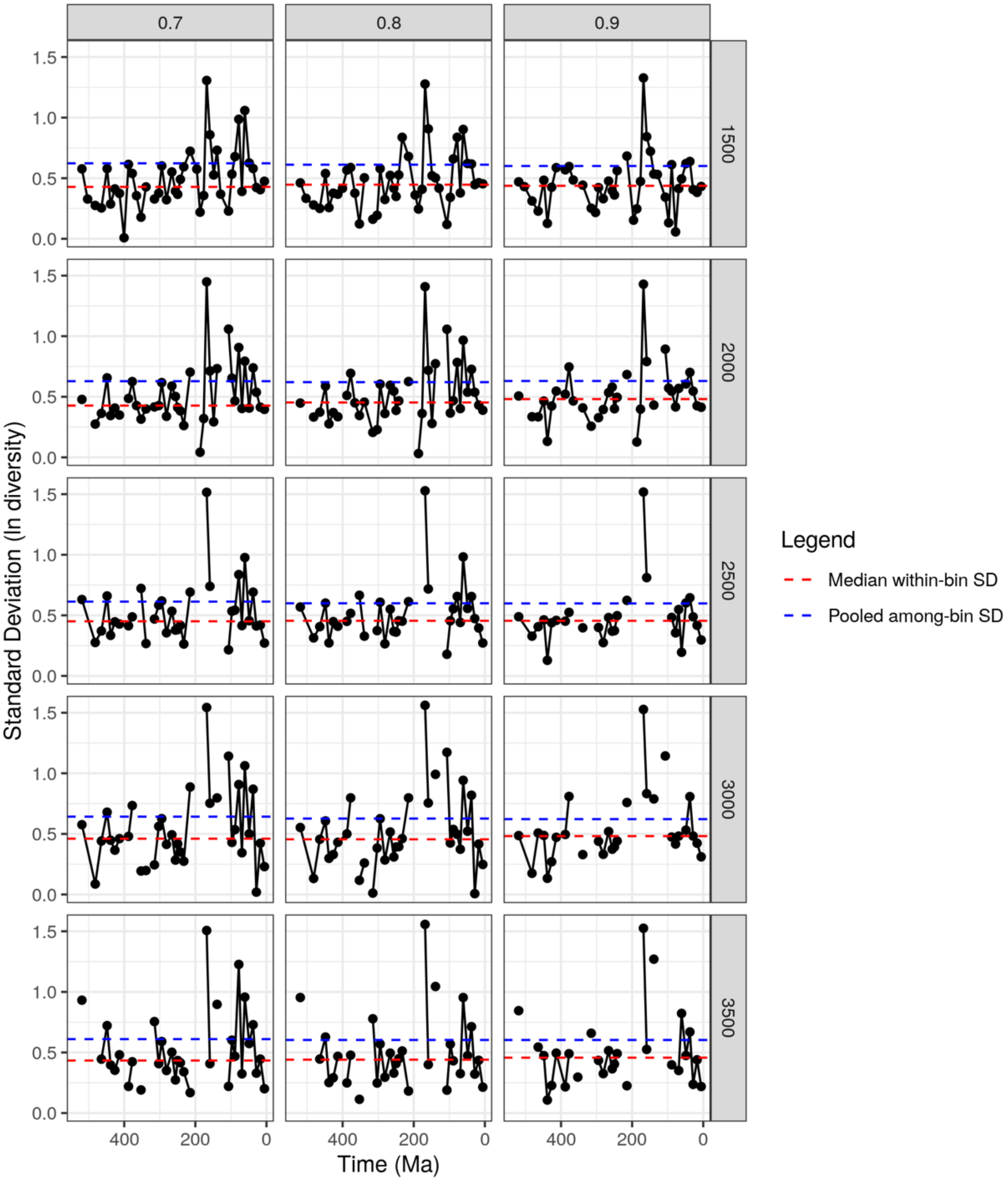

Fig. S2. Comparison of variance in SQS diversity (log-transformed) across standardized spatial regions among and within time intervals. Patterns shown for multiple SQS quorum levels (facetted across columns) and spatial scales (summed MST distances, facetted across rows). Black lines and points indicate standard deviations (SD) for diversity of spatial regions within individual time bins. Red line indicates median value of all within-bin standard deviations. Blue line indicates standard deviation of all pooled regional diversity estimates across the Phanerozoic. On average, the standard deviation of regional diversity estimates within bins is 74% of the standard deviation for all regional diversity estimates pooled among time bins. In some individual bins, the within-bin standard deviation is even higher than the pooled Phanerozoic average.

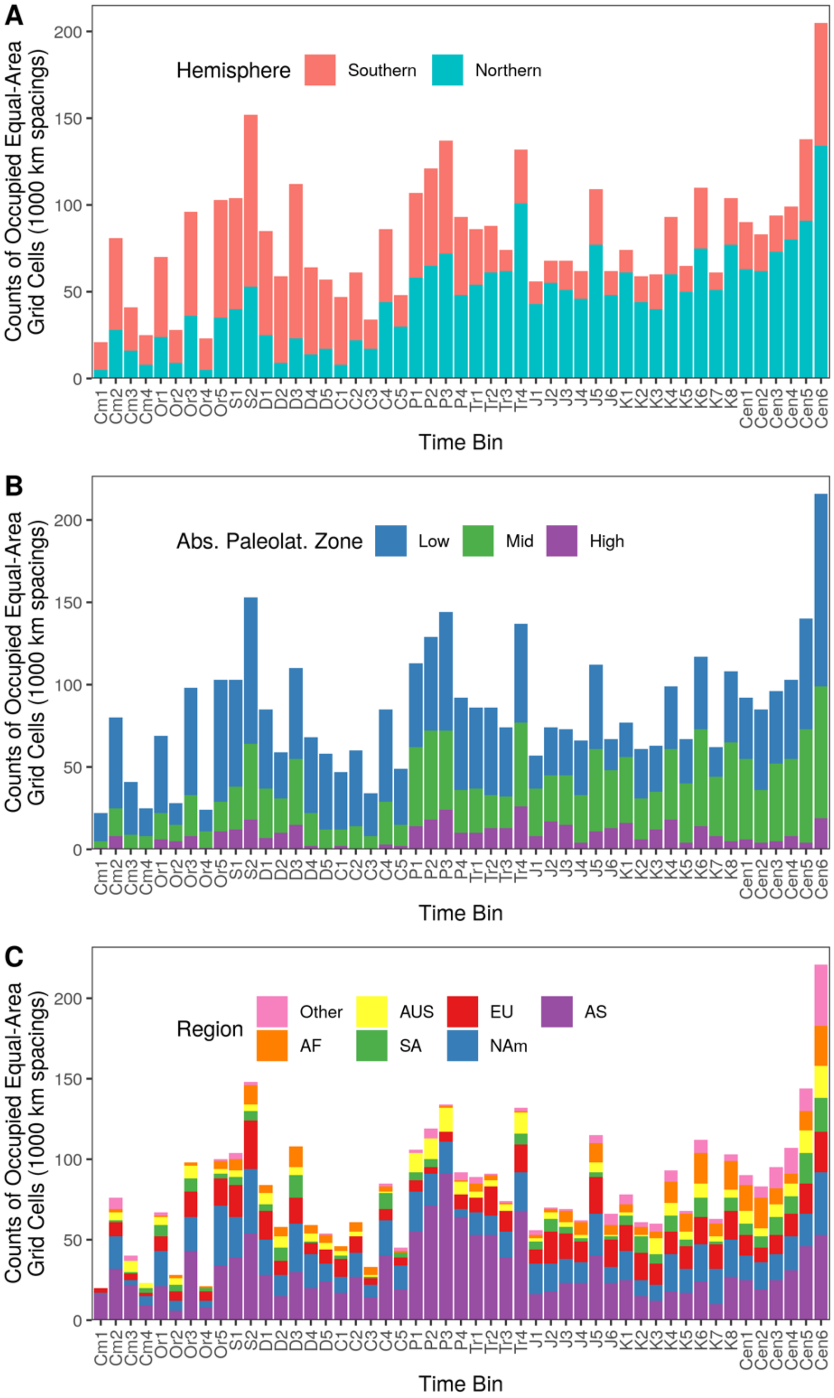

Fig. S3. Counts of equal-area grid cells (1000 km spacings) occupied by fossil localities through the Phanerozoic. Counts broken down by (A) southern and northern hemispheres; (B) low (0–30°), mid (30–60°) and high (60–90°) paleolatitudinal zones; and (C) continental region. Region abbreviations: NAm = North America, SA = South America, EU = Europe, AS = Asia, AUS = Australasia, AF = Africa.

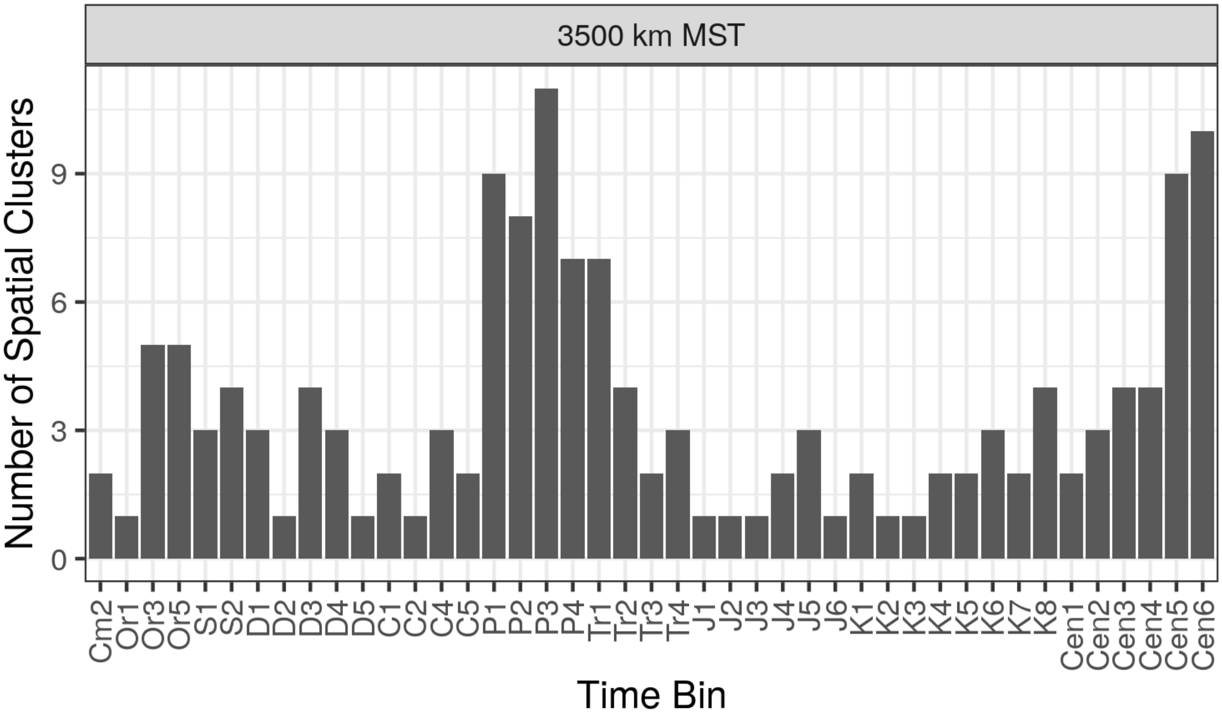

Fig. S4. Counts of clustered spatially-standardized regions (3500 km MST length) per bin through the Phanerozoic. Diversity estimates for especially many distinct spatial regions are available during the Permian–Triassic and during the Neogene.

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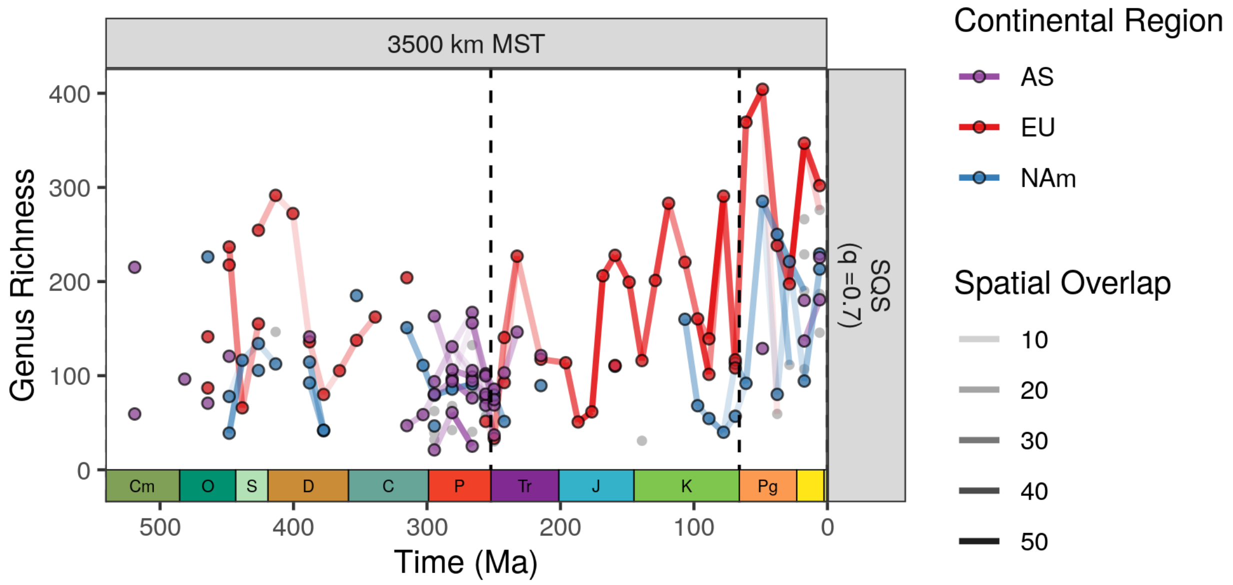

Fig. S5. Spatially-standardized marine animal diversity patterns at 3000 km summed MST length, tracing specific geographic regions through time. For clarity, only the best-sampled continental regions are highlighted; other regions are shown in grey. Transparency of lines corresponds to similarity of geographic regions from bin to bin.

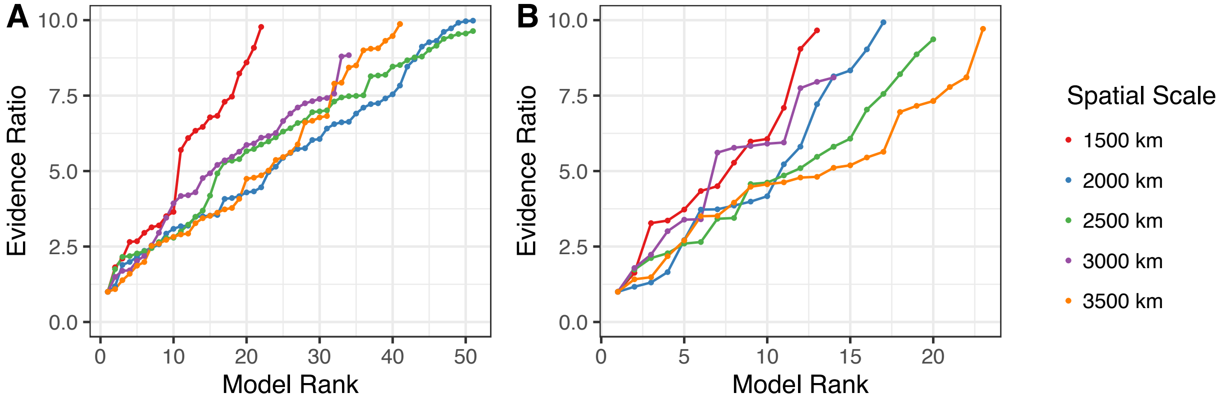

Fig. S6. Evidence ratios ≤10 for models across all spatial standardization scales. Evidence ratios represent the strength of evidence favoring the best-ranked model over each subsequent model, and are equal to the Akaike weight of the best model divided by each lower ranked model. Models were fitted to spatially-standardized diversity estimates using SQS (quorum = 0.9). (A) Low paleolatitudes. (B) Mid paleolatitudes.

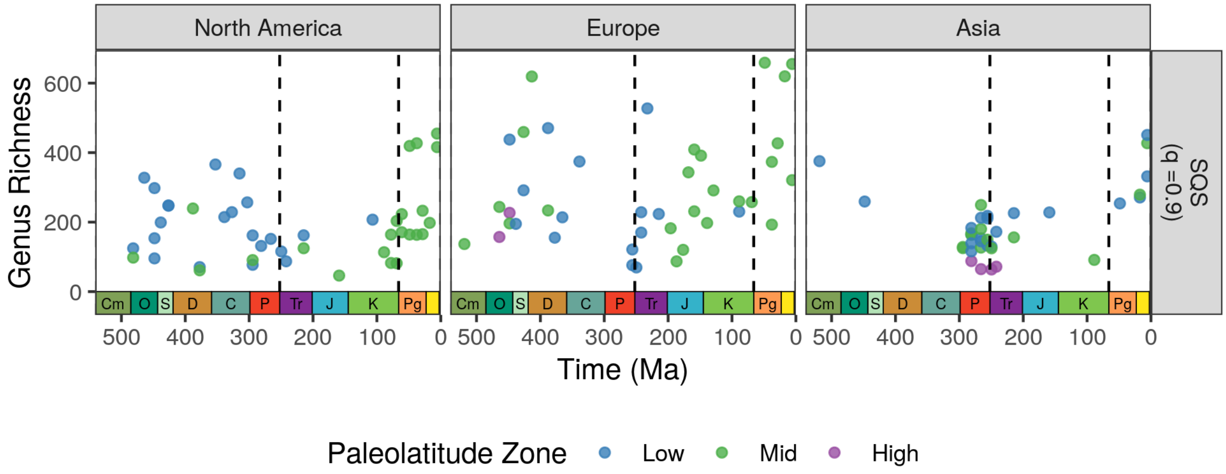

Fig. S7. Spatially-standardized diversity patterns for best-sampled continental regions. Spatial scale = 2500 km MST distance, SQS quorum = 0.9.

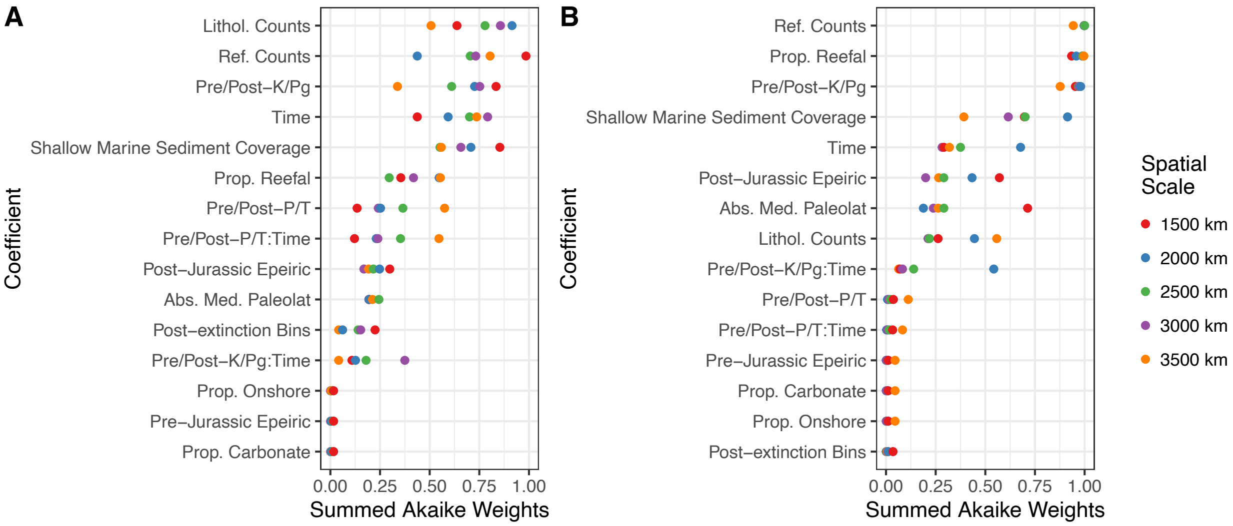

Fig. S8. Summed Akaike weights, reflecting weighted importance of variables within confidence set of models. Summed Akaike weights were calculated by summing weights across all models for each spatial scale at an SQS quorum of 0.9. (A) Low paleolatitudes. (B) Mid paleolatitudes.

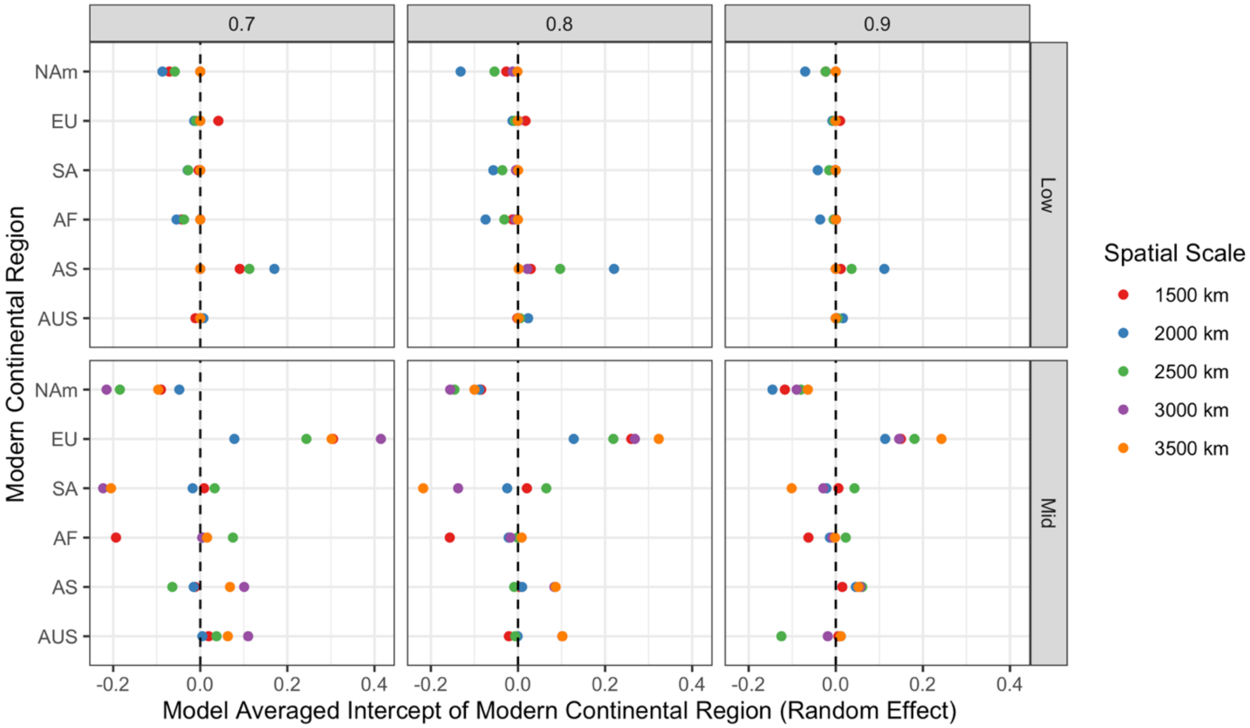

Fig. S9. Model-averaged estimates of intercept for modern continental region (random effect) across spatial scales. Columns correspond to SQS quorum levels; rows correspond to paleolatitude zones. At mid paleolatitudes, Europe consistently has higher diversity than average, while North America is slightly lower.

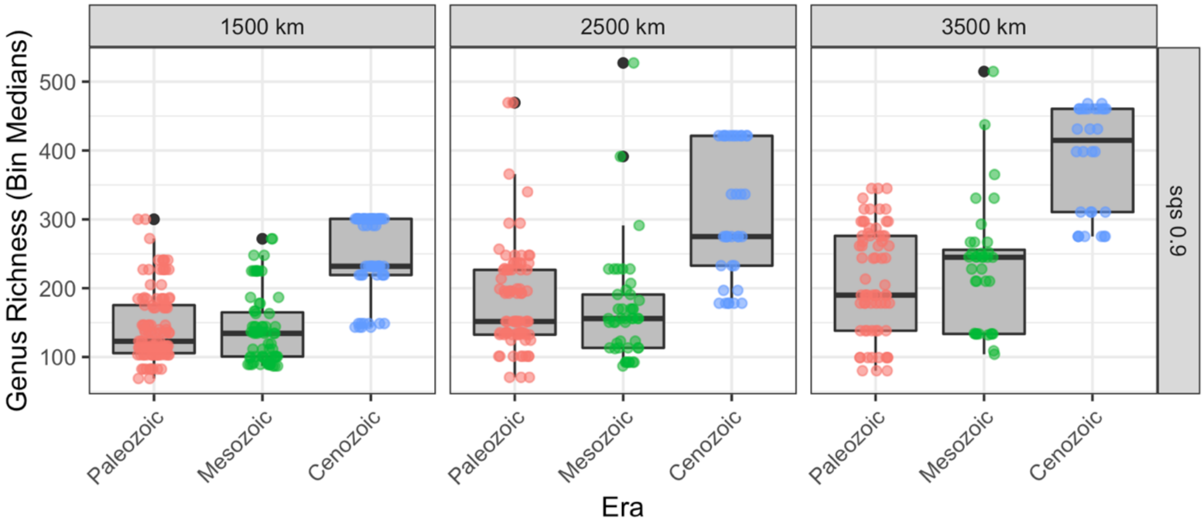

Fig. S10. Per-era distributions of spatially-standardized diversity for all spatial scales and richness estimators. The distribution of spatially-standardized richness is consistently higher in the Cenozoic, but peak levels often do not exceed peaks that occurred in earlier eras.

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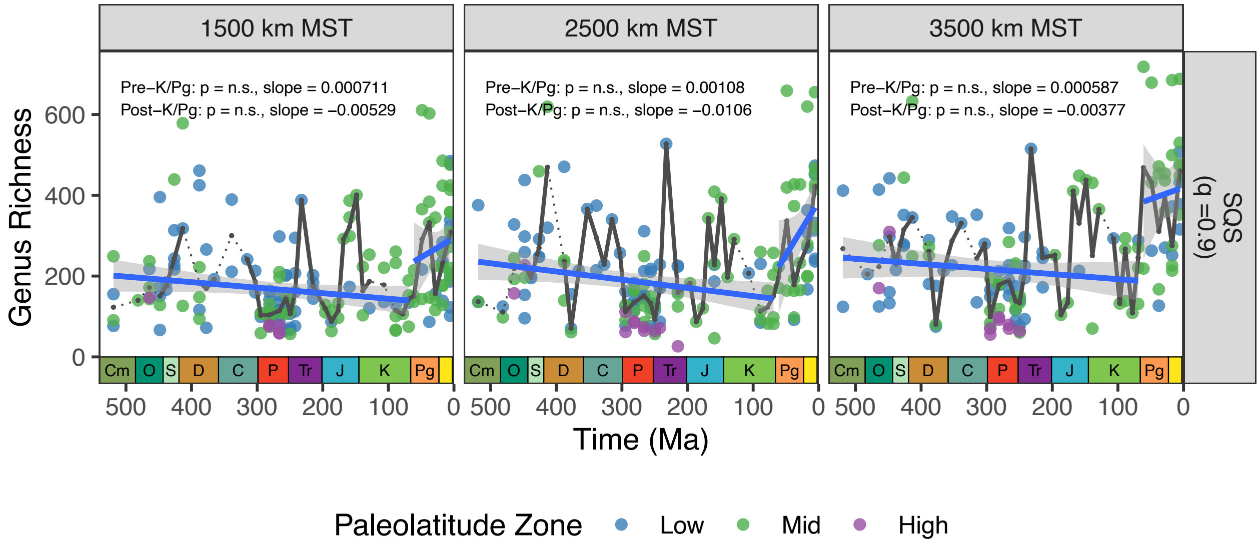

Fig. S11. Linear regressions of log diversity as a function of time within pre- and post-K/Pg diversification phases. Although regressions within the pre-K/Pg phase are sometimes significant, this is due to a weak but statistically significant decrease in diversity through time. Compared to existing "global" curves, increases into the Cenozoic are modest; median diversity within bins are often comparable to those from the pre-Cenozoic, while the maximum richness of data points is only slightly higher.

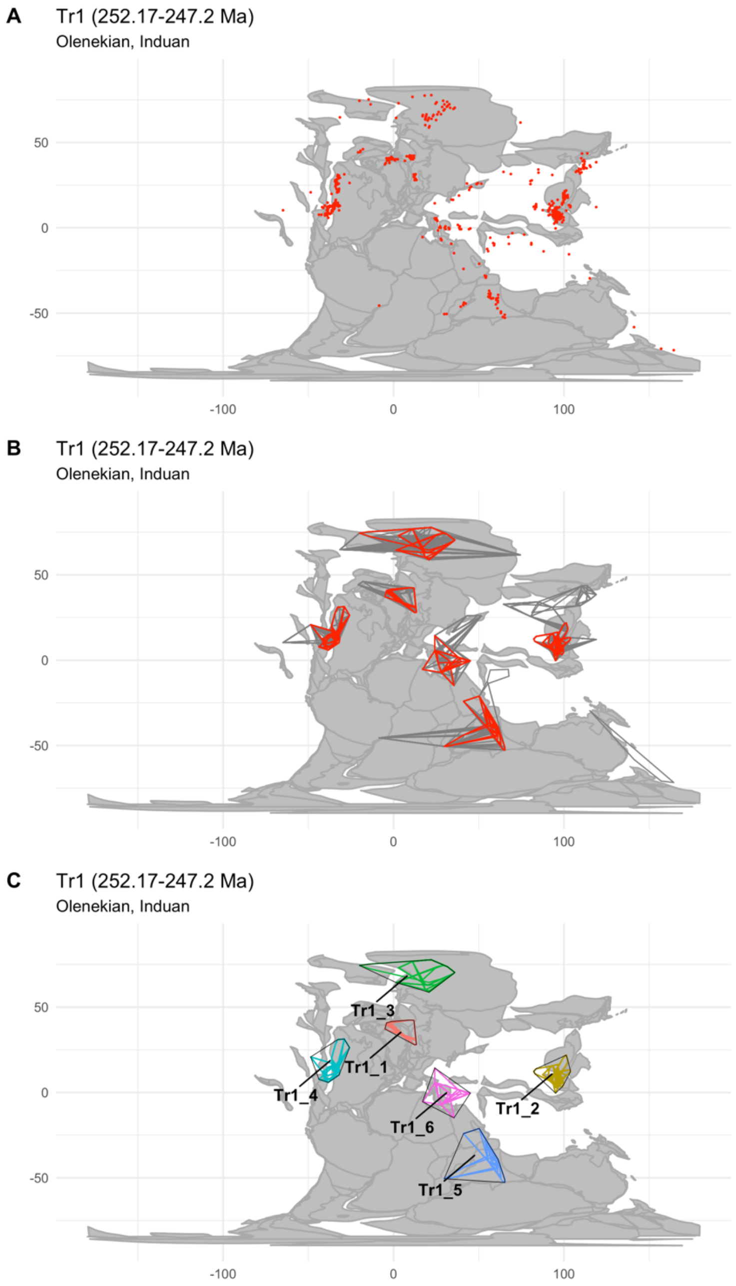

Fig. S12. Spatial standardization procedure. Showing standardization steps for time interval Tr1 (A) Underlying fossil localities, binned within equal-sized grid cells with 100 km spacings. (B) All spatial regions, showing regions meeting spatial standardization criteria (2500 km MST distance) in red (other regions in dark grey). (C) Clustered spatial regions.

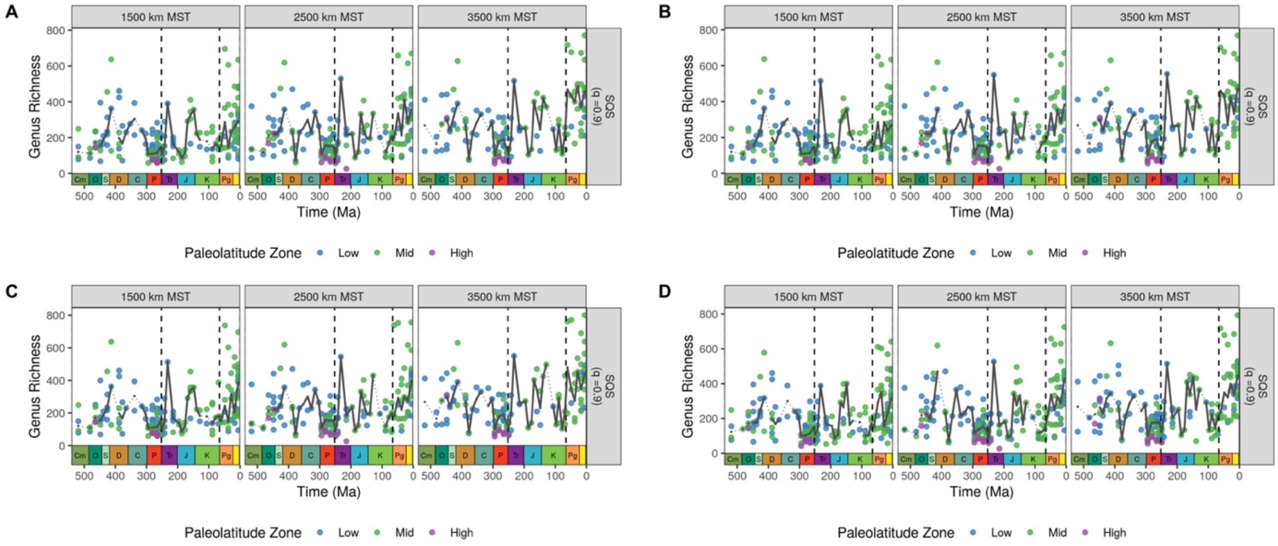

Fig. S13. Spatially-standardized genus richness patterns for sensitivity analyses. As for Fig. 2, but using alternative analysis settings. (A) Retaining silicified occurrences. (B) Retaining original aragonite. (C) Minimal cleaning protocol that retained original aragonite, silicified occurrences, unlithified and poorly-lithified-and-sieved sediments. (D) Alternate spatial clustering settings. See "Supplementary Materials: Sensitivity Analyses" for details of sensitivity analyses shown in panels C–D.

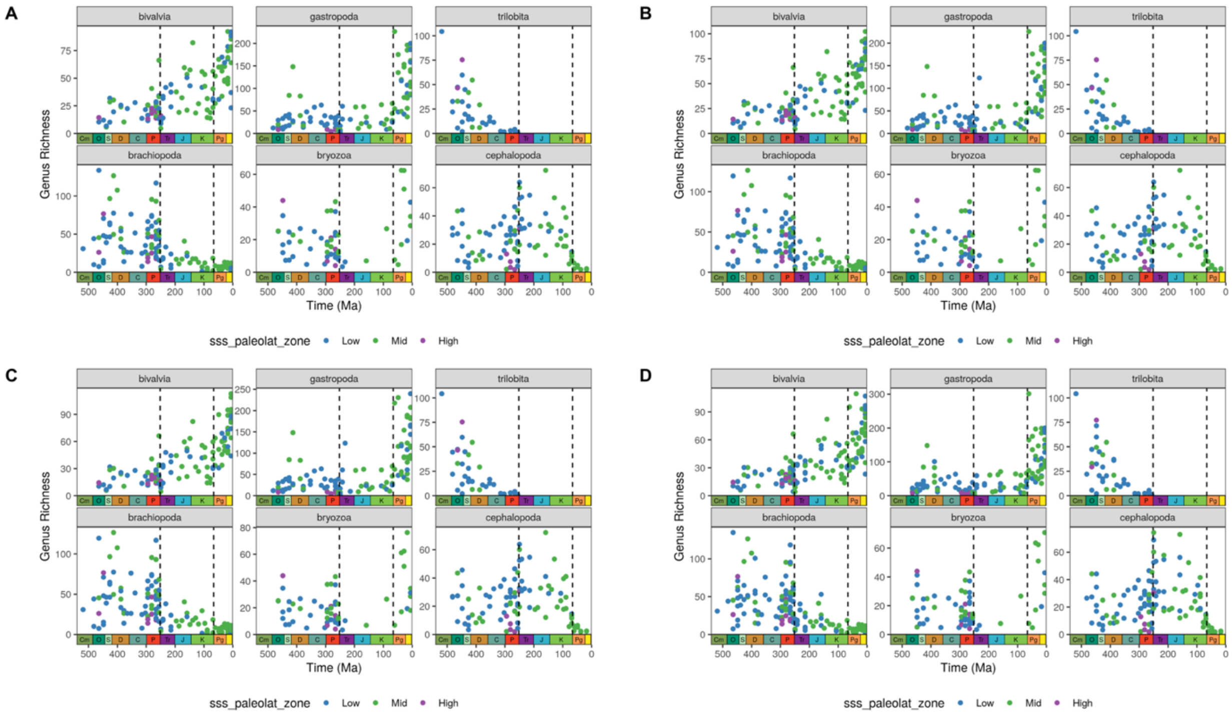

Fig. S14. Spatially-standardized genus richness patterns for sensitivity analyses. As for Fig. S14, but using alternative analysis settings. (A) Retaining silicified occurrences. (B) Retaining original aragonite. (C) Minimal cleaning protocol that retained original aragonite, silicified occurrences, unlithified and poorly-lithified-and-sieved sediments. (D) Alternate spatial clustering settings. See "Supplementary Materials: Sensitivity Analyses" for details of sensitivity analyses shown in panels C–D.

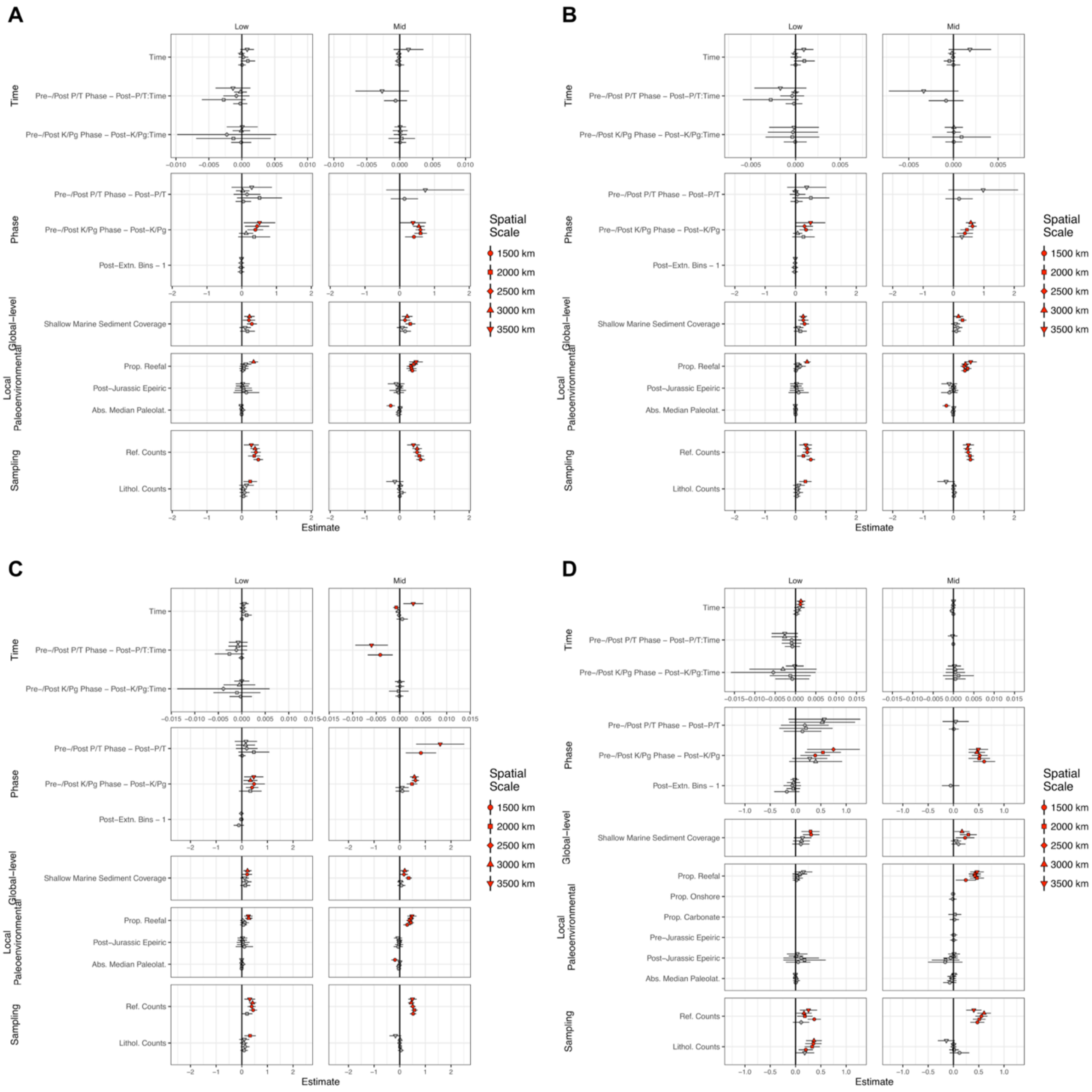

Fig. S15. Spatially-standardized genus richness patterns for sensitivity analyses. As for Fig. 4, but using alternative analysis settings. (A) Retaining silicified occurrences. (B) Retaining original aragonite. (C) Minimal cleaning protocol that retained original aragonite, silicified occurrences, unlithified and poorly-lithified-and-sieved sediments. (D) Alternate spatial clustering settings. See "Supplementary Materials: Sensitivity Analyses" for details of sensitivity analyses shown in panels C–D.

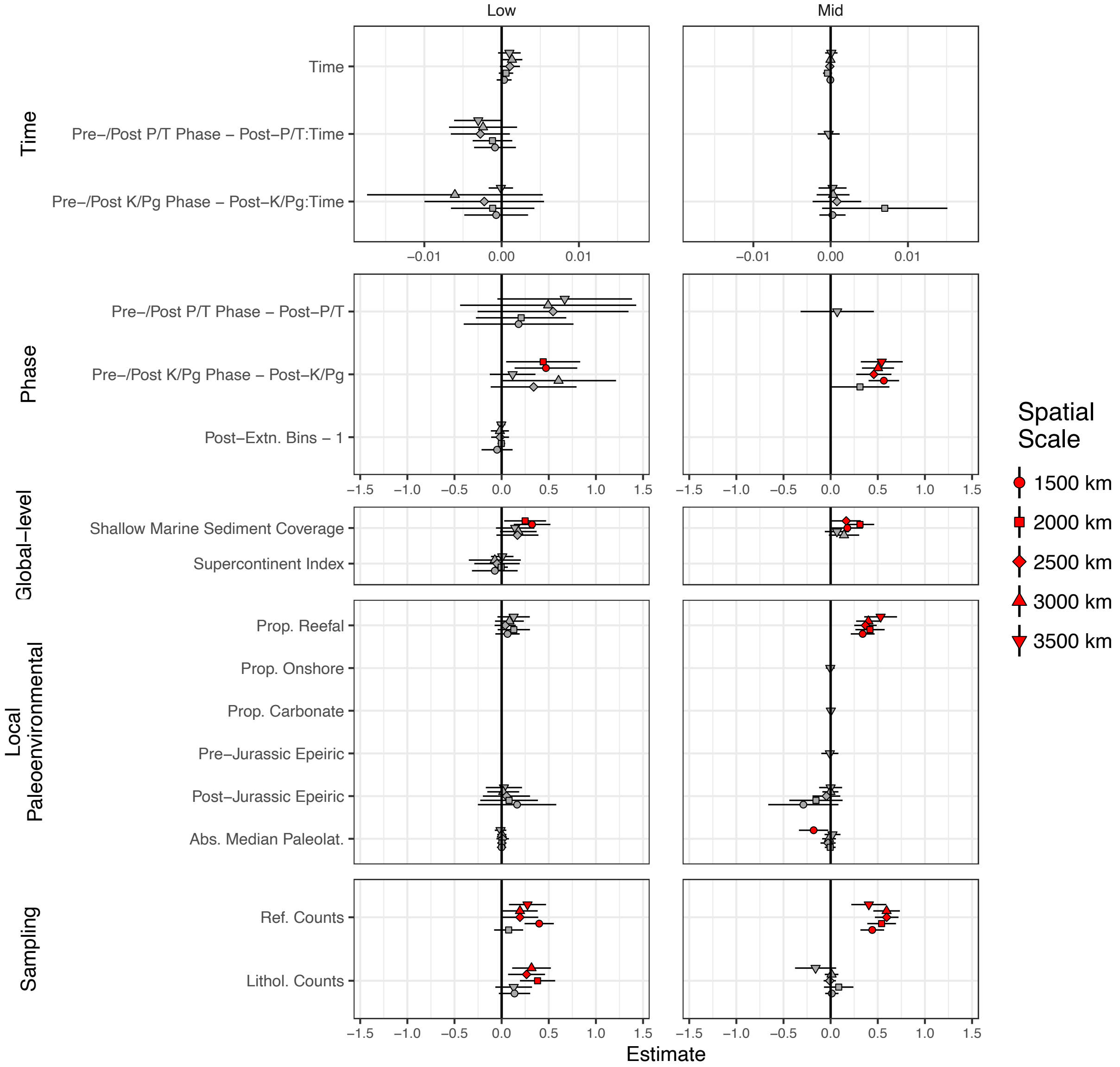

Fig. S16. Model-averaged parameter estimates for coefficients at low and mid paleolatitudes (alternate analysis including supercontinent index variable). Models were fitted to spatially-standardized diversity estimates using SQS (quorum = 0.9). See Table S1 for descriptions of explanatory variables. Red points signify estimates that do not overlap with zero; grey points indicate points that do. Note that supercontinent index (i.e., continental fragmentation index) only appears in model comparisons for low paleolatitudes, and model-averaged parameter estimates are non-significant (strongly overlap with zero). At mid paleolatitudes, Akaike weights for models including supercontinent index were not high enough to be included when computing model average parameter estimates.

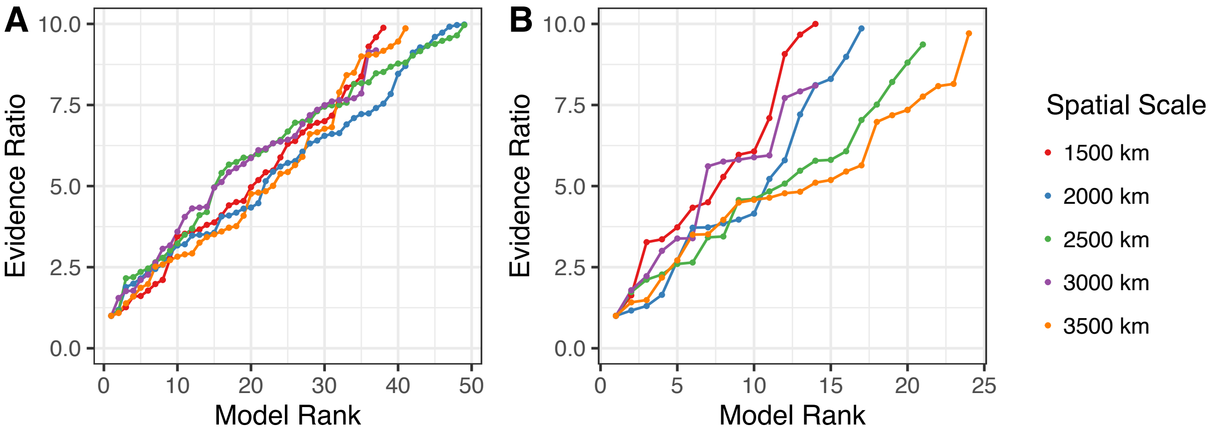

Fig. S17. Evidence ratios ≤10 for models across all spatial standardization scales (alternate analysis including supercontinent index variable). Evidence ratios represent the strength of evidence favoring the best-ranked model over each subsequent model, and are equal to the Akaike weight of the best model divided by each lower ranked model. Models were fitted to spatially-standardized diversity estimates using SQS (quorum = 0.9). (A) Low paleolatitudes. (B) Mid paleolatitudes.

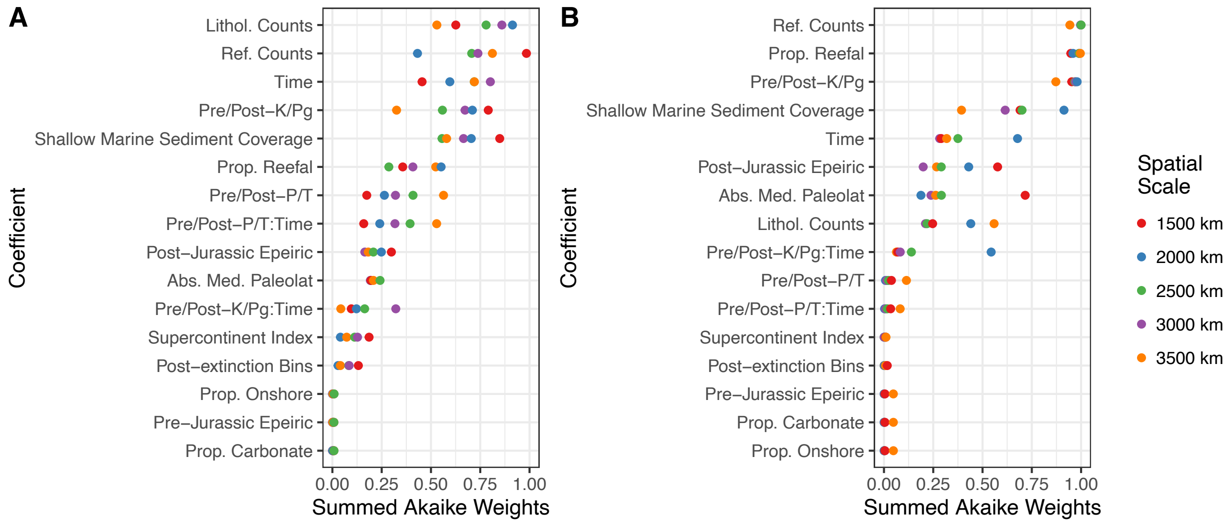

Fig. S18. Summed Akaike weights, reflecting weighted importance of variables within confidence set of models (alternate analysis including supercontinent index variable). Summed Akaike weights were calculated by summing weights across all models for each spatial
5 scale at an SQS quorum of 0.9. (A) Low paleolatitudes. (B) Mid paleolatitudes. Note that supercontinent index has low summed Akaike weights.

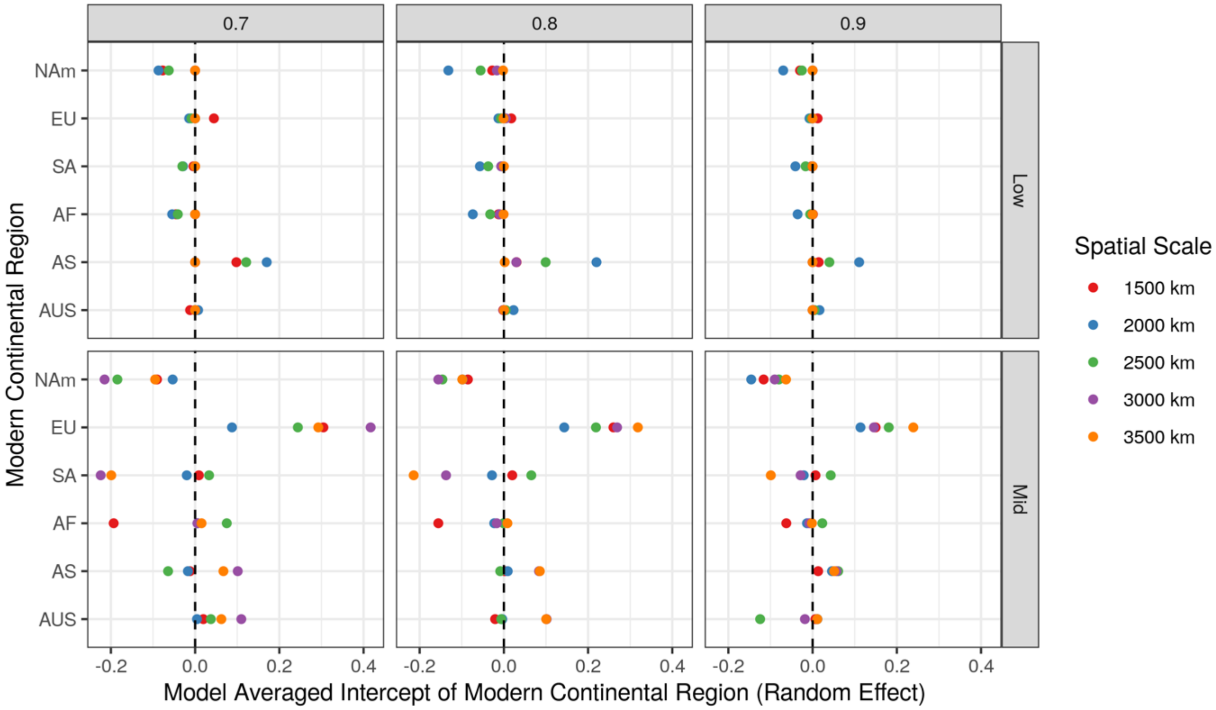

Fig. S19. Model-averaged estimates of intercept for modern continental region (random effect) across spatial scales (alternate analysis including supercontinent index variable). Columns correspond to SQS quorum levels; rows correspond to paleolatitude zones. At mid paleolatitudes, Europe consistently has higher diversity than average, while North America is slightly lower.

Supplementary Tables

Variable Grouping	**Variable Name**	**Explanation**	**Source**
Diversification Phase	Pre-/Post-K/Pg Phase	Diversification phase variable dividing data into separate intervals before and after the K/Pg mass extinction.	Calculated using Paleobiology Database occurrence data fields.
Diversification Phase	Pre-/Post-P/T Phase	Diversification phase variable dividing data into separate intervals before and after the P/T mass extinction.	Calculated using Paleobiology Database occurrence data fields.
Global Environmental Variables	Shallow Marine Coverage	Estimate of shallow marine areal coverage using counts of stratigraphic columns from Macrostrat.	Peters and Husson {Peters:2017do} Supplementary Data.
Local Environmental Variables	Water Depth	Bathymetry data. Calculated for paleocoordinates in our data using Scotese and Wright's paleo-digital elevation models (paleoDEMs). Depths were binned into shallow and deep water (above/below 600 m depth).	Calculated using Paleobiology Database occurrence data and data from Scotese and Wright {Scotese:2018wz}.
Local Environmental Variables	Pre-Jurassic Epeiric, Post-Jurassic Epeiric	Epeiric/open-ocean-facing oceanic setting prior to the Jurassic (pre-Jurassic) or from the Jurassic onwards (post-Jurassic). Calculated for paleocoordinates in our data using Scotese paleo digital elevation models (paleoDEMs). Collections more than 700 km from the nearest continental margin were considered to represent epeiric seas.	Calculated using Paleobiology Database occurrence data and data from Scotese and Wright {Scotese:2018wz}.
Local Environmental Variables	Proportion Onshore	Proportion of Paleobiology Database collections in the spatial region representing onshore environments (see supplementary analysis code for environment classifications).	Calculated using Paleobiology Database occurrence data fields.
Local Environmental Variables	Proportion Carbonate	Proportion of Paleobiology Database collections in the spatial region representing carbonate lithologies (see supplementary analysis code for lithology classifications).	Calculated using Paleobiology Database occurrence data fields.
Local Environmental Variables	Proportion Reefal	Proportion of Paleobiology Database collections in the spatial region representing reefal environments (see supplementary analysis code for environment classifications).	Calculated using Paleobiology Database occurrence data fields.

Variable Grouping	**Variable Name**	**Explanation**	**Source**
Local Environmental Variables	Absolute Median Paleolatitude	Absolute median paleolatitude of collections in each spatial region, using Scotese paleocoordinates.	Calculated using Paleobiology Database occurrence data fields.
Region Identity	Dominant Continental Region	The continental region contributing most data to each spatial region.	Calculated using Paleobiology Database occurrence data fields.
Sampling Variables	Environmental Counts	Counts of distinct environmental types in each spatial region, using Paleobiology Database metadata.	Calculated using Paleobiology Database occurrence data fields.
Sampling Variables	Lithology Counts	Counts of distinct lithological types in each spatial region, using Paleobiology Database metadata.	Calculated using Paleobiology Database occurrence data fields.
Sampling Variables	Reference Counts	Counts of unique references (i.e., publications) describing Paleobiology Database fossil occurrences in each spatial region.	Calculated using Paleobiology Database occurrence data fields.
Temporal Factors	Post-extinction Bins	Binary factor identifying bins immediately following the big five mass extinction events.	Calculated using Paleobiology Database occurrence data fields.
Temporal Factors	Post-P/T Bin	Binary factor identifying the bin immediately following the P/T mass extinction (i.e., Tr1).	Calculated using Paleobiology Database occurrence data fields.

Table S1. Details of explanatory variables used in statistical models.

Low Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
1500 km							
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	9	-22.0	65.9	0.0000	0.10400	0.1040	1.00
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	8	-23.9	66.8	0.8620	0.06740	0.1710	1.54
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-24.0	67.0	1.1600	0.05810	0.2290	1.79
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-25.7	67.8	1.8700	0.04070	0.2700	2.55
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-23.0	67.8	1.9500	0.03920	0.3090	2.65
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic	9	-23.0	67.9	1.9700	0.03880	0.3480	2.68
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-23.1	68.1	2.1600	0.03520	0.3830	2.95
Time + Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	10	-21.9	68.5	2.6400	0.02780	0.4110	3.74
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-	10	-22.0	68.7	2.8500	0.02500	0.4360	4.16
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Glob. Mod. Sans Local Env.	10	-22.0	68.8	2.9300	0.02390	0.4600	4.33
Time * Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	11	-20.5	68.9	3.0400	0.02260	0.4820	4.58
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	8	-25.1	69.3	3.4100	0.01890	0.5010	5.49
Time + Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	9	-23.8	69.4	3.4800	0.01820	0.5200	5.71
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Global-level Variables + Sampling Variables	9	-23.9	69.6	3.6900	0.01640	0.5360	6.32
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-23.9	69.7	3.8300	0.01530	0.5510	6.79
Time * Pre/Post-P/T Phase + Sampling Variables	9	-24.0	69.7	3.8400	0.01520	0.5660	6.83

Low Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Time * Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	10	-22.5	69.8	3.9600	0.01440	0.5810	7.23
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-24.0	69.9	3.9800	0.01420	0.5950	7.31
2000 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-26.3	71.6	0.0000	0.06940	0.0694	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.2	72.2	0.6590	0.04990	0.1190	1.39
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-28.3	72.8	1.2400	0.03740	0.1570	1.86
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-27.0	72.9	1.2700	0.03680	0.1930	1.89
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.8	73.3	1.7000	0.02970	0.2230	2.34
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-25.9	73.6	2.0300	0.02510	0.2480	2.77
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic	9	-26.0	73.8	2.2100	0.02300	0.2710	3.02
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	8	-27.5	73.9	2.3300	0.02170	0.2930	3.20
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-	10	-24.7	74.0	2.4500	0.02040	0.3130	3.40
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.2	74.1	2.4700	0.02020	0.3340	3.43
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.6	74.1	2.5100	0.01980	0.3530	3.50
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-27.6	74.1	2.5400	0.01950	0.3730	3.55
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	9	-26.2	74.2	2.5800	0.01910	0.3920	3.63
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Shallow Marine Sediment Coverage +	9	-26.3	74.4	2.8100	0.01700	0.4090	4.07

Low Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Lithol. Counts	8	-27.7	74.4	2.8100	0.01700	0.4260	4.07
Time * Pre/Post-P/T Phase + Sampling Variables	9	-26.3	74.4	2.8300	0.01680	0.4430	4.12
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-24.9	74.6	2.9600	0.01580	0.4590	4.40
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.5	74.8	3.1700	0.01420	0.4730	4.89
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	8	-28.0	75.0	3.4400	0.01240	0.4850	5.59
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-25.2	75.1	3.4800	0.01220	0.4980	5.70
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-25.2	75.2	3.5800	0.01160	0.5090	5.97
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts + Post-	10	-25.2	75.2	3.5900	0.01150	0.5210	6.02
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-26.7	75.2	3.6000	0.01150	0.5320	6.04
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.3	75.2	3.6500	0.01120	0.5430	6.19
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol. Counts	8	-28.2	75.4	3.7800	0.01050	0.5540	6.63
Pre/Post-P/T Phase + Lithol. Counts	6	-31.0	75.6	4.0100	0.00936	0.5630	7.42
Time * Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	10	-25.5	75.6	4.0400	0.00922	0.5730	7.53
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-27.0	75.7	4.0800	0.00903	0.5820	7.68
Time * Pre/Post-P/T Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.5	75.7	4.1500	0.00872	0.5900	7.96
2500 km							
Time * Pre/Post-P/T Phase + Sampling Variables	9	-24.1	70.1	0.0000	0.06040	0.0604	1.00

Low Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	9	-24.7	71.3	1.1200	0.03440	0.0948	1.75
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-26.1	71.3	1.2000	0.03310	0.1280	1.82
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	8	-26.2	71.4	1.2300	0.03260	0.1600	1.85
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-26.5	72.0	1.8700	0.02370	0.1840	2.54
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-27.9	72.1	1.9600	0.02270	0.2070	2.66
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-23.7	72.2	2.0600	0.02150	0.2280	2.81
Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-23.7	72.3	2.1500	0.02060	0.2490	2.93
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	10	-23.8	72.4	2.3100	0.01910	0.2680	3.17
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.3	72.5	2.3400	0.01870	0.2870	3.22
Time * Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	11	-22.3	72.5	2.3800	0.01840	0.3050	3.28
Time * Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	10	-23.8	72.5	2.4000	0.01810	0.3230	3.33
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-23.8	72.5	2.4100	0.01810	0.3410	3.33
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-24.1	73.0	2.8600	0.01440	0.3560	4.18
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts	9	-25.5	73.0	2.8700	0.01440	0.3700	4.20
Time * Pre/Post-P/T Phase + Ref. Counts	8	-27.1	73.3	3.1600	0.01240	0.3830	4.85
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.7	73.3	3.2000	0.01220	0.3950	4.95
Time + Pre/Post-K/Pg Phase + Lithol. Counts	7	-28.6	73.5	3.3700	0.01120	0.4060	5.38

Low Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic	9	-25.8	73.5	3.3800	0.01110	0.4170	5.42
Time * Pre/Post-K/Pg Phase + Lithol. Counts	8	-27.2	73.5	3.3800	0.01110	0.4280	5.43
Time + Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	9	-25.8	73.6	3.4700	0.01070	0.4390	5.66
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Global-level Variables + Sampling Variables	9	-25.9	73.7	3.5400	0.01030	0.4490	5.88
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.3	73.7	3.5500	0.01020	0.4600	5.90
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.3	73.7	3.5600	0.01020	0.4700	5.93
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-26.0	73.8	3.6900	0.00956	0.4790	6.31
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Glob. Mod. Sans Local Env.	10	-24.5	73.8	3.6900	0.00956	0.4890	6.31
Time + Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	10	-24.5	73.9	3.7100	0.00942	0.4980	6.41
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-26.0	73.9	3.8000	0.00904	0.5070	6.68
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-28.8	74.0	3.8300	0.00890	0.5160	6.78
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-26.1	74.1	3.9800	0.00826	0.5240	7.31
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.1	74.2	4.0300	0.00805	0.5320	7.50
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.6	74.2	4.0700	0.00791	0.5400	7.63
3000 km							
Time * Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	11	-15.7	59.5	0.0000	0.05820	0.0582	1.00
Time * Pre/Post-P/T Phase + Sampling Variables	9	-18.8	59.6	0.0633	0.05640	0.1150	1.03

Low Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.0	59.8	0.3350	0.04920	0.1640	1.18
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	60.0	0.4920	0.04550	0.2090	1.28
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.1	60.2	0.6750	0.04150	0.2510	1.40
Time * Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	10	-17.6	60.2	0.6750	0.04150	0.2920	1.40
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-18.2	61.3	1.7800	0.02390	0.3160	2.44
Time * Pre/Post-K/Pg Phase + Lithol. Counts	8	-21.1	61.3	1.8000	0.02370	0.3400	2.46
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-16.7	61.4	1.8600	0.02290	0.3630	2.54
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.4	61.6	2.1000	0.02040	0.3830	2.86
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-21.5	62.0	2.4600	0.01700	0.4000	3.43
Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-18.5	62.0	2.4800	0.01690	0.4170	3.45
Time + Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	10	-18.6	62.0	2.5400	0.01630	0.4330	3.56
Time * Pre/Post-K/Pg Phase + Sampling Variables + Temporal Factors	10	-18.7	62.2	2.7400	0.01480	0.4480	3.94
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-21.6	62.3	2.7900	0.01450	0.4630	4.03
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	10	-18.7	62.3	2.8100	0.01430	0.4770	4.08
Time * Pre/Post-K/Pg Phase + Sampling Variables	9	-20.2	62.4	2.9000	0.01370	0.4910	4.26
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-21.7	62.4	2.9200	0.01350	0.5040	4.31
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-18.8	62.4	2.9200	0.01350	0.5180	4.31

Low Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-20.3	62.4	2.9400	0.01340	0.5310	4.34
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.8	62.5	2.9800	0.01310	0.5440	4.43
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-18.8	62.5	3.0100	0.01290	0.5570	4.51
Time + Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	9	-20.3	62.5	3.0500	0.01270	0.5700	4.59
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Glob. Mod. Sans Local Env.	12	-15.7	62.6	3.1400	0.01210	0.5820	4.81
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-	10	-18.9	62.7	3.1700	0.01190	0.5940	4.89
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-18.9	62.7	3.2500	0.01150	0.6050	5.07
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.4	62.8	3.2600	0.01140	0.6170	5.10
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-20.4	62.8	3.3100	0.01110	0.6280	5.23
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic	11	-17.5	63.0	3.4600	0.01030	0.6380	5.63
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol.	10	-19.1	63.0	3.5300	0.00995	0.6480	5.85
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-19.1	63.1	3.5700	0.00976	0.6580	5.97
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-19.1	63.1	3.6000	0.00961	0.6670	6.05
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Global-level Variables + Sampling Variables	11	-17.6	63.1	3.6200	0.00954	0.6770	6.10
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	9	-20.6	63.1	3.6200	0.00952	0.6870	6.11
Time + Pre/Post-K/Pg Phase + Lithol. Counts	7	-23.4	63.2	3.6900	0.00921	0.6960	6.32
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-20.7	63.4	3.8800	0.00837	0.7040	6.95

Low Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	9	-20.8	63.5	3.9500	0.00807	0.7120	7.21
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-17.8	63.5	4.0100	0.00785	0.7200	7.42
3500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-19.6	58.4	0.0000	0.07060	0.0706	1.00
Time * Pre/Post-P/T Phase + Sampling Variables	9	-18.3	58.6	0.1830	0.06440	0.1350	1.10
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-20.0	59.2	0.7660	0.04820	0.1830	1.47
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts	9	-18.6	59.3	0.8350	0.04650	0.2300	1.52
Time * Pre/Post-P/T Phase + Ref. Counts	8	-20.5	60.1	1.6800	0.03050	0.2600	2.31
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-17.6	60.3	1.8100	0.02860	0.2890	2.47
Time + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	60.3	1.8300	0.02830	0.3170	2.50
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-17.6	60.4	1.9300	0.02690	0.3440	2.63
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.3	60.8	2.3100	0.02220	0.3660	3.18
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-19.3	60.8	2.3300	0.02200	0.3880	3.20
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	10	-17.9	60.9	2.4600	0.02060	0.4090	3.43
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-18.0	61.1	2.6300	0.01890	0.4280	3.73
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-19.5	61.1	2.6500	0.01880	0.4460	3.77
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-19.5	61.1	2.7000	0.01830	0.4650	3.86

Low Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-18.1	61.4	2.9300	0.01630	0.4810	4.32
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-18.2	61.6	3.1300	0.01480	0.4960	4.78
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	10	-18.3	61.7	3.2200	0.01410	0.5100	5.00
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.8	61.8	3.3200	0.01350	0.5230	5.25
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-19.8	61.8	3.3400	0.01330	0.5370	5.30
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	10	-18.3	61.8	3.3700	0.01310	0.5500	5.40
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-19.9	61.8	3.4000	0.01290	0.5630	5.48
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Ref. Counts	9	-19.9	62.0	3.5500	0.01200	0.5750	5.90
Time * Pre/Post-P/T Phase + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.0	62.0	3.5700	0.01180	0.5870	5.97
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-16.9	62.0	3.5900	0.01170	0.5980	6.03
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-20.0	62.1	3.6400	0.01140	0.6100	6.17
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-23.0	62.3	3.9000	0.01000	0.6200	7.04
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-23.0	62.5	4.0800	0.00920	0.6290	7.68
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	11	-17.1	62.5	4.0800	0.00918	0.6380	7.69
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	8	-21.7	62.5	4.0900	0.00912	0.6470	7.74

Table S2. Model selection results for low paleolatitudes (Evidence Ratio ≤ 8).

Mid Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
1500 km							
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-16.0	57.0	0.0000	0.1660	0.166	1.00
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-17.8	57.6	0.6070	0.1220	0.288	1.35
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	9	-18.6	59.3	2.2700	0.0533	0.341	3.10
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-18.8	59.6	2.5700	0.0459	0.387	3.61
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-20.2	59.6	2.6200	0.0447	0.432	3.70
Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	11	-15.8	59.8	2.7600	0.0416	0.473	3.98
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	11	-15.8	59.8	2.8200	0.0405	0.514	4.09
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-17.5	60.0	3.0100	0.0368	0.551	4.51
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-20.5	60.2	3.2100	0.0333	0.584	4.97
Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	10	-17.8	60.6	3.5800	0.0277	0.612	5.98
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.8	60.8	3.8300	0.0244	0.636	6.78
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-22.4	61.1	4.1300	0.0210	0.657	7.90
2000 km							
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-20.1	64.9	0.0000	0.1290	0.129	1.00
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic	11	-18.6	65.0	0.0678	0.1250	0.255	1.03
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-18.8	65.5	0.6080	0.0955	0.350	1.36

Mid Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-22.2	66.3	1.3400	0.0661	0.416	1.96
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts +	12	-17.7	66.4	1.4700	0.0622	0.478	2.08
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-23.8	66.6	1.6600	0.0564	0.535	2.29
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-22.7	67.1	2.2100	0.0430	0.578	3.01
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-	10	-21.3	67.3	2.4000	0.0390	0.617	3.32
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	11	-19.9	67.6	2.7000	0.0336	0.650	3.85
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic	10	-21.7	68.2	3.2200	0.0259	0.676	5.00
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	12	-18.5	68.2	3.2300	0.0258	0.702	5.02
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-23.4	68.7	3.7500	0.0199	0.722	6.51
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	12	-18.8	68.7	3.7700	0.0197	0.741	6.58
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-22.0	68.9	3.9400	0.0181	0.760	7.16
2500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-13.5	46.2	0.0000	0.1640	0.164	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-15.6	47.5	1.3200	0.0847	0.248	1.93
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-12.8	47.7	1.4400	0.0796	0.328	2.06
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-13.0	48.1	1.8400	0.0652	0.393	2.51
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-13.2	48.5	2.2500	0.0531	0.446	3.08

Mid Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-11.9	48.9	2.6600	0.0434	0.490	3.77
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-13.5	49.0	2.8000	0.0403	0.530	4.06
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic	10	-12.2	49.4	3.1800	0.0333	0.563	4.91
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-15.3	49.7	3.5100	0.0283	0.591	5.79
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-15.3	49.7	3.5200	0.0282	0.620	5.81
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-15.4	49.8	3.6100	0.0269	0.647	6.07
Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine	10	-12.5	50.0	3.7500	0.0251	0.672	6.51
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-12.5	50.0	3.7700	0.0249	0.697	6.57
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-15.6	50.3	4.0400	0.0217	0.718	7.52
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-12.7	50.3	4.1100	0.0210	0.739	7.80
3000 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	59.9	0.0000	0.2020	0.202	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-22.2	60.8	0.8560	0.1320	0.334	1.53
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-20.0	61.9	1.9300	0.0771	0.411	2.62
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-20.3	62.5	2.5300	0.0571	0.468	3.54
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.4	62.7	2.7700	0.0507	0.519	3.99
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-20.4	62.7	2.7700	0.0506	0.570	4.00

Mid Paleolatitudes

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-22.2	63.4	3.5000	0.0351	0.605	5.76
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-22.2	63.4	3.5200	0.0347	0.640	5.82
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-22.2	63.5	3.5500	0.0343	0.674	5.89
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-22.2	63.5	3.5700	0.0340	0.708	5.95
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-19.6	64.0	4.1200	0.0257	0.734	7.86
3500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-15.9	51.3	0.0000	0.1310	0.131	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-16.3	52.0	0.7900	0.0879	0.218	1.48
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-15.0	52.3	1.0800	0.0760	0.294	1.72
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-17.9	52.4	1.2000	0.0717	0.366	1.82
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Lithol. Counts	9	-15.6	53.6	2.3800	0.0398	0.406	3.28
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-17.3	54.0	2.7500	0.0330	0.439	3.95
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	9	-15.9	54.1	2.8900	0.0307	0.470	4.25
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	9	-15.9	54.2	2.9000	0.0306	0.500	4.27
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	9	-16.2	54.7	3.4500	0.0232	0.523	5.62
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-17.6	54.7	3.4600	0.0231	0.547	5.65
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-16.2	54.8	3.5100	0.0225	0.569	5.79

Mid Paleolatitudes

Model Description	**DF**	**Log Lik**	**AICc**	**Delta**	**Weight**	**Cumulative Weight**	**Evidence Ratio**
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-16.3	54.9	3.6800	0.0207	0.590	6.29
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-14.8	55.2	3.9400	0.0182	0.608	7.19
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-17.9	55.2	3.9900	0.0178	0.626	7.34
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment	10	-14.9	55.3	4.0600	0.0171	0.643	7.63

Table S3. Model selection results for mid paleolatitudes (evidence ratio ≤ 8).

SQS Quorum	Paleolatitude Zone	Conditional R^2 (Weighted Mean)
0.7	Low	0.28
0.7	Mid	0.58
0.8	Low	0.28
0.8	Mid	0.65
0.9	Low	0.38
0.9	Mid	0.68

Table S4. Akaike-weighted means of conditional pseudo-R^2 values for all linear mixed models, summarized according to SQS quorum level and paleolatitude zone.

Region Name	Region Code	Countries
Africa	AF	Algeria; Angola; Cameroon; Cape Verde; Congo - Brazzaville; Congo - Kinshasa; Cote d'Ivoire; Côte d’Ivoire; Democratic Republic of the Congo; Djibouti; Egypt; Eritrea; Ethiopia; Gabon; Ghana; Guinea; Kenya; Lesotho; Libya; Madagascar; Malawi; Mali; Mauritania; Mauritius; Mayotte; Morocco; Mozambique; Namibia; Niger; Nigeria; Senegal; Somalia; South Africa; Sudan; Swaziland; Tanzania; Togo; Tunisia; Western Sahara; Zambia; Zimbabwe
Antarctica	ATA	Antarctica
Asia	AS	Afghanistan; Armenia; Azerbaijan; Bahrain; Bhutan; Cambodia; China; Democratic People's Republic of Korea; Hong Kong SAR China; India; Indonesia; Iran; Iraq; Israel; Japan; Jordan; Kuwait; Kyrgyzstan; Lao People's Democratic Republic; Laos; Lebanon; Malaysia; Mongolia; Myanmar (Burma); Nepal; North Korea; Oman; Pakistan; Palestinian Territories; Philippines; Republic of Korea; Russia; Saudi Arabia; South Korea; Sri Lanka; Syria; Taiwan; Taiwan, Province of China; Tajikistan; Thailand; Turkey; Turkmenistan; United Arab Emirates; Uzbekistan; Vietnam; Yemen
Atlantic Ocean Islands	AOC	Anguilla; Antigua & Barbuda; Bahamas; Barbados; Bermuda; Cayman Islands; Cuba; Dominican Republic; Grenada; Guadeloupe; Haiti; Jamaica; Puerto Rico; Trinidad & Tobago
Australasia	AUS	Australia; New Caledonia; New Zealand; Papua New Guinea; Timor-Leste
Central America	CAm	Belize; Costa Rica; El Salvador; Guatemala; Honduras; Nicaragua; Panama
Europe	EU	Albania; Austria; Belarus; Belgium; Bosnia & Herzegovina; Bulgaria; Croatia; Cyprus; Czechia; Denmark; Estonia; Finland; France; Georgia; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Moldova; Moldova, Republic of; Netherlands; Norway; Poland; Portugal; Romania; San Marino; Serbia; Slovakia; Slovenia; Spain; Sweden; Switzerland; Ukraine; United Kingdom

Region Name	Region Code	Countries
Indian Ocean Islands	IOC	Maldives; Northern Mariana Islands; Seychelles
North America	NAm	Canada; Mexico; United States
Other	Other Countries	French Southern Territories
Other Countries	Other	Greenland; Iceland; Svalbard & Jan Mayen; United States Minor Outlying Islands (the)
Pacific Ocean Islands	POC	Cook Islands; Fiji; French Polynesia; Guam; Marshall Islands; Palau; Pitcairn Islands; Tonga; Tuvalu; Vanuatu
South America	SA	Argentina; Bolivia; Brazil; Chile; Colombia; Ecuador; Paraguay; Peru; Suriname; Uruguay; Venezuela

Table S5. Continental region definitions.

Model Description	**Formula**
Shallow Marine Sediment Coverage	qD ~ shallow_marine_coverage
Pre-Jurassic Epeiric	qD ~ pre_jurassic_epeiric
Post-Jurassic Epeiric	qD ~ post_jurassic_epeiric
Prop. Onshore	qD ~ prop_onshore
Prop. Carbonate	qD ~ prop_carbonate
Prop. Reefal	qD ~ prop_reefal
Lithol. Counts	qD ~ n_lithologies
Ref. Counts	qD ~ n_refs
Post-extinction Bins	qD ~ post_extinction_bins
Local Paleoenvironmental Variables	qD ~ pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal
Sampling Variables	qD ~ n_lithologies + n_refs

Model Description	Formula
Global-level Variables + Local Paleoenvironmental Variables	qD ~ shallow_marine_coverage + pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal
Global-level Variables + Sampling Variables	qD ~ shallow_marine_coverage + n_lithologies + n_refs
Global-level Variables + Temporal Factors	qD ~ shallow_marine_coverage + post_extinction_bins
Local Paleoenvironmental Variables + Sampling Variables	qD ~ pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + n_lithologies + n_refs
Local Paleoenvironmental Variables + Temporal Factors	qD ~ pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + post_extinction_bins
Sampling Variables + Temporal Factors	qD ~ n_lithologies + n_refs + post_extinction_bins
Global-level Variables + Local Paleoenvironmental Variables + Sampling Variables	qD ~ shallow_marine_coverage + pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + n_lithologies + n_refs
Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	qD ~ prop_reefal + n_refs + shallow_marine_coverage + n_lithologies + post_jurassic_epeiric
Glob. Mod. Sans Local Env.	qD ~ shallow_marine_coverage + n_lithologies + n_refs + post_extinction_bins

Model Description	Formula
Glob. Mod. Sans Global Env.	qD ~ pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + n_lithologies + n_refs + post_extinction_bins
Glob. Mod. Sans Sampling	qD ~ shallow_marine_coverage + pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + post_extinction_bins
Glob. Mod. Sans Region Ident.	qD ~ shallow_marine_coverage + pre_jurassic_epeiric + post_jurassic_epeiric + prop_onshore + prop_carbonate + prop_reefal + n_lithologies + n_refs + post_extinction_bins
Prop. Reefal + Ref. Counts	qD ~ prop_reefal + n_refs
Prop. Reefal + Shallow Marine Sediment Coverage	qD ~ prop_reefal + shallow_marine_coverage
Prop. Reefal + Lithol. Counts	qD ~ prop_reefal + n_lithologies
Prop. Reefal + Post-Jurassic Epeiric	qD ~ prop_reefal + post_jurassic_epeiric
Ref. Counts + Shallow Marine Sediment Coverage	qD ~ n_refs + shallow_marine_coverage
Ref. Counts + Post-Jurassic Epeiric	qD ~ n_refs + post_jurassic_epeiric
Shallow Marine Sediment Coverage + Lithol. Counts	qD ~ shallow_marine_coverage + n_lithologies

Model Description	**Formula**
Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	qD ~ shallow_marine_coverage + post_jurassic_epeiric
Lithol. Counts + Post-Jurassic Epeiric	qD ~ n_lithologies + post_jurassic_epeiric
Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	qD ~ prop_reefal + n_refs + shallow_marine_coverage
Prop. Reefal + Ref. Counts + Lithol. Counts	qD ~ prop_reefal + n_refs + n_lithologies
Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	qD ~ prop_reefal + n_refs + post_jurassic_epeiric
Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	qD ~ prop_reefal + shallow_marine_coverage + n_lithologies
Prop. Reefal + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	qD ~ prop_reefal + shallow_marine_coverage + post_jurassic_epeiric
Prop. Reefal + Lithol. Counts + Post-Jurassic Epeiric	qD ~ prop_reefal + n_lithologies + post_jurassic_epeiric
Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	qD ~ n_refs + shallow_marine_coverage + post_jurassic_epeiric
Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	qD ~ n_refs + n_lithologies + post_jurassic_epeiric

Model Description	**Formula**
Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	qD ~ shallow_marine_coverage + n_lithologies + post_jurassic_epeiric
Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	qD ~ prop_reefal + n_refs + shallow_marine_coverage + n_lithologies
Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	qD ~ prop_reefal + n_refs + shallow_marine_coverage + post_jurassic_epeiric
Prop. Reefal + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	qD ~ prop_reefal + n_refs + n_lithologies + post_jurassic_epeiric
Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	qD ~ prop_reefal + shallow_marine_coverage + n_lithologies + post_jurassic_epeiric
Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	qD ~ n_refs + shallow_marine_coverage + n_lithologies + post_jurassic_epeiric

Table S6. Definitions of model formulae. These base model formulae were fitted with and without time (midpoint ages of bins in Ma); diversification phase (pre-/post-P/T, pre-/post-K/Pg, mass-extinction boundaries and geological eras) as a covariate of or interaction term with time; and with and without absolute median paleolatitude. See Table S1 for details of variables.

Table S7. Model selection results for low paleolatitudes (±0-30º) for alternate analysis including supercontinent index variable (evidence ratio ≤ 8). Note that supercontinent index does not appear in any of these models due to insufficient Akaike weights.

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
1500 km							
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	8	-23.9	66.8	0.000	0.06950	0.0695	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-24.0	67.0	0.297	0.05990	0.1290	1.16
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	10	-21.2	67.3	0.501	0.05410	0.1840	1.28
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-25.7	67.8	1.010	0.04200	0.2260	1.66
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-23.0	67.8	1.090	0.04040	0.2660	1.72
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	9	-23.0	67.9	1.110	0.04000	0.3060	1.74
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-23.1	68.1	1.300	0.03630	0.3420	1.92
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-22.0	68.7	1.990	0.02570	0.3680	2.70
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	9	-23.6	68.9	2.190	0.02330	0.3910	2.98
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	11	-20.6	69.0	2.240	0.02270	0.4140	3.06
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	8	-25.1	69.3	2.540	0.01950	0.4340	3.57
Time + Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-23.8	69.4	2.620	0.01870	0.4520	3.71

Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-23.9	69.6	2.830	0.01690	0.4690	4.11
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-23.9	69.7	2.970	0.01580	0.4850	4.41
Time * Pre/Post-P/T Phase + Sampling Variables	9	-24.0	69.7	2.980	0.01570	0.5010	4.44
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-22.5	69.8	3.090	0.01480	0.5150	4.70
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-24.0	69.9	3.120	0.01470	0.5300	4.75
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Glob. Mod. Sans Local Env.	11	-21.1	70.1	3.390	0.01280	0.5430	5.45
Time + Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	11	-21.2	70.2	3.430	0.01250	0.5550	5.55
Time + Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-22.7	70.3	3.510	0.01200	0.5670	5.77
Time + Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	8	-25.7	70.4	3.620	0.01140	0.5790	6.10
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Ref. Counts + Shallow Marine Sediment Coverage	8	-25.7	70.5	3.720	0.01080	0.5900	6.42
Time * Pre/Post-P/T Phase + Ref. Counts	8	-25.8	70.5	3.770	0.01060	0.6000	6.58
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-22.9	70.5	3.790	0.01040	0.6110	6.66
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-22.9	70.6	3.890	0.00994	0.6210	7.00
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-22.9	70.6	3.890	0.00992	0.6310	7.01

Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	9	-24.5	70.8	4.000	0.00940	0.6400	7.40
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-23.0	70.8	4.040	0.00921	0.6490	7.55
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	11	-21.5	70.8	4.070	0.00907	0.6580	7.66
2000 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-26.3	71.6	0.000	0.07010	0.0701	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.2	72.2	0.659	0.05050	0.1210	1.39
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-28.3	72.8	1.240	0.03780	0.1580	1.86
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-27.0	72.9	1.270	0.03710	0.1950	1.89
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.8	73.3	1.700	0.03000	0.2260	2.34
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-25.9	73.6	2.030	0.02540	0.2510	2.77
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	9	-26.0	73.8	2.210	0.02320	0.2740	3.02
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.5	73.9	2.330	0.02190	0.2960	3.20
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-24.7	74.0	2.450	0.02060	0.3170	3.40
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.2	74.1	2.470	0.02040	0.3370	3.43
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.6	74.1	2.510	0.02000	0.3570	3.50

Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-27.6	74.1	2.540	0.01970	0.3770	3.55
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.3	74.4	2.810	0.01720	0.3940	4.07
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Lithol. Counts	8	-27.7	74.4	2.810	0.01720	0.4110	4.07
Time * Pre/Post-P/T Phase + Sampling Variables	9	-26.3	74.4	2.830	0.01700	0.4280	4.12
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-24.9	74.6	2.960	0.01590	0.4440	4.40
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.5	74.8	3.170	0.01440	0.4590	4.89
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	8	-28.0	75.0	3.440	0.01250	0.4710	5.59
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-25.2	75.1	3.480	0.01230	0.4830	5.70
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.2	75.2	3.580	0.01170	0.4950	5.97
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-25.2	75.2	3.590	0.01160	0.5070	6.02
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-26.7	75.2	3.600	0.01160	0.5180	6.04
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.3	75.2	3.650	0.01130	0.5300	6.19
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol. Counts	8	-28.2	75.4	3.780	0.01060	0.5400	6.63
Pre/Post-P/T Phase + Lithol. Counts	6	-31.0	75.6	4.010	0.00946	0.5500	7.42
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.5	75.6	4.040	0.00932	0.5590	7.53

Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-27.0	75.7	4.080	0.00913	0.5680	7.68
Time * Pre/Post-P/T Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-25.5	75.7	4.150	0.00881	0.5770	7.96
2500 km							
Time * Pre/Post-P/T Phase + Sampling Variables	9	-24.1	70.1	0.000	0.05940	0.0594	1.00
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	11	-21.6	71.2	1.030	0.03550	0.0950	1.67
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-26.1	71.3	1.200	0.03260	0.1280	1.82
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	8	-26.2	71.4	1.230	0.03210	0.1600	1.85
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-26.5	72.0	1.870	0.02340	0.1830	2.54
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-27.9	72.1	1.960	0.02230	0.2050	2.66
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-23.7	72.2	2.060	0.02120	0.2260	2.81
Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-23.7	72.3	2.150	0.02020	0.2470	2.93
Time * Pre/Post-P/T Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-23.8	72.4	2.310	0.01880	0.2650	3.17
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.3	72.5	2.340	0.01850	0.2840	3.22
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-23.8	72.5	2.400	0.01790	0.3020	3.33
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-23.8	72.5	2.410	0.01780	0.3200	3.33
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-24.1	73.0	2.860	0.01420	0.3340	4.18

Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts	9	-25.5	73.0	2.870	0.01410	0.3480	4.20
Time * Pre/Post-P/T Phase + Ref. Counts	8	-27.1	73.3	3.160	0.01220	0.3600	4.85
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.7	73.3	3.200	0.01200	0.3720	4.95
Time + Pre/Post-K/Pg Phase + Lithol. Counts	7	-28.6	73.5	3.370	0.01100	0.3830	5.38
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	9	-25.8	73.5	3.380	0.01100	0.3940	5.42
Time * Pre/Post-K/Pg Phase + Lithol. Counts	8	-27.2	73.5	3.380	0.01090	0.4050	5.43
Time + Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.8	73.6	3.470	0.01050	0.4160	5.66
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-25.9	73.7	3.540	0.01010	0.4260	5.88
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.3	73.7	3.550	0.01010	0.4360	5.90
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.3	73.7	3.560	0.01000	0.4460	5.93
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-26.0	73.8	3.690	0.00941	0.4550	6.31
Time * Pre/Post-P/T Phase + Glob. Mod. Sans Local Env.	12	-21.3	73.9	3.750	0.00912	0.4640	6.52
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-26.0	73.9	3.800	0.00890	0.4730	6.68
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-28.8	74.0	3.830	0.00876	0.4820	6.78
Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	10	-24.6	74.0	3.900	0.00847	0.4910	7.02
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Global-level Variables + Sampling Variables	12	-21.4	74.1	3.970	0.00818	0.4990	7.26

Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-26.1	74.1	3.980	0.00813	0.5070	7.31
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-26.1	74.2	4.030	0.00793	0.5150	7.50
Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	9	-26.1	74.2	4.050	0.00785	0.5230	7.56
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol. Counts	8	-27.6	74.2	4.070	0.00778	0.5300	7.63
3000 km							
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	11	-15.7	59.4	0.000	0.05910	0.0591	1.00
Time * Pre/Post-P/T Phase + Sampling Variables	9	-18.8	59.6	0.141	0.05500	0.1140	1.07
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.0	59.8	0.413	0.04800	0.1620	1.23
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	60.0	0.570	0.04440	0.2070	1.33
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.1	60.2	0.752	0.04050	0.2470	1.46
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-17.6	60.2	0.753	0.04050	0.2880	1.46
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-18.2	61.3	1.860	0.02330	0.3110	2.54
Time * Pre/Post-K/Pg Phase + Lithol. Counts	8	-21.1	61.3	1.880	0.02310	0.3340	2.56
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-16.7	61.4	1.940	0.02240	0.3560	2.64
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.4	61.6	2.180	0.01990	0.3760	2.97
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-21.5	62.0	2.540	0.01660	0.3930	3.56

Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-18.5	62.0	2.560	0.01650	0.4090	3.59
Time * Pre/Post-P/T Phase + Glob. Mod. Sans Local Env.	12	-15.4	62.1	2.710	0.01520	0.4240	3.88
Time * Pre/Post-K/Pg Phase + Sampling Variables + Temporal Factors	10	-18.7	62.2	2.820	0.01440	0.4390	4.10
Time + Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	8	-21.6	62.3	2.860	0.01410	0.4530	4.19
Time * Pre/Post-P/T Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.7	62.3	2.890	0.01390	0.4670	4.24
Time * Pre/Post-K/Pg Phase + Sampling Variables	9	-20.2	62.4	2.970	0.01330	0.4800	4.43
Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	8	-21.7	62.4	3.000	0.01320	0.4930	4.48
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-18.8	62.4	3.000	0.01320	0.5070	4.48
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-20.3	62.4	3.010	0.01310	0.5200	4.51
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.8	62.5	3.060	0.01280	0.5330	4.61
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-18.8	62.5	3.090	0.01260	0.5450	4.69
Time + Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-20.3	62.5	3.120	0.01240	0.5580	4.77
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Global-level Variables + Sampling Variables	12	-15.7	62.6	3.210	0.01190	0.5690	4.97
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-18.9	62.7	3.250	0.01160	0.5810	5.08
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-18.9	62.7	3.330	0.01120	0.5920	5.27

Time * Pre/Post-K/Pg Phase + Glob. Mod. Sans Local Env.	12	-15.7	62.8	3.330	0.01120	0.6030	5.29
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.4	62.8	3.330	0.01110	0.6150	5.30
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.4	62.8	3.390	0.01090	0.6250	5.44
Time * Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	11	-17.5	63.0	3.530	0.01010	0.6350	5.85
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Shallow Marine Sediment Coverage + Lithol. Counts	10	-19.1	63.0	3.610	0.00971	0.6450	6.08
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-19.1	63.1	3.650	0.00952	0.6550	6.20
Time * Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-19.1	63.1	3.680	0.00938	0.6640	6.29
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-17.6	63.1	3.690	0.00931	0.6730	6.34
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Shallow Marine Sediment Coverage + Lithol. Counts	9	-20.6	63.1	3.700	0.00929	0.6830	6.36
Time * Pre/Post-K/Pg Phase + Global-level Variables + Sampling Variables	11	-17.6	63.1	3.730	0.00916	0.6920	6.45
Time + Pre/Post-K/Pg Phase + Lithol. Counts	7	-23.4	63.2	3.760	0.00899	0.7010	6.57
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-20.7	63.4	3.960	0.00817	0.7090	7.23
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-17.8	63.5	4.090	0.00766	0.7170	7.71
3500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-19.6	58.4	0.000	0.06690	0.0669	1.00

Time * Pre/Post-P/T Phase + Sampling Variables	9	-18.3	58.6	0.183	0.06100	0.1280	1.10
Time * Pre/Post-P/T Phase + Lithol. Counts	8	-20.0	59.2	0.766	0.04560	0.1730	1.47
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts	9	-18.6	59.3	0.835	0.04400	0.2180	1.52
Time * Pre/Post-P/T Phase + Ref. Counts	8	-20.5	60.1	1.680	0.02890	0.2460	2.31
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	10	-17.6	60.3	1.810	0.02700	0.2730	2.47
Time + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	60.3	1.830	0.02680	0.3000	2.50
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-17.6	60.4	1.930	0.02550	0.3260	2.63
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.3	60.8	2.310	0.02100	0.3470	3.18
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-19.3	60.8	2.330	0.02090	0.3680	3.20
Time * Pre/Post-P/T Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-17.9	60.9	2.460	0.01950	0.3870	3.43
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Sampling Variables	10	-18.0	61.1	2.630	0.01790	0.4050	3.73
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-19.5	61.1	2.650	0.01780	0.4230	3.77
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-19.5	61.1	2.700	0.01730	0.4400	3.86
Time * Pre/Post-P/T Phase + Sampling Variables + Temporal Factors	10	-18.1	61.4	2.930	0.01550	0.4560	4.32
Global-level Variables + Sampling Variables	8	-21.2	61.5	3.060	0.01450	0.4700	4.62
Time * Pre/Post-P/T Phase + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	10	-18.2	61.6	3.130	0.01400	0.4840	4.78

Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	10	-18.3	61.7	3.220	0.01340	0.4970	5.00
Time * Pre/Post-P/T Phase + Shallow Marine Sediment Coverage + Lithol. Counts	9	-19.8	61.8	3.320	0.01270	0.5100	5.25
Time * Pre/Post-P/T Phase + Prop. Reefal + Lithol. Counts	9	-19.8	61.8	3.340	0.01260	0.5230	5.30
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	10	-18.3	61.8	3.370	0.01240	0.5350	5.40
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Lithol. Counts	9	-19.9	61.8	3.400	0.01220	0.5470	5.48
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Ref. Counts	9	-19.9	62.0	3.550	0.01130	0.5590	5.90
Time * Pre/Post-P/T Phase + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.0	62.0	3.570	0.01120	0.5700	5.97
Time * Pre/Post-P/T Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-16.9	62.0	3.590	0.01110	0.5810	6.03
Time * Pre/Post-P/T Phase + Global-level Variables + Sampling Variables	11	-16.9	62.0	3.600	0.01110	0.5920	6.04
Time * Pre/Post-P/T Phase + Lithol. Counts + Post-Jurassic Epeiric	9	-20.0	62.1	3.640	0.01080	0.6030	6.17
Pre/Post-K/Pg Phase + Shallow Marine Sediment Coverage + Lithol. Counts	7	-23.0	62.3	3.900	0.00950	0.6120	7.04
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage	7	-23.0	62.5	4.080	0.00871	0.6210	7.68
Time * Pre/Post-P/T Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	11	-17.1	62.5	4.080	0.00869	0.6300	7.69
Pre/Post-K/Pg Phase + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	8	-21.7	62.5	4.090	0.00864	0.6380	7.74

Table S8. Model selection results for mid paleolatitudes (±30-60º) for alternate analysis including supercontinent index variable (evidence ratio ≤ 8). Note that supercontinent index does not appear in any of these models due to insufficient Akaike weights.

Model Description	DF	Log Lik	AICc	Delta	Weight	Cumulative Weight	Evidence Ratio
1500 km							
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-16.0	57.0	0.0000	0.1690	0.169	1.00
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-17.8	57.6	0.6070	0.1250	0.294	1.35
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	9	-18.6	59.3	2.2700	0.0545	0.348	3.10
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-18.8	59.6	2.5700	0.0468	0.395	3.61
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-20.2	59.6	2.6200	0.0456	0.441	3.70
Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	11	-15.8	59.8	2.7600	0.0424	0.483	3.98
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	11	-15.8	59.8	2.8200	0.0414	0.525	4.09
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-17.5	60.0	3.0100	0.0375	0.562	4.51
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-20.5	60.2	3.2100	0.0340	0.596	4.97

Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-17.8	60.6	3.5800	0.0283	0.624	5.98
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.8	60.8	3.8300	0.0249	0.649	6.78
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-22.4	61.1	4.1300	0.0214	0.671	7.90
2000 km							
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-20.1	64.9	0.0000	0.1310	0.131	1.00
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	11	-18.6	65.0	0.0678	0.1260	0.257	1.03
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	11	-18.8	65.5	0.6080	0.0963	0.353	1.36
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-22.2	66.3	1.3400	0.0666	0.420	1.96
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	12	-17.7	66.4	1.4700	0.0627	0.482	2.08
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-23.8	66.6	1.6600	0.0569	0.539	2.29
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-22.7	67.1	2.2100	0.0433	0.583	3.01
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts + Post-Jurassic Epeiric	10	-21.3	67.3	2.4000	0.0393	0.622	3.32

Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	11	-19.9	67.6	2.7000	0.0339	0.656	3.85
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-21.7	68.2	3.2200	0.0261	0.682	5.00
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	12	-18.5	68.2	3.2300	0.0260	0.708	5.02
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-23.4	68.7	3.7500	0.0201	0.728	6.51
Time * Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	12	-18.8	68.7	3.7700	0.0198	0.748	6.58
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-22.0	68.9	3.9400	0.0182	0.766	7.16
2500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-13.5	46.2	0.0000	0.1640	0.164	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-15.6	47.5	1.3200	0.0847	0.248	1.93
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-12.8	47.7	1.4400	0.0796	0.328	2.06
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-13.0	48.1	1.8400	0.0652	0.393	2.51
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-13.2	48.5	2.2500	0.0531	0.446	3.08

Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-11.9	48.9	2.6600	0.0434	0.490	3.77
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-13.5	49.0	2.8000	0.0404	0.530	4.06
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-12.2	49.4	3.1800	0.0333	0.563	4.91
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-15.3	49.7	3.5100	0.0283	0.592	5.79
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-15.3	49.7	3.5200	0.0282	0.620	5.81
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-15.4	49.8	3.6100	0.0270	0.647	6.07
Time + Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-12.5	50.0	3.7500	0.0252	0.672	6.51
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	10	-12.5	50.0	3.7700	0.0249	0.697	6.57
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-15.6	50.3	4.0400	0.0218	0.719	7.52
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-12.7	50.3	4.1100	0.0210	0.740	7.80
3000 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-20.5	59.9	0.0000	0.2030	0.203	1.00

Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-22.2	60.8	0.8560	0.1320	0.335	1.53
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.0	61.9	1.9300	0.0772	0.412	2.62
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-20.3	62.5	2.5300	0.0572	0.469	3.54
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-20.4	62.7	2.7700	0.0508	0.520	3.99
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-20.4	62.7	2.7700	0.0507	0.571	4.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-22.2	63.4	3.5000	0.0352	0.606	5.76
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-22.2	63.4	3.5200	0.0348	0.641	5.82
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-22.2	63.5	3.5500	0.0344	0.675	5.89
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-22.2	63.5	3.5700	0.0341	0.709	5.95
Time * Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	10	-19.6	64.0	4.1200	0.0258	0.735	7.86
3500 km							
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	8	-15.9	51.3	0.0000	0.1300	0.130	1.00
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	8	-16.3	52.0	0.7900	0.0877	0.218	1.48

Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	9	-15.0	52.3	1.0800	0.0758	0.294	1.72
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	7	-17.9	52.4	1.2000	0.0715	0.365	1.82
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Lithol. Counts	9	-15.6	53.6	2.3800	0.0397	0.405	3.28
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts	8	-17.3	54.0	2.7500	0.0329	0.438	3.95
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts	9	-15.9	54.1	2.8900	0.0306	0.468	4.25
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Lithol. Counts + Post-Jurassic Epeiric	9	-15.9	54.2	2.9000	0.0305	0.499	4.27
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-16.2	54.7	3.4500	0.0232	0.522	5.62
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Post-Jurassic Epeiric	8	-17.6	54.7	3.4600	0.0231	0.545	5.65
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage	9	-16.2	54.8	3.5100	0.0225	0.568	5.79
Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Post-Jurassic Epeiric	9	-16.3	54.9	3.6800	0.0207	0.588	6.29
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-14.8	55.2	3.9400	0.0181	0.606	7.19
Time + Pre/Post-K/Pg Phase + Prop. Reefal + Ref. Counts	8	-17.9	55.2	3.9900	0.0177	0.624	7.34
Pre/Post-K/Pg Phase + Absolute Median Paleolatitude + Prop. Reefal + Ref. Counts + Shallow Marine Sediment Coverage + Lithol. Counts	10	-14.9	55.3	4.0600	0.0171	0.641	7.63