Peaks in species richness at mid-elevation bands have been observed in ecosystems and taxa around the globe. A number of ecological processes may contribute to this including varying autotrophic productivity, tradeoffs between competitive ability and environmental tolerance, and differences in area and isolation. Evolutionary processes have also been suggested; however, such explanations are difficult to support, as it is often unclear how speciation and extinction rates have changed over time.

Here, we use records of historical temperature and topographic changes over the past 65 Myr to construct an agent-based simulation model of Plethodontid salamander evolution in eastern North America. We then explore possible mechanisms constraining species to mid-elevation bands by using the model to predict Plethodontid evolutionary history and contemporary geographic distributions.

Our results show that models which incorporate both temperature and topographic changes are better able to predict observed patterns, suggesting that both processes may have played an important role in driving Plethodontid evolution in the region. Additionally, our model represents a proof of concept to encourage future work that takes advantage of recent advances in computing power to combine models of ecology, evolution, and earth history to better explain the abundance and distribution of species over time.

Our model tracks the evolutionary history of a single progenitor species, and all of its descendant species, from an origin 65 Mya to the present. Climatic and geologic change are inexpensive simulated for this period, allowing us to tease apart their effects.

Each species is represented by one or more populations. Dynamics within populations are not explicitly simulated. Rather, we assume that individuals within a population are proximal, share the same traits, and are genetically identical. Between populations, these aspects can vary. The abundance of a species is determined by the number of populations of that species. If the genetic differences among populations within a single species become large enough, the populations diverge into separate species.

We fit this model to data species' ranges, richness, and phylogenies drawn from 95 Appalachian Plethodontid taxon groups found predominantly the Mississippi. Finally, we compared model fits across scenarios to determine which factors were most important in driving evolution.


Figure 1: Comparison of observed and predicted metrics when both climatic and geologic change are included as processes (ET scenario). Black lines show observed data, while blue lines show results from simulations. Grey shaded regions in (a) and blue shaded regions in (c–e) show 95% confidence intervals for observed values, or median for simulated values. Lines in (b–f) show smoothed kernel density estimates, points show frequency calculated empirically from binned data.

Figure 2: Examples of metric comparisons and time trends for other metric scenarios. Panels (a), (b), and (c) are for the scenario with directed dispersal. Panels (d), (e), and (f) are for the scenario with multiple invasions. Symbols and intervals for (d–f), respectively. Colors and intervals in (d–f) are as described in Fig. 2 (b).

Figure 3: Time trends predicted from the fitted scenario with climatic and geologic change (ET scenario). Lines show means ± one standard deviation. (a) Black line shows temperature trend over time, and orange shows rates for speciation and extinction, respectively. Darker regions show overlap between confidence intervals.