Global plate model choice impacts reconstructions of the latitudinal biodiversity gradient

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¶ Abstract

Here goes the abstract…

# Keywords

Latitudinal biodiversity gradient, marine invertebrates, macroecology, global plate model, palaeogeographic uncertainty

# Introduction (600 words)

Today, species richness decreases from the tropics to the poles. This phenomenon is known as the latitudinal biodiversity gradient (LBG), and is one of Earth’s longest recognised macroecological patterns [1–4]. While observed across numerous taxonomic groups in the terrestrial [2,3,**kinlock2017?**] and marine realm today [5,6,but see 7,8,9], the fossil record suggests this broadly unimodal gradient was not always present, with flattened and bimodal gradients observed across a range of taxonomic groups at various points in Earth’s geological history [e.g. 10,11–19]. Several studies have demonstrated that tropical peaks and poleward declines in taxonomic richness have been restricted to the last 30 million years (Myr), and intervals of the Palaeozoic when cool icehouse climatic regimes persisted [4,19,e.g. 20,21–23]. Conversely, during intervals of warmer climatic conditions (i.e. greenhouse and interglacial periods), various taxonomic groups have exhibited flattened LBGs, or even temperate peaks in biodiversity [e.g. 11,12,14–16,24,25]. However, recent work suggests that our ability to recognise different types of LBG in deep time is hindered by incomplete and heterogeneous spatial sampling in the fossil record [26,27].

When examining the LBG in the present day, neontologists use the geographic coordinates where they collected their samples to infer the spatial distributions of taxa. However, palaeobiologists must contend with the migration of tectonic plates over geological timescales; the geographic location of a fossil occurrence on the Earth’s surface today does not necessarily represent its location *in* *vivo*. Being able to accurately translate modern-day locality coordinates into the geographic distributions of fossil taxa is therefore a fundamental step in reconstructing the LBG in deep time. To do this, palaeobiologists routinely use Global Plate Models–sometimes also called ‘palaeorotation models’ or ‘plate rotation models’– [17,18,23,25,28,29]. These models aim to reconstruct the tectonic evolution of the Earth by modelling the motion of the continental– and sometimes marine–plates across its surface through geological time. Many Global Plate Models have been constructed [e.g. 30,31–33], varying in the way they define the geological boundaries of continents and how they rotate them through time, having consequence for how fossil occurrences might be palaeogeographically reconstructed [34]. However, to date, few palaeobiological studies (though see ref. [35,36]) have considered how different Global Plate Models might influence reconstructions of the latitudinal distributions of fossil occurrences.

Here, we test how much Global Plate Model choice influences the recognition of ‘unimodal-type’ latitudinal biodiversity gradients throughout the Phanerozoic (the last 540 million years). To do so, we reconstruct the palaeogeographic distribution of fossil occurrences for five major marine invertebrate groups, using data from the Paleobiology Database, and three Global Plate Models. We then describe the raw latitudinal distribution of occurrences before reconstructing the latitudinal biodiversity gradient using coverage-based rarefaction–a common sampling-standardisation approach–and quantify the strength of the gradient through time and the variability between Global Plate Models. We hypothesise that reconstructions of the latitudinal biodiversity gradient are more sensitive to plate rotation model choice with increasing age of rotation.

# Materials and Methods (600 words)

## Occurrence data

We downloaded Fortunian–Piacenzian (541–0 Ma) fossil occurrence data from the Paleobiology Database (PBDB; <https://paleobiodb.org/>) for five major marine invertebrate groups (Bivalvia, Brachiopoda, Cephalopoda, Gastropoda, Trilobita) on March 16 2023. Fossil occurrence data were downloaded using the PBDB API service and were restricted to marine environments and regular preservation (i.e. excluding form taxa and ichnotaxa). Occurrence data were subsequently binned into stratigraphic stage-level time bins following the Geological Timescale 2020 [37], with the exception of Holocene and Pleistocene stages which were collapsed into their equivalent Epoch-level bins (i.e. Holocene and Pleistocene). Temporal binning was carried out using the bin\_time() function from the palaeoverse R package ver. 1.1.1.900, using the ‘majority’ approach [38]. Subsequently, we removed all occurrences with less than 95% of their age range covered by their assigned temporal bin. After data preparation, the occurrence dataset contained 443,815 occurrences from 78,730 collections.

## Palaeogeographic reconstruction and binning

To reconstruct the palaeogeographic distributions of fossil occurrences, we used localities’ present-day coordinates and midpoint age from their assigned temporal bins with three Global Plate Models: PALEOMAP [32], GOLONKA [31], and MERDITH2021 [33]. Palaeogeographic reconstructions were generated using the GPlates Web Service (<https://gwsdoc.gplates.org>) via the palaeorotate() function in palaeoverse ver. 1.1.1.900 [38]. For each Global Plate Model, fossil occurrences were binned into one of twelve equal-area latitudinal bins, using the estimated palaeolatitudes ([Table 1](#tbl-bins)).

Table 1: Equal-area latitudinal bins used in this study. Bins are generated assumming a regular spheroid Earth model with a mean radius of ~6,371 km.

| Bin | Maximum | Midpoint | Minimum | Area (m2) | Proportion of Area |
| --- | --- | --- | --- | --- | --- |
| 1 | 90.00 | 73.235 | 56.47 | 4.24e+13 | 0.083 |
| 2 | 56.47 | 49.150 | 41.83 | 4.25e+13 | 0.083 |
| 3 | 41.83 | 35.920 | 30.01 | 4.25e+13 | 0.083 |
| 4 | 30.01 | 24.745 | 19.48 | 4.25e+13 | 0.083 |
| 5 | 19.48 | 14.540 | 9.60 | 4.25e+13 | 0.083 |
| 6 | 9.60 | 4.800 | 0.00 | 4.25e+13 | 0.083 |
| 7 | 0.00 | -4.800 | -9.60 | 4.25e+13 | 0.083 |
| 8 | -9.60 | -14.540 | -19.48 | 4.25e+13 | 0.083 |
| 9 | -19.48 | -24.745 | -30.01 | 4.25e+13 | 0.083 |
| 10 | -30.01 | -35.920 | -41.83 | 4.25e+13 | 0.083 |
| 11 | -41.83 | -49.150 | -56.47 | 4.25e+13 | 0.083 |
| 12 | -56.47 | -73.235 | -90.00 | 4.24e+13 | 0.083 |

## Quantifying the latitudinal biodiveristy gradient

* Metrics used to quantify the gradient

# Results (600 words)

* Summary of reconstructions (could all points be reconstructed for each model?)
* Summary of results from metrics, do different gradients emerge?

# Discussion (700 words)

* Recap on importance of GPMs for deep time macroecology?
* What have we shown?
* Are some times or areas more problematic than others?
* Importance for other fields beyond palaeobiology?
* Consider importance of GPM choice in future work… or not?

# Data accessibility

# Authors’ contributions

# Funding

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