

3. Fossil record biases

Emma Dunne

FAU Erlangen-Nürnberg

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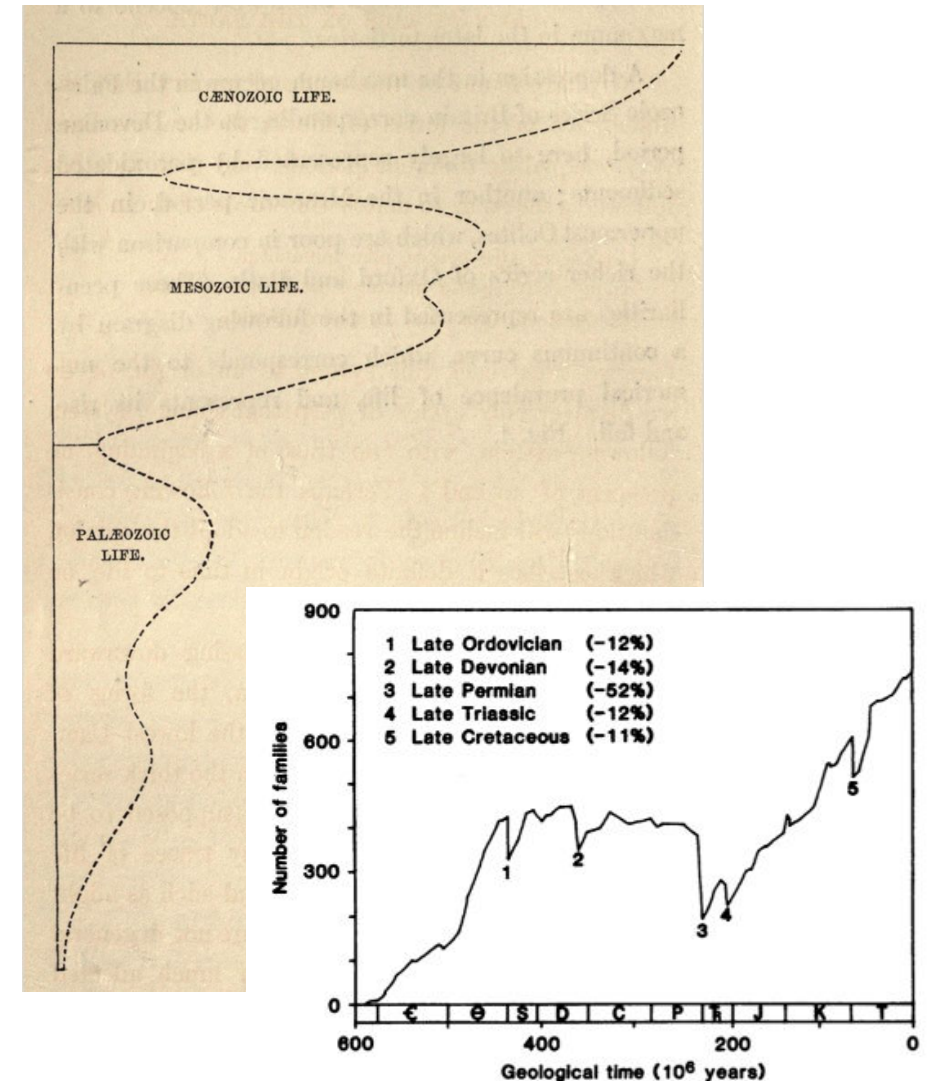
Friedrich-Alexander-Universität
Erlangen-Nürnberg



A. Understanding fossil record biases

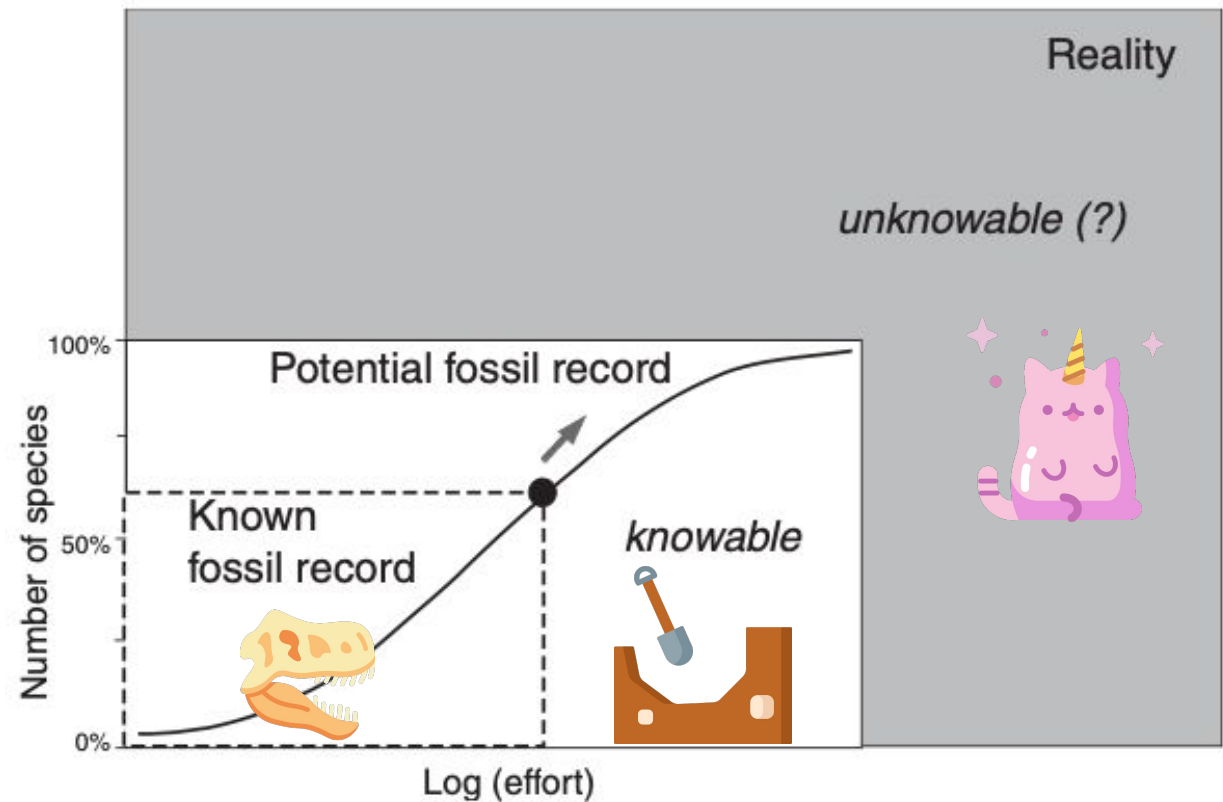
Early paleodiversity studies

- Early palaeodiversity studies took the fossil record at **face value**
- Even **Darwin** back in 1959 noted that sampling was uneven and incomplete
- It wasn't until the last half century that we started to appreciate the impacts of fossil record biases



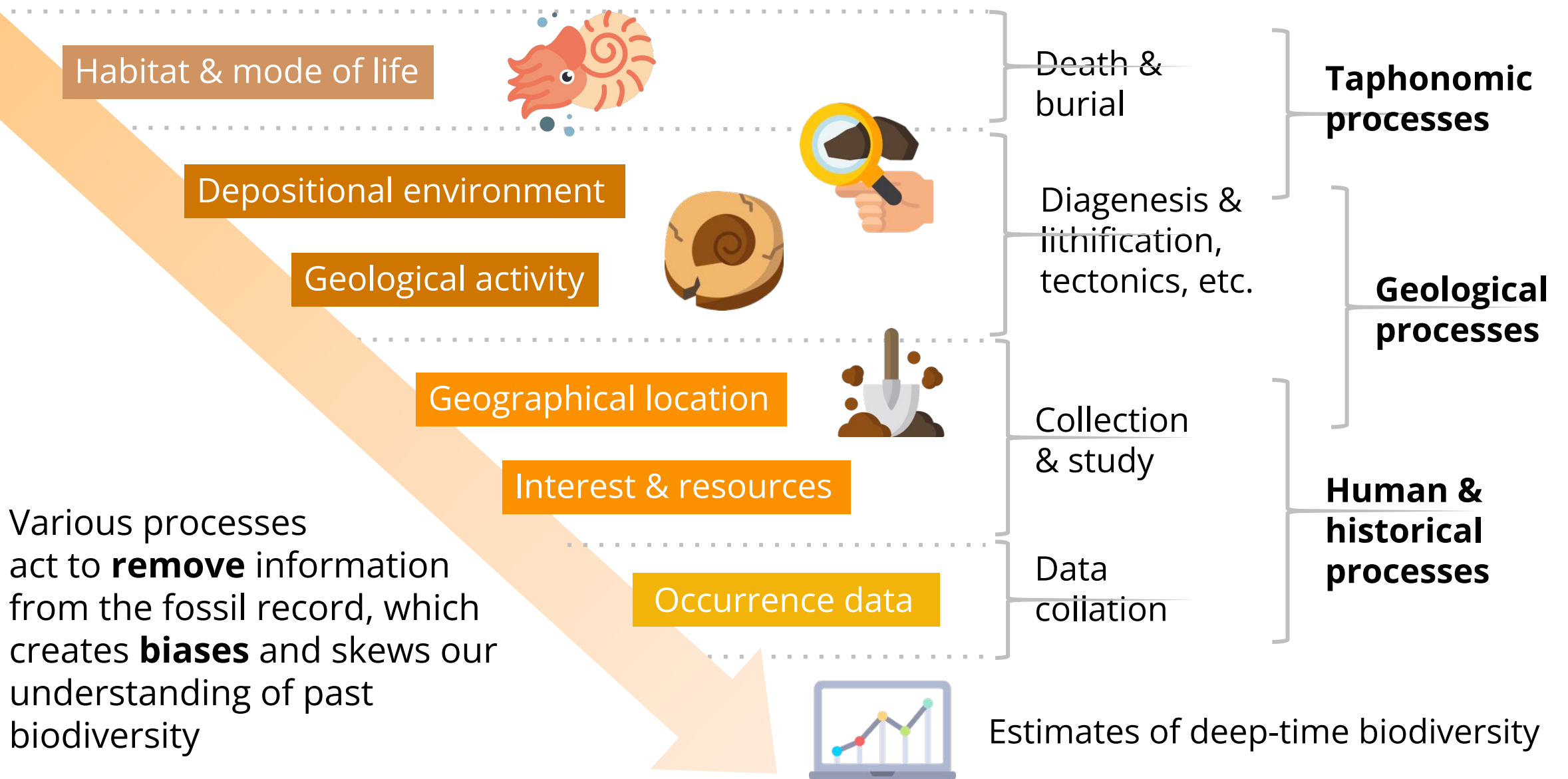
How much of the fossil record do we even know?

- The known fossil record is barely a **fraction** of what actually exists
- Even the potential fossil record contains only a tiny fraction of life that has ever lived!



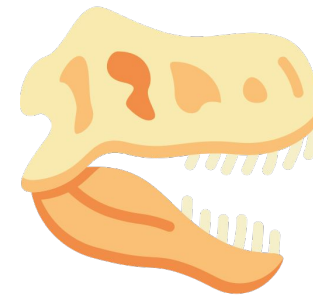
Benton *et al.* (2011)

FROM DEATH TO DATABASE



Raup's “7 Sources of Error”

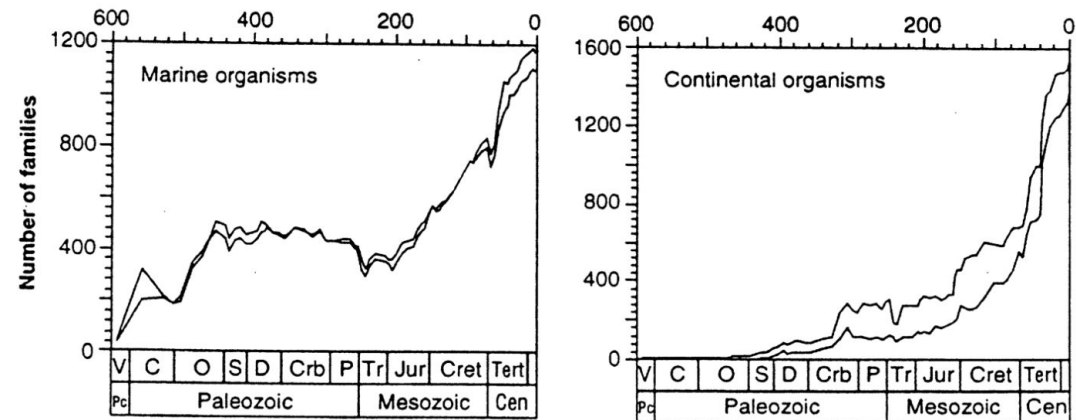
1. Range charts
2. The 'Pull of the Recent'
3. **Durations of geological units**
4. Monographic effects
5. **Lagerstätten**
6. **Area-diversity relationships**
7. Sediment volume



Raup (1972)

Taphonomic biases

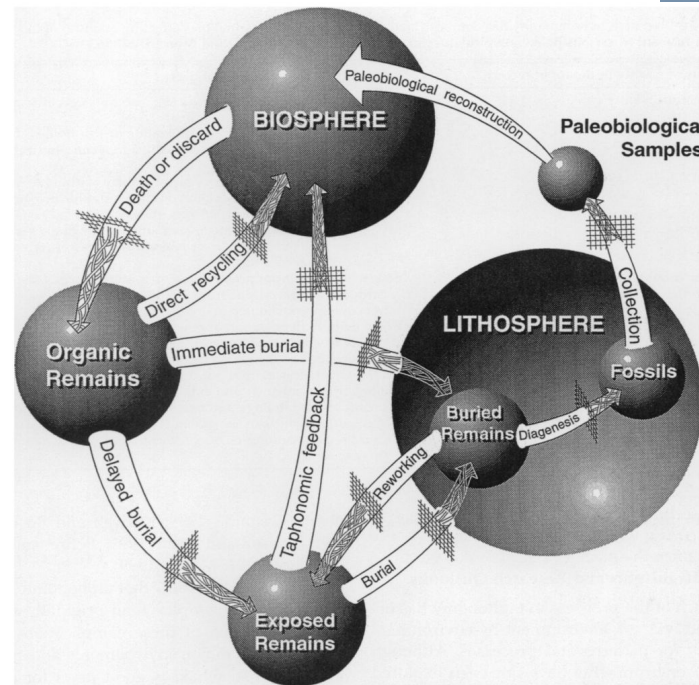
- **Susan Kidwell** (Chicago)
- Relationship between fossil diversity and sedimentation rates
- More sedimentary rock means more opportunities to find fossils
- Also, experimental taphonomy - how do fossils fossilise?



Kidwell, & Sepkoski (1999)

Taphonomic biases

- **Anna 'Kay' Behrensmeyer**
(Smithsonian NMNH)
- Composition of fossil faunas vary with sedimentary environment (channel, floodplain, lake margin)
- Importance of accounting for taphonomic biases in paleoecological studies



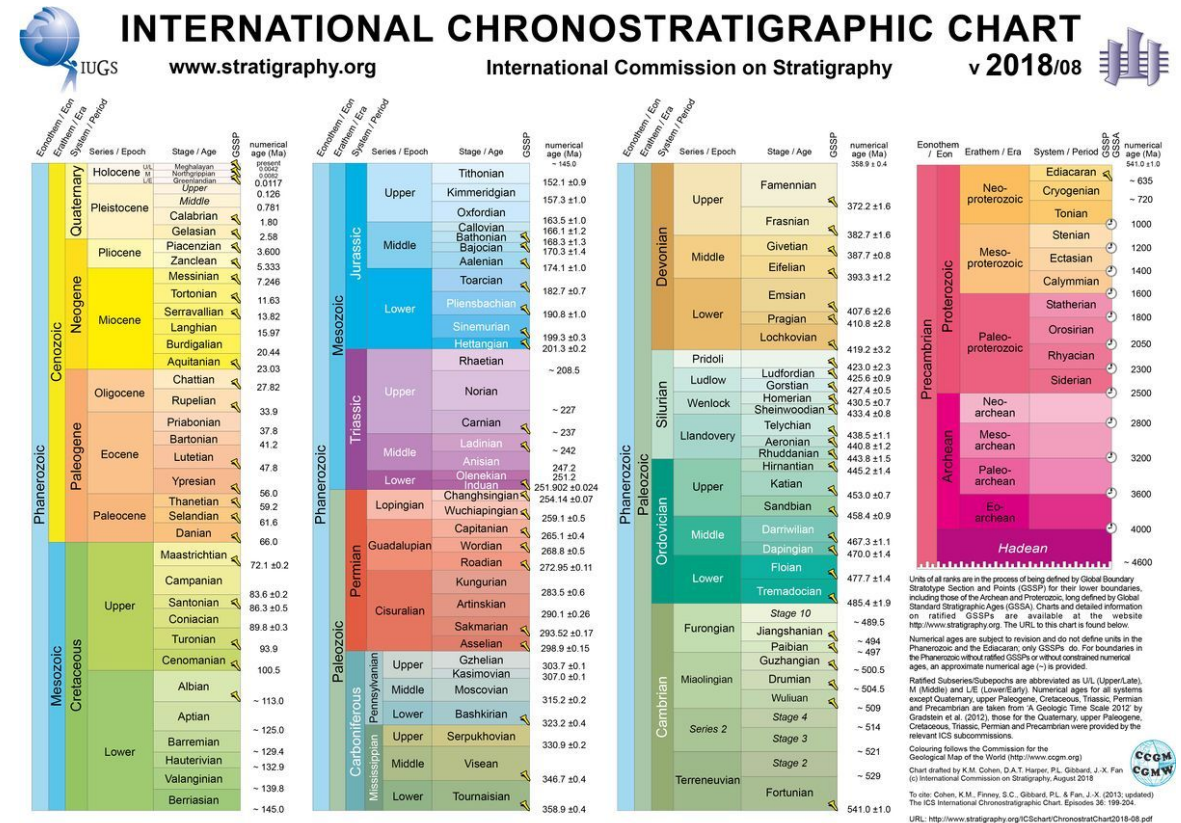
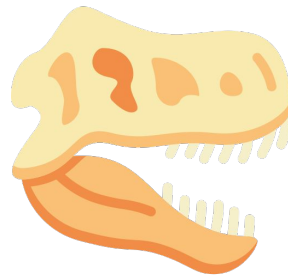
Behrensmeyer et al. (2000)

Temporal resolution in the fossil record

Geological time intervals are not equal in length

Example: Late Triassic epochs:

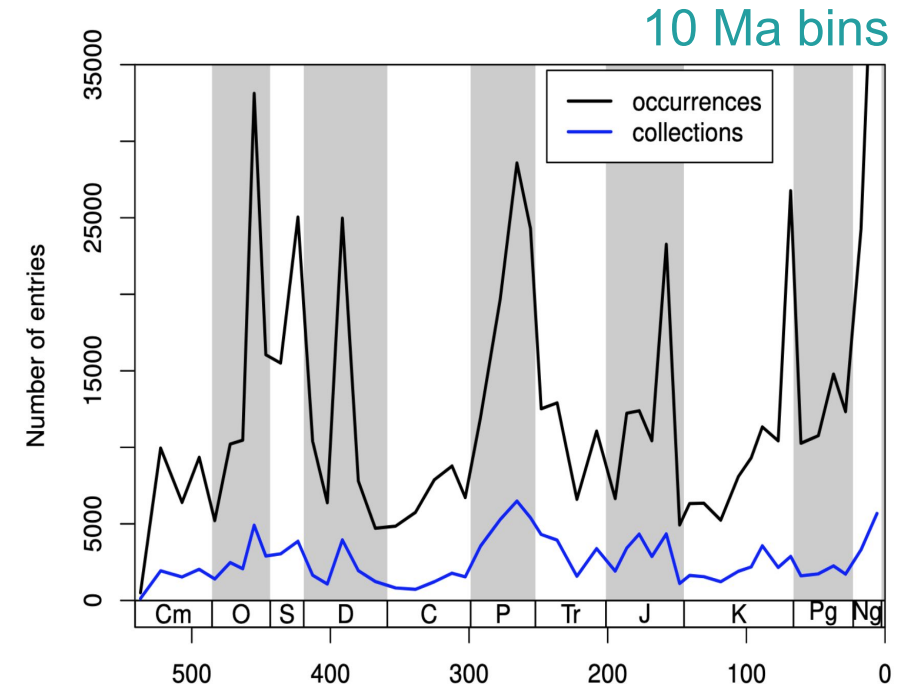
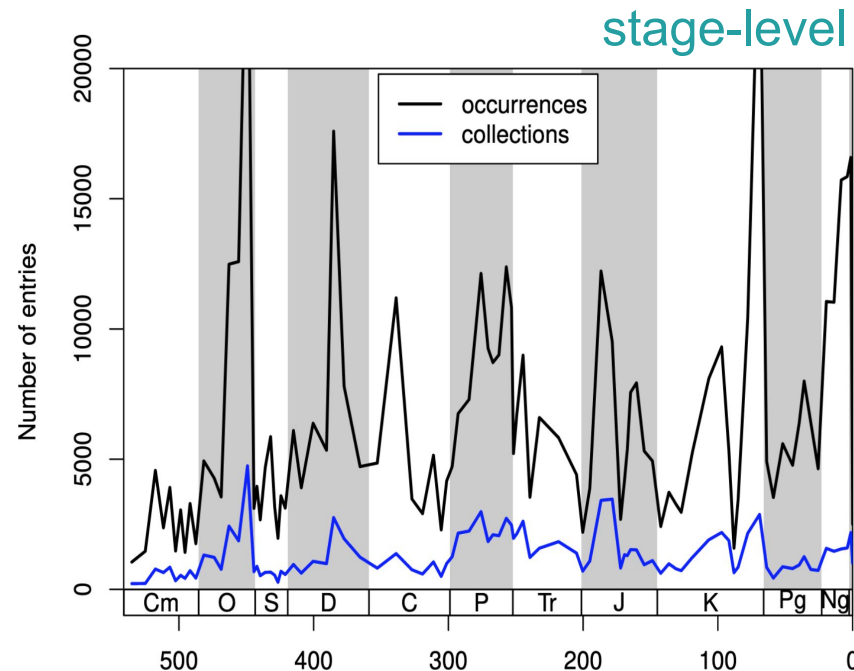
- Rhaetian ~8 Ma
- Norian ~20 Ma
- Carnian ~10 Ma



Temporal resolution in the fossil record

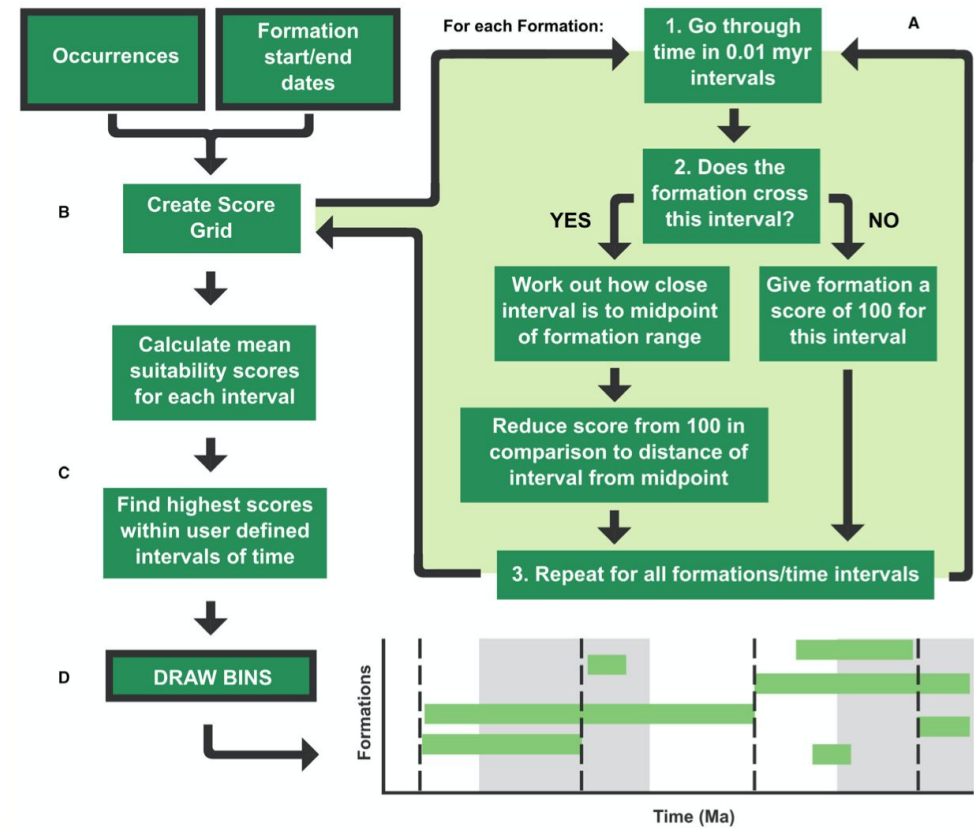
- Many studies focus on stage-level or equal-interval ages

Kocsis *et al.* (2019)
divDyn R package



Temporal resolution in the fossil record

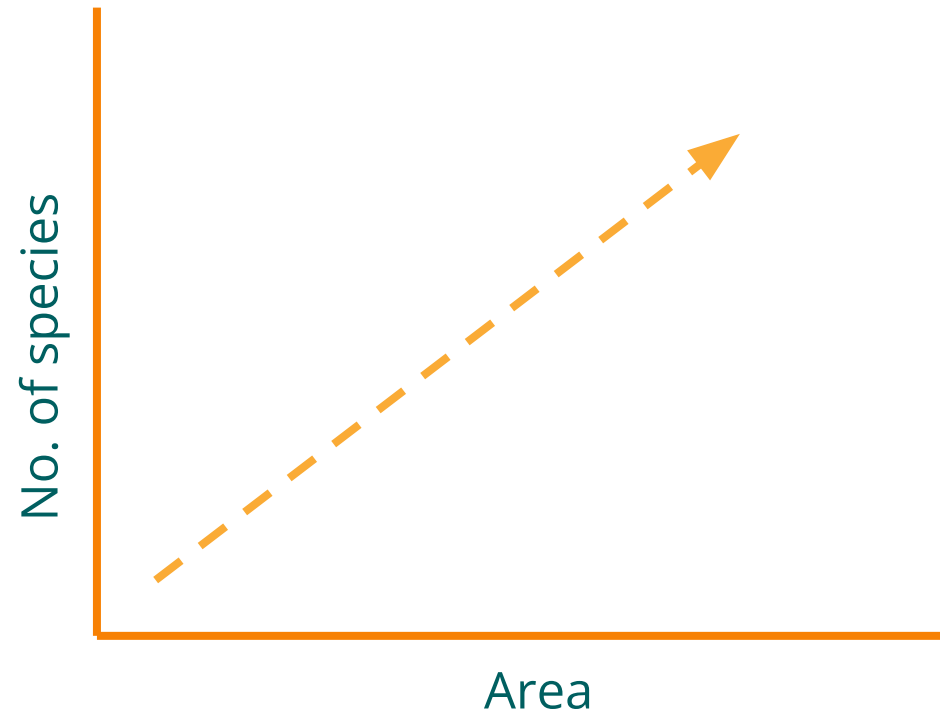
- Many studies focus on stage-level or equal-interval ages
- Not suitable for regional studies
- More recently, statistical methods have been developed to bin data (e.g. using regional stratigraphy)



Dean *et al.* (2020) *Palaeontology*

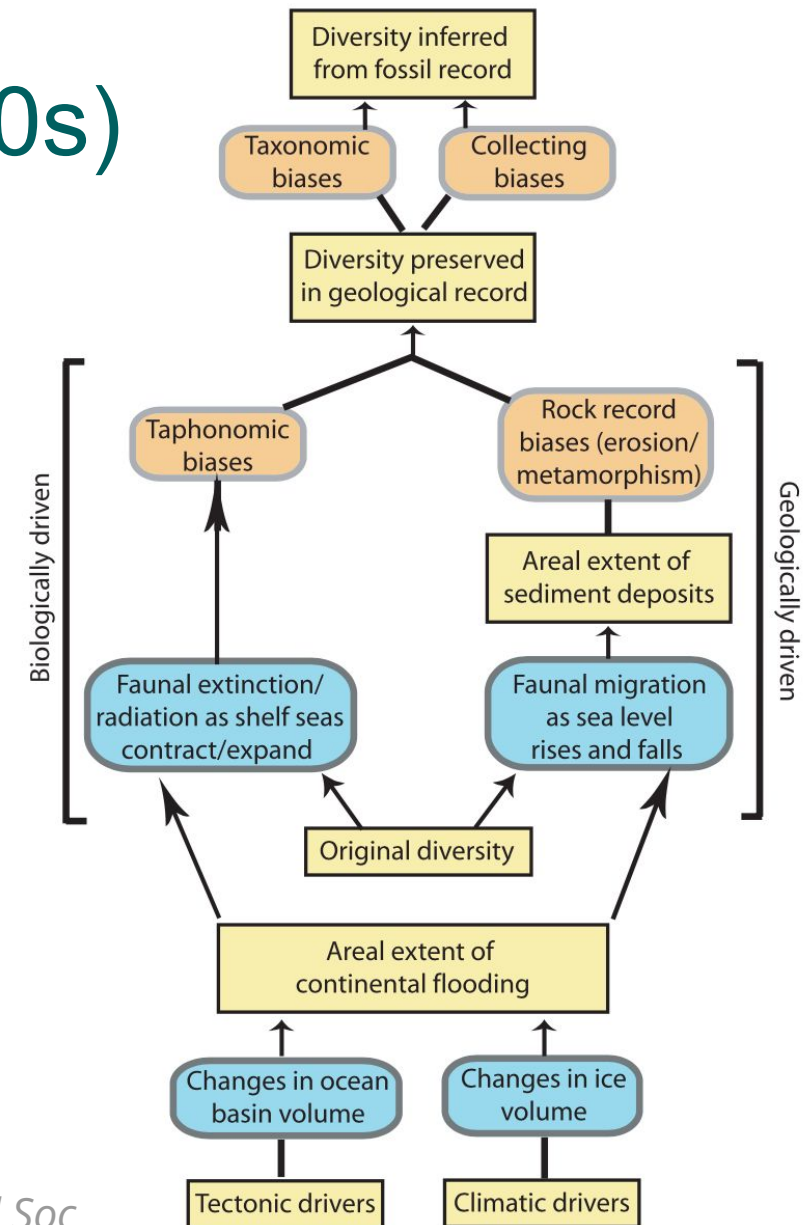
Spatial resolution in the fossil record

- Species-area effect
- Larger areas tend to contain larger numbers of species
- Opening of new areas to search for fossils inevitably leads to new species being described



Renewed interest in biases (2000-10s)

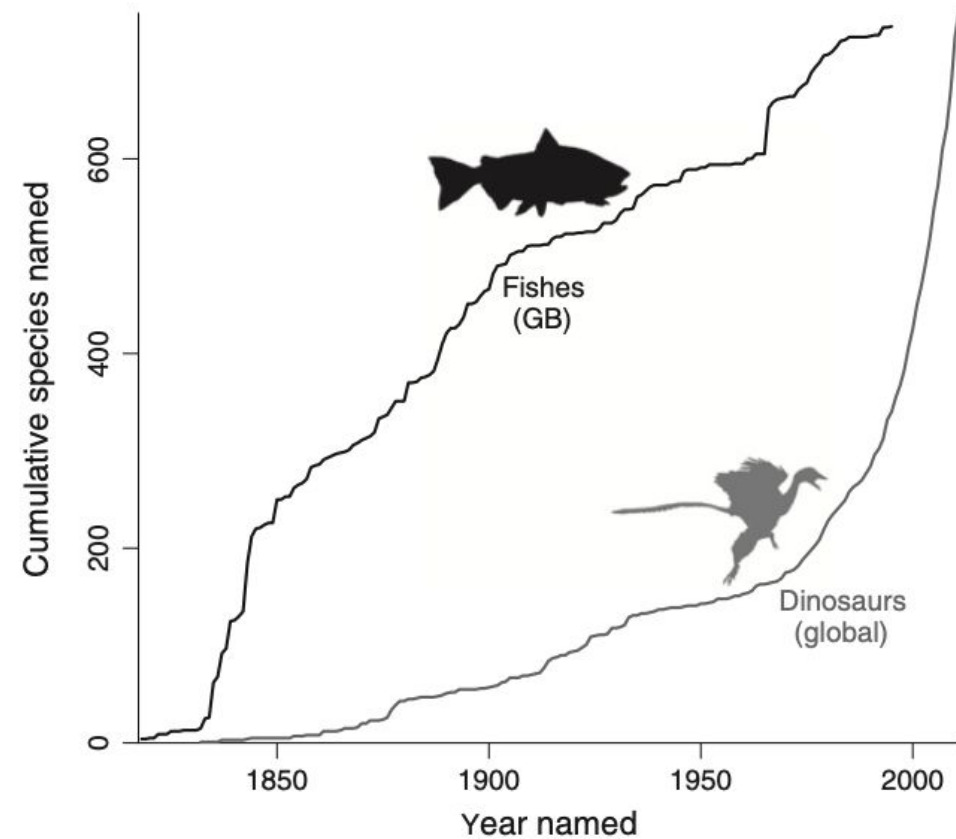
- Resulted in an even **greater exploration** of the factors that influence analyses of the fossil record
- **Sampling standardisation** methods begin to be developed
- Also, large compilations of data (e.g. PBDB) and data sharing/open data have been making even more analyses possible



Smith (2007) *Geol Soc*

Research interest over time

- Some groups are well understood and well sampled e.g. **British fossil fishes**
- Other groups have only become popular relatively recently (e.g. **dinosaurs**), or some have stalled in the number of new taxa named each year

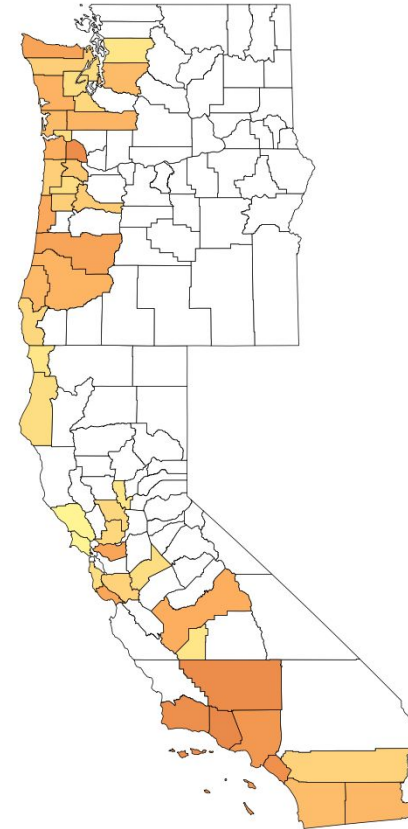


Lloyd & Friedman (2013) *Palaeo3*

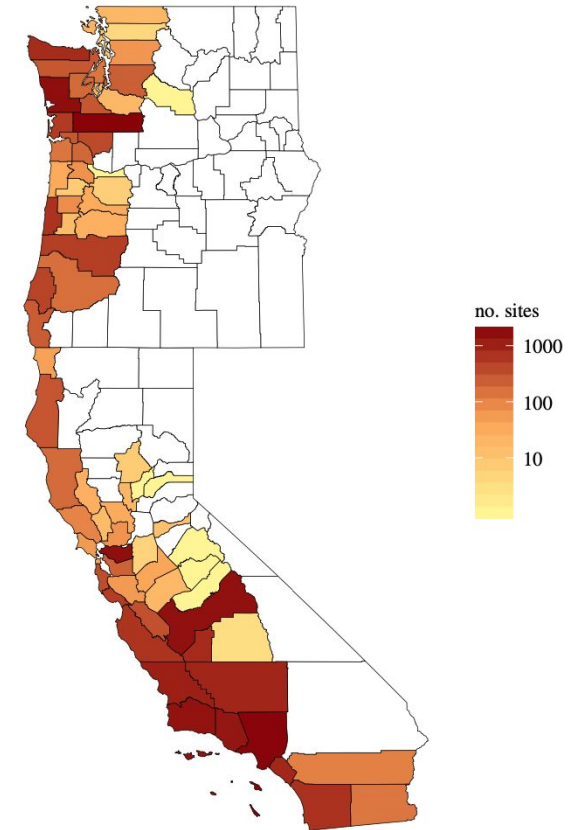
Insights into collecting biases

- Online occurrence databases rely on data from published literature
- Museum collection could hold up to 23 times more data (at least for marine invertebrates on the west coast of America)

(a) literature database



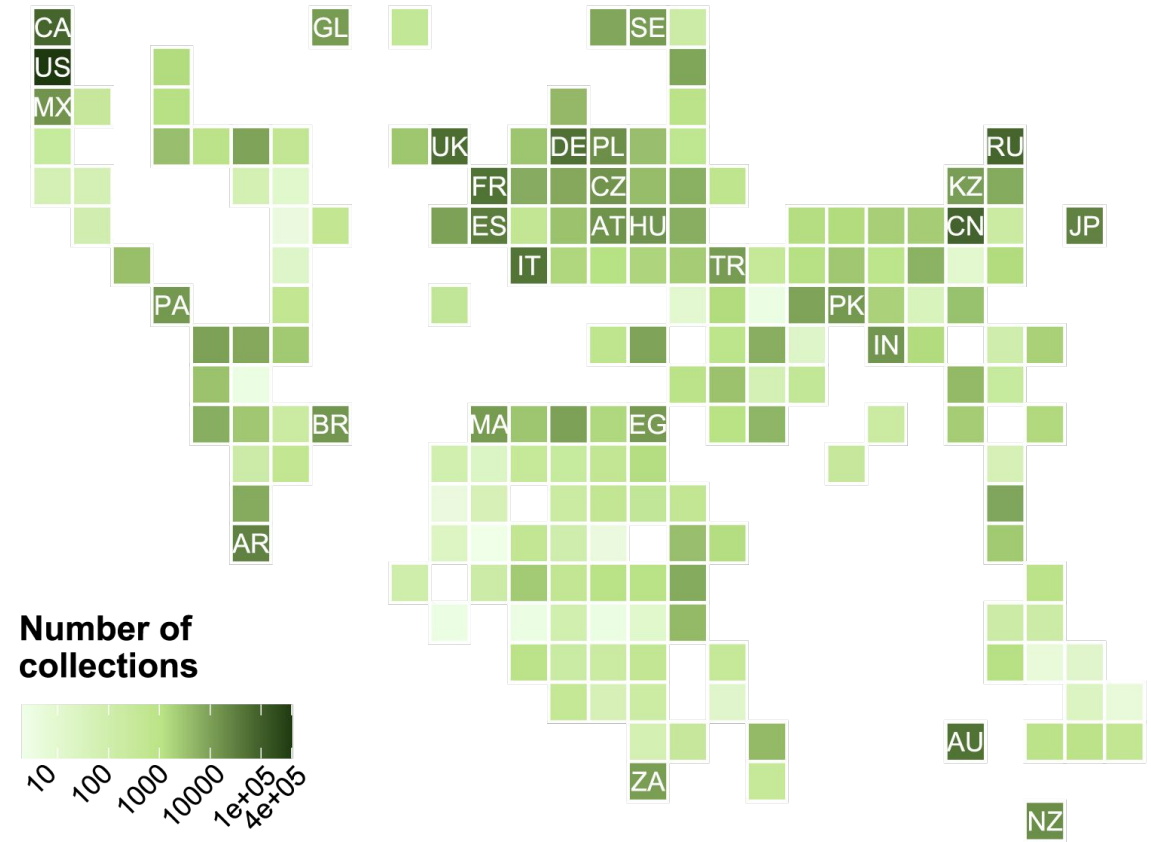
(b) museum collections



Marshall *et al.* (2018) *Biol. Lett.*

Insights into socio-economic biases

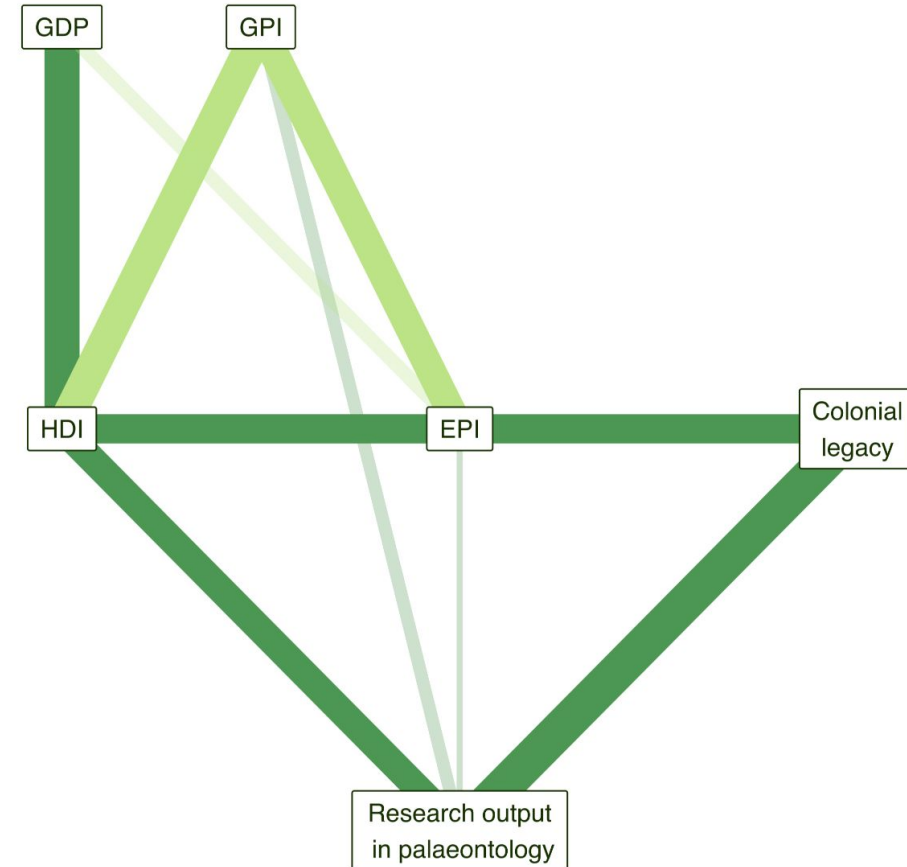
- Palaeontological research is dominated by researchers based in high- or upper middle-income countries
- **97%** of fossil occurrence data in the PBDB were generated by researchers in Northern America and Europe



Raja & Dunne *et al.* (2022) *Nat. Ecol. Evol.*

Insights into socio-economic biases

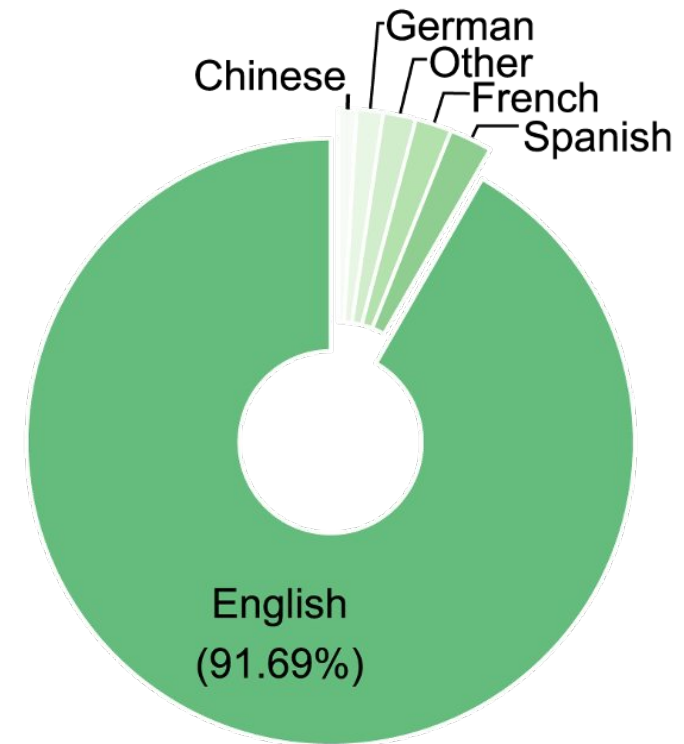
- Greater research output in palaeo (counted as co-authored publications) is linked to:
 - Higher GDP
 - Higher HDI
 - Greater security (GPI)
 - A history of, or profiting from, colonialism



Raja & Dunne *et al.* (2022) *Nat. Ecol Evol.*

Insights into socio-economic biases

- **English** is the dominant language in palaeodiversity studies
- Knowledge in other languages is overlooked – this has been shown to **bias outcomes of meta- analyses** (see Konno *et al.* 2020 *Ecol. Evol.*)
- Impedes the communication of science



Languages of references in the PBDB

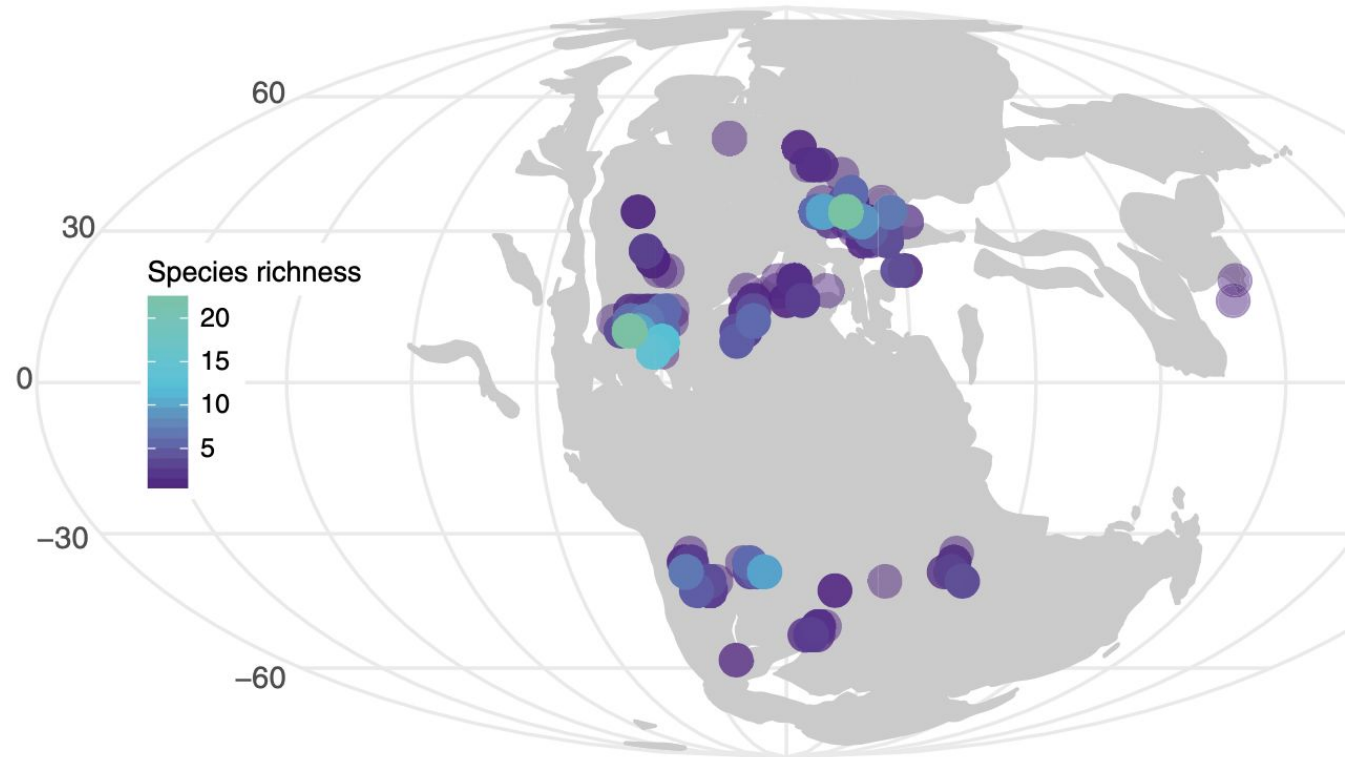
Raja & Dunne *et al.* (2022) *Nat. Ecol Evol.*

B. Detecting and quantifying fossil record biases

Data visualisations

An **important step** in any research project!

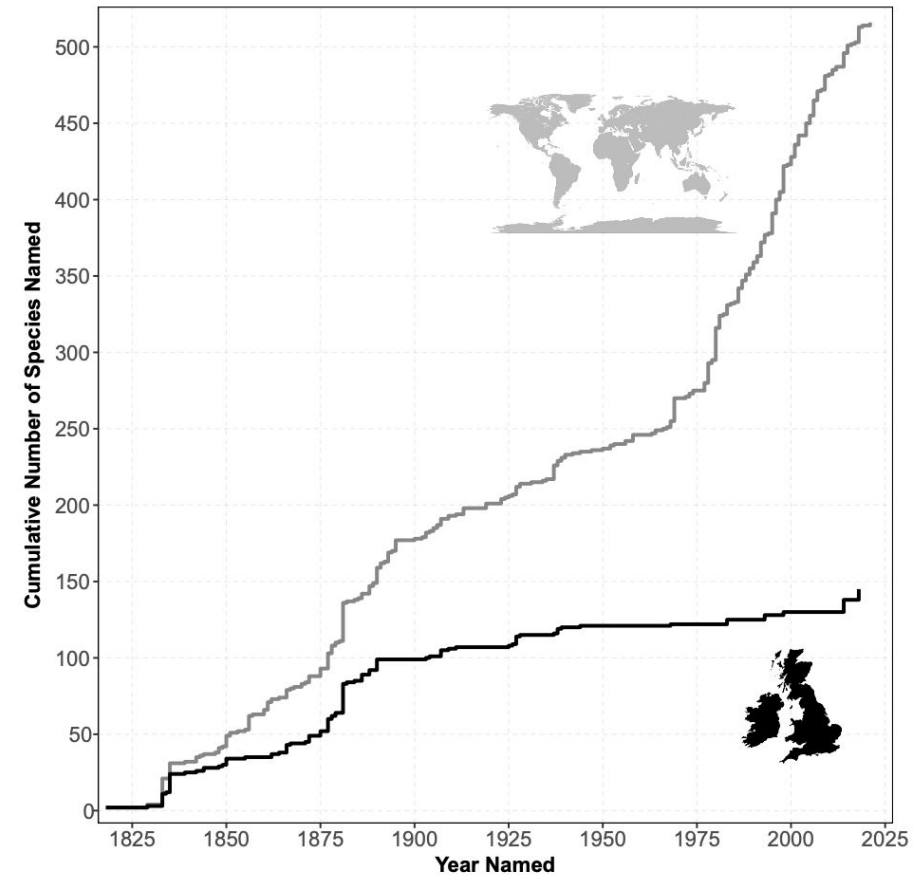
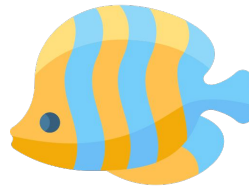
- What do your data look like?
- What patterns jump out at you?
- What happens when you use a different method/scale/colour scheme?



Dunne *et al.* (2020) *Paleontology*

Collector's / species accumulation curves

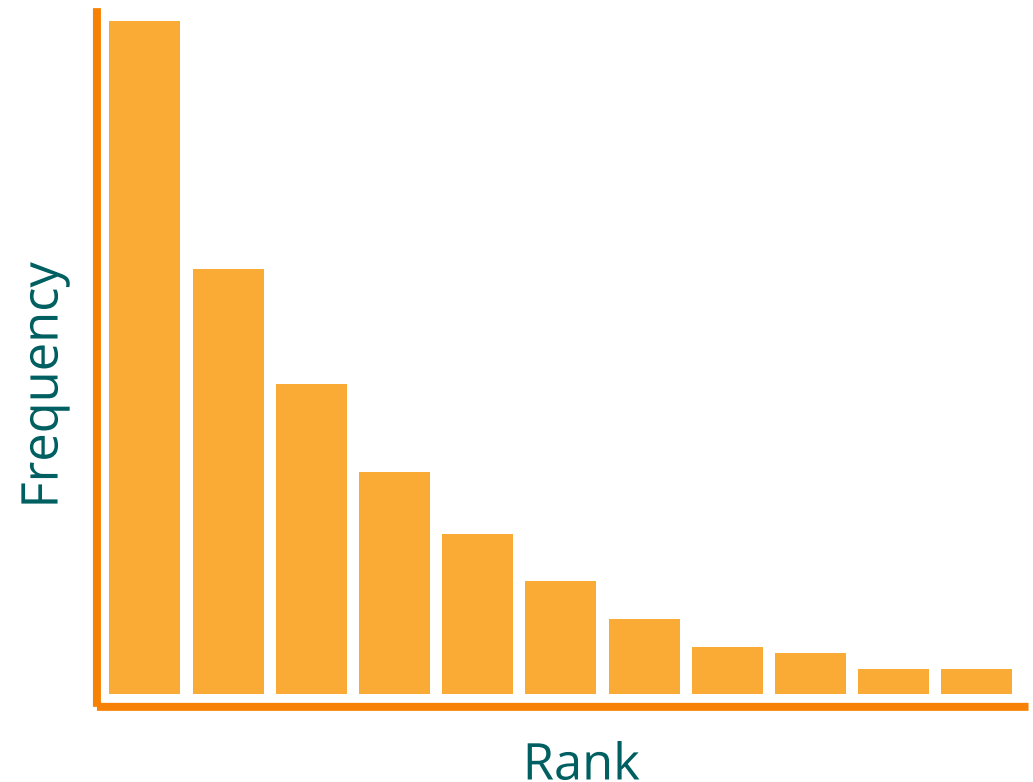
- Allow comparison of diversity across assemblages or to evaluate the benefits of additional sampling
- **Example:** Species named each year in different regions
- As research interest grows (and new areas open up) - expect pattern to increase and eventually level off



Henderson *et al.* (2021) *EarthArXiv*

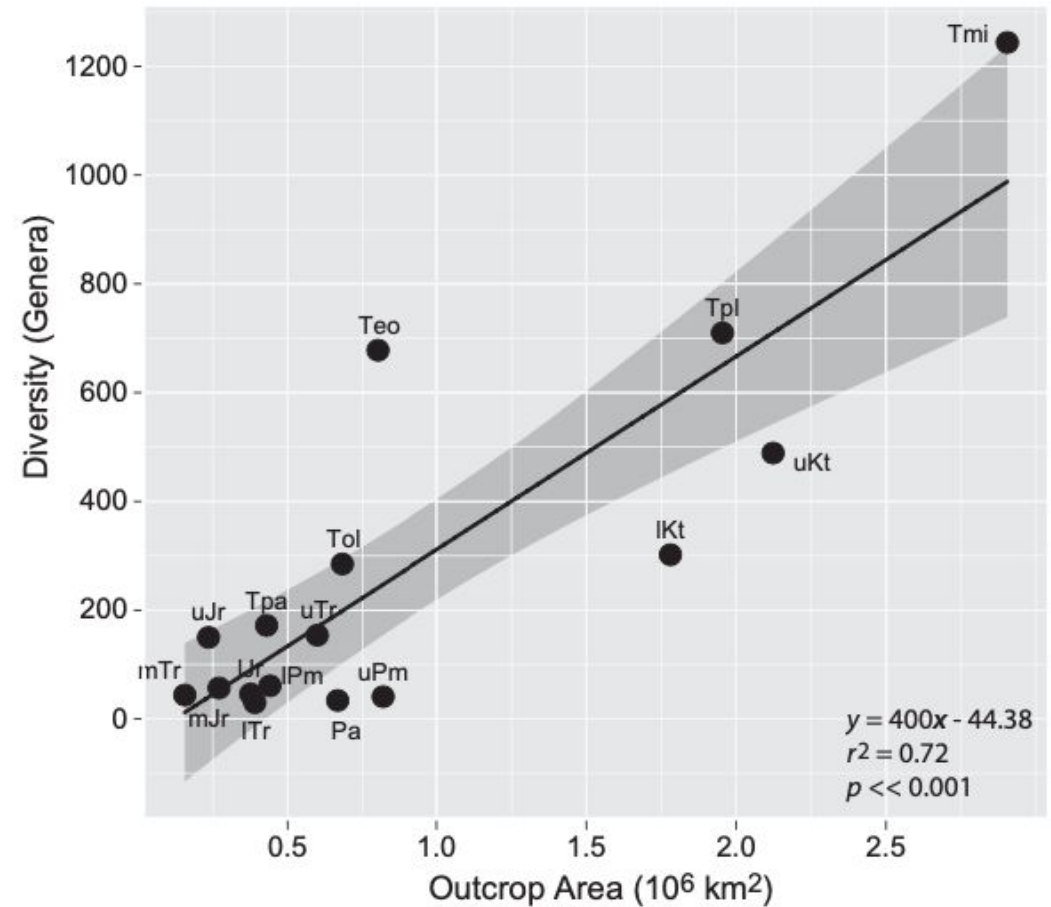
Rank order abundance

- Visualise species richness and species evenness
- Most abundant species = rank 1
- Least abundant species will be recorded less often



Simple correlations

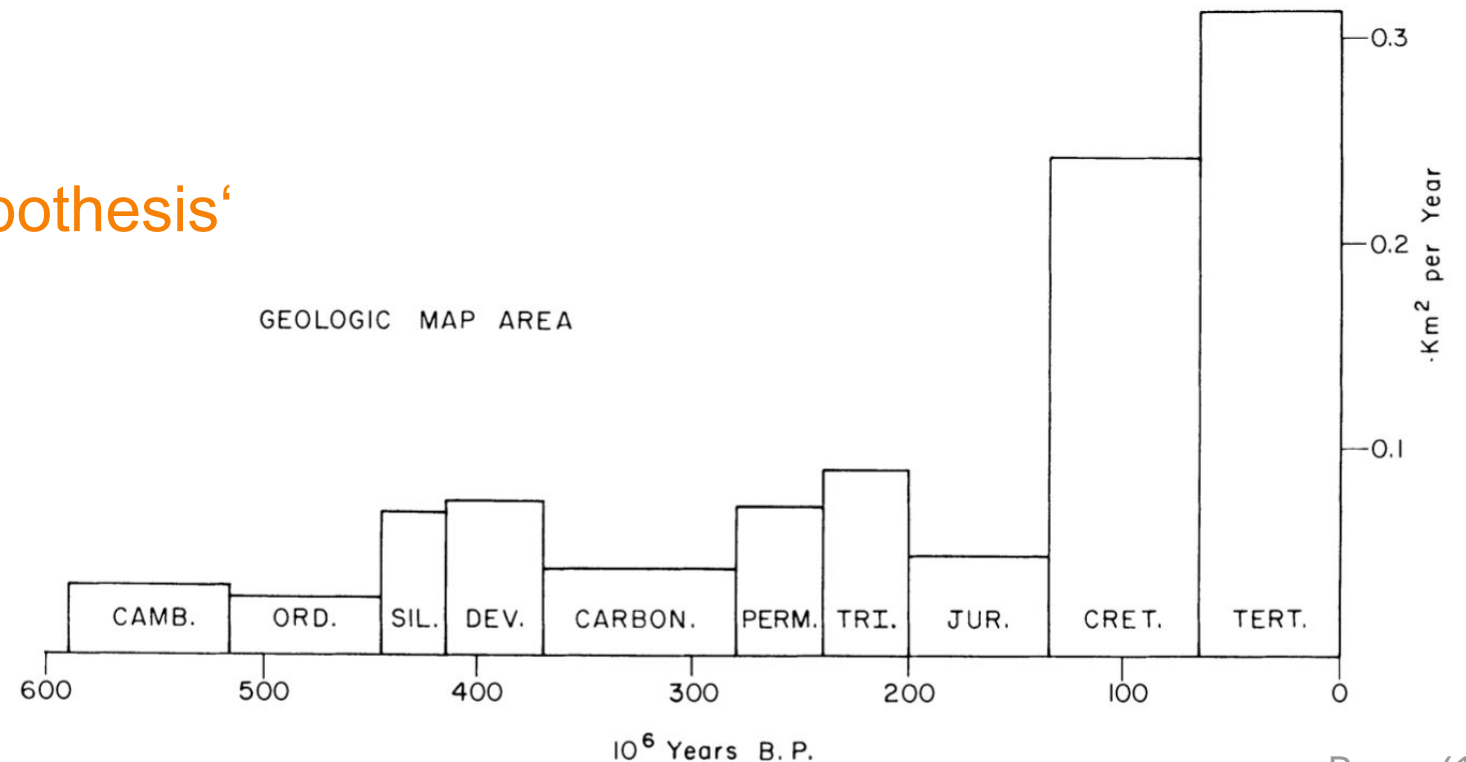
- Use regression plots and simple statistics to quantify the strength of the correlation between **proxies for sampling effort** and fossil diversity
- But what to use as a proxy for sampling?



Wall *et al.* (2011) *Geol Soc*

Proxies for sampling & the 'sampling hypothesis'

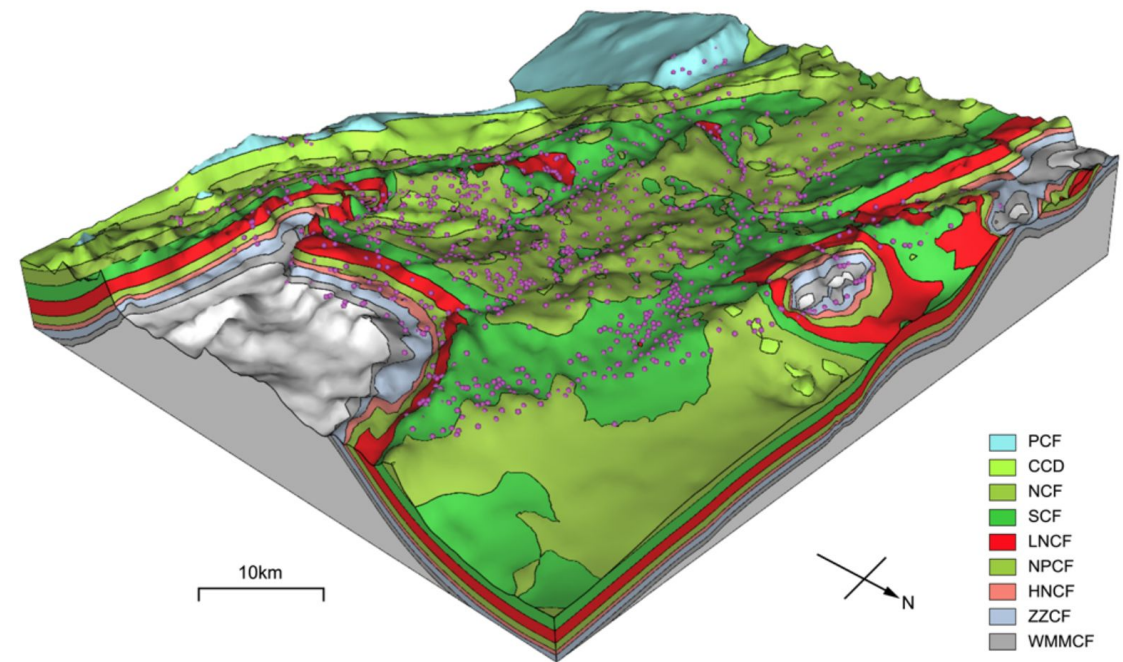
- Raup documented that species diversity correlates with sedimentary rock volume and area
- This is the 'sampling hypothesis' or 'bias hypothesis'



Raup (1976)

Proxies for sampling - 1. Outcrop area

- **Definition:** The amount of rock available for sampling
- Good proxy for rock volume and area
- Rock must be exposed for fossils to be sampled

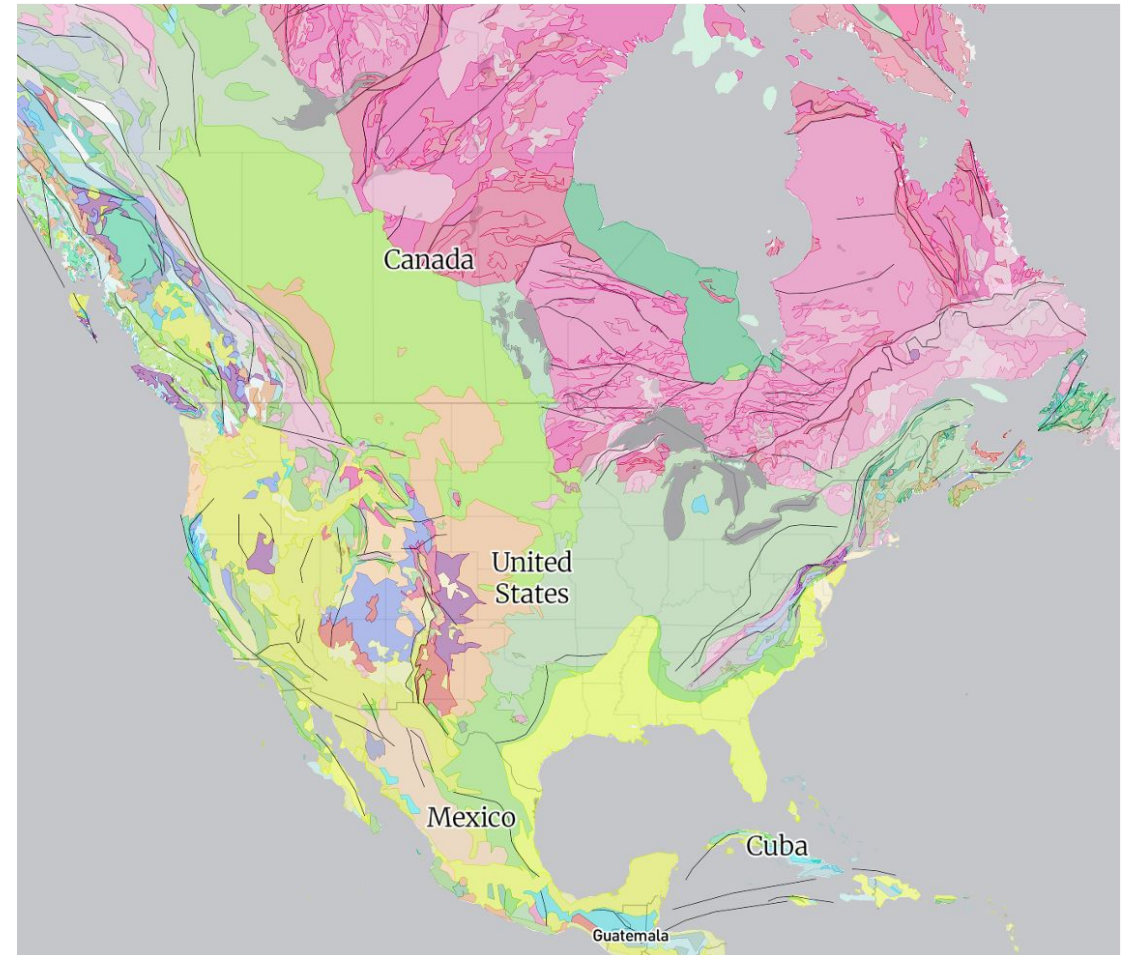


Walker *et al.* (2017)

Proxies for sampling - 1. Outcrop area

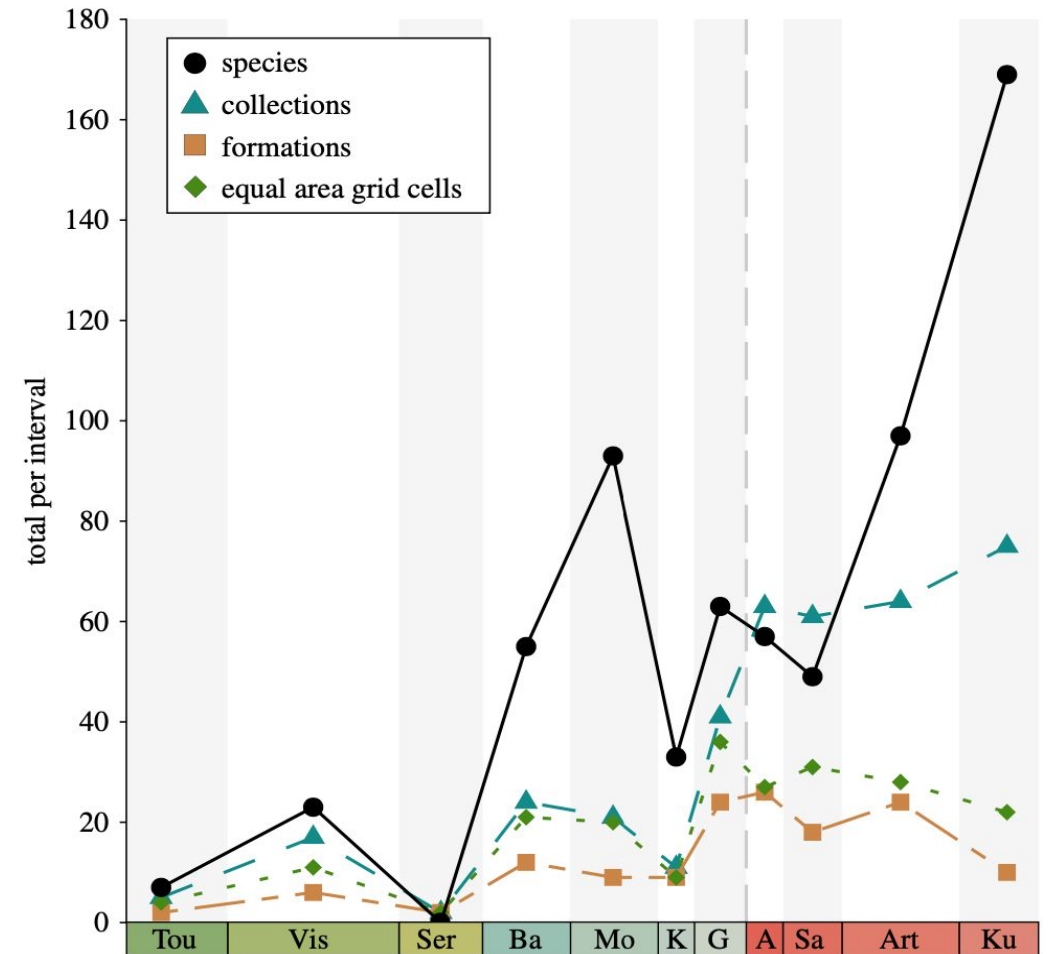
Macrostrat

- Geologic map database
- Focus on North American and other specific regions e.g. the Caribbean
- Download geological maps from various providers



Proxies for sampling - 2. Formations

- **Definition:** lithostratigraphic units that contain fossils (fossiliferous)
- Mostly well-studied, geologically constrained areas
- Good proxy for rock area and volume as well as human effort
- Vary in their geographic size



Dunne *et al.* (2018) *Proc Royl Soc B*

Proxies for sampling - 3. Fossil sites / collections

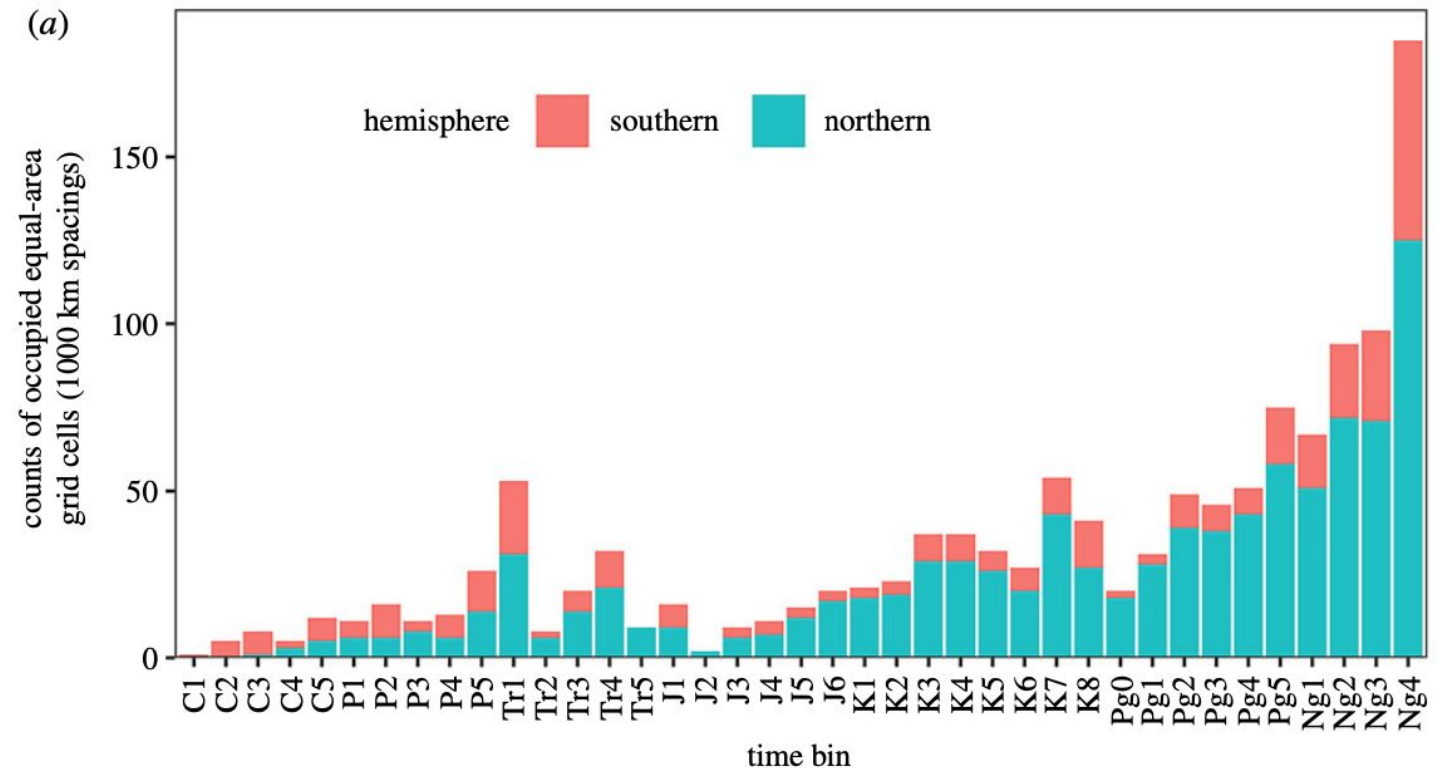
- **Definition:** distinct localities that contain fossils ('collections' in the PDBD)
- Definitions vary between research groups, taxa, etc.
- Great proxy for human effort



Image: A.A. Chiarenza

Proxies for sampling - 4. Occupied grid cells

- **Definition:** Equal-area grid cells on a map that contain fossils
- Standardised geographical areas
- Check out the R package dggridR



Close *et al.* (2020) *Proc. Royl. Soc. B.*

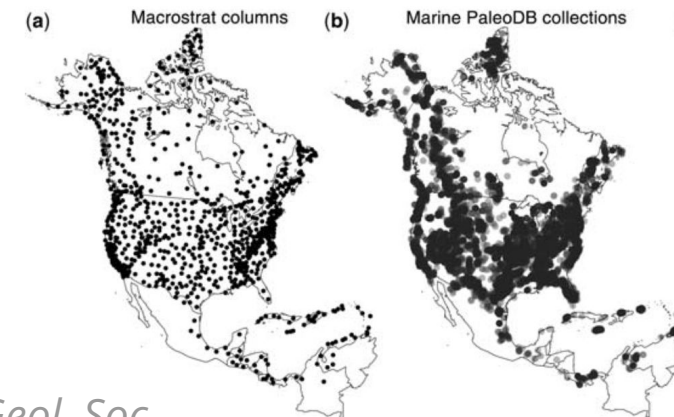
Other sampling hypotheses

Redundancy hypothesis

- **Definition:** Sampling and diversity are entirely or partially redundant with each other
- Proxies for sampling can rely on the presence of fossils (rarely their absence)
- Formations are sometimes defined by fossils

Common-cause hypothesis

- **Definition:** Both sampling and diversity are driven by some common factor(s)
- Examples: fluctuations in sea level, environmental perturbations or tectonic activity



Peters & Heim (2011) *Geol. Soc.*