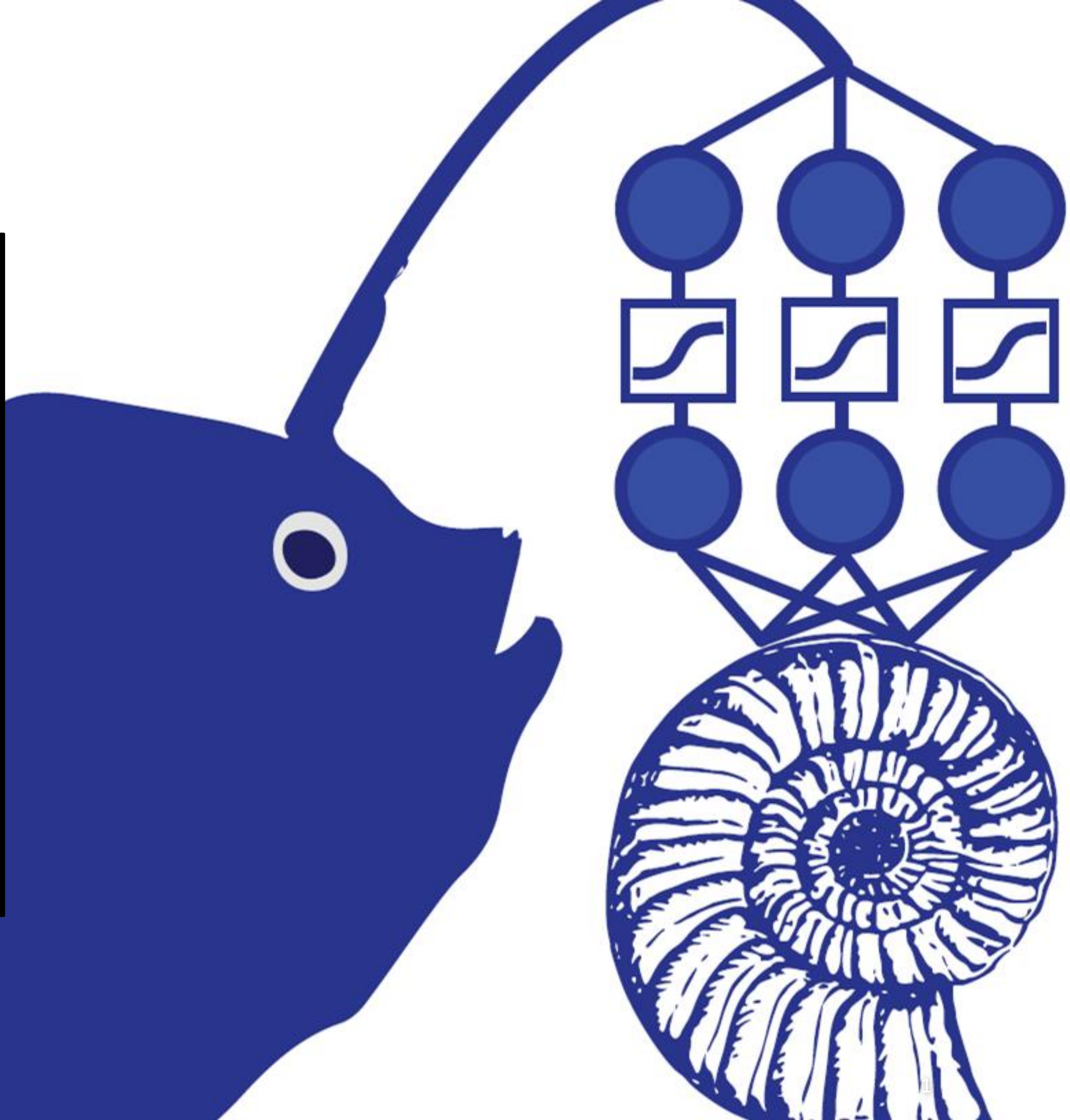
Introduction

DeepDive: Deep learning Diversity Estimation

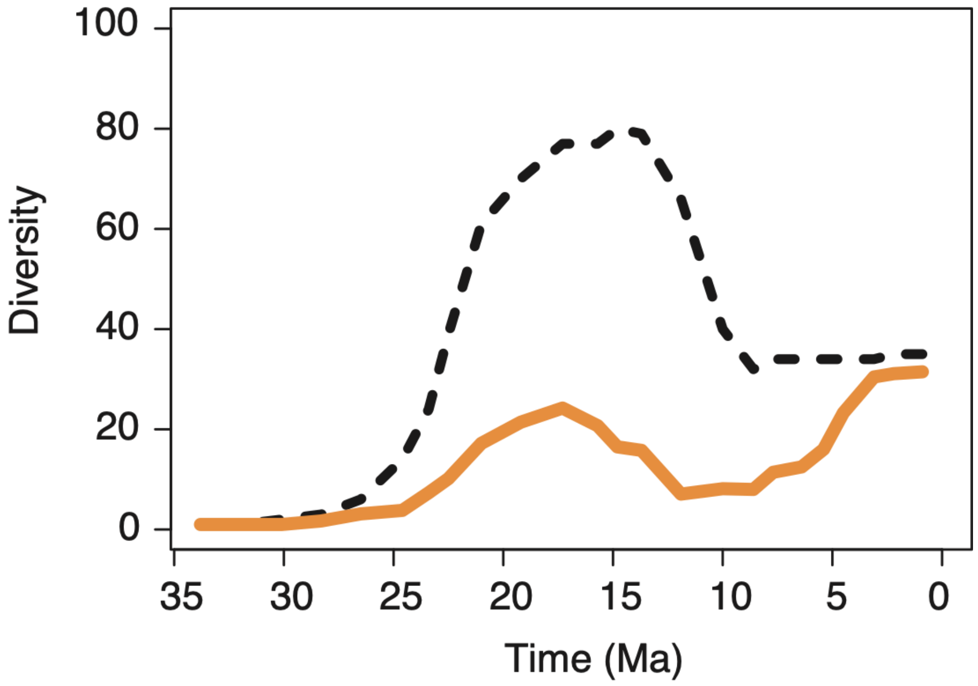
CPEG 2025



Estimating biodiversity from fossil data

- Fossils are our only direct evidence of past biodiversity.
- Non-random biases at spatial, taxonomic and temporal scales.
- Available methods are based on rarefaction or simple models assuming random sampling.

True vs observed diversity



Alroy 2010 Science; Starrfelt & Liow 2016 Phil Trans B; Flannery-Sutherland et al. 2022 Nature Comm

Problems in estimating biodiversity from fossils

- Spatial biases make global biodiversity patterns unidentifiable using the current methods.

Science AAAS

PALEONTOLOGY

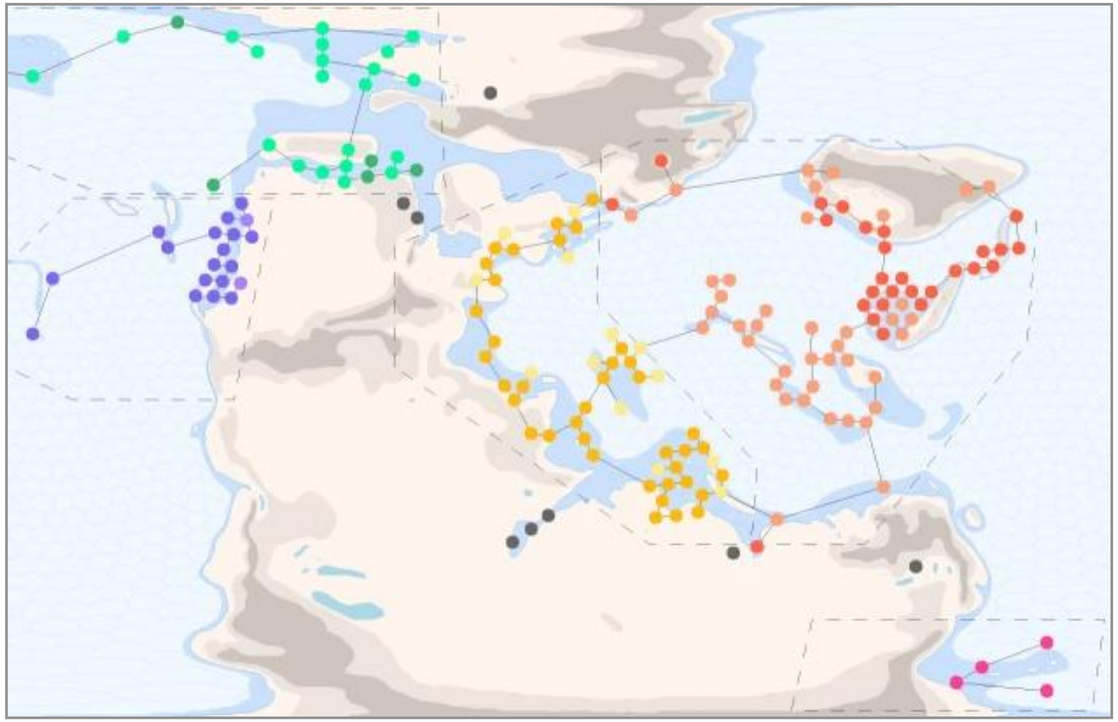
The spatial structure of Phanerozoic marine animal diversity

R. A. Close[1]*, R. B. J. Benson[2], E. E. Saupe[2], M. E. Clapham[3], R. J. Butler[1]

PROCEEDINGS B

royalsocietypublishing.org/journal/rspb

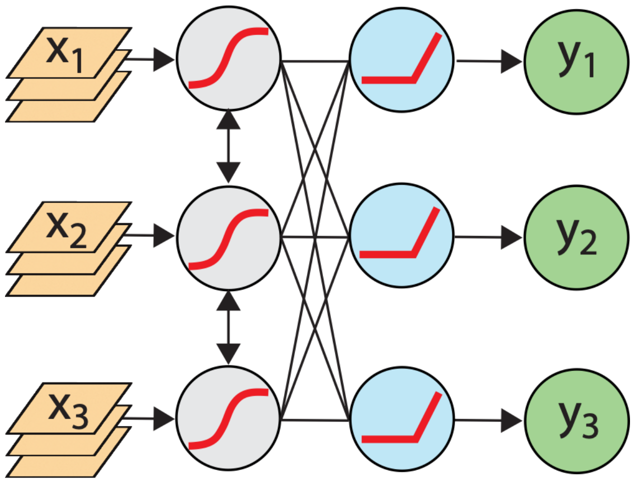
The apparent exponential radiation of Phanerozoic land vertebrates is an artefact of spatial sampling biases



Alroy 2010 Science; Starrfelt & Liow 2016 Phil Trans B; Flannery-Sutherland et al. 2022 Nature Comm

DeepDive: deep learning estimation of biodiversity through time

Input: fossil distribution in space and time



Output: diversity estimates through time

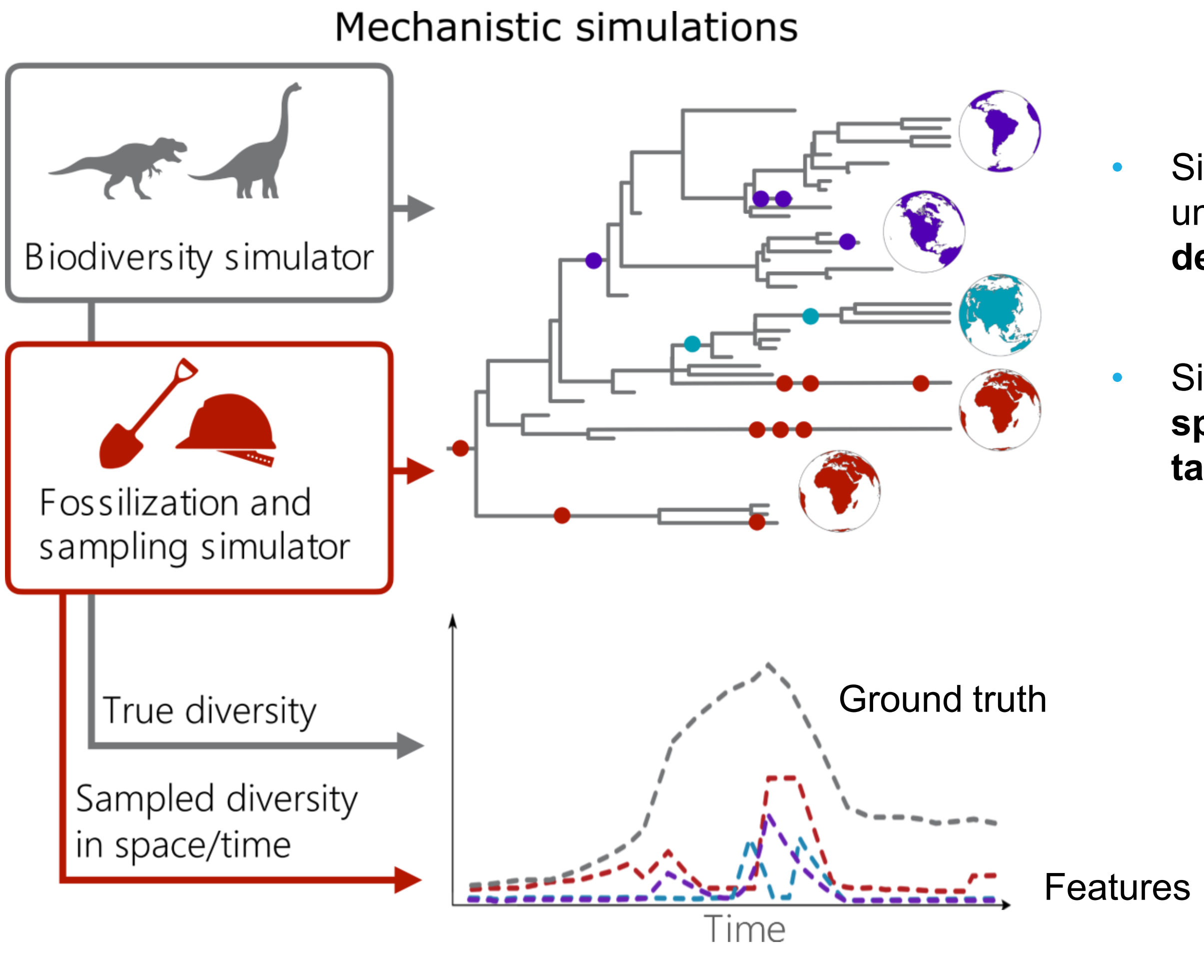

nature communications

Article
https://doi.org/10.1038/s41467-024-48434-7

DeepDive: estimating global biodiversity patterns through time using deep learning

Cooper et al. 2024 Nature Comms
Cooper et al. 2024 biorXiv

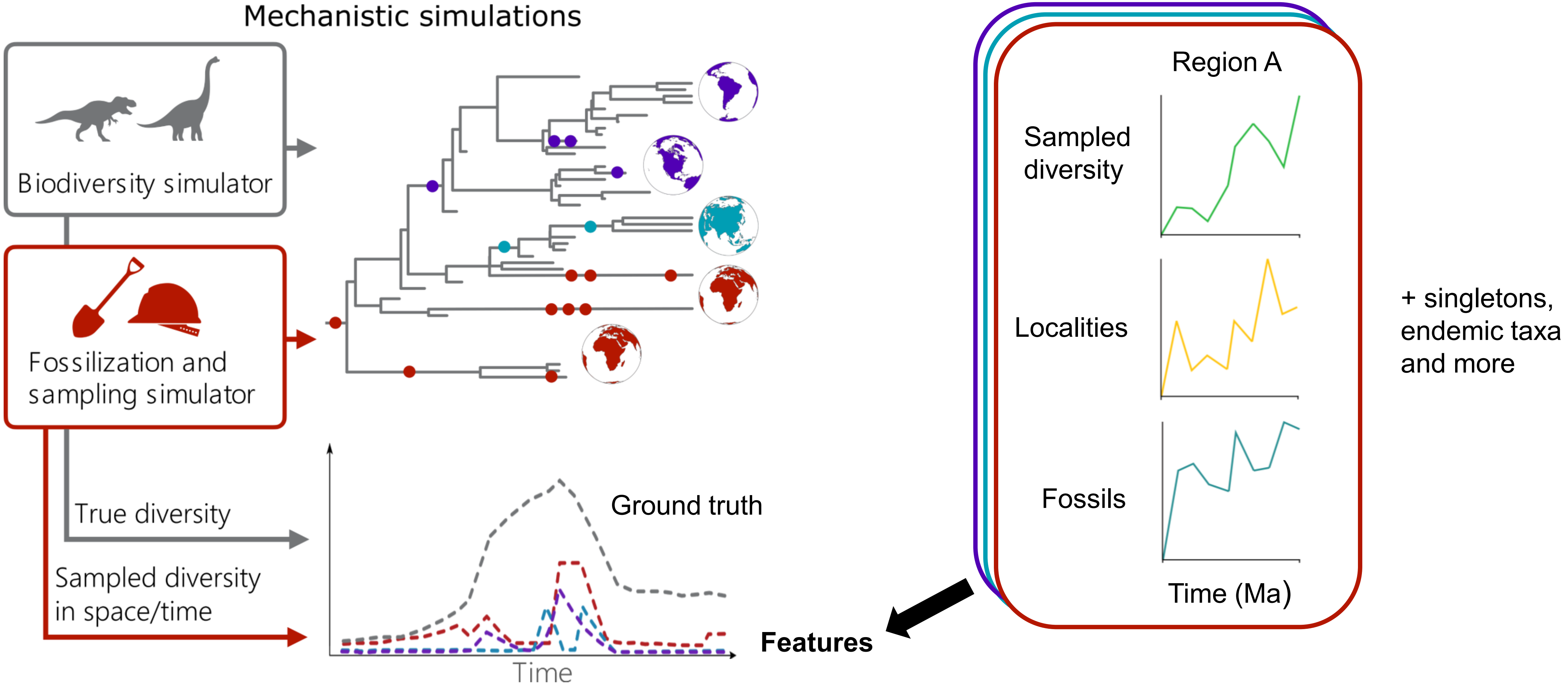
DeepDive



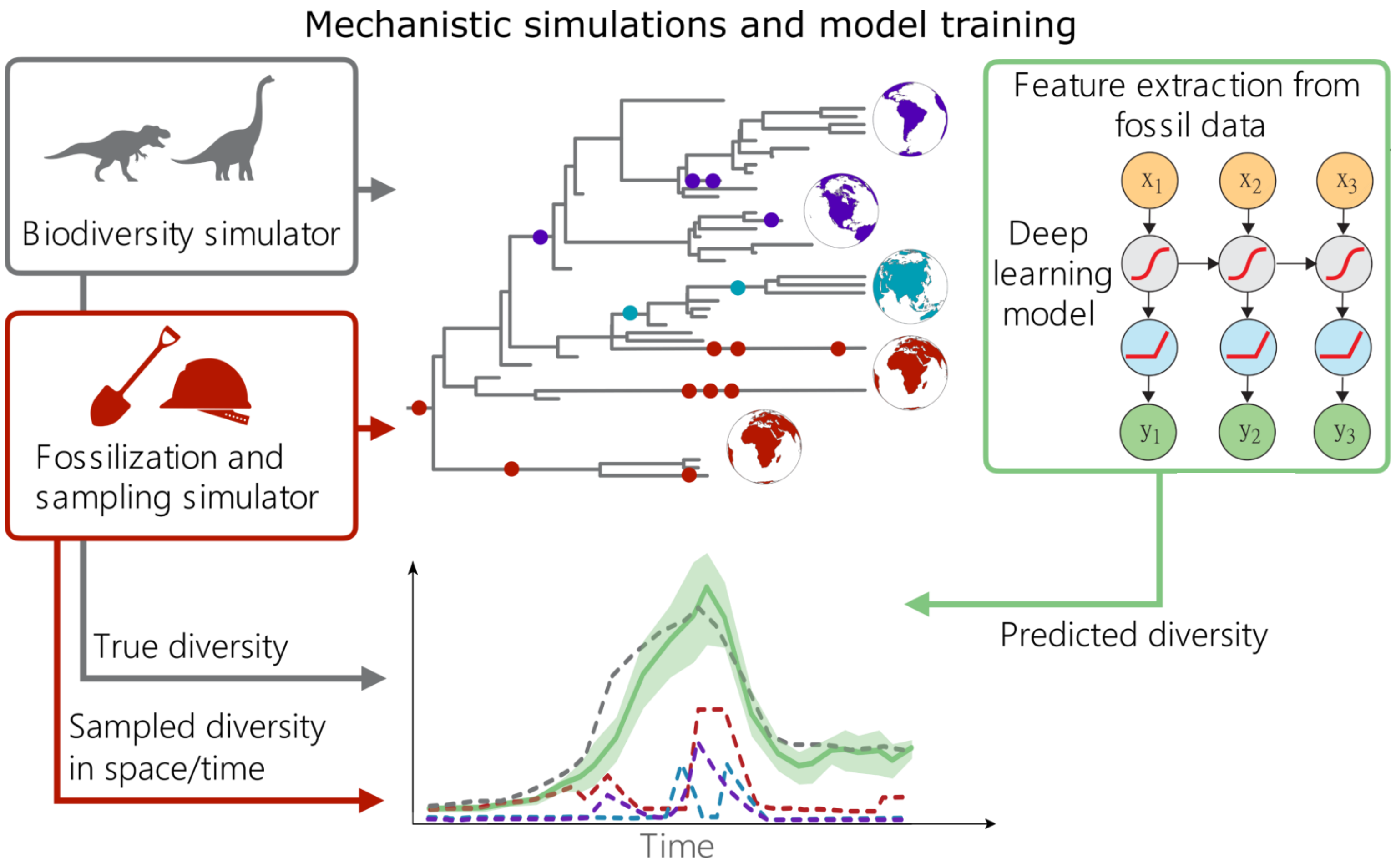
- Simulating clade evolution under spatial-explicit **birth-death processes**
- Simulating fossil data with **spatial, temporal, and taxonomic biases**

Cooper et al. 2024 Nature Communications

DeepDive


Mechanistic simulations
Biodiversity simulator
Fossilization and sampling simulator
True diversity
Sampled diversity in space/time
Ground truth
Time
Features
Region A
Sampled diversity
Localities
Fossils
Time (Ma)
+ singletons, endemic taxa and more

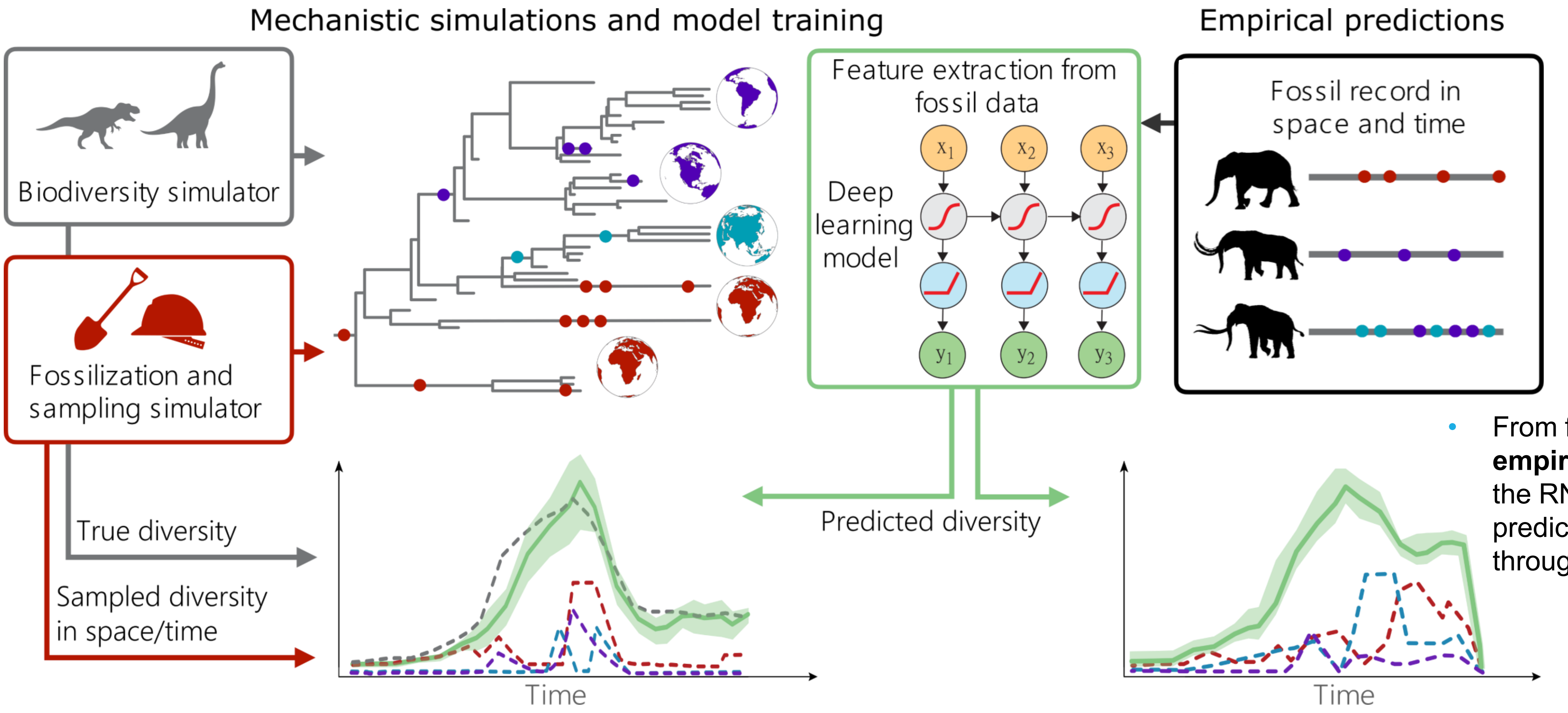
DeepDive



Deep learning models for diversity estimation

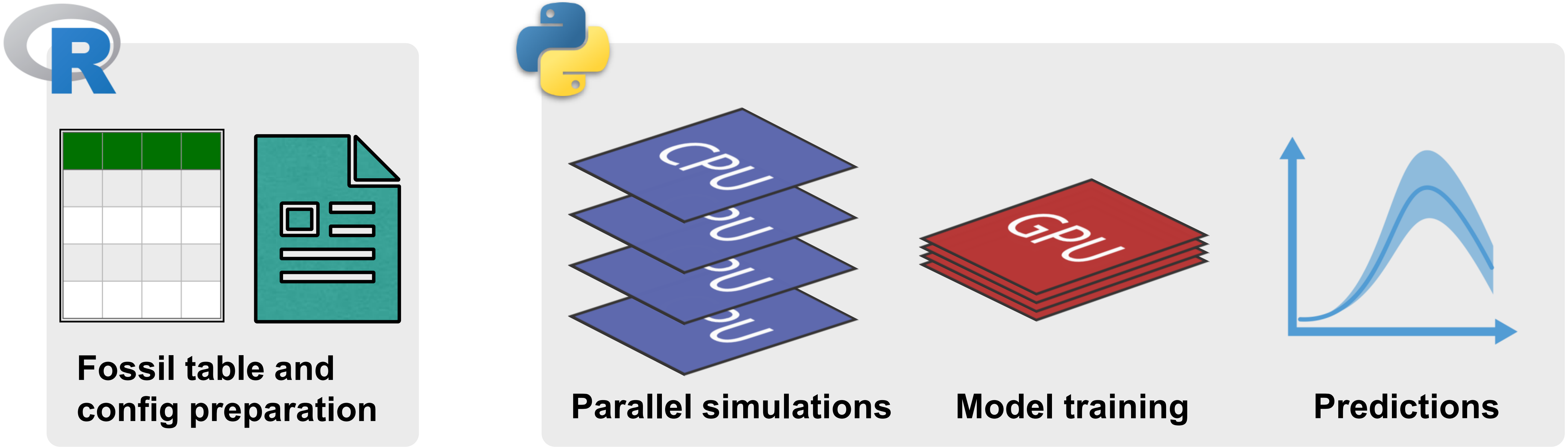
- Training a **Recurrent Neural Network** to predict true diversity from sparse fossil data

DeepDive



- From features of **empirical data**, the RNN can predict diversity through time

DeepDiveR



DeepDiveR

DeepDive

github.com/DeepDive-project

Data preparation

- Occurrence data e.g. from the Paleobiology Database can be formatted as input for DeepDive using the function prep_dd_input()

Taxon	Region	MinAge	MaxAge	Locality
Ailurus	Asia	0.6	1.3	1
Ailurus	Asia	9.5	10.35	2
Alopecocyon	Asia	9.5	10.35	2
Alopecocyon	Europe	9.7	11.11	3
…	…	…	…	…

	A	B	C	D	E	F
1	Replicate	Type	Region	t1	t2	t3
2	1	bin_start	NA	66.043	65	64
3	1	bin_mid	NA	65.5215	64.5	63.5
4	1	bin_dur	NA	1.043	1	1
5	1	locs	Africa	0	0	0
6	1	locs	Asia	1	0	0
7	1	locs	Europe	0	0	0
8	1	locs	NorthAme	0	2	1
9	1	locs	SouthAme	0	0	0
10	1	occs	Africa	0	0	0
11	1	occs	Africa	0	0	0
12	1	occs	Africa	0	0	0

Configuration

1. General:
Settings called at every stage of the analysis.

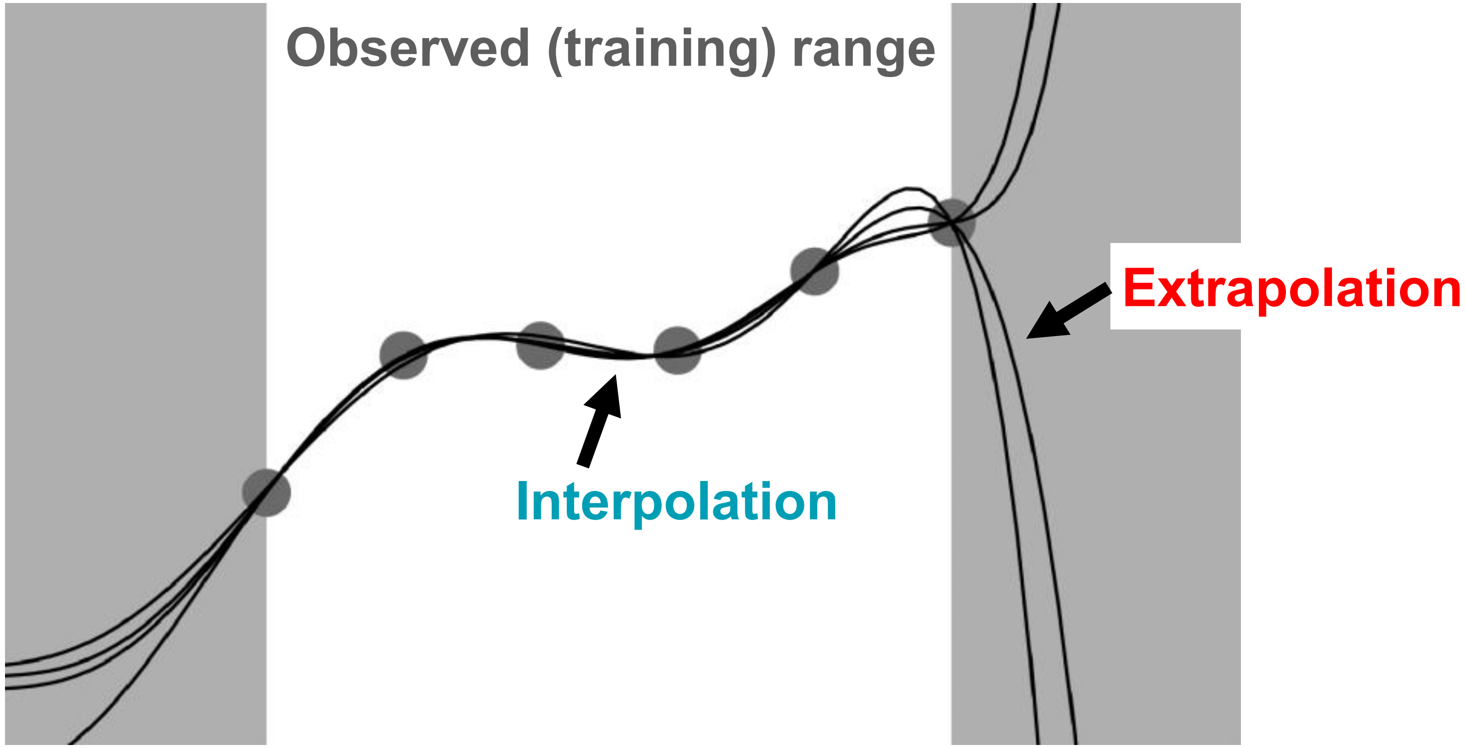
2. Simulations:
Settings for generating training and test data sets.

3. Regional constraints:
The ages at which regions become available or unavailable.

4. Model training:
Specification of deep learning models to be trained.

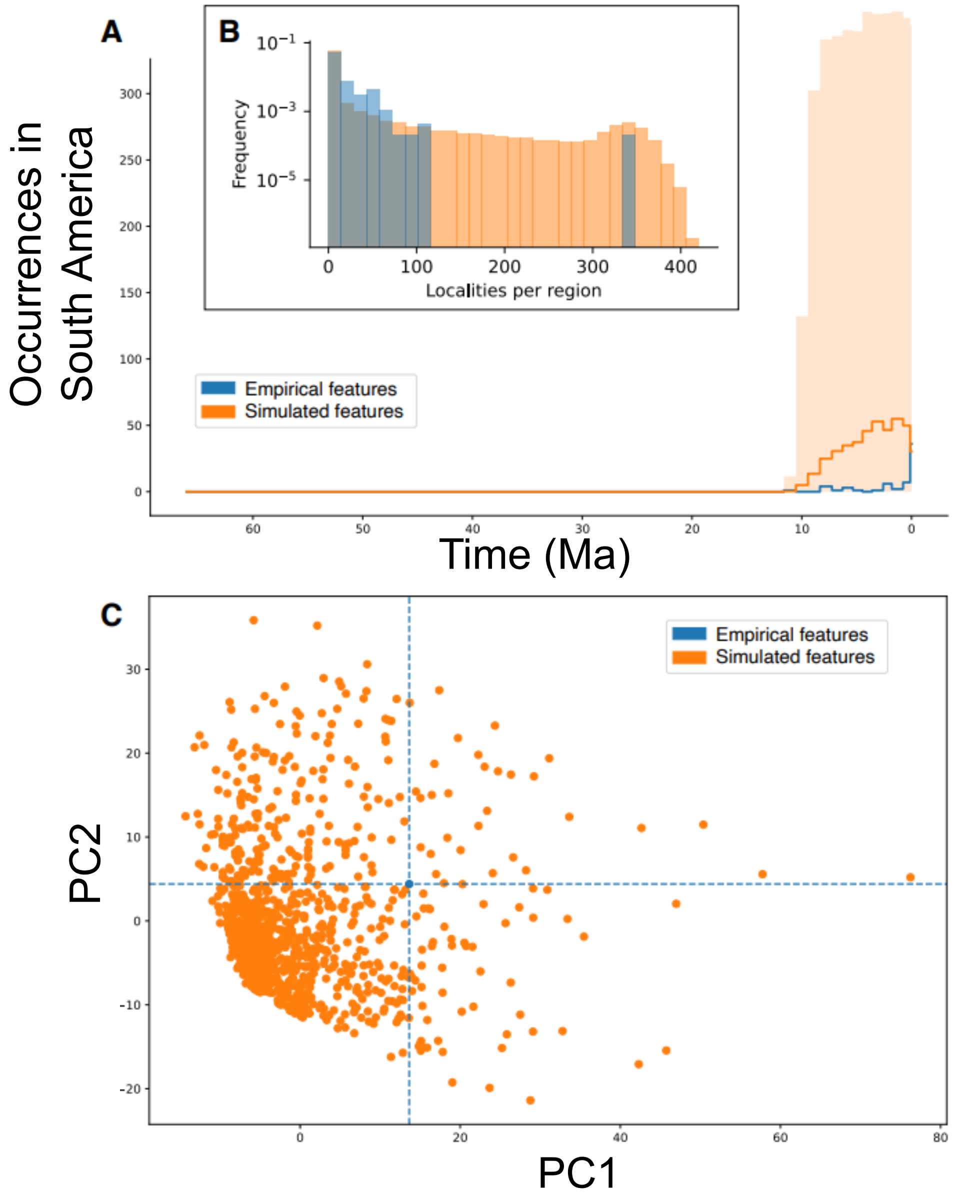
5. Empirical predictions:
Settings for generating predictions from empirical data.

Training simulations must reflect the data

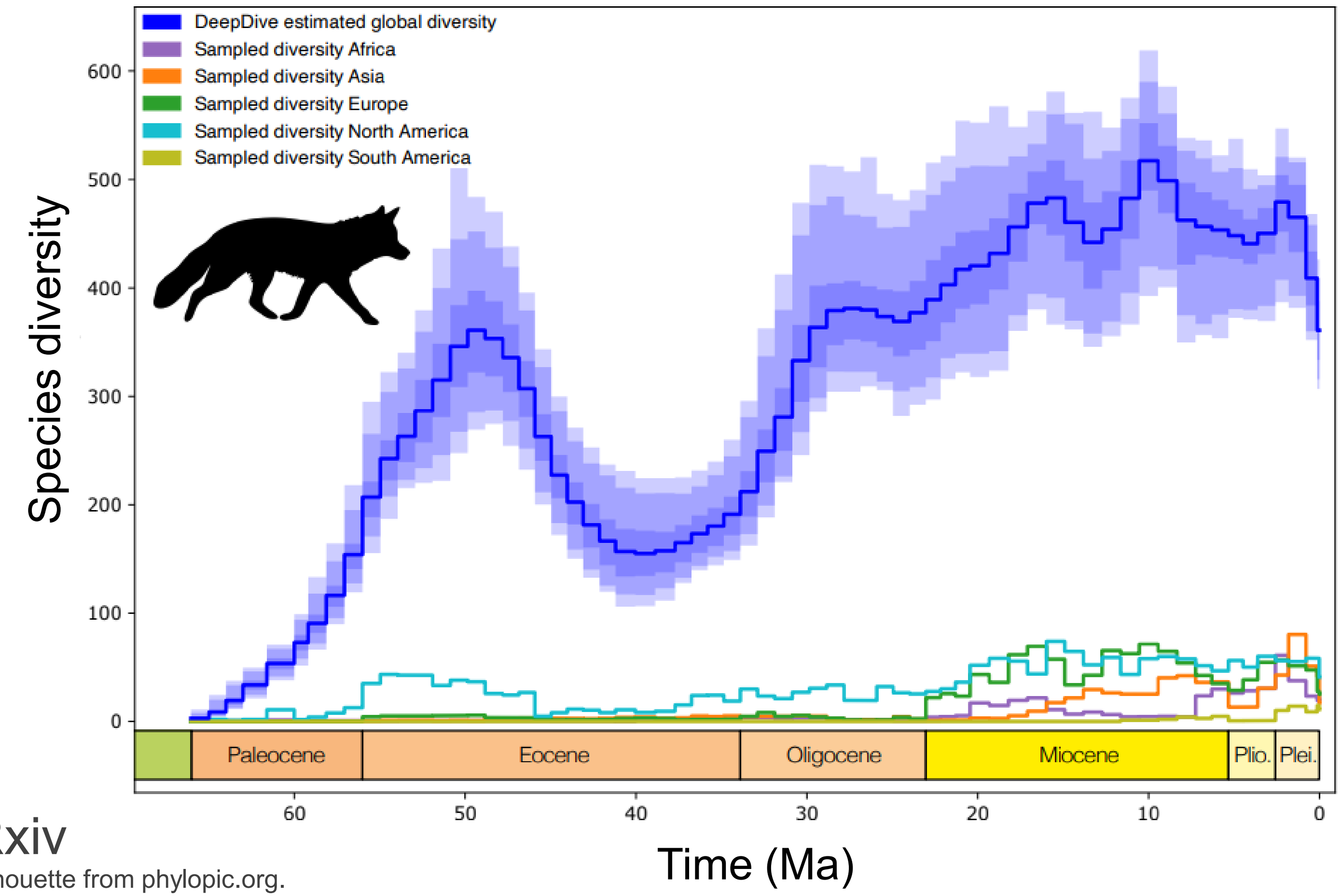


Autotune adjusts simulations to reflect empirical data

- Parameters with default NA are adjusted automatically and a new configuration saved unless user specified
- E.g. Across each region:
  - Sampled species
  - Longevity
  - Singletons
  - Gaps in data
  - Occurrences



Inferred diversity curve



Cooper et al. 2024 bioRxiv

Data from Faurby et al 2024 Proceedings B, silhouette from phylopic.org.

Let’s get started!

You can access the next tutorial at:

https://github.com/thauffe/cpeg25/tree/main/deepdive_analysis

or by following the QR code

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SIB Swiss Institute of Bioinformatics

Swiss National Science Foundation

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Practical

DeepDive and DeepDiveR

Rebecca B. Cooper

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