Using evolutionary modelling to investigate the Latitudinal Biodiversity Gradient

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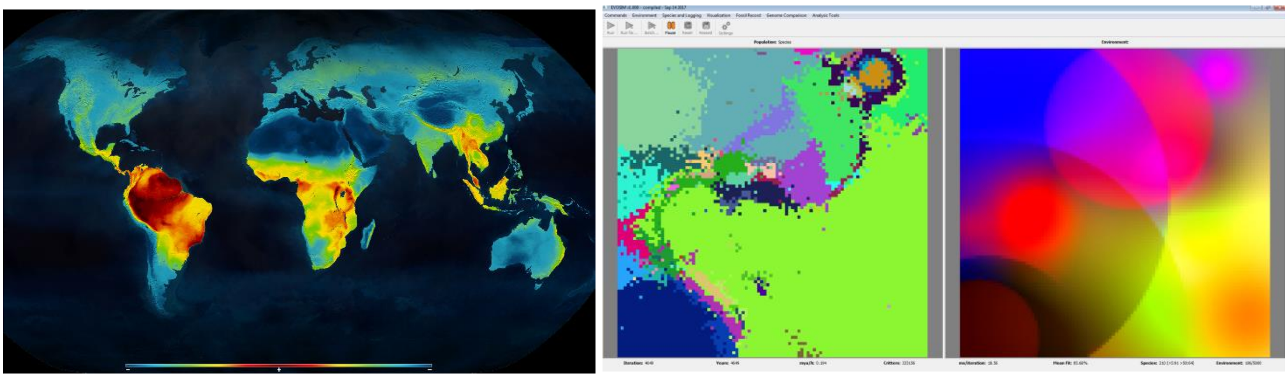
The Latitudinal Biodiversity Gradient (LBG), the phenomenon where biodiversity increases along a pole-to-equator transect, is one of the most widely recognized patterns in macroecology. The LBG occurs in most studied groups of organisms, and in widely varying environments (e.g. terrestrial and marine). Understanding what generates it and how it relates to climate is fundamental to any attempt to understand how biodiversity will react to ongoing global warming. Many mechanisms for LBG generation have been proposed (e.g. latitudinal seasonality variations, continental configuration, historical contingency, and many others), but the relative merit of these explanations, and the ways in which they might have interacted to produce the observed gradient, remain poorly resolved. In short, we do not fully understand why the LBG exists. In part, this is because of the simplicity of the pattern observed in the Recent, which lacks sufficient information to enable us to decide between mechanisms. Palaeontological data, however, suggest that, for some groups at least, the LBG observed in the Recent does not have a long geological history; it differed in the past, in complex ways that are still being investigated. The investigation of past latitudinal biodiversity variation hence provides a more information–rich dataset with which to compare predictions from models for LBG generation.

This project will approach the LBG problem from a novel angle. An evolutionary simulation system (*EvoSim*) developed by one of the supervisors (MDS) will be used to investigate the development of LBG-like patterns in synthetic environments, under a variety of conditions intended to implement suggested mechanisms for LBG-generation. This will enable the student to determine experimentally (rather than theoretically) which mechanisms are plausible, and what elements of a real biological system are necessary for such a pattern to appear (e.g. ecological interactions? seasonality?). Further, the student will compare simulations not only with the LBG from the Recent time-slice, but with patterns from palaeontological time-slices for which environmental data are also available. By determining what combination of causal models and simulation parameters best fits the real world data over long periods of geological time, a more nuanced understanding of the likely underlying cause(s) of the LBG phenomenon will be sought.



Left: Terrestrial vertebrate species-richness, demonstrating the LBG. *Right*: *EvoSim.* Left image shows species in different colours; right image shows environment.

EvoSim uses a computationally efficient, bottom-up evolutionary model, capable of simulating populations of >1 million individuals over millions of generations, using modest hardware; it can operate at macroevolutionary scales, i.e. over geological time. It simulates individual organisms, and models the core aspects of biological evolution. EvoSim uses an environmental 'grid' of colour pixels, which can be spatially/temporally homogenous or heterogeneous, as desired. In each pixel live digital organisms with a binary genome, comprising coding and non-coding portions. Individuals procreate sexually, with random mutation; their propagation chance being controlled by a fitness computed from their coding genome and the colour of their environment. Species arise naturally; the software identifies and tracks these, enabling generation of and quantification of biodiversity. EvoSim is highly customizable, allowing users to modify and assess the impact of many variables, or code new additions to the model for specific purposes. Developing EvoSim to enable testing and implementation of LBG models will form a core part of the PhD.

The student who undertakes this project will: undertake simulation runs and coding of EvoSim to test a range of LBG scenarios; further develop palaeontological understanding of the LBG, building on existing work by one of the supervisors (PM) but broadening data sampling (using the Paleobiology Database [www.paleobiodb.org]), both taxonomically and stratigraphically; synthesise results from simulation work and time-slice analysis into a new and fuller understanding of the drivers of the LBG; finally, analyze the potential significance of these results for the effects of climate change on the LBG.

This project sits at the interface between palaeontology, computer science, and evolutionary macroecology. The ideal candidate will have a good degree in the biological or geological sciences, but also possess programmer-grade computing skills, or show potential to acquire them. During the course of this project, the student will learn skills in software development, statistical analysis (especially palaeobiodiversity reconstruction), evolutionary simulation, and the oral and written presentation of scientific results. The student will also join a thriving community of palaeobiologists at Imperial College, as well as a wider London network (comprising the Natural History Museum, University College London, and the Zoological Society of London).

Key reading:

Fine, P. V. A. 2015. Ecological and evolutionary drivers of geographic variation in species diversity. *Annual Review of Ecology, Evolution, and Systematics* 46: 369–392.

Jablonski, D., Huang, S., Roy, K. and Valentine, J. W. 2017. Shaping the Latitudinal Diversity Gradient: New Perspectives from a Synthesis of Paleobiology and Biogeography. *The American Naturalist* 189: 1–12.

Mannion, P.D., Upchurch, P., Benson, R.B.J. and Goswami, A. 2014. The latitudinal biodiversity gradient through deep time. *TRENDS in Ecology and Evolution* 29: 42–50.