EGU2020-20627
https://doi.org/10.5194/egusphere-egu2020-20627
EGU General Assembly 2020

GEN3SIS: An engine for simulating eco-evolutionary processes in the context of plate tectonics and deep-time climate variations

Oskar Hagen[1,2], Renske E. Onstein[3], Benjamin Flück[2], Fabian Fopp[2], Florian Hartig[4], Mikael Pontarp[5], Camille Albouy[6], Ao Luo[7], Lydian Boschman[2], Juliano S. Cabral[8], Yaowu Xing[7], Zhiheng Wang[7], Thiago F. Rangel[9], Christopher Scotese[10], and Loïc Pellissier[2]

[1]Swiss Federal Institute Swiss Federal Institute of Technology in Zurich, Terrestrial Ecosystems, Environmental Sciences, Switzerland (oskar@hagen.bio)

[2]Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland

[3]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Deutscher Platz 5e, 04103 Leipzig, Germany

[4]Theoretical Ecology, University of Regensburg, Regensburg, Germany

[5]Department of Biology, Lund University, Biology Building, Sölvegatan 35, 223 62 Lund, Sweden

[6]IFREMER, unité Ecologie et Modèles pour l'Halieutique, rue de l'Ile d'Yeu, BP21105, Nantes cedex 3, France

[7]Institute of Ecology, College of Urban and Environmental Sciences, and Key Laboratory of Earth Surface Processes of Ministry of Education, Peking University, Beijing 100871, China

[8]Ecosystem Modeling, Center for Computational and Theoretical Biology (CCTB), University of Würzburg, Clara-Oppenheimer-Weg 32, 97074 Würzburg, Germany

[9]Departamento de Ecologia, Universidade Federal de Goiás, Brasil

[10]Department of Earth and Planetary Sciences, Northwestern University, Evanston, IL, USA

Explaining the origin of large-scale biodiversity gradients has been a key aspiration of early naturalists such as Wegener, Darwin and Humboldt; who looked at natural processes in an integrated way. Early on, these naturalists acknowledged the role of plate tectonics and climate variations in shaping modern day biodiversity patterns.

As science advanced, the complexity of ecological, evolutionary, geological and climatological processes became evident while research became increasingly fragmented across different disciplines. Nevertheless, recent development in mechanistic modeling approaches now enable bringing disciplines back together, opening a new interdisciplinary scientific pathway.

Here, we present GEN3SIS, the GENeral Engine for Eco-Evolutionary SImulationS. It is the first spatially explicit eco-evolutionary model that incorporates deep-time Earth history, including plate tectonics, as well as climate variations in a modular way. The modular design allows exploring the consequences of user-defined biological processes that act across “real world” spatio-temporal landscapes. Emerging from the model are specie’s ranges, alpha and beta diversity patterns, ecological traits as well as phylogenies. Subsequently, these patterns can be compared to empirical data. Furthermore, GEN3SIS allows assessing paleoclimatic and paleogeographic hypotheses by using different Earth history scenarios and comparing simulation outputs with empirical biological data.

As a case study, we explore the cold-adapted plant biodiversity dynamics throughout the Earth's Cenozoic history, based on a deep-time tectonic and climate reconstruction. The Cenozoic India-Asia collision formed the Himalayan mountain range. In this highly elevated region, the first cold niches of the Cenozoic appeared, demanding adaptation from the local living flora. We hindcast diversification of cold-adapted species with GEN3SIS, for which we use a topo-climatic reconstruction for the last 55 Myr. The model predicts the emergence of current cold-species richness patterns. Moreover, simulations indicate that cold-adapted flora emerged in the Oligocene, first in the Himalayas, followed by a spread to the Arctic. This agrees with observed low species richness and high nestedness of Arctic assemblages compared to those of the Himalayan mountain ranges. Under ongoing climate change a major loss of cold-adapted plant diversity is expected by the end of the century, particularly in lower latitude mountain ranges. Hindcasting and forecasting dynamics of cold-adapted lineages highlights the transient fate of cold organisms in a warming world.

GEN3SIS is made available as an R package, which allows customizing (i) the simulated landscape including environmental variables and (ii) all the processes interacting under different spatial and temporal scales. Consequently, GEN3SIS fosters collaborations between different natural disciplines and therefore contributes to an interdisciplinary understanding of the processes that shaped Earth's history.