My Field For Dummies Webinar

-

Biogeography and Bats

Pedro Ivo Mônico

Rutgers, the State University of New Jersey

The American Museum of Natural History

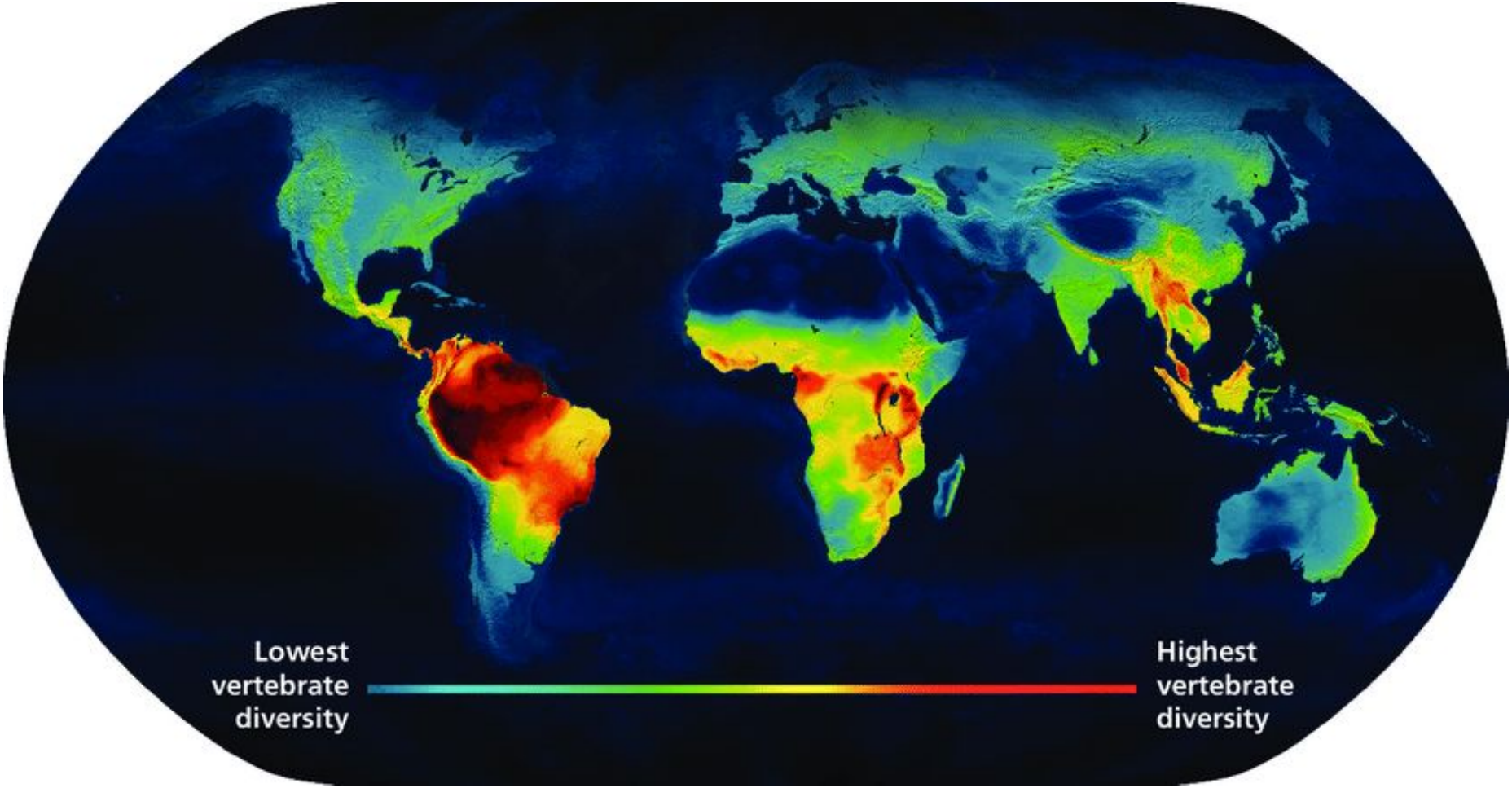
March 05, 2025

About me

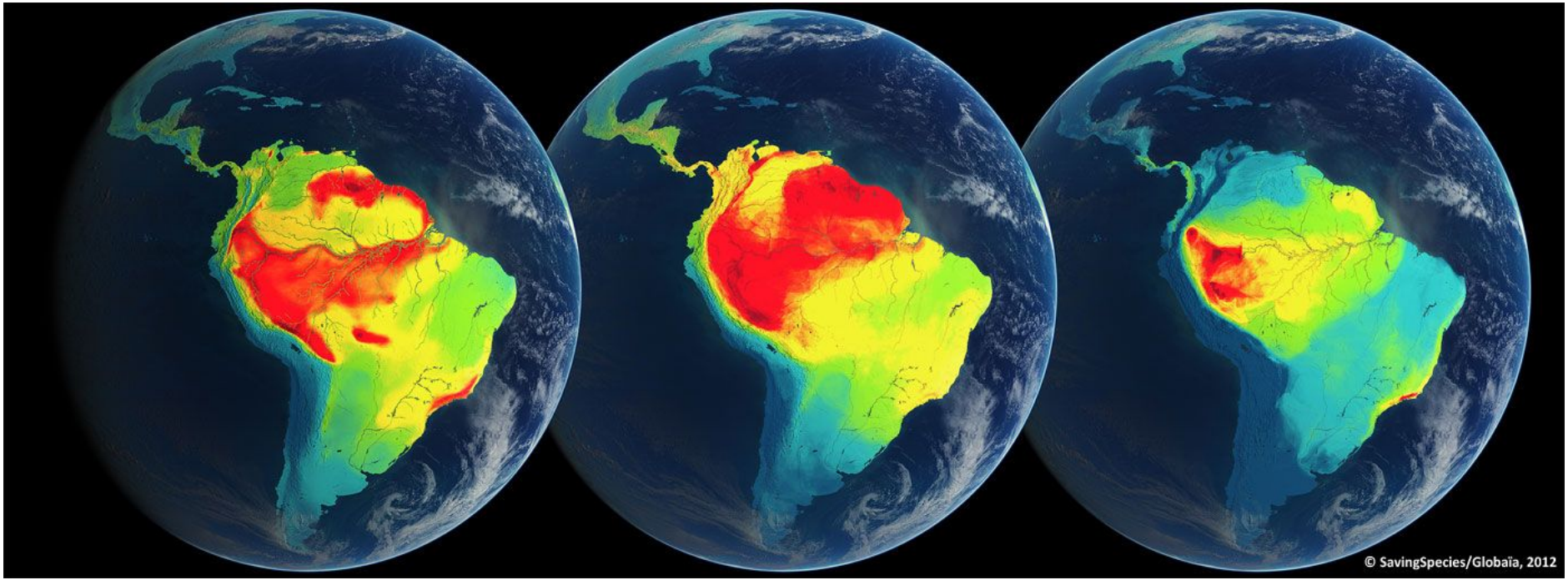
- Bachelor in Biological Sciences, *and* Licensed Natural Sciences Teacher, both at the Federal University of Espirito Santo, Brazil (UFES)
- PhD candidate class of 2026 - Rutgers, and associate at the American Museum of Natural History (AMNH)
- GBatNet Student representative
- Working with Bats for 10 years! (and counting)
- Obsessed for Island biogeography

Meeting agenda

- “What is biogeography?” And “exploring world biogeographic areas”
- Key factors shaping biodiversity we see today
- Historical and contemporary biogeography
- Bats as study models
- Island as study models
- Study case: evolution and biogeography of a widely-distributed bat in a Tropical Island system



https://www.researchgate.net/figure/The-tropics-have-higher-levels-of-biological-diversity-This-map-shows-levels-of_fig2_273320508



BIRDS X MAMMALS X AMPHIBIANS

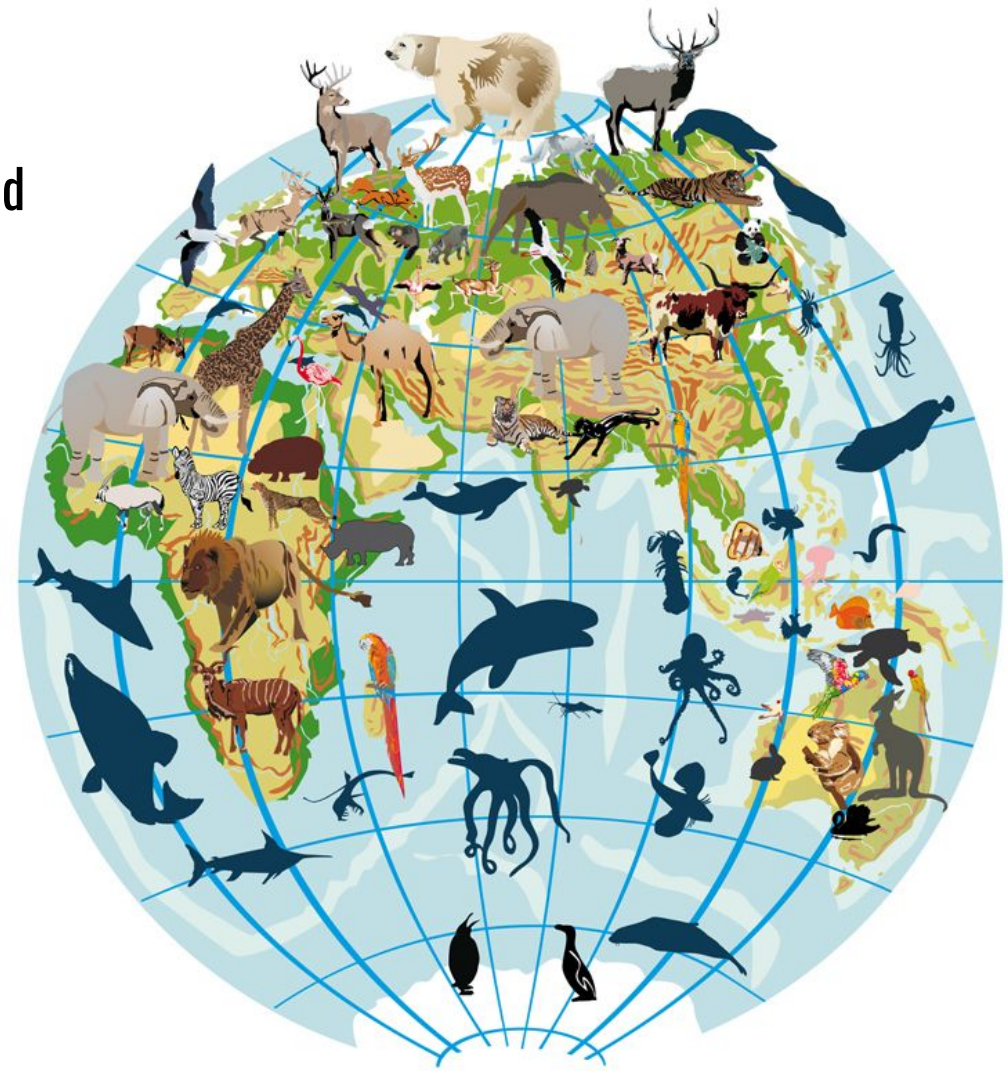
BIOGEOGRAPHY

The study of the distribution of species and ecosystems in space and through time

Why certain species live only in particular regions?

How did the species get there?

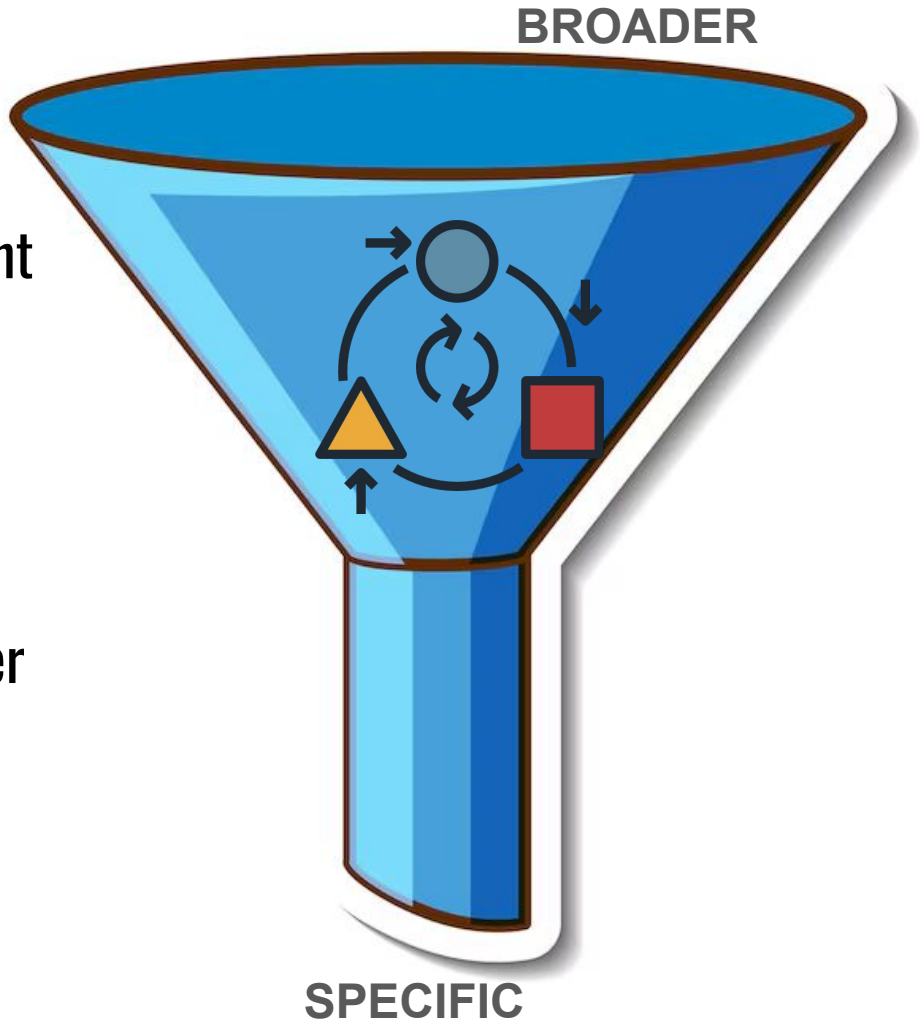
What mechanisms created such distribution patterns?



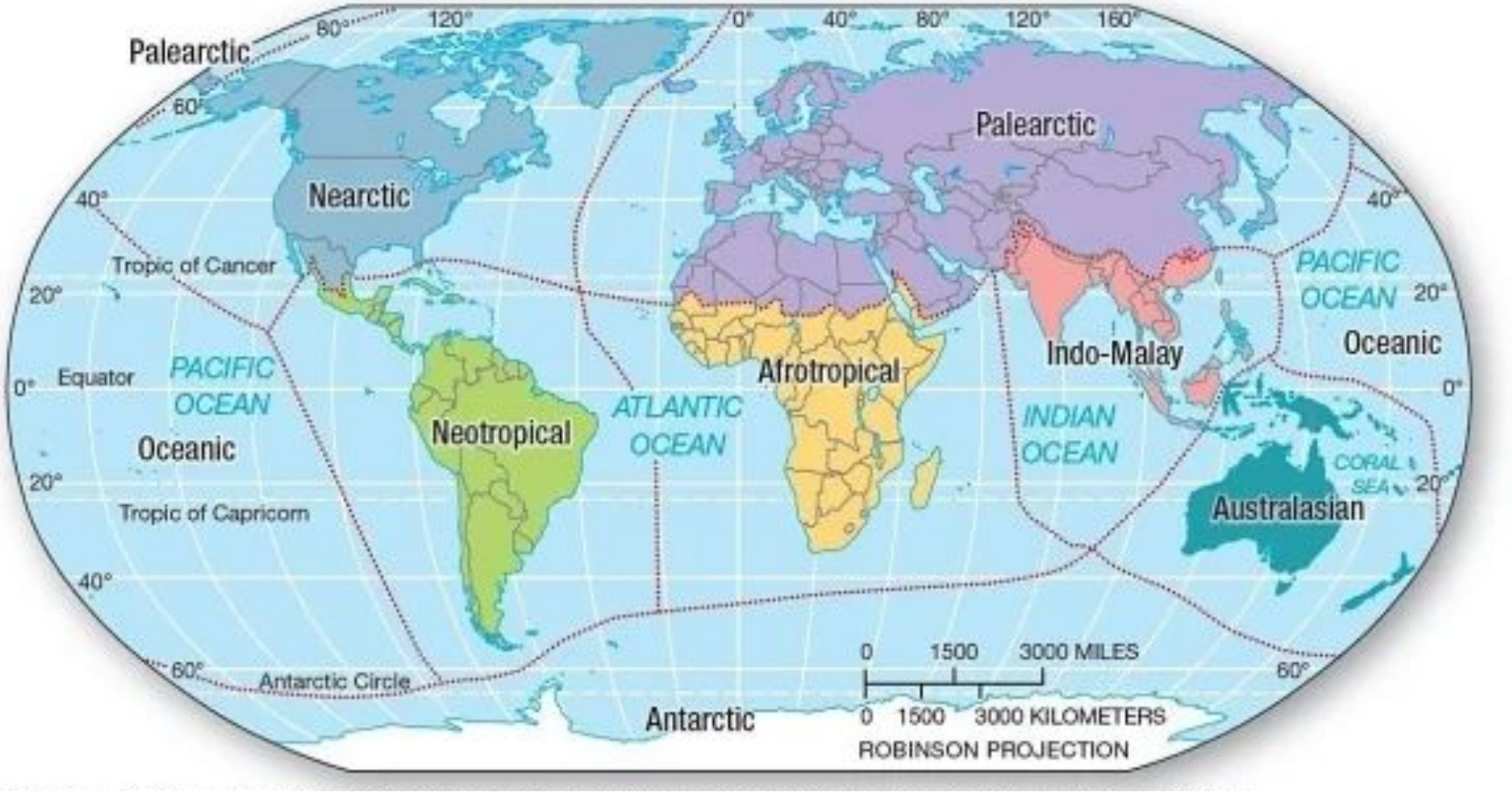
Important disclaimer

Evolution mechanisms work over different temporal and spatial scales;

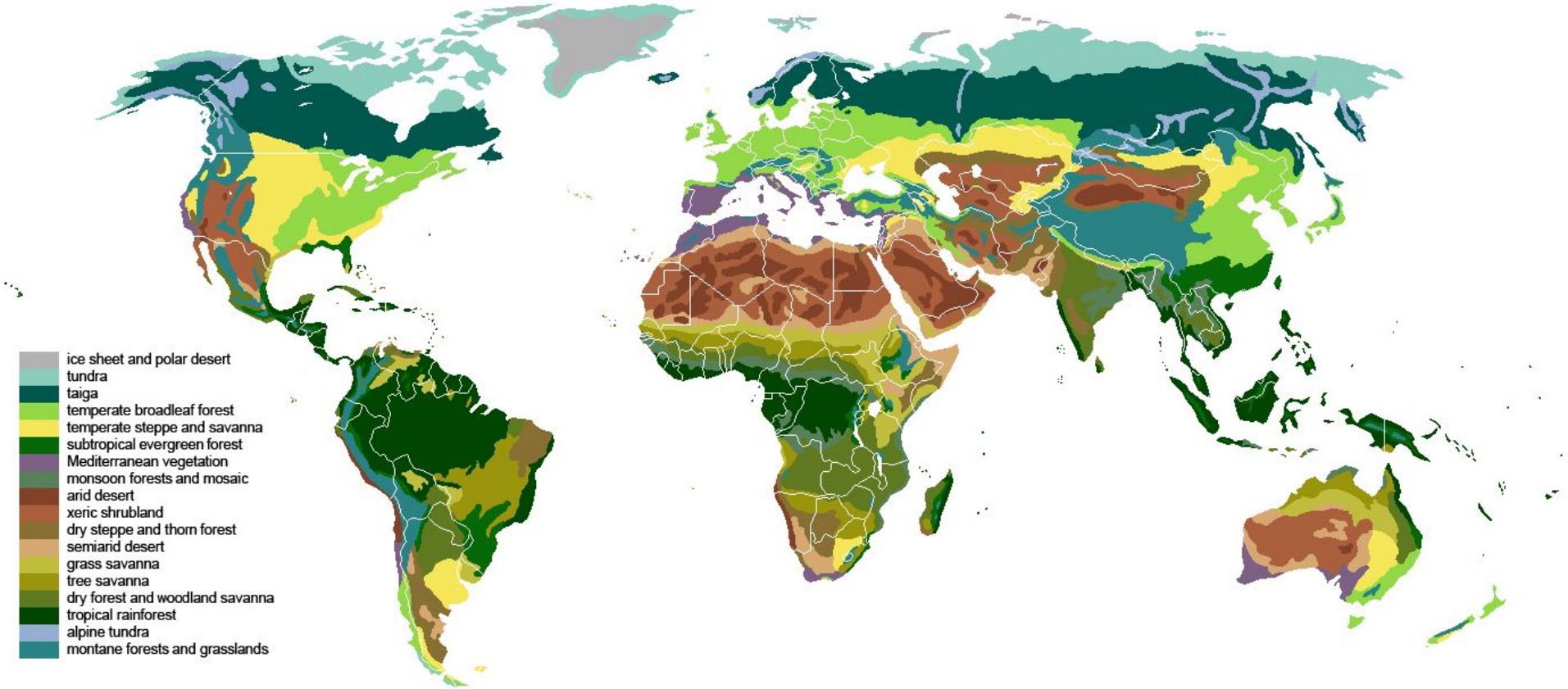
Sometimes we must narrow our perspectives to explore the details, but sometimes we need to search for broader patterns and major rules;



The world have 8 terrestrial realms...

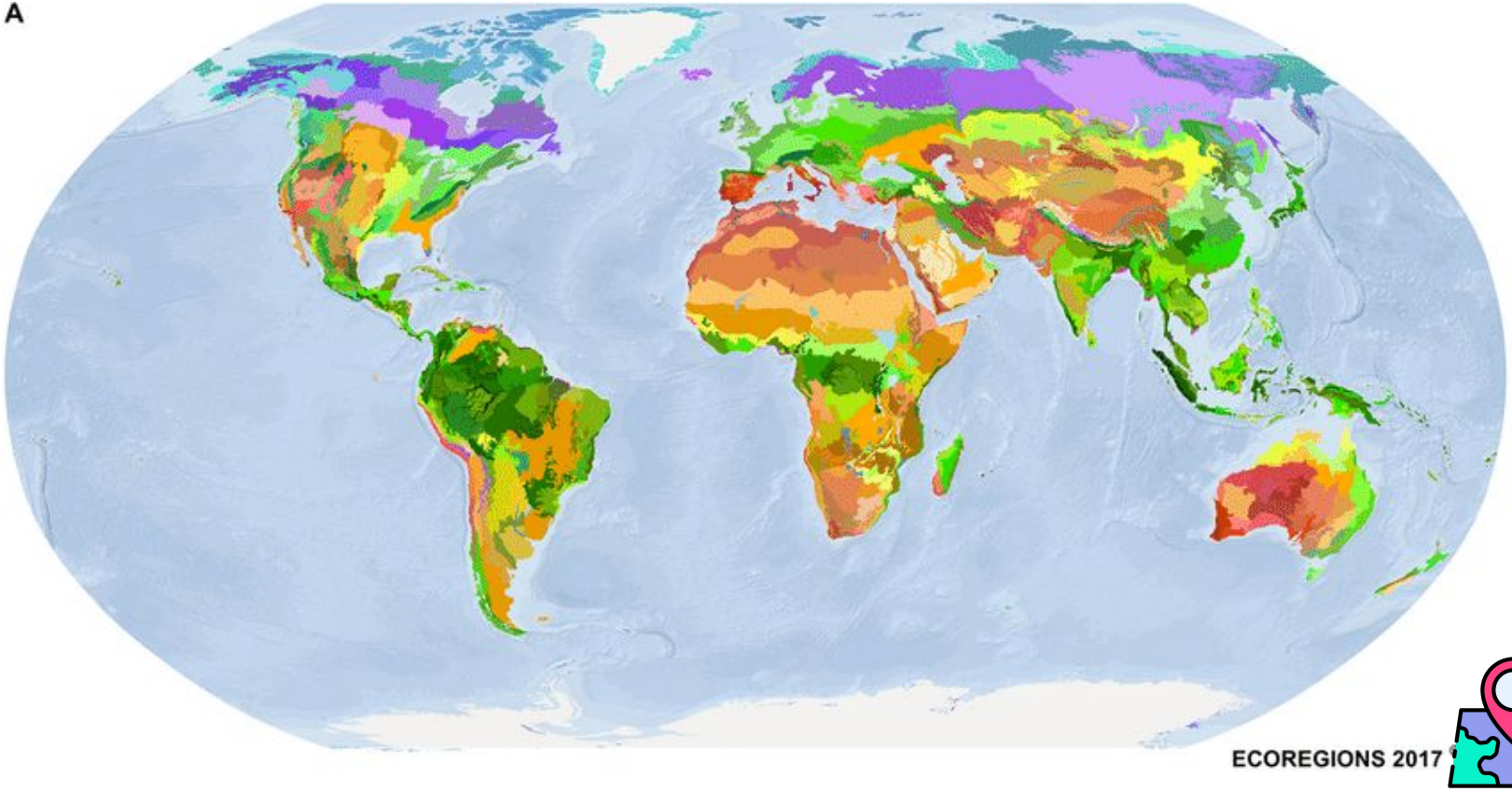


… a few more biomes…



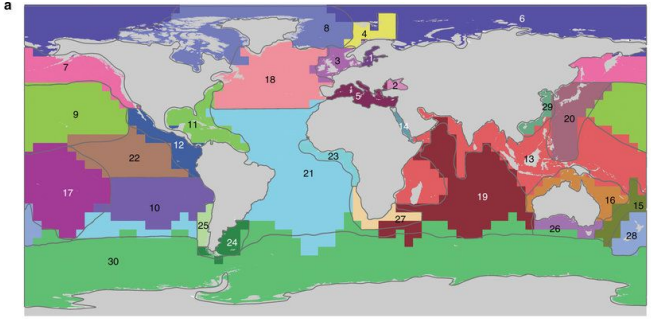
https://upload.wikimedia.org/wikipedia/commons/e/e4/Vegetation.png

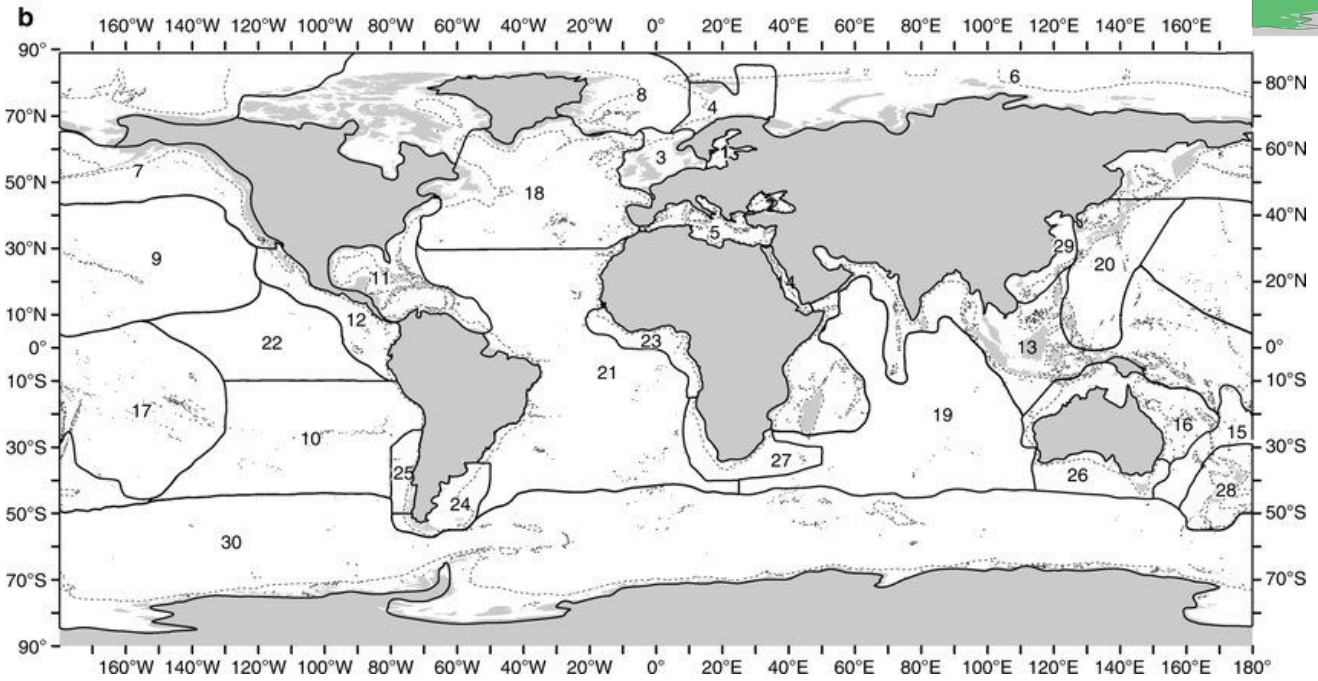
...and 846 terrestrial Bioregions



https://ecoregions.appspot.com/

The world have 30 marine realms





Bioregions

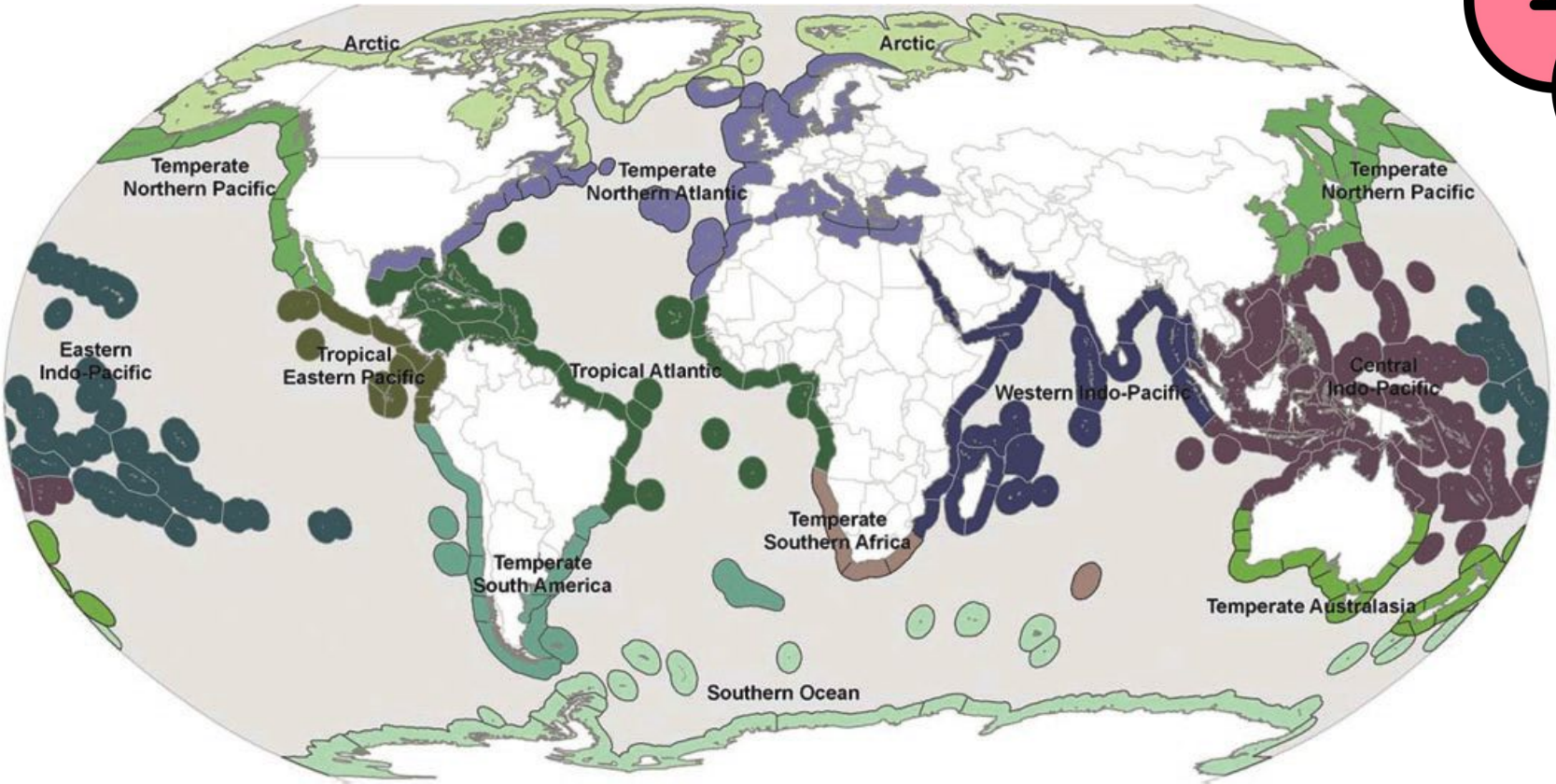
- Smaller, often tied to specific ecosystems or more localized regions.

Relms

- Based on large-scale evolutionary patterns and historical biogeography

https://www.researchgate.net/figure/The-biogeographic-realms-as-numbered-1-30-in-Fig1-a-Shows-realms-denoted-by-solid_fig3_320532847

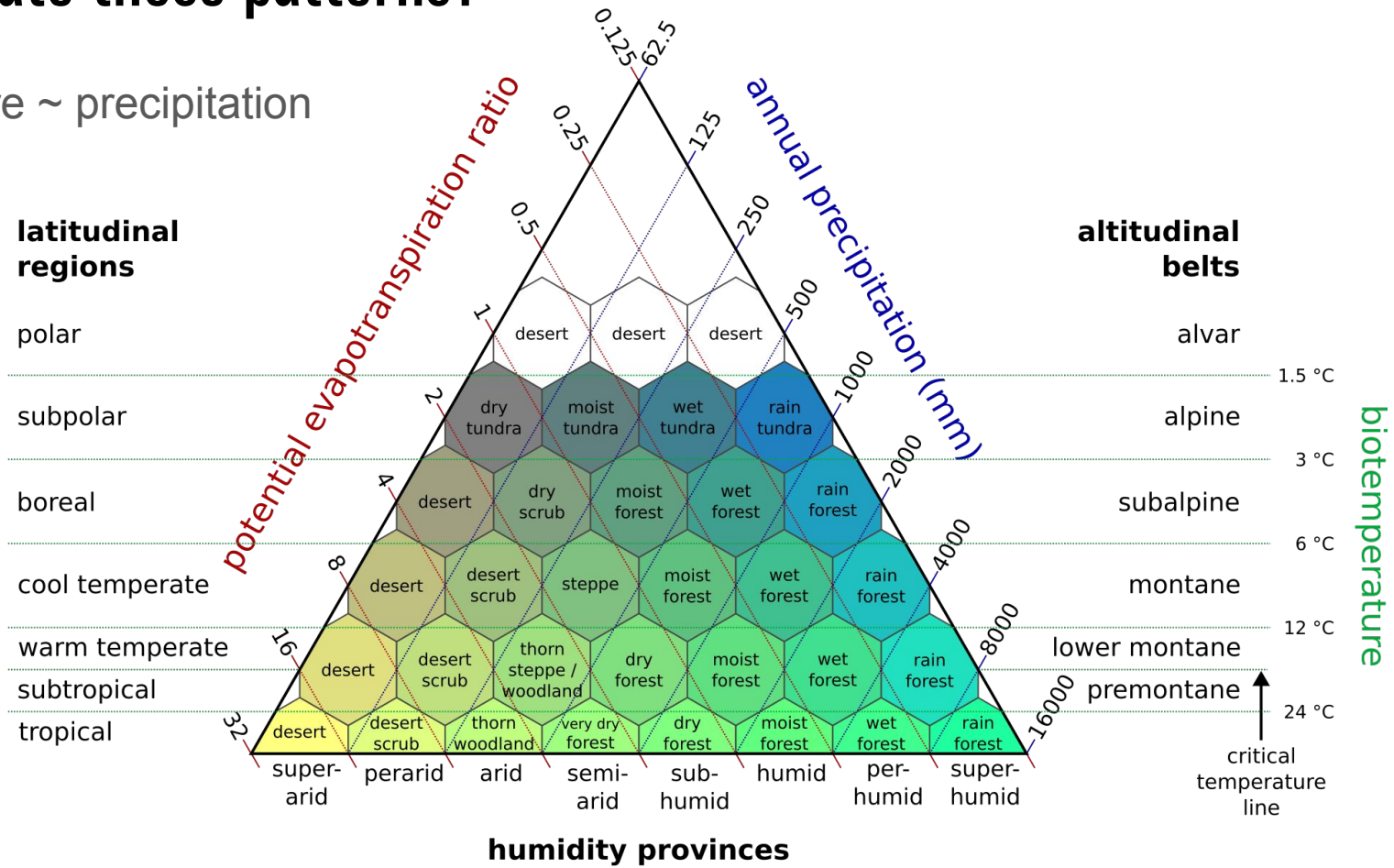
biogeographic framework for coastal and inshore areas



https://www.researchgate.net/figure/Final-biogeographic-framework-for-coastal-and-inshore-areas-Realms-and-provinces_fig2_226827787

What dictate those patterns?

Temperature ~ precipitation



What produced the contemporary biodiversity patterns

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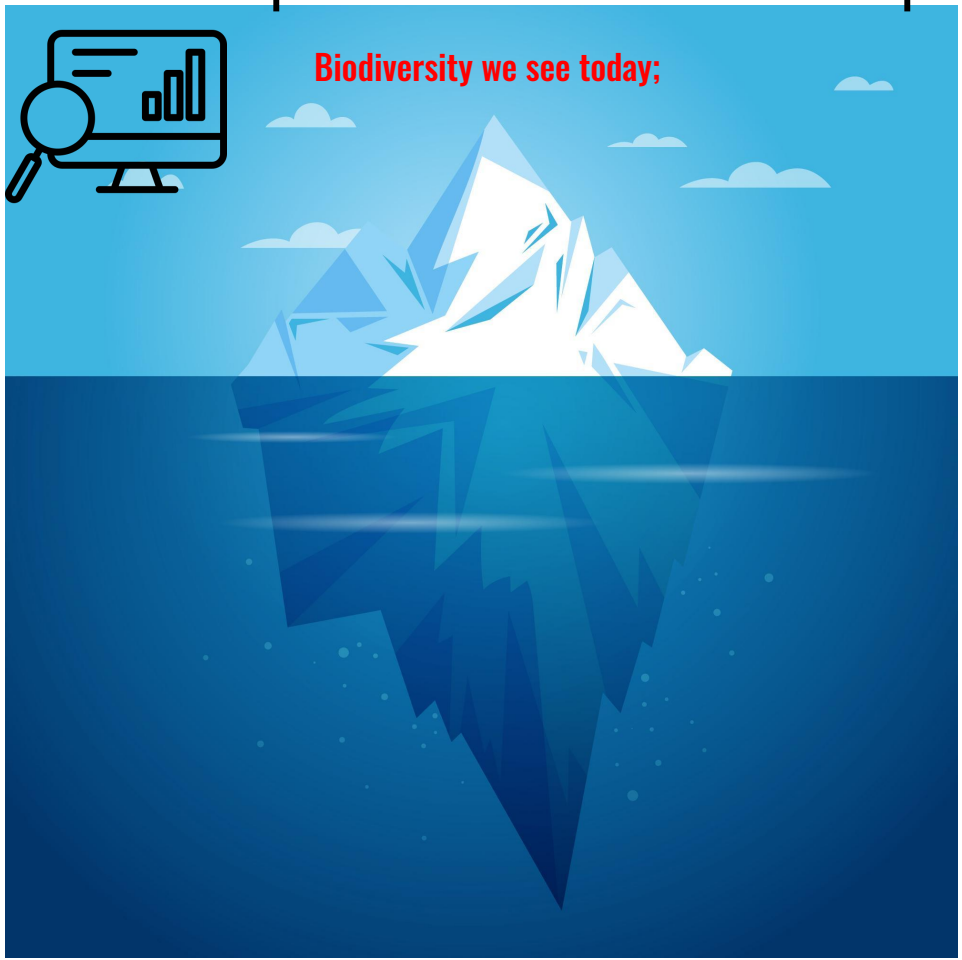
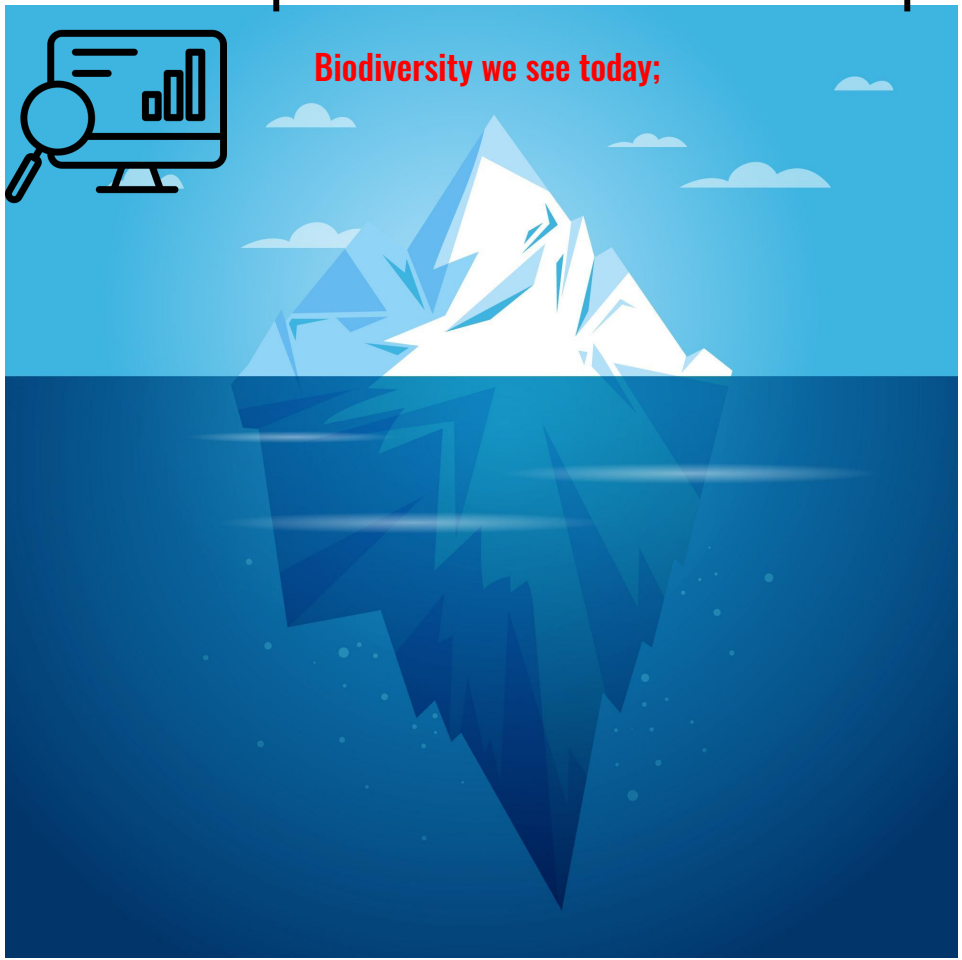


Contemporary patterns of distributions
(temperature ~ precipitation)

What produced the contemporary biodiversity patterns



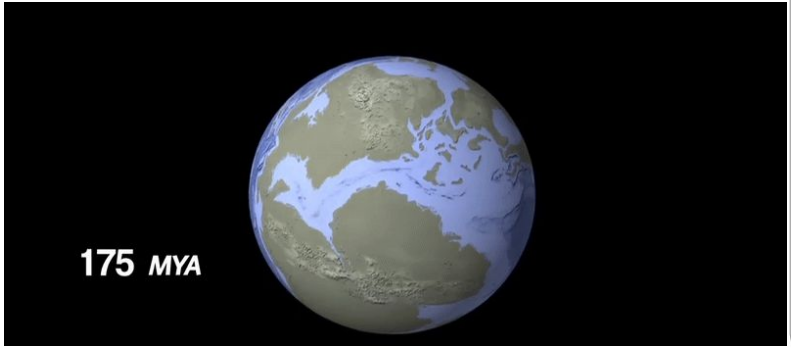
Contemporary patterns of distributions
(temperature ~ precipitation)

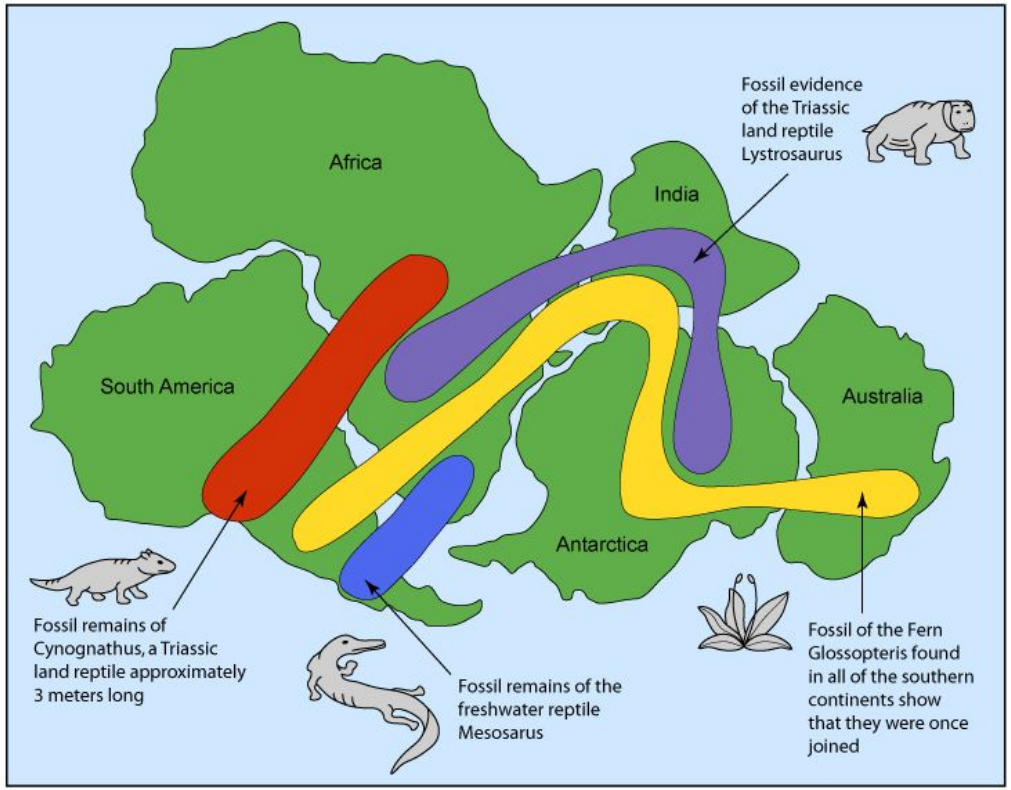
Historical events that shaped the current patterns;
Evolutionary mechanisms;
Species natural histories;
Interactions with extinct species;
Sea level fluctuations;
Random mass extinctions;
...

Tectonic plates and continental drift

The movement of Earth's tectonic plates over millions of years has dramatically influenced the **distribution of species**

Fossils used as evidence!





Marsupials (Metatheria) example

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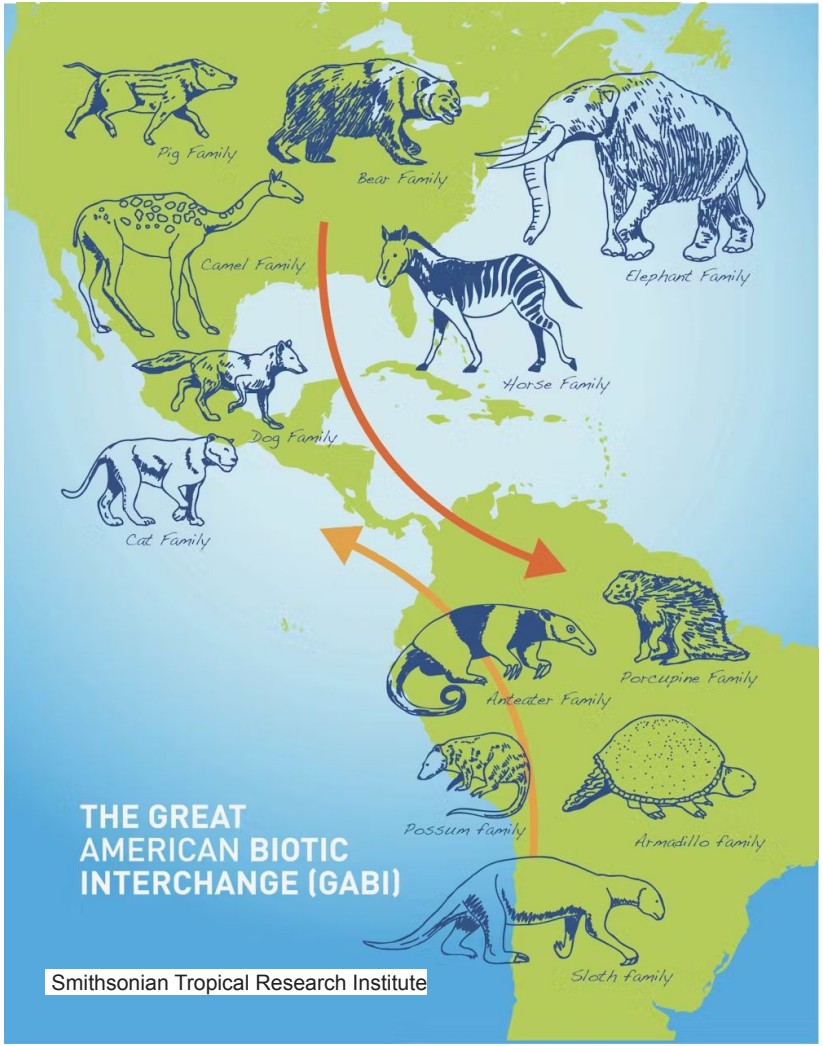
Jurassic period - 160 mya

Another example of large-scale interchange of Biodiversity



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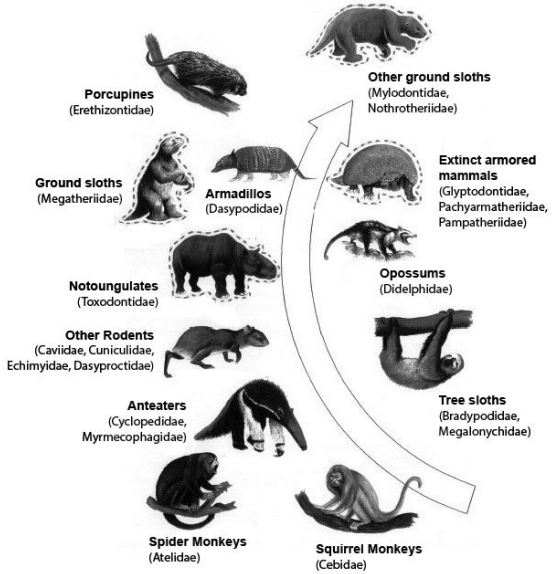
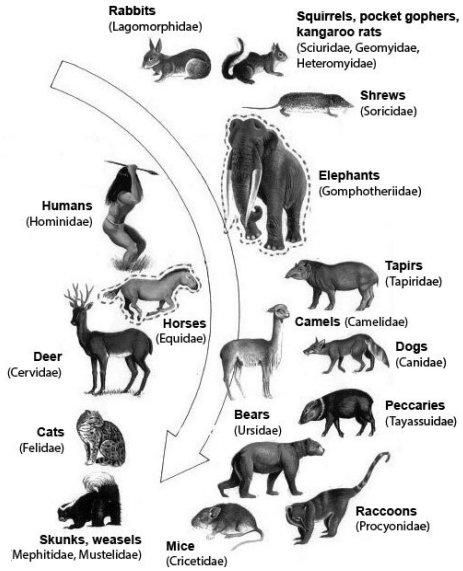
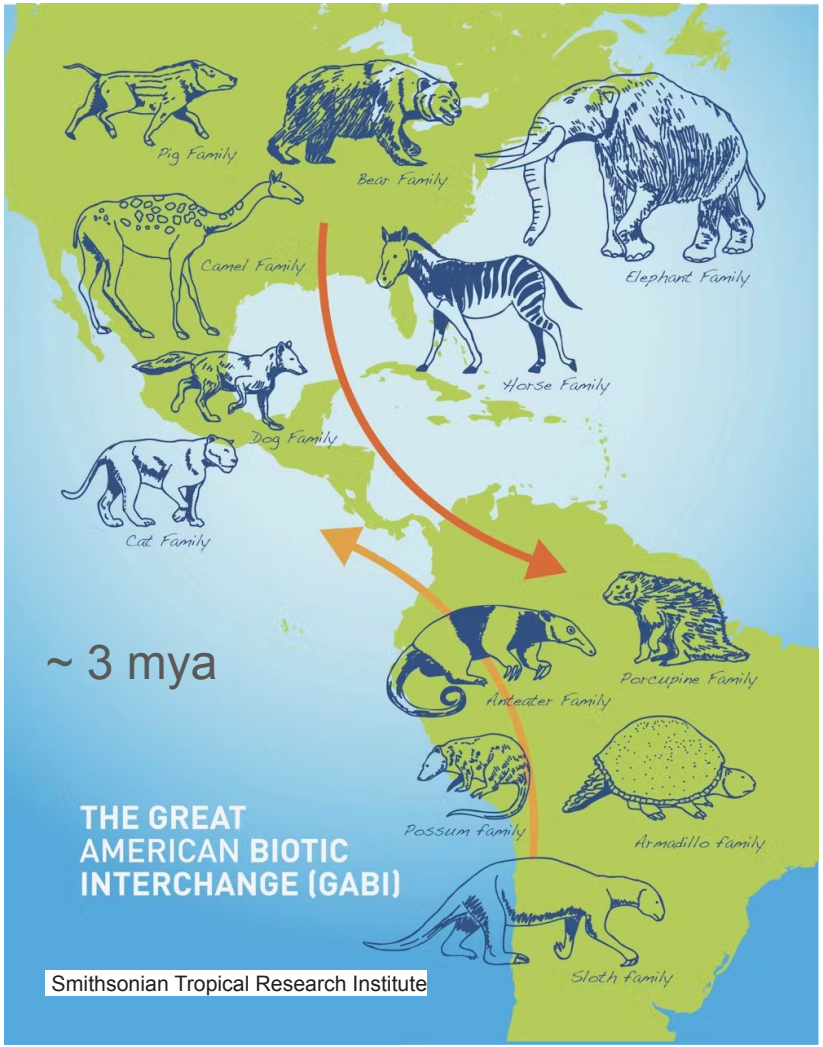
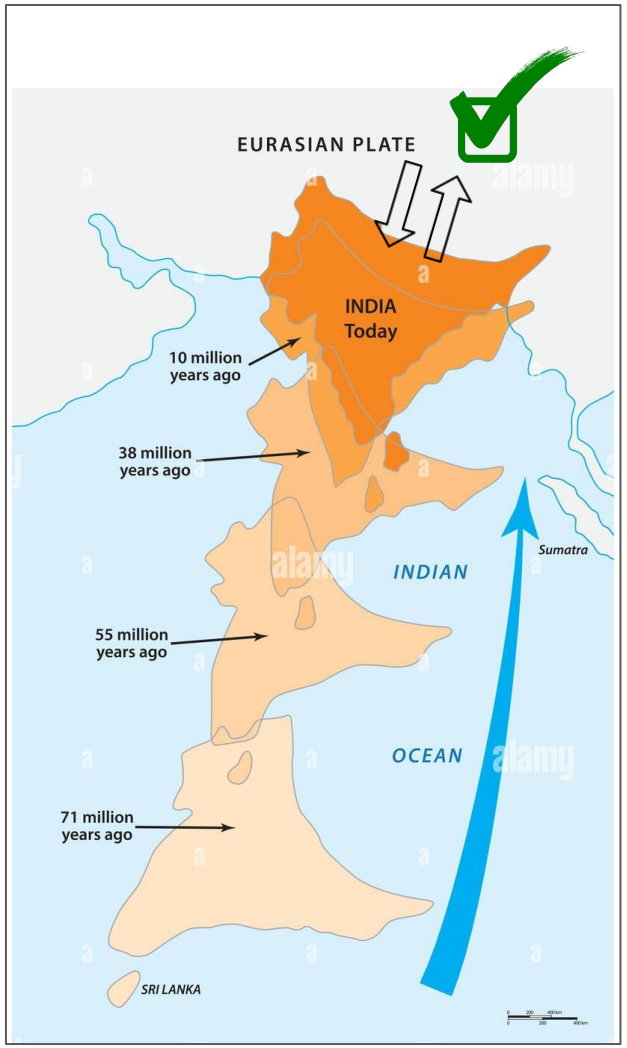
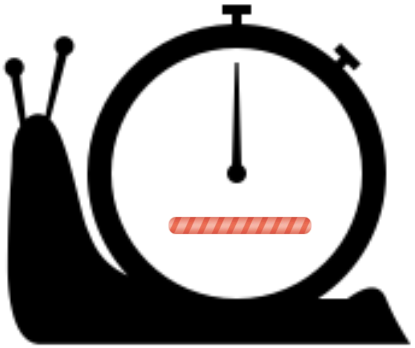


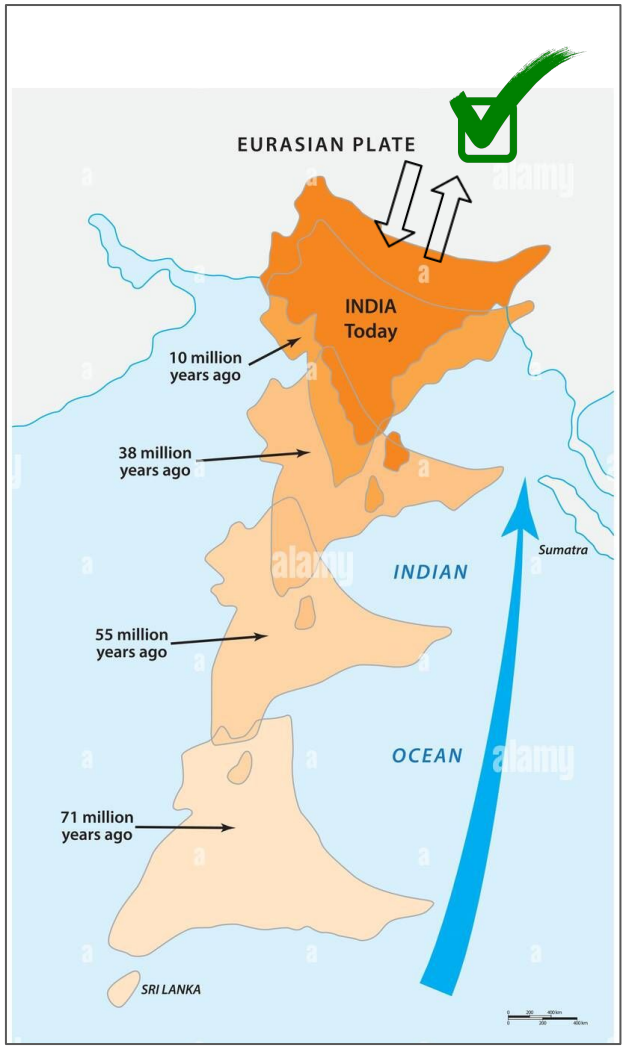






When land masses collide (Indian subcontinent example)





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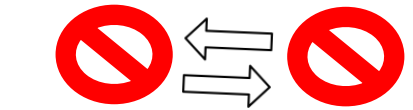
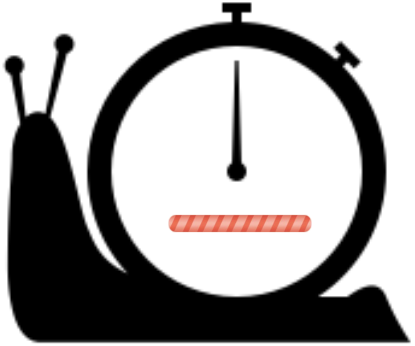
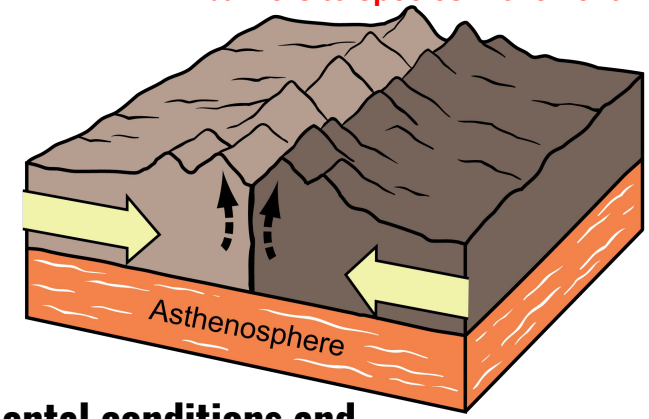






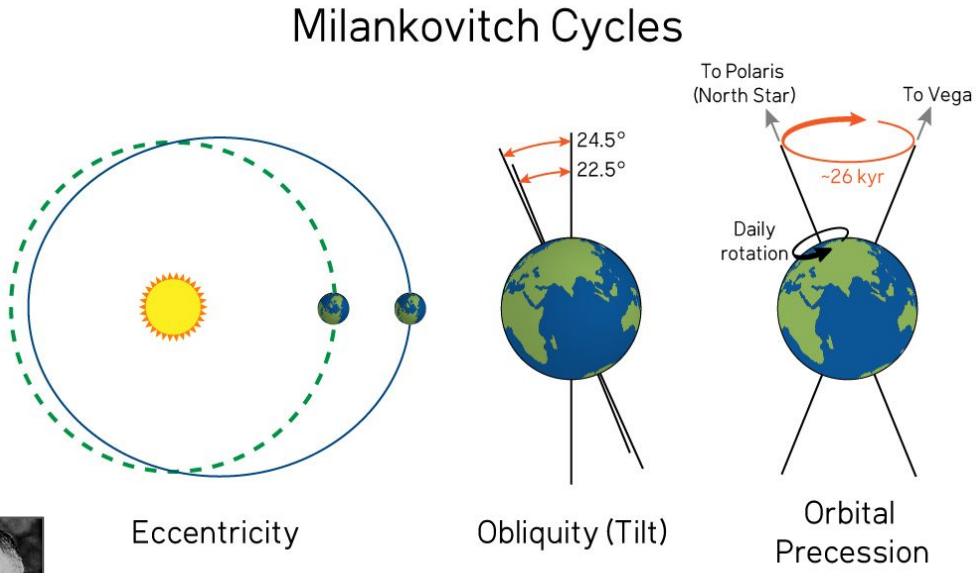
Influencing the environmental conditions and biological interactions:

Climatic shifts

Barrier to Gene Flow

Promotes Altitude-Driven Evolution

Drivers of biodiversity in a even broader scale



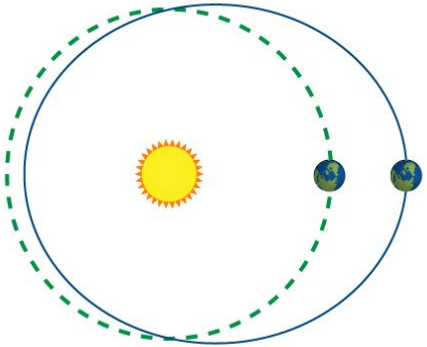
changes in the shape of Earth's orbit

changes in the tilt of Earth's axis

wobble of Earth's axis

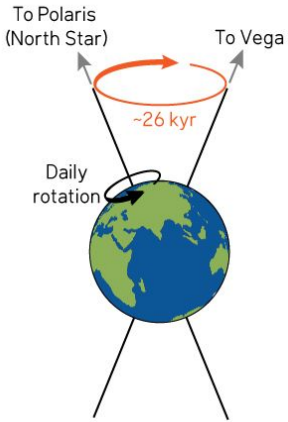
Drivers of biodiversity in a even broader scale

Milankovitch Cycles

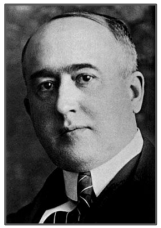


Eccentricity

Obliquity (Tilt)



Orbital
Precession



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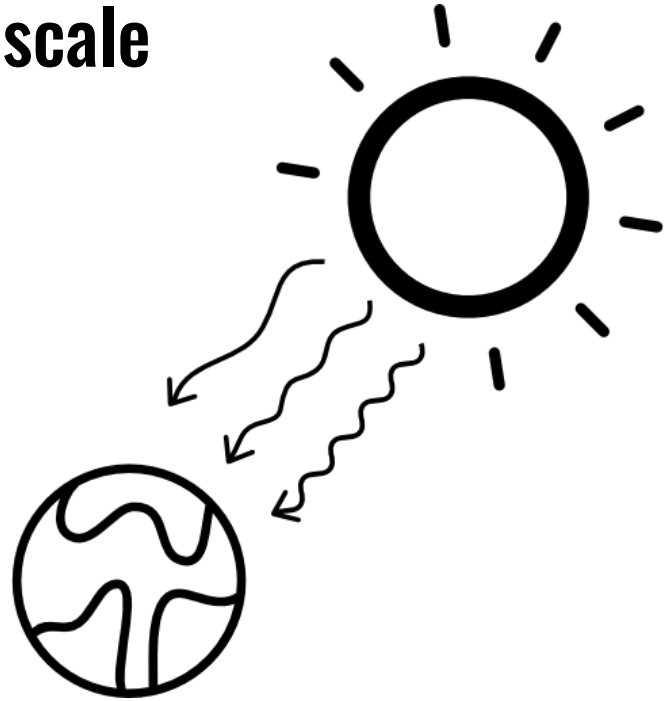
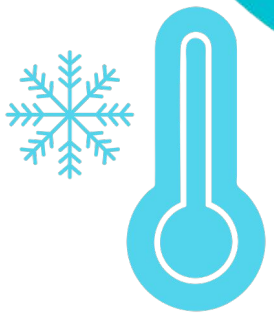
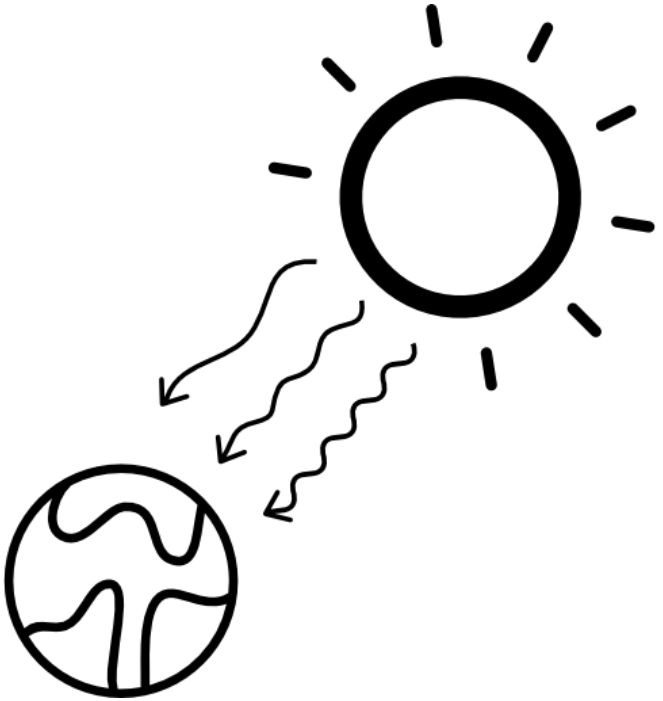


Change on the amount of solar radiation



Decrease or increase of the ice-sheets



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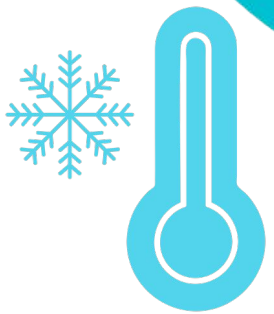

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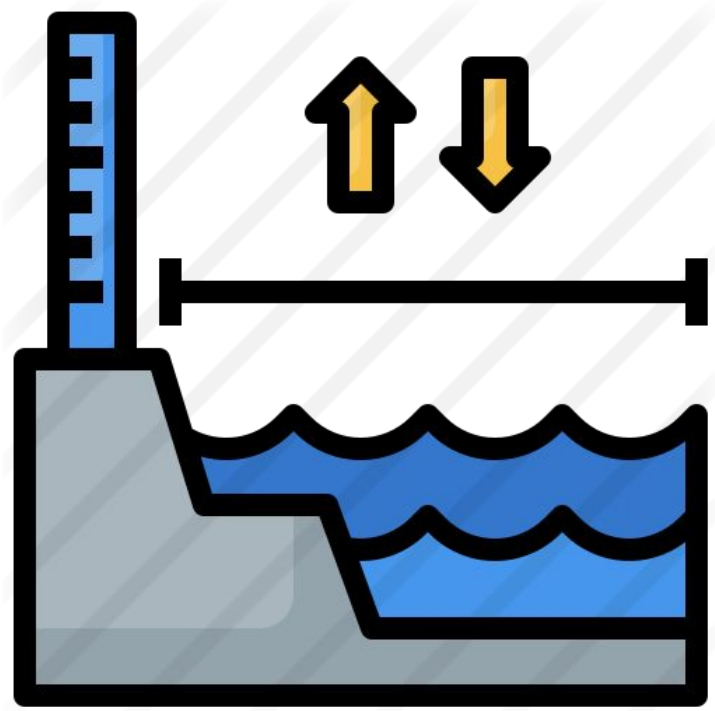
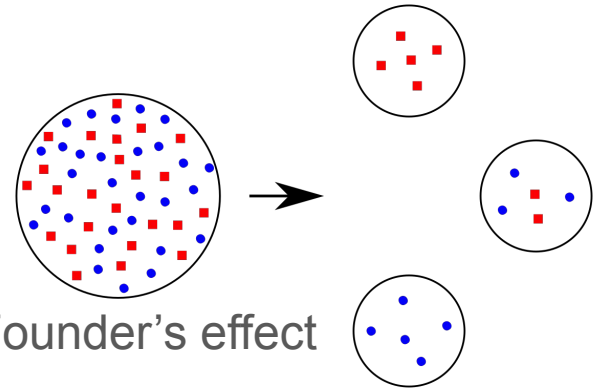


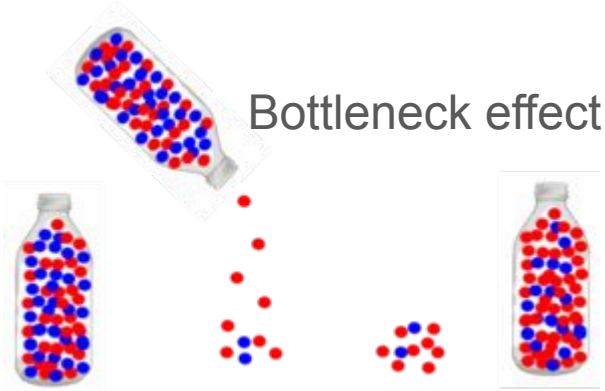
Fluctuation of sea levels (increase or decrease)

How did the first humans arrived American continent?

Evolutionary processes



Founder's effect



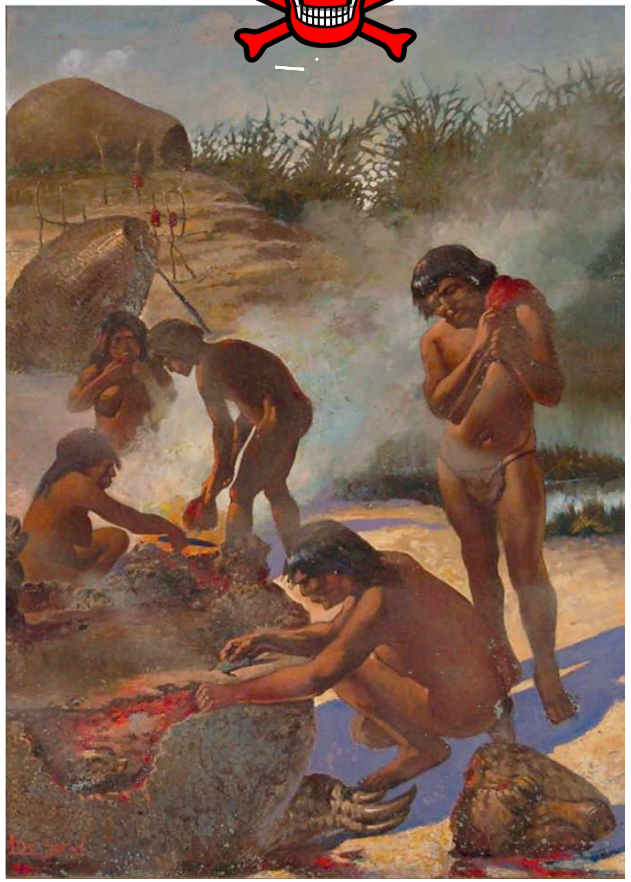
Bottleneck effect

Adaptive radiation

Anthropogenic action also shaped current diversity

Humans and extinctions walk together

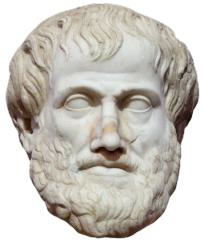
Anthropogenic action also shaped current diversity



So when did we start studying Biogeography?

Biogeography: quick history overview

Aristotle early observations

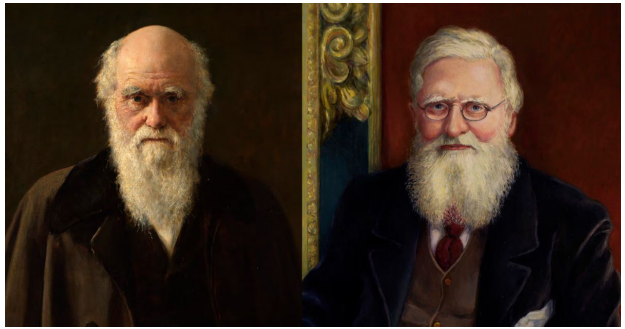


~ 300 BC

Comte de Buffon, and the first scientific thoughts

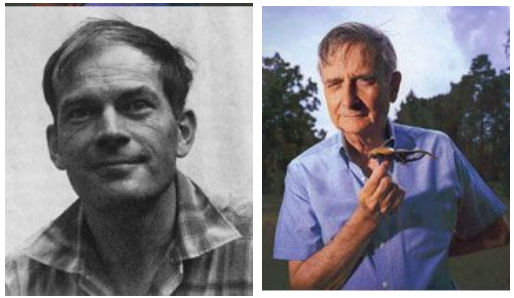
18th century

Darwin, Wallace, and the Rise of Evolutionary Thought



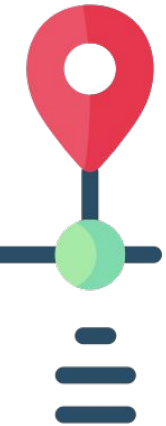
19th century

MacArthur & Wilson, and the island biogeography theory



20th century

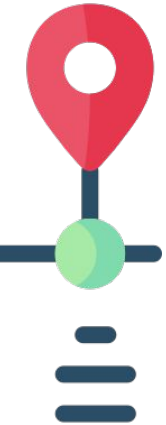
Contemporary Biogeography (21th century)



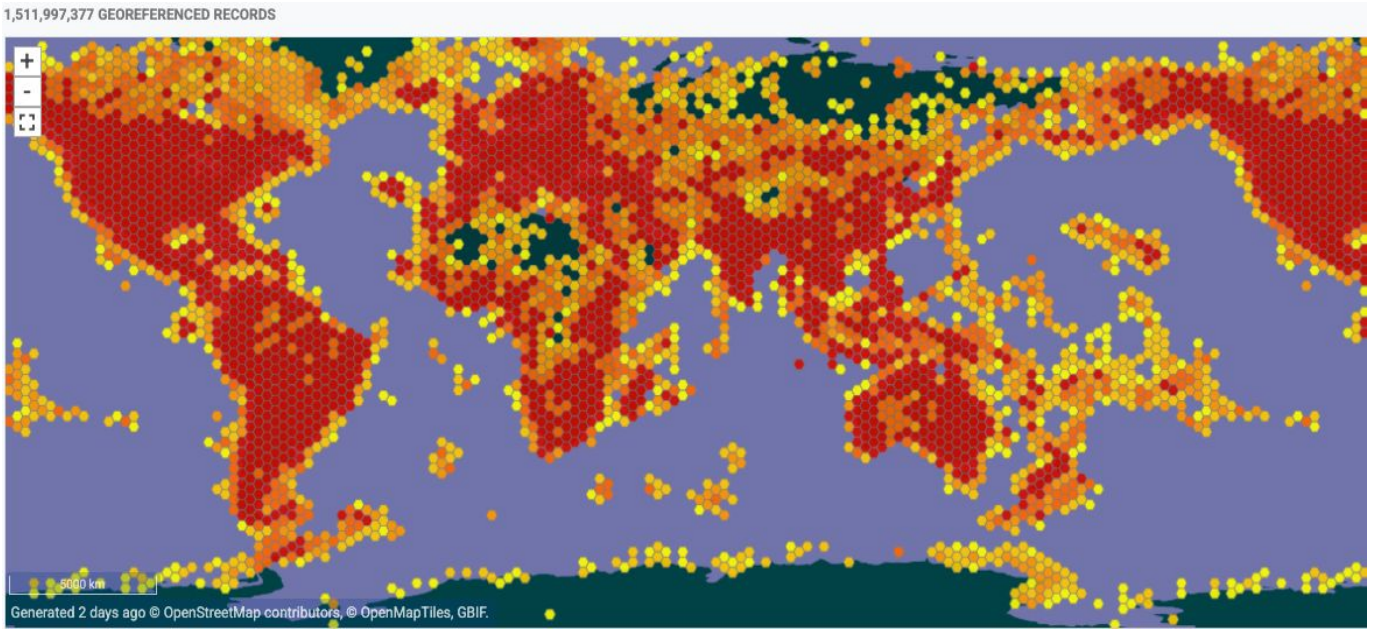
Contemporary Biogeography (21th century)

Online databases

GBIF
Global Biodiversity Information Facility



etc. etc. etc. etc. etc. etc. etc.



Example: EOD – eBird Observation Dataset

Museum collections and other online repositories

Smithsonian

FLORIDA MUSEUM OF NATURAL HISTORY

ROM
Royal Ontario Museum

AMERICAN MUSEUM of NATURAL HISTORY

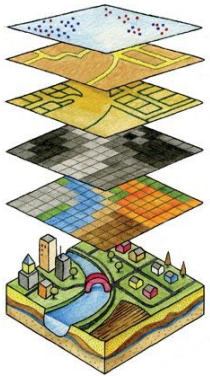
MUSEO Nacional de HISTORIA NATURAL
Prof. Eugenio de Jesús Marcano

TEXAS TECH UNIVERSITY

KU
THE UNIVERSITY OF KANSAS

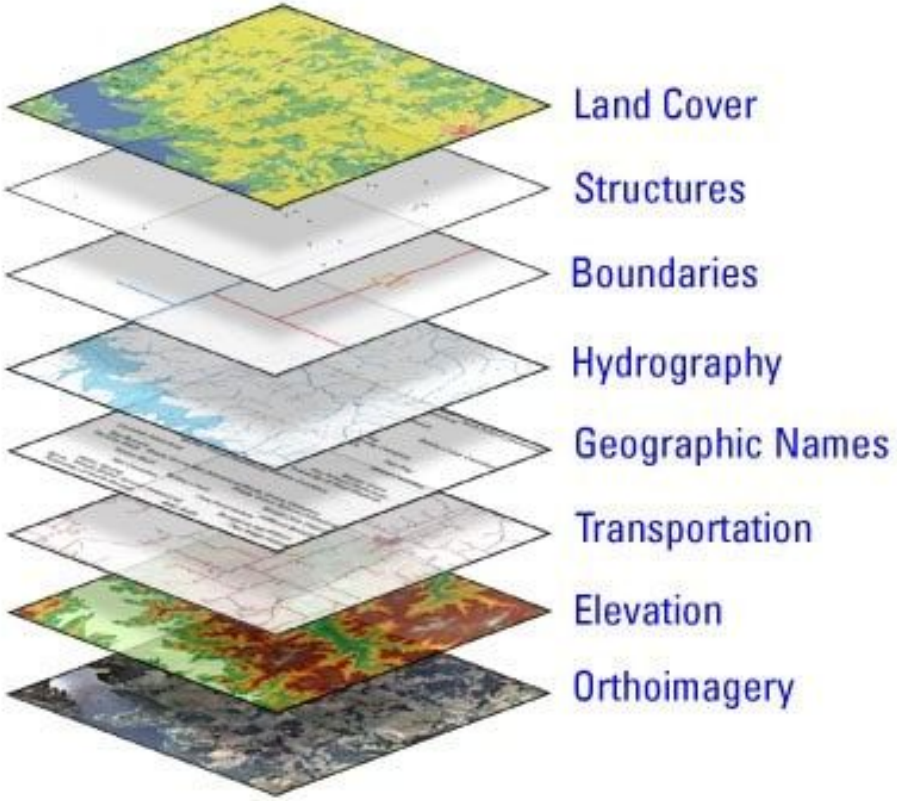
Contemporary Biogeography (21th century)

QGIS

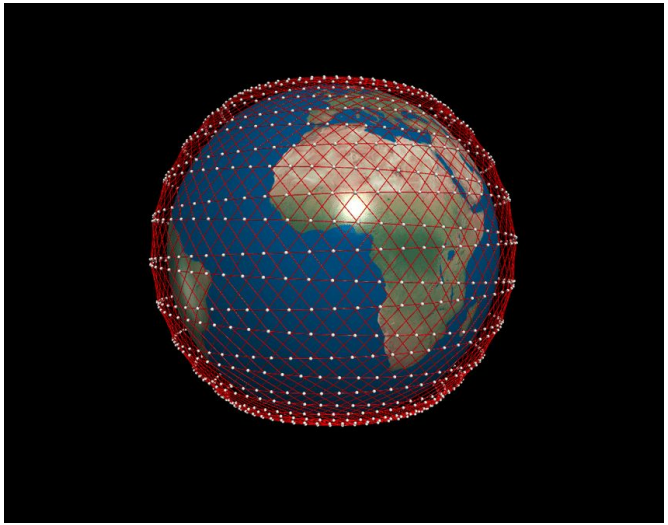


ArcGIS

Geographic Information Systems (GIS)
& Spatial analyses



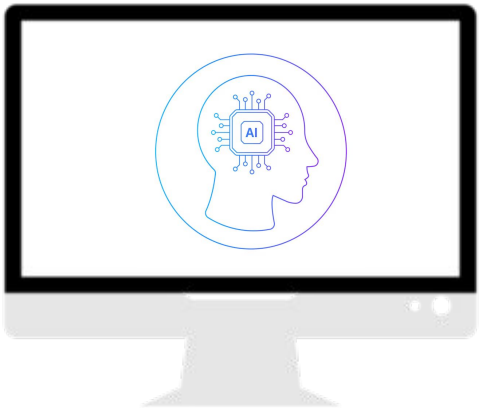
Contemporary Biogeography (21th century)



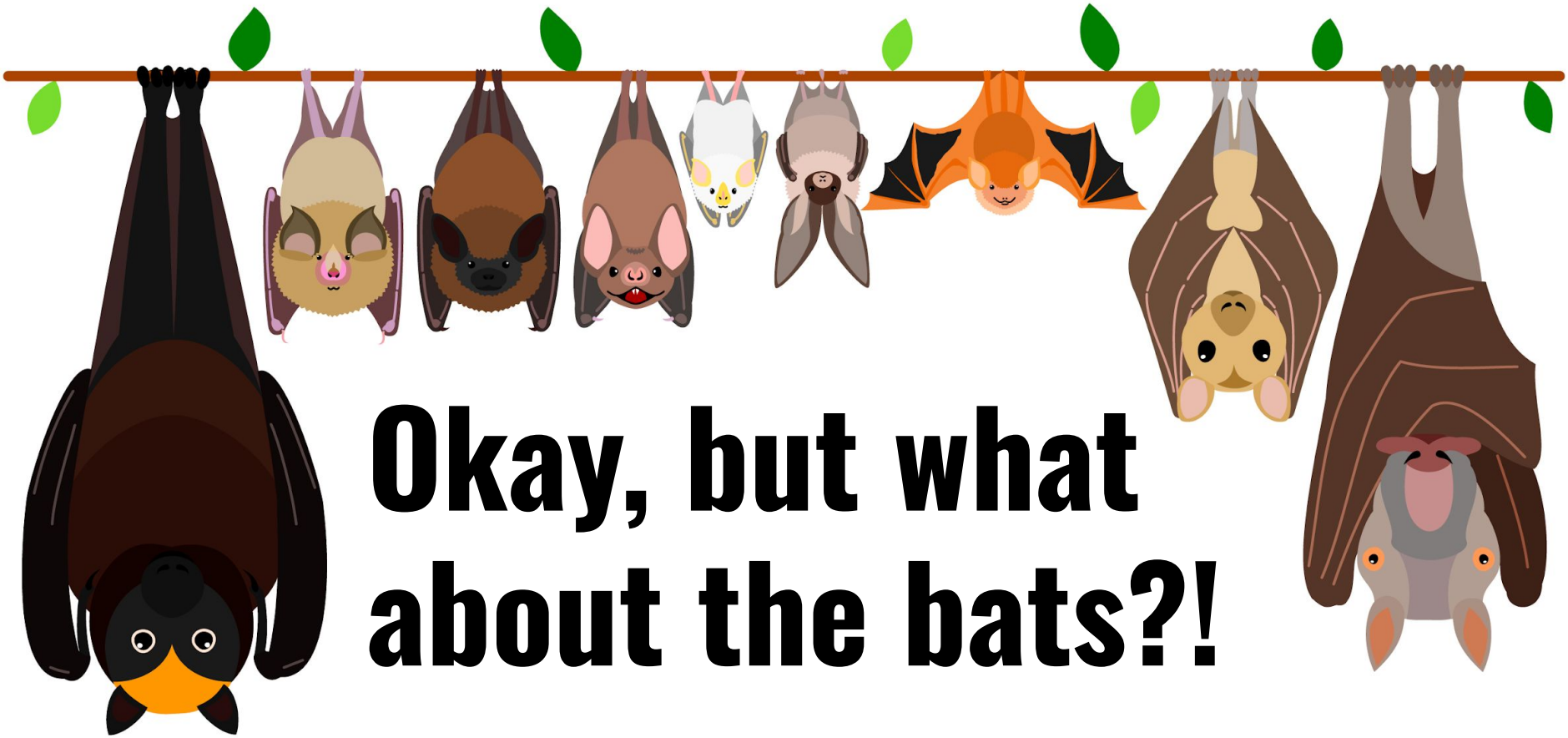
Satellite information

WorldClim

Historic and present environmental and climatic data



Artificial Intelligence



Okay, but what about the bats?!

Bats are great objects of study for biogeographical questions!

Bats are great objects of study of biogeographical questions!

1 - Rich evolutionary history and many adaptive radiations

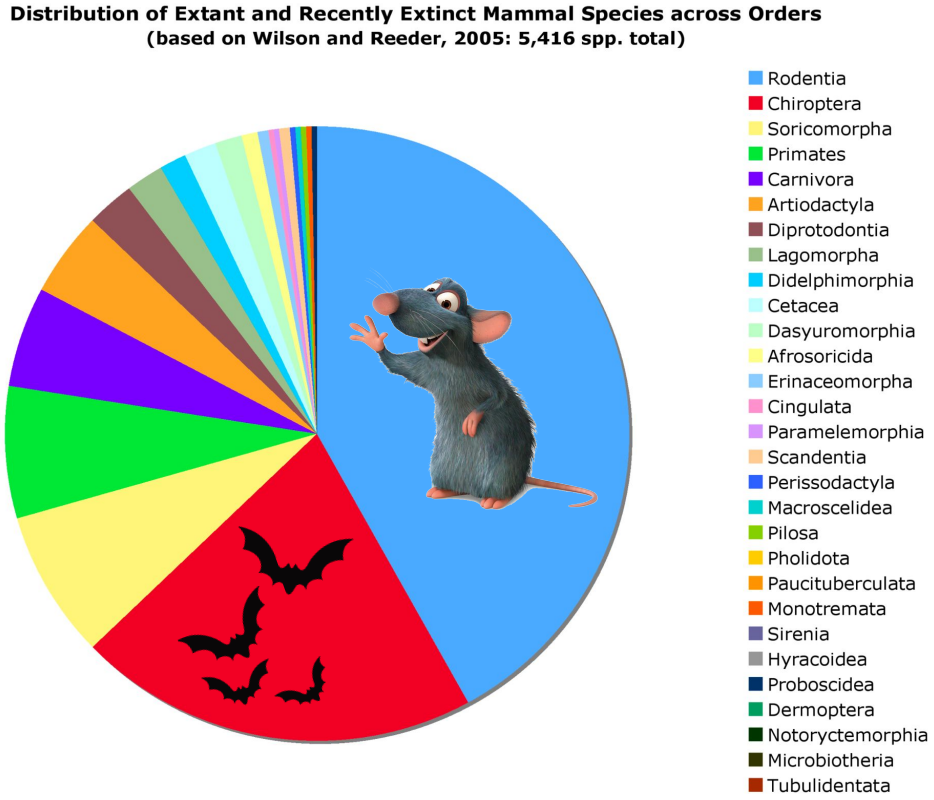
Bats are great objects of study of biogeographical questions!

1 - Rich evolutionary history and many adaptive radiations

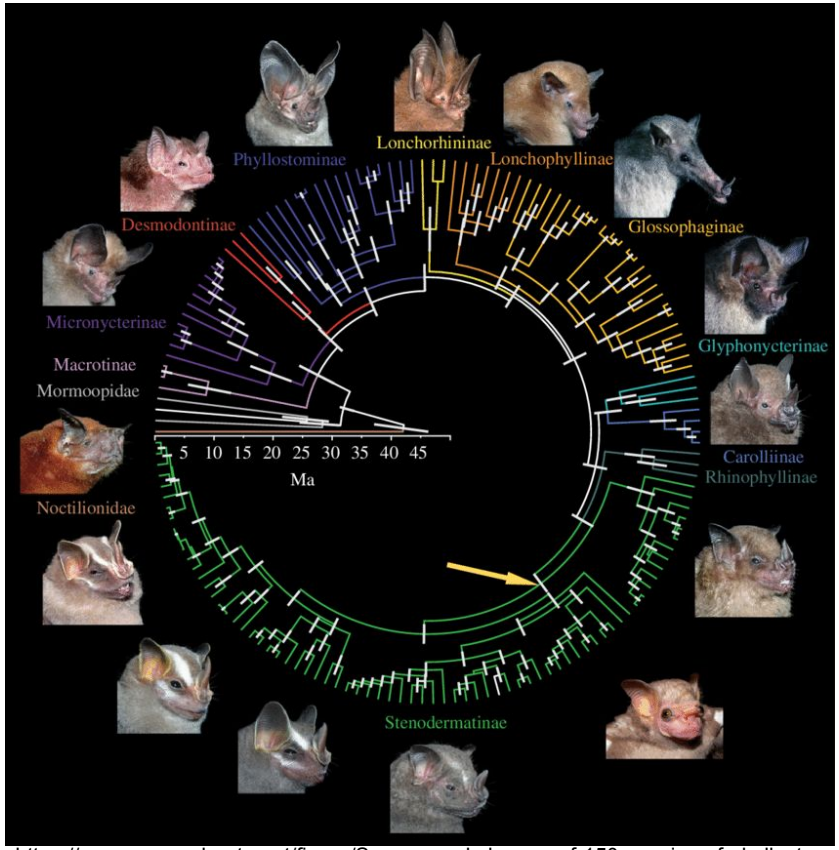
- 1487 bat species (and counting)

Bats of the World (Mar 4 2025)
A Taxonomic and Geographic Database

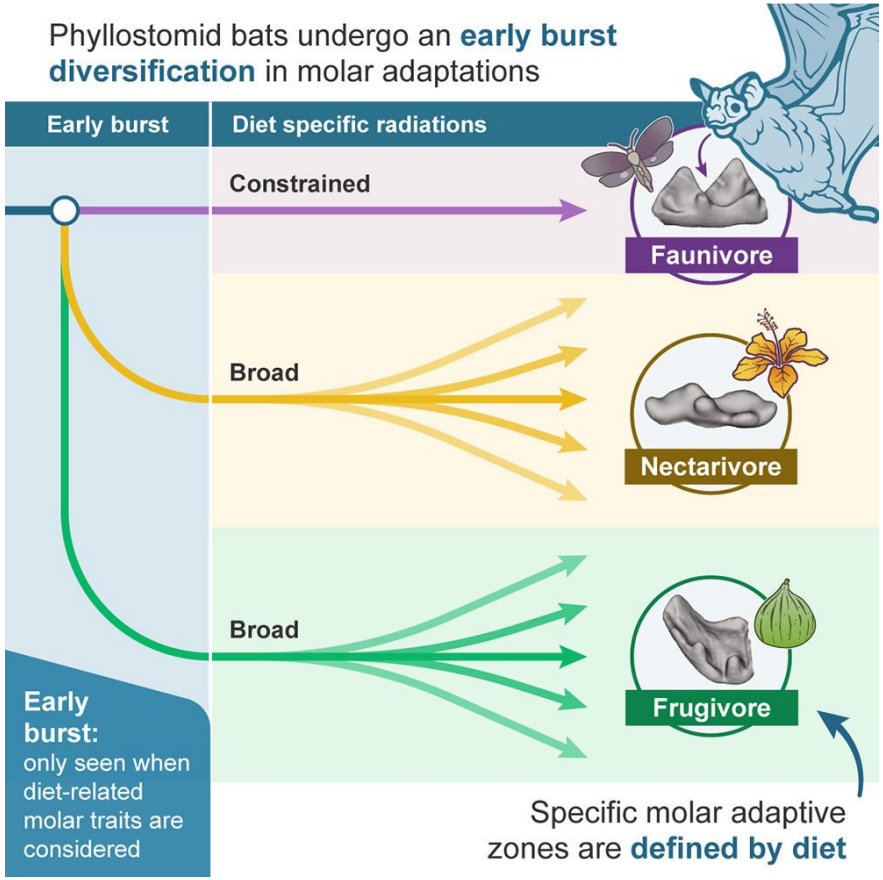
- ~ 20% of all mammal species
  - Every 5 mammals species, 1 is a bat!



Bats are great objects of study of biogeographical questions!



https://www.researchgate.net/figure/Summary-phylogeny-of-150-species-of-phyllostomid-bats-illustrating-diversity-in-lineages_fig2_51824867



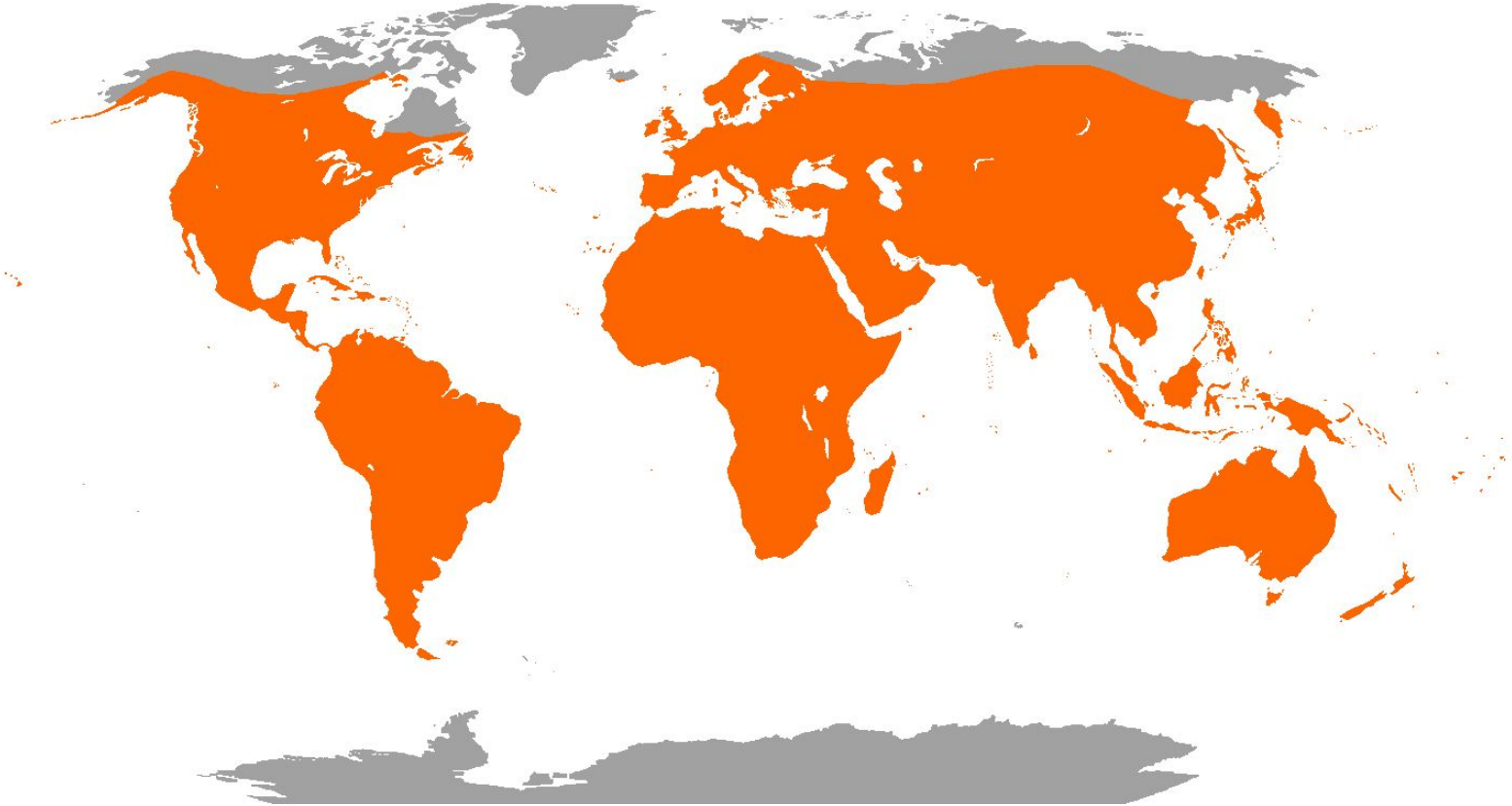
https://doi.org/10.1016/j.cub.2024.02.027

Bats are great objects of study of biogeographical questions!

2 - Wide Geographic Distribution due true flight: bats are (almost) everywhere!

Bats are great objects of study of biogeographical questions!

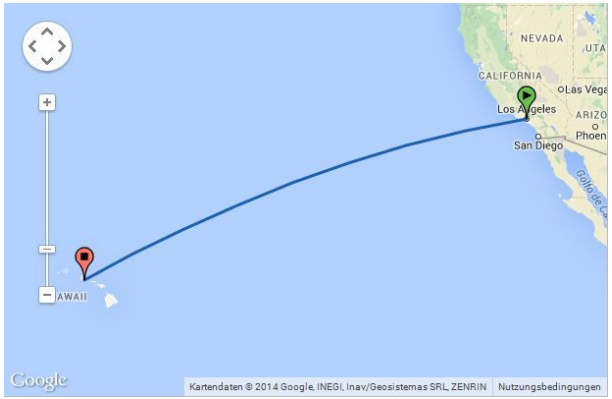
2 - Wide Geographic Distribution due true flight: bats are (almost) everywhere!

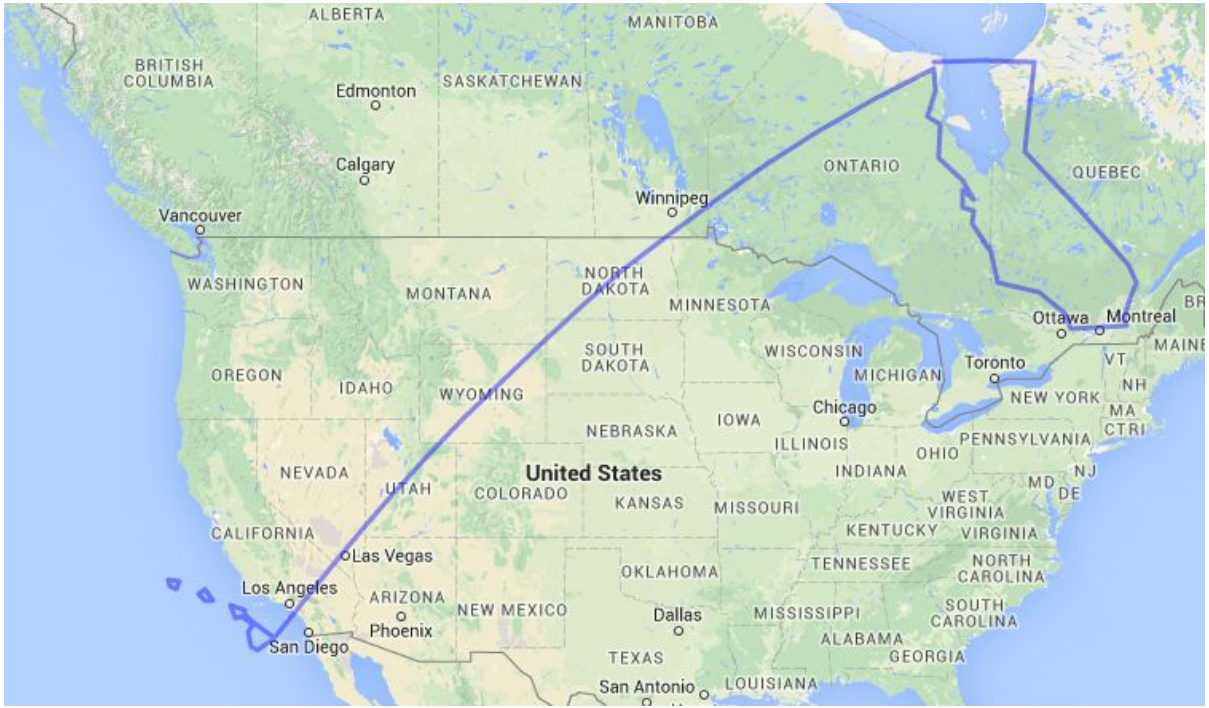


Example of the incredible dispersal capabilities of bats

Hawaiian Hoary bat and the biggest invasive movement ever made by a terrestrial mammal! happened once or twice?

16 inches wingspan
(40 centimeters)





Bats are great objects of study of biogeographical questions!

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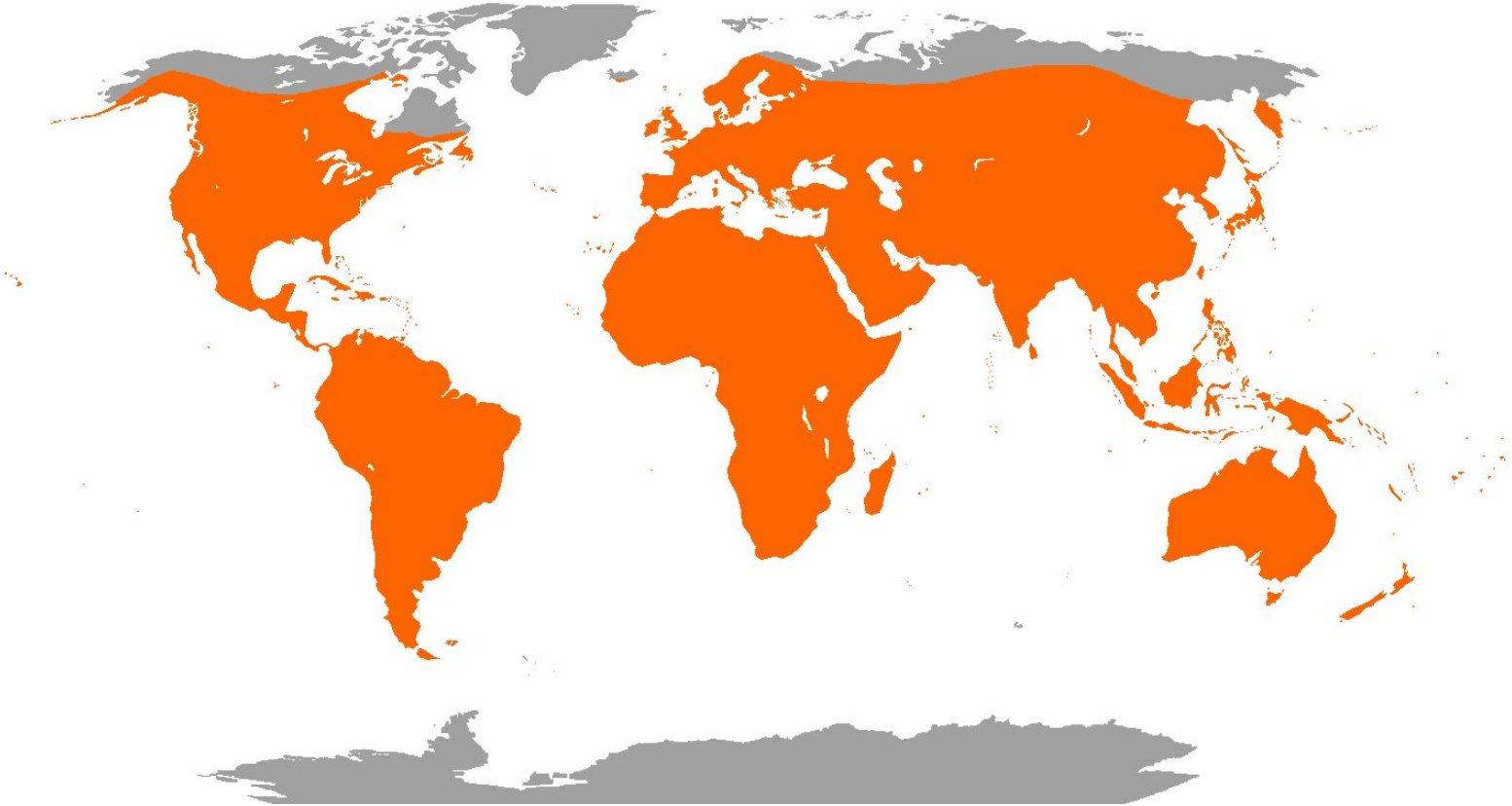

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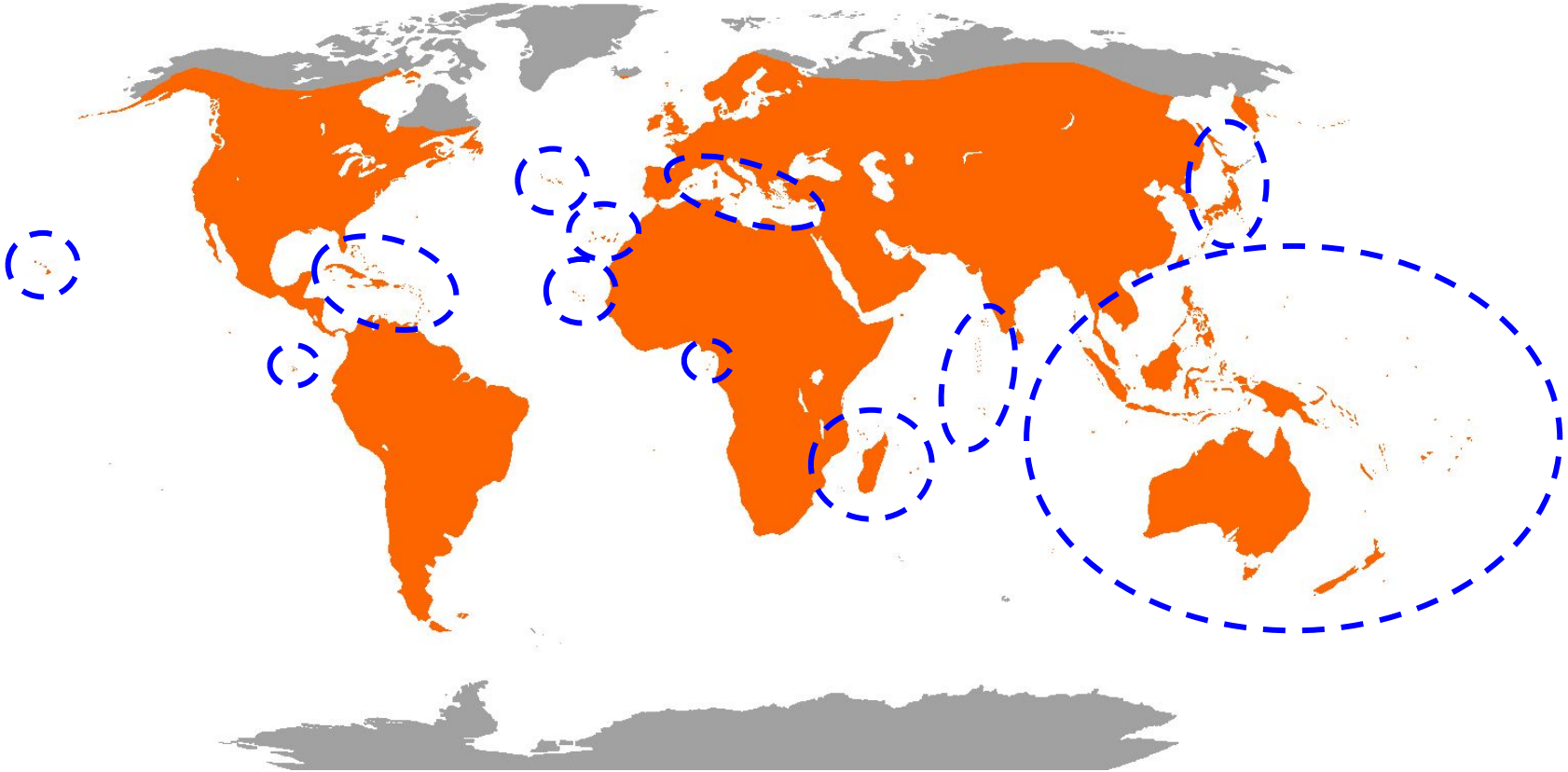
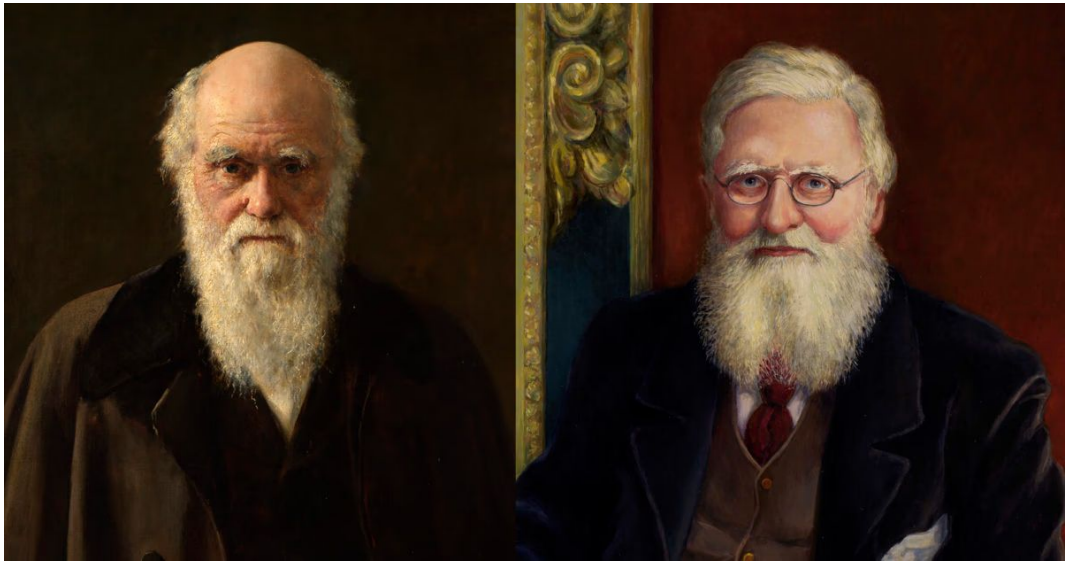


Islands are a valuable sites for studying biogeography



Darwin in Galapagos

Wallace in the pacific islands

The processes of speciation, extinction, dispersal, and evolution can be observed in a more controlled and isolated context

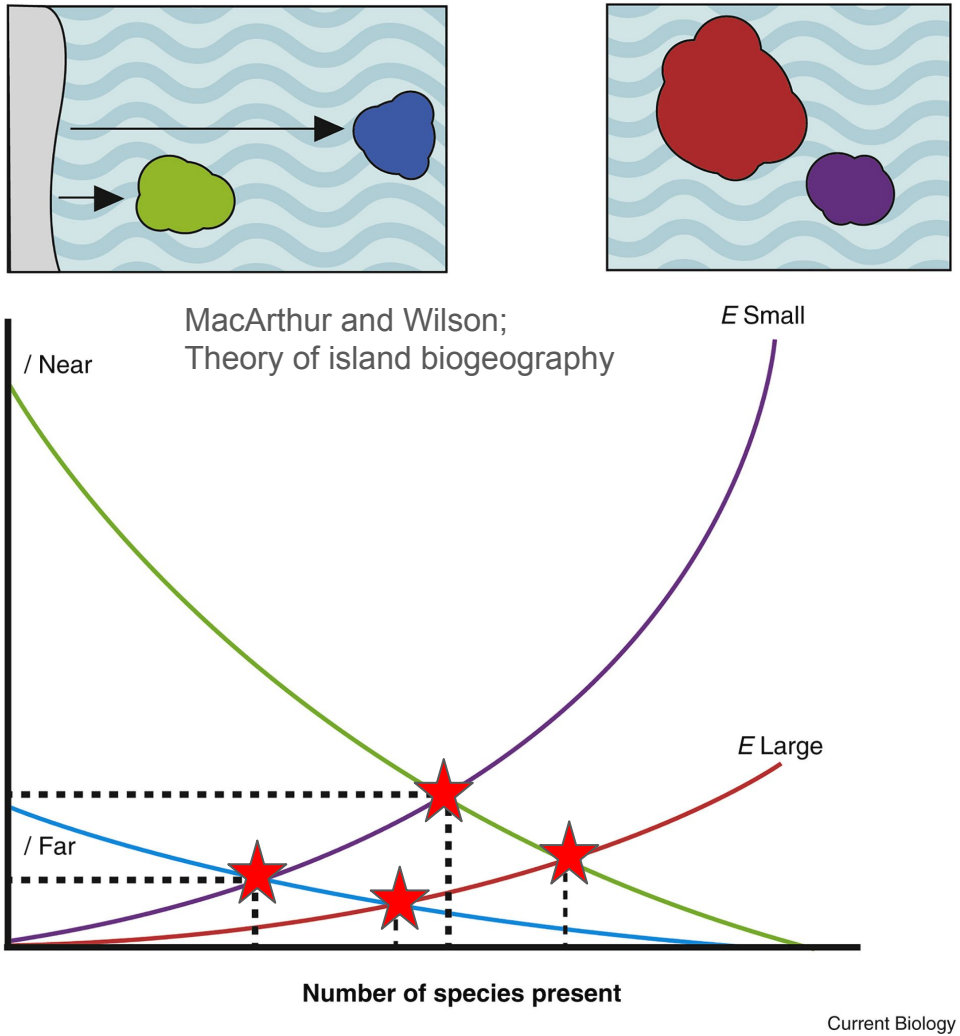
- Isolation and well defined boundaries
- Controlled Conditions
- Simplified Ecosystems
- High rates of Endemism
- Historical collections
- Etc.

"Island are natural laboratories"
David Attenborough

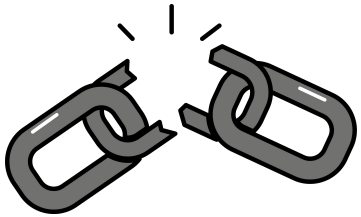
Clear relationship between area, distance from mainland and species composition

Dictate by the levels of immigration and extinction events

However, Evolution and Environmental Dynamics also contribute for diversity



Prisoner dilemma and island syndromes



In islands, populations can often be in a **sink** position due to the limited space and resources available. However, over time, these populations might **evolve** and become specialized for island life

- flightlessness and loss of dispersal powers, naïveté toward predators, and body size changes, etc”

Mystacina tuberculata, a New Zealand bat with broader omnivorous diet and semi-terrestrial locomotion

Okay, so think about an island!

Okay, so think about an island!

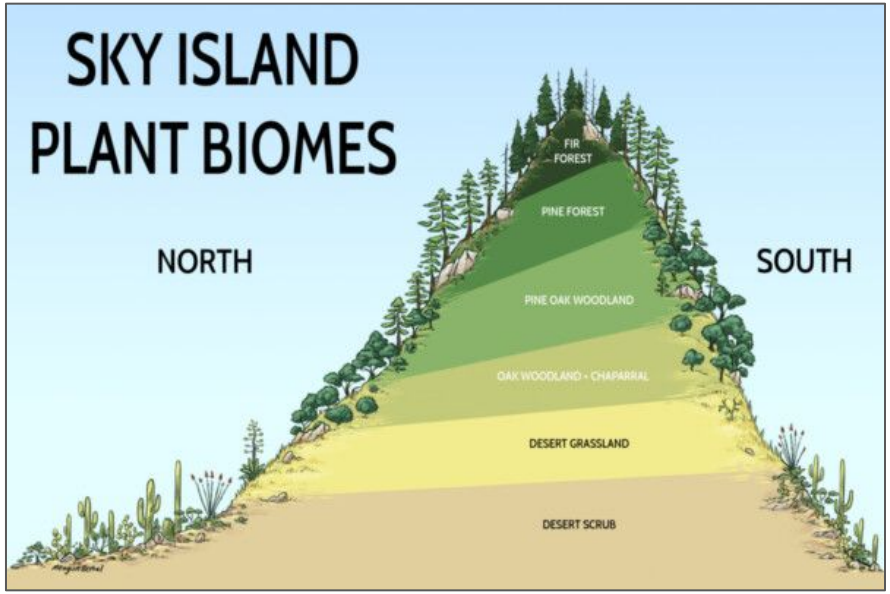
Islands are synonyms for isolation

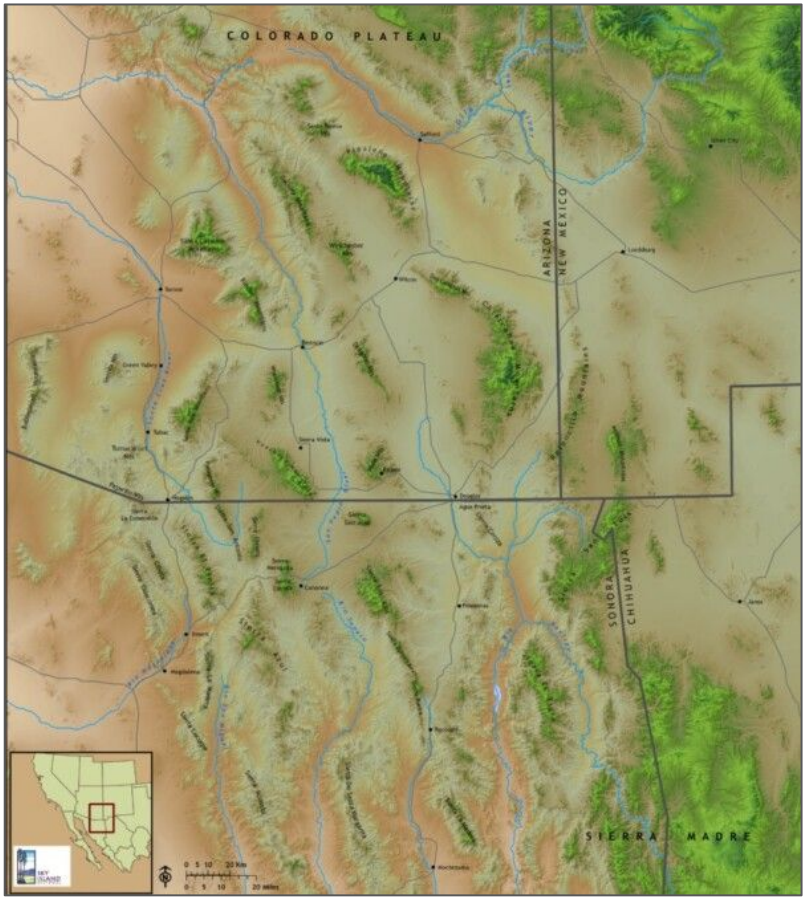
the term "insular" typically refers to ecosystems, environments that are **isolated** or **separated from other regions** by barriers such as oceans, mountains, or deserts, which restrict movement or gene flow

Mountain ranges and highlands as islands

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.behance.net%2Fgallery%2F71745667%2FFrench-Alps-above-the-clouds%2Fmodules%2F418062035&psig=AOvVaw1yLjDcD_rlSKCy8XQNx6o6&ust=1741183170525000&source=images&cd=vfe&opi=89978449&ved=0CBEQjRxqFwoTCJDo9_bK8IsDFQAAAAAdAAAAABAJ

Mountain ranges and highlands as islands



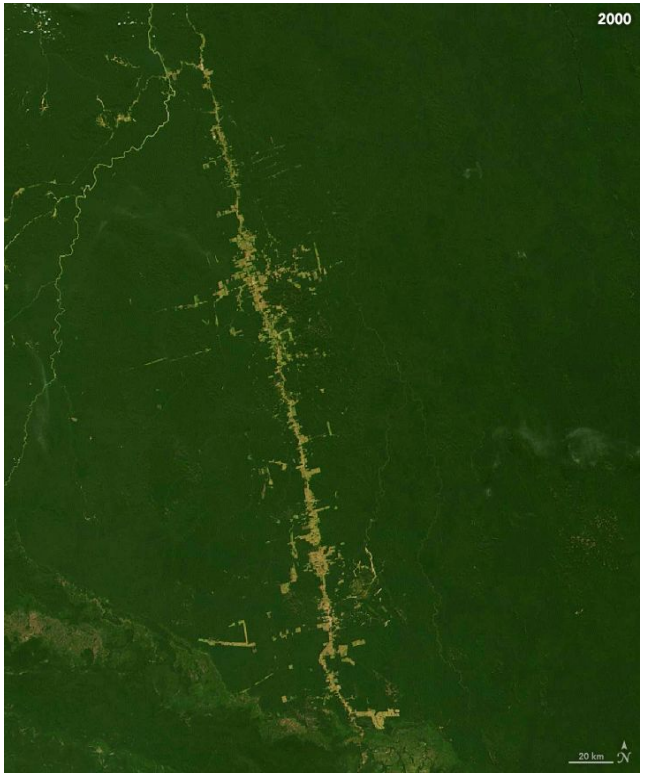


https://skyislandalliance.org/our-region/the-sky-islands/

Some caves are also insular systems

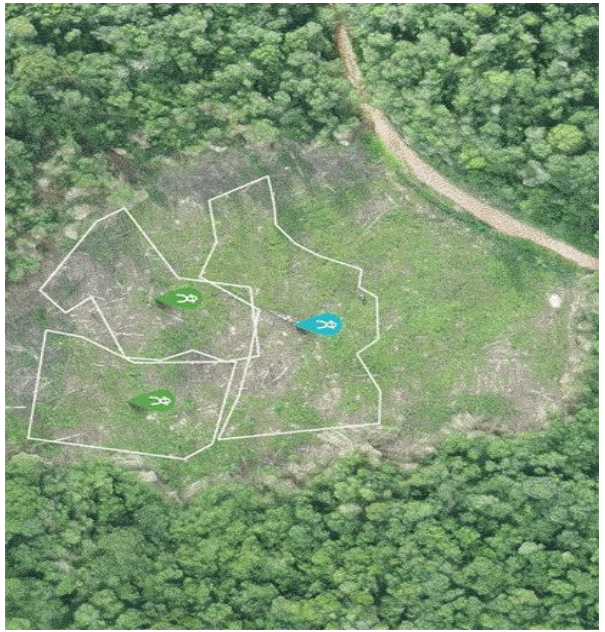
Some caves are also insular systems

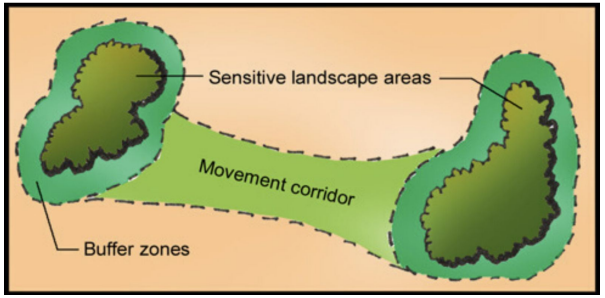
Forest fragmentation patches as islands



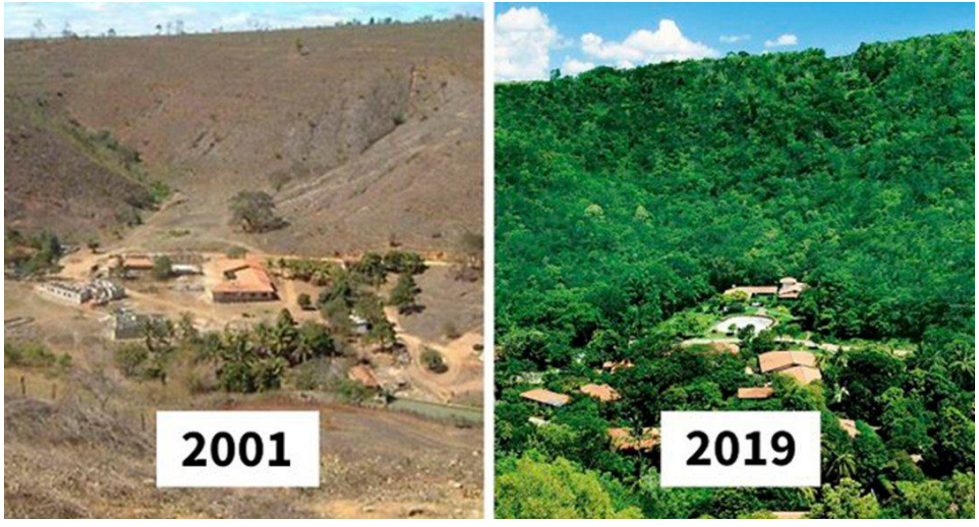
https://eoimages.gsfc.nasa.gov/images/imagerecords/145000/145888/br163defores_tmo_amo_2019.gif

Forest fragmentation patches as islands





Changes on landscape in eighteen years



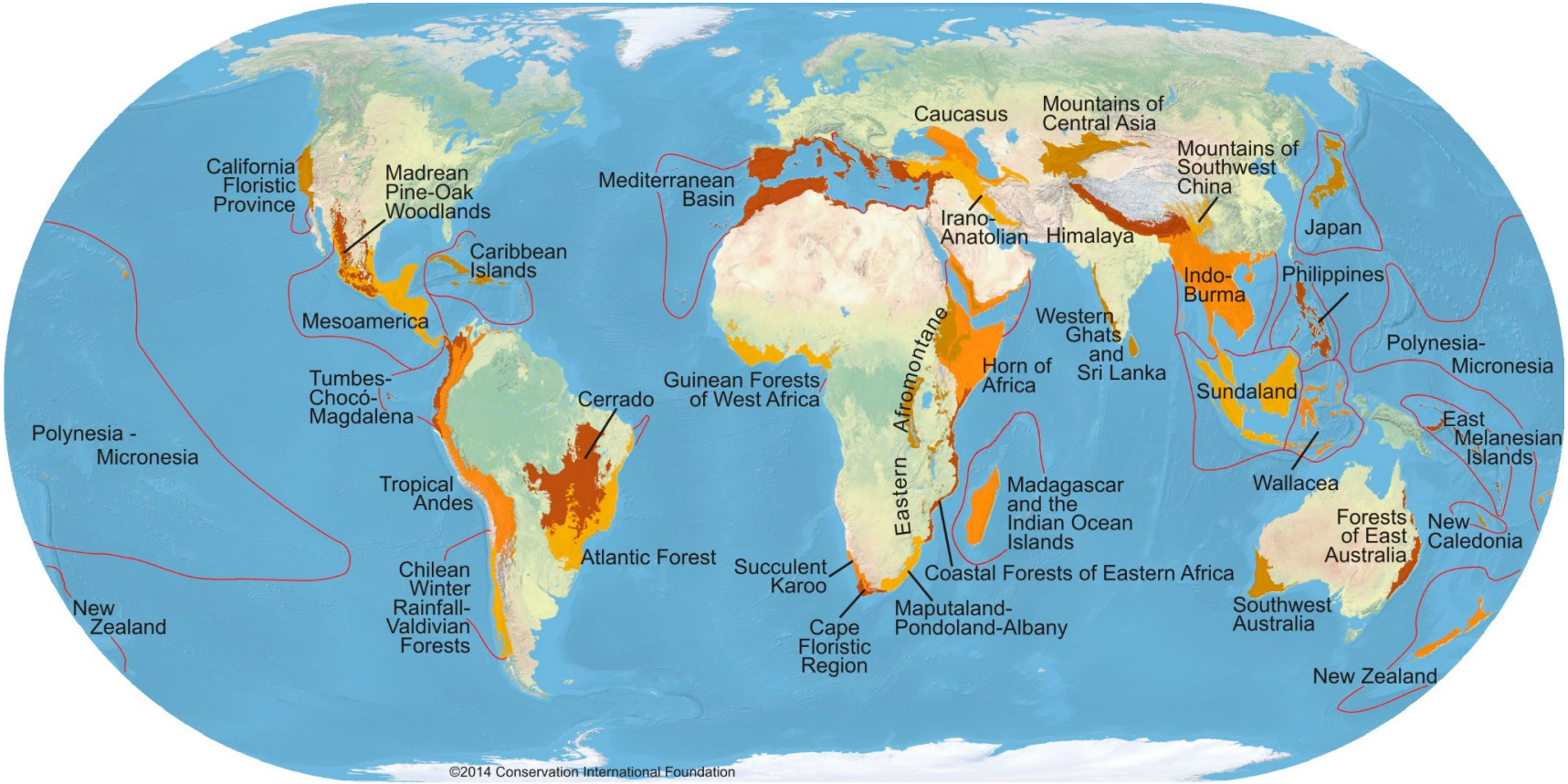
https://www.intelligentliving.co/wp-content/uploads/2019/05/sebastiao-salgado-reforestation.jpg

https://allthatsinteresting.com/wordpress/wp-content/uploads/2019/04/tress-planted-in-brazil-before-and-after-featured.jpg

Our species is changing the environment faster than ever before

ANTHROPOGENIC ACTION AFFECT SPECIES BIOGEOGRAPHY

Biodiversity Hotspots and Conservation urges



A study case: evolution and biogeography of a widely-distributed bat in a Tropical Island system

Material from Pedro Ivo Mônico dissertation

2021

Which bat species can help us to better understand the drivers of speciation?

2021

Which bat species can help us to better understand the drivers of speciation?

Species that occupy broad geographic ranges across fragmented landscapes

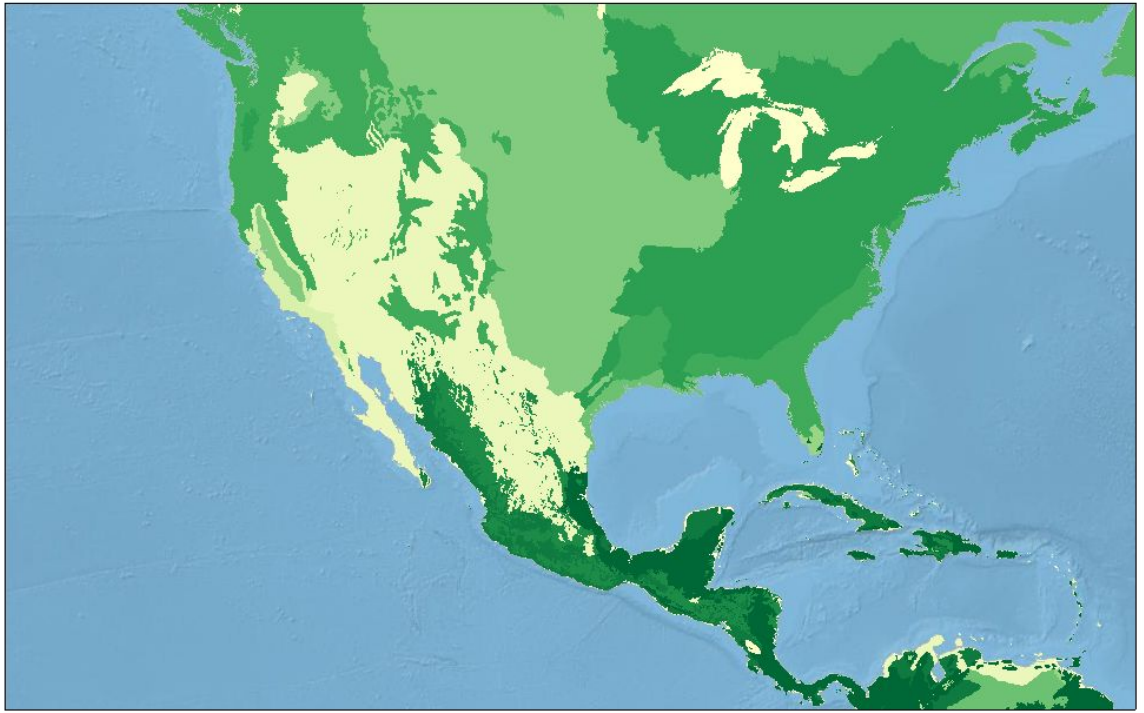
Eptesicus fuscus as a model for speciation studies

Donna Naughton, 2012. The Natural History of Canadian Mammals

Eptesicus fuscus as a model for speciation studies

Donna Naughton, 2012. The Natural History of Canadian Mammals

Ecoregions



July 25, 2022

1:36,978,595

0 265 530 1,060 mi

0 420 840 1,680 km

Eptesicus fuscus as a model for speciation studies

Donna Naughton, 2012. The Natural History of Canadian Mammals

Ecoregions

July 25, 2022

1:9,244,649

0 70 140 280 mi

0 115 230 460 km

The taxonomic state of *Eptesicus fuscus*

13 recognized subspecies, with six occurring across mainland and seven throughout the Caribbean

- The Caribbean
  - *E. f. dutertreus* (Cuba) Gervais, 1837
  - *E. f. bahamensis* (the Bahamas) Miller, 1897
  - *E. f. wetmorei* (Puerto Rico) Jackson, 1916
  - *E. f. hispaniolae* (Hispaniola) Miller, 1918
  - *E. f. lynni* (Jamaica) Shamel, 1945
- Mesoamerica
  - *E. f. miradorensis* Allen, 1866
- southeastern North America
  - *E. f. osceola* Rhoads, 1902

The taxonomic state of *Eptesicus fuscus*

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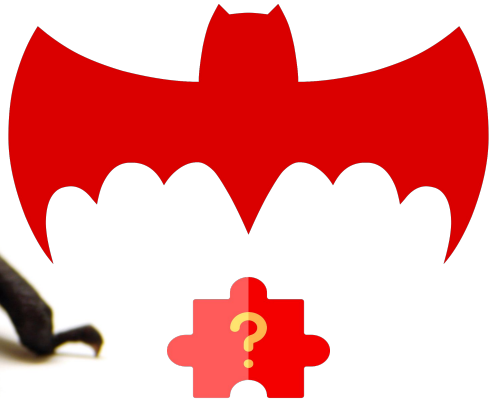

- Mesoamerica
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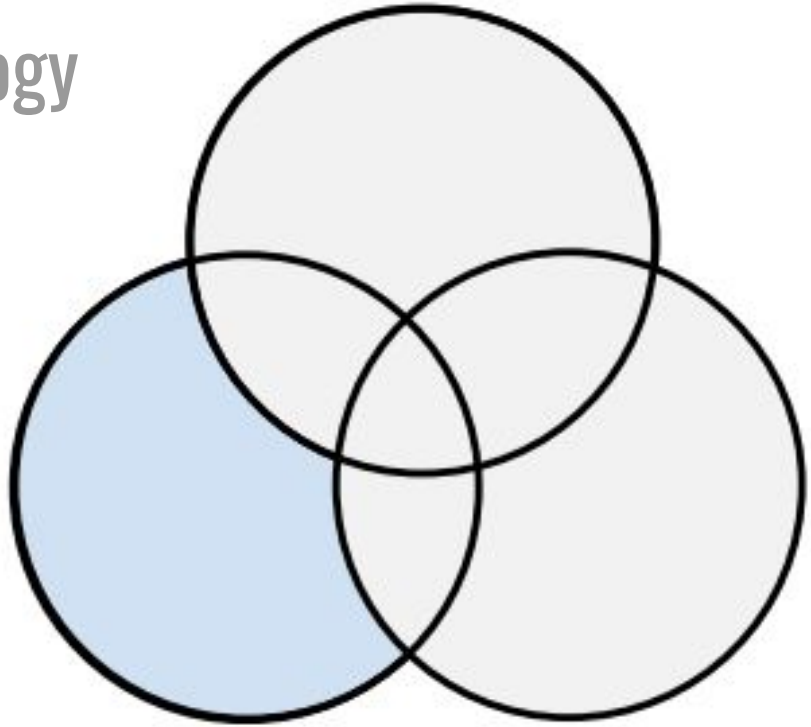
Morphology



Phylogenetics +

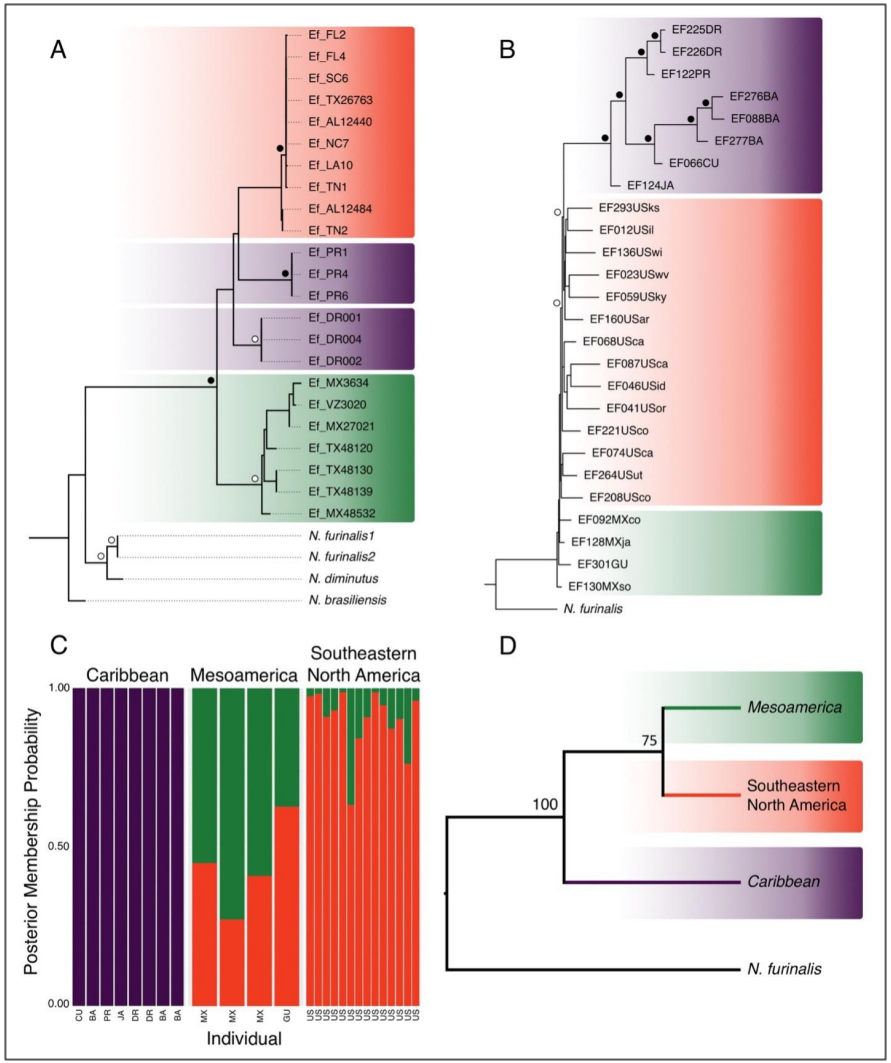
Habitat suitability & Niches

Caribbean *E. fuscus* supported as unique compared to the mainland

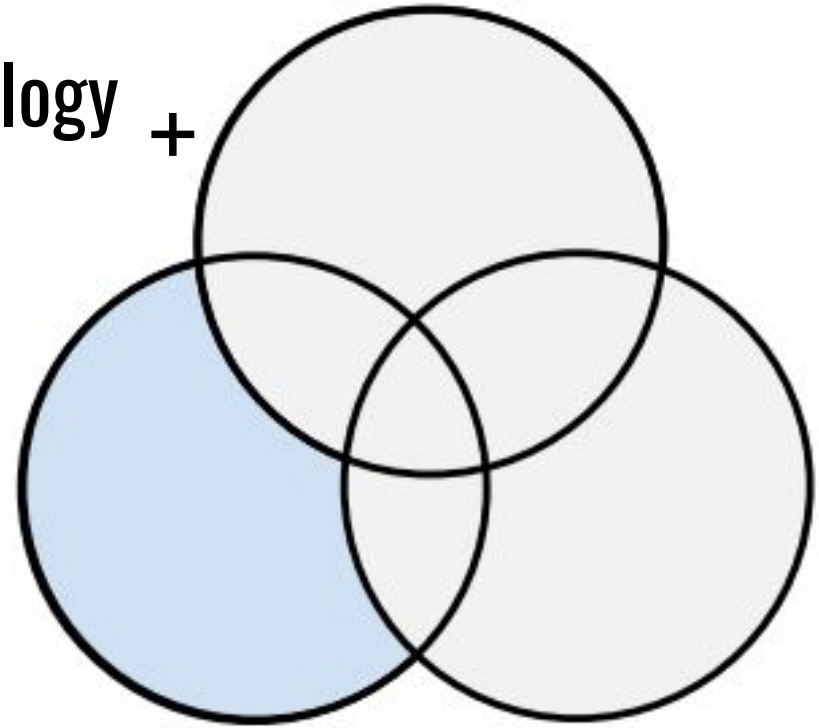
Although mitochondrial data resulted in different topology (A) , Nuclear tree provided high support for monophyly (B)

Caribbean group structured and with no admixture with other partitions (C)

Species delimitation analysis supported the Caribbean *E. fuscus* as a species (D)



Morphology +



Phylogenetics

Habitat suitability & Niches

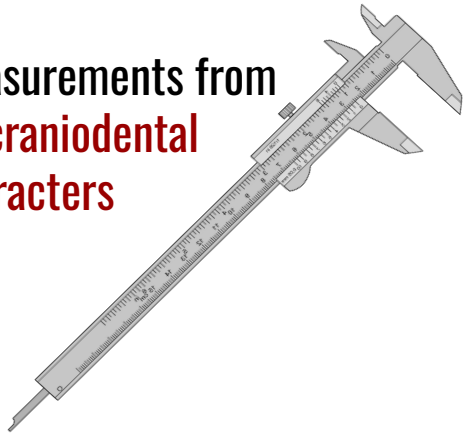
Phenotypic species delimitation from morphological data

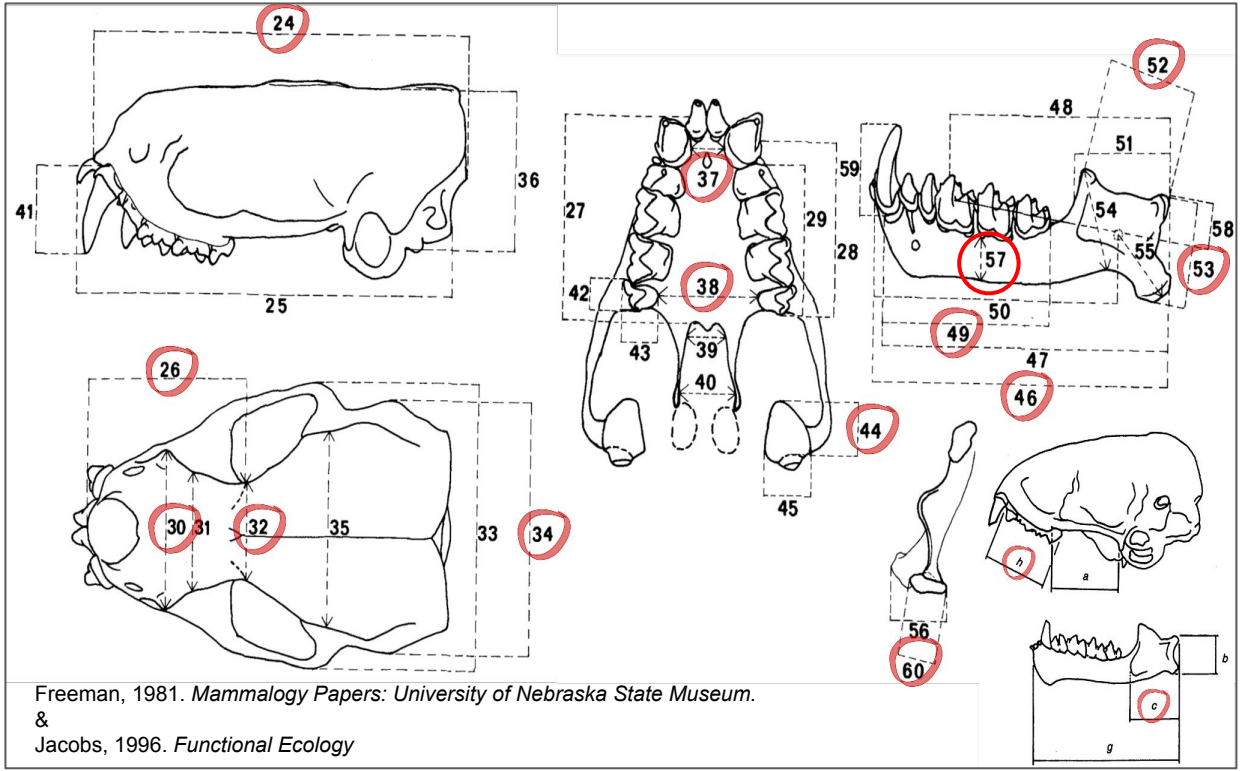
We tested the hypothesis of morphological species disparities among biological partitions

82 specimens, being:

- 52 from the Caribbean
- 24 from the Mesoamerica
- 6 from the Florida peninsula

Measurements from 16 craniodental characters

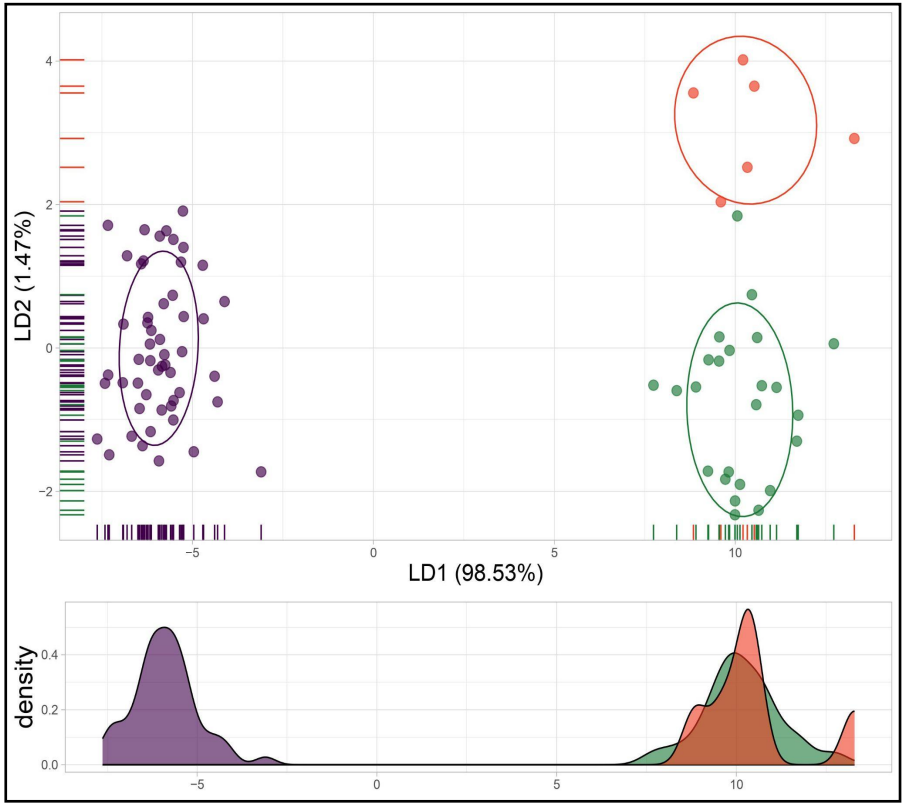




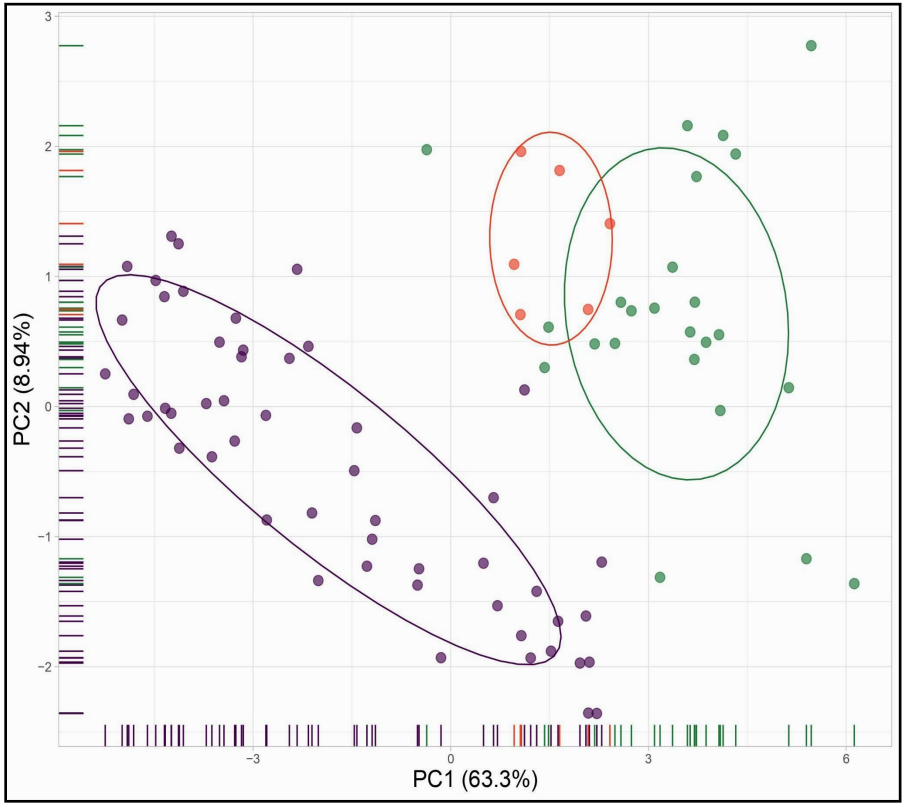
Freeman, 1981. *Mammalogy Papers: University of Nebraska State Museum.*
&
Jacobs, 1996. *Functional Ecology*

The Caribbean *Eptesicus fuscus* have distinctive craniofacial relationships

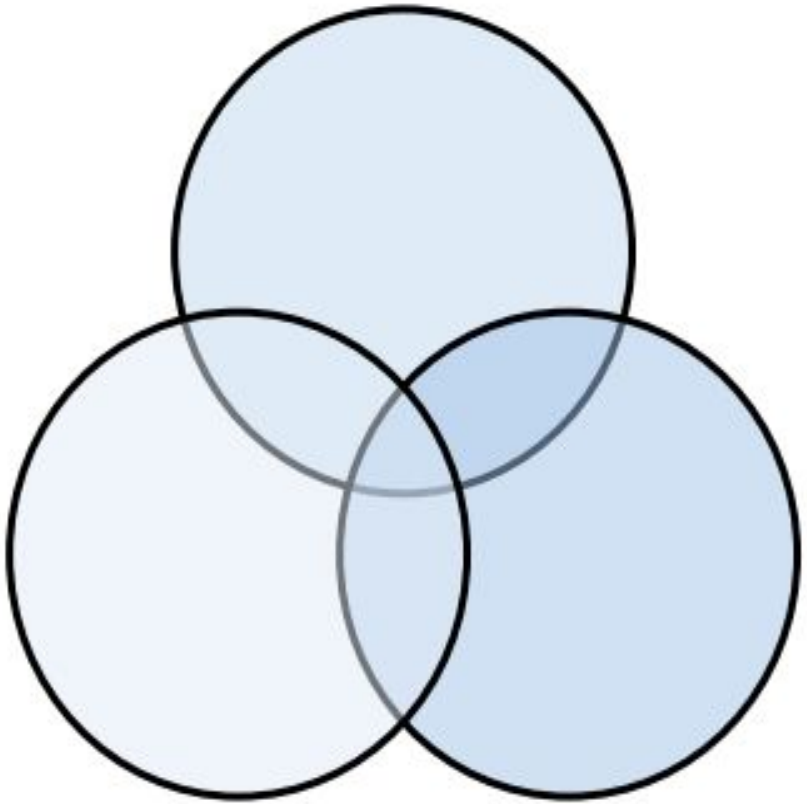
Linear discriminant analysis (LDA)



Principal component analysis (PCA)



Morphology



Phylogenetics

\+ Habitat suitability & Niches

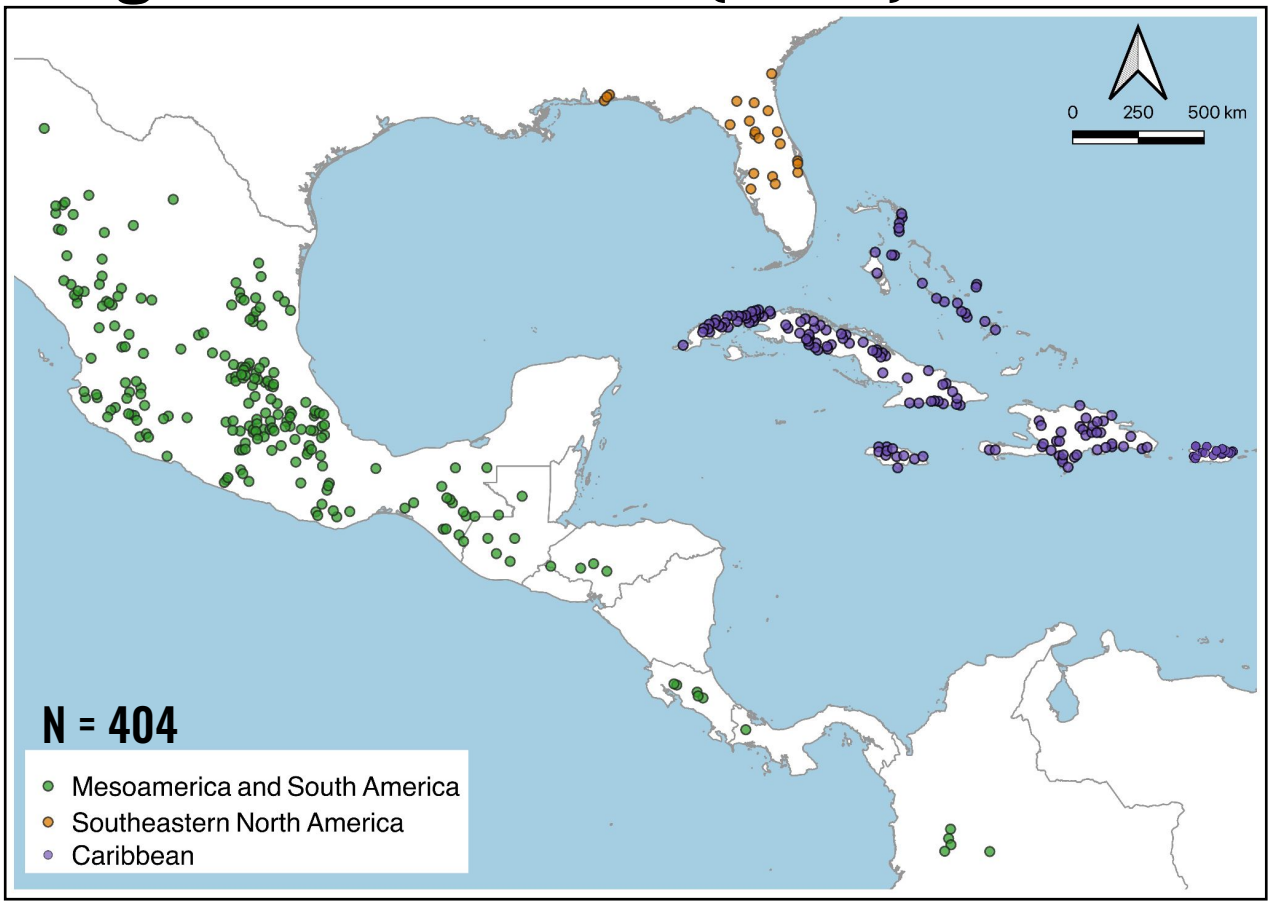
Data mining + extra records from literature

GBIF
Global Biodiversity Information Facility

"*Eptesicus fuscus*", filtered by locality

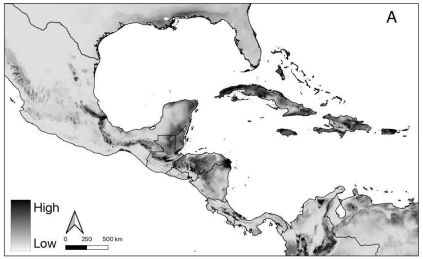
+ Silva-Taboada, 1979 *(Cuba)*
+ Genoways et al., 2005 *(Jamaica)*
+ Speer et al., 2015 *(the Bahamas)*
+ Núñez-Novas et al., 2019 *(Hispaniola)*

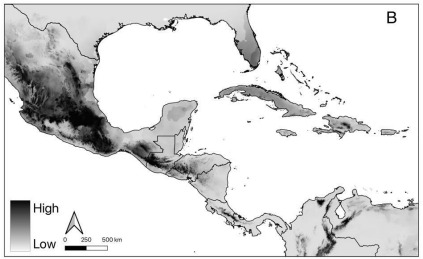
Ecological niche models (ENMs) final dataset

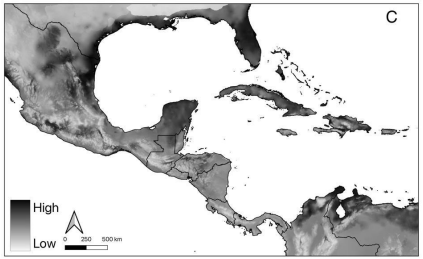


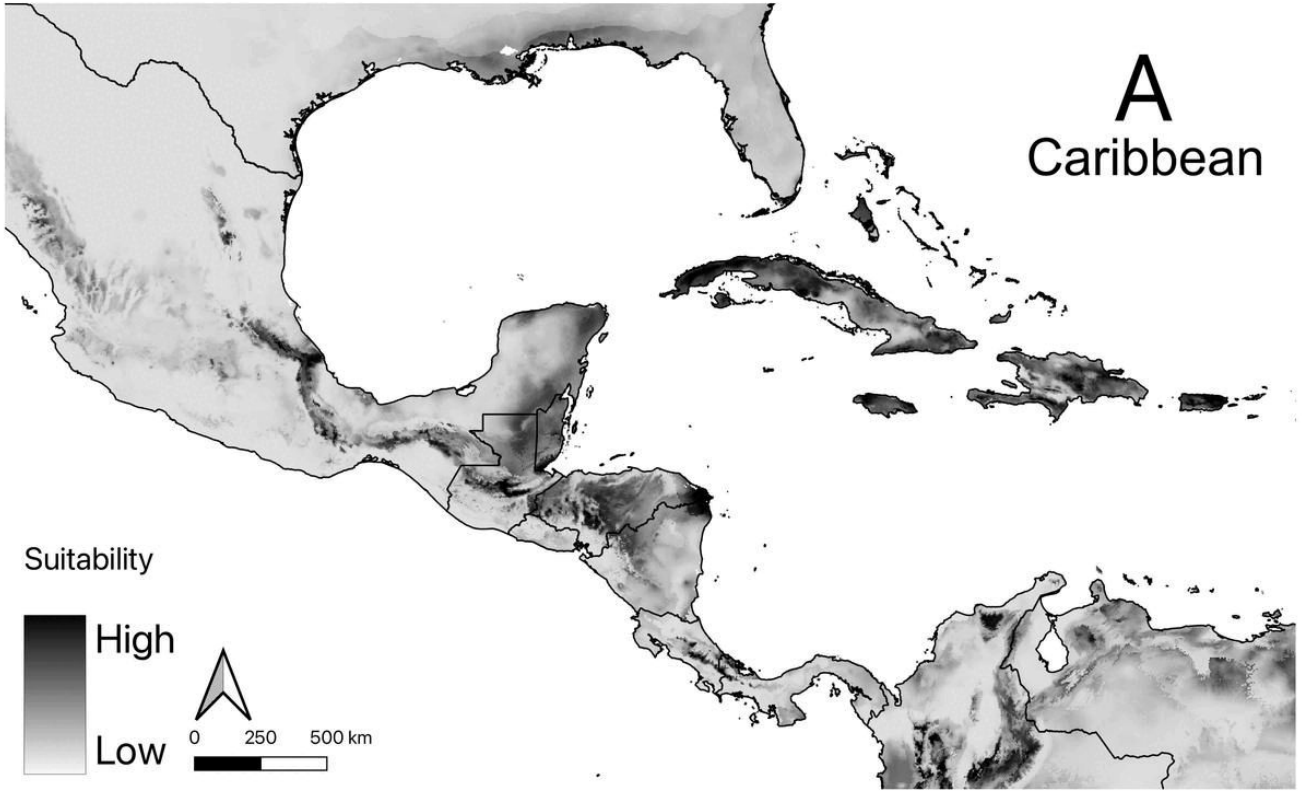
Models show regional speciation signals

We tested the hypothesis of species-like differences among suitable habitats



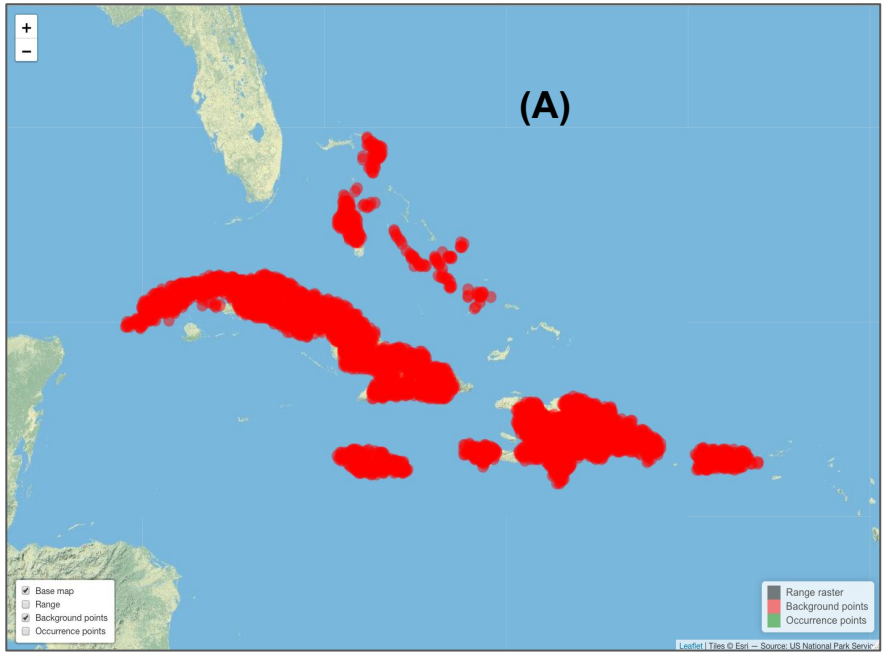


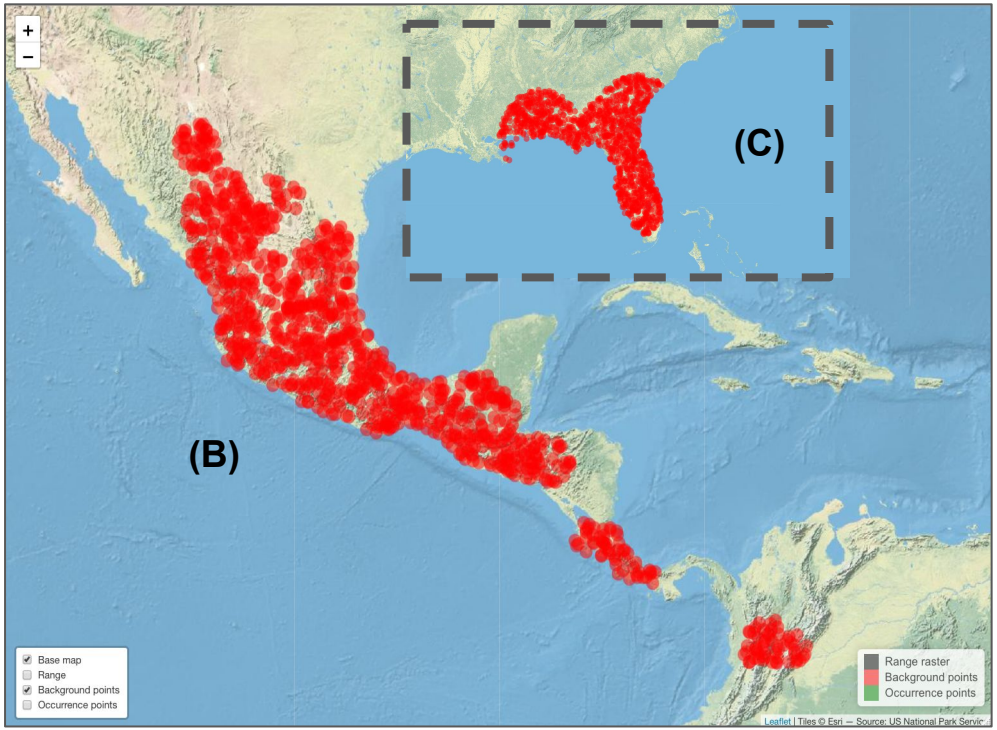




Niche overlap, niche equivalency, and background similarity

Collecting background points to quantify the differences & performing pairwise comparisons





All comparisons showed significant differences between biologically relevant partitions niches

Conclusions and considerations about Caribbean big brown bats

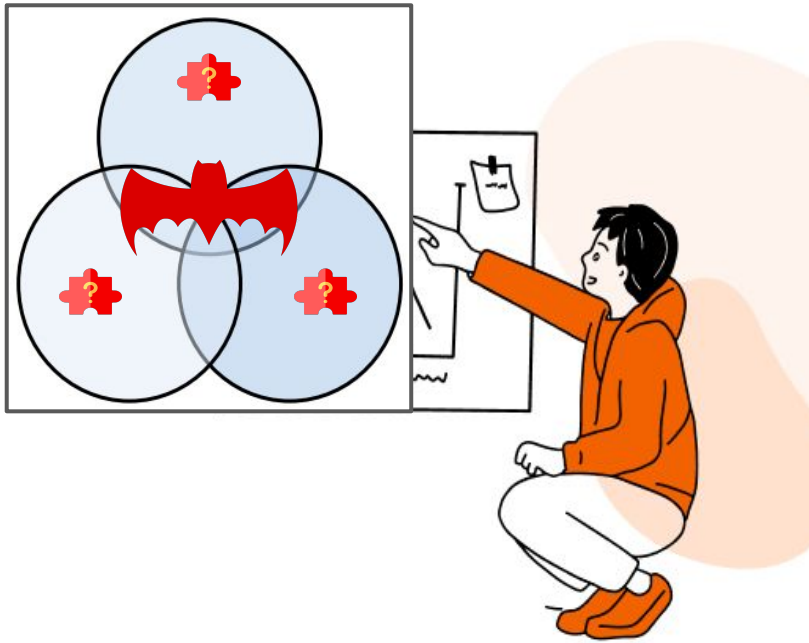
We uncovered signals of divergence supporting the Caribbean clade of *Eptesicus fuscus* as unique through an integrative framework

Genomic data indicated group highly structured, without admixture with continental lineages

Morphological data showed high phenotypic disparity

Ecological Niche Models revealed differences in habitat suitability

We endorse re-evaluating the taxonomic status of Caribbean big brown bats as *Eptesicus dutertreus*



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Research

Cite this article: Mônico PI, Soto-Centeno JA. 2024 Phylogenetic, morphological and niche differentiation unveil new species limits for the big brown bat (*Eptesicus fuscus*). *R. Soc. Open Sci.* **11**: 231384.

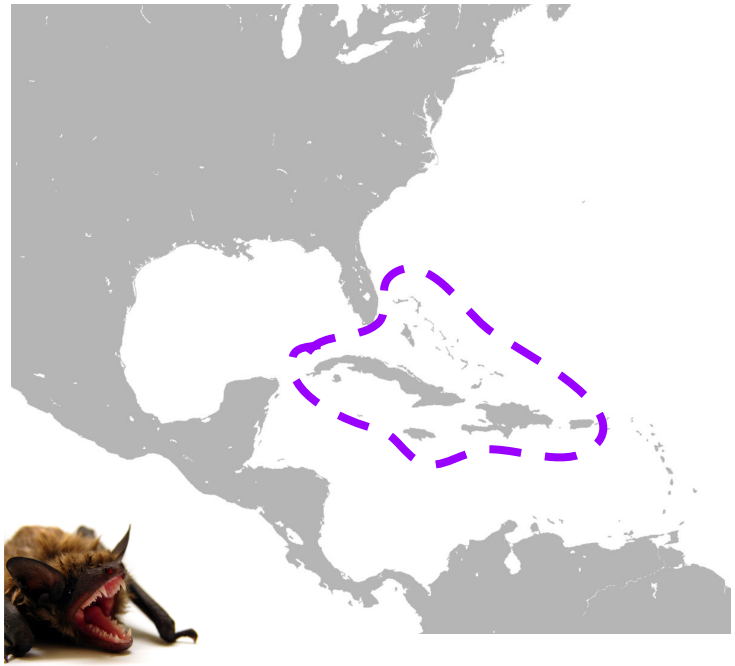
Phylogenetic, morphological and niche differentiation unveil new species limits for the big brown bat (*Eptesicus fuscus*)

Pedro Ivo Mônico[1] and J. Angel Soto-Centeno[1,2]

[1]Department of Earth and Environmental Sciences, Rutgers University, Newark, NJ 07102, USA
[2]Department of Mammalogy, American Museum of Natural History, New York, NY 10024, USA

Okay, island bats are different from the mainland bats...
But what is the next step?

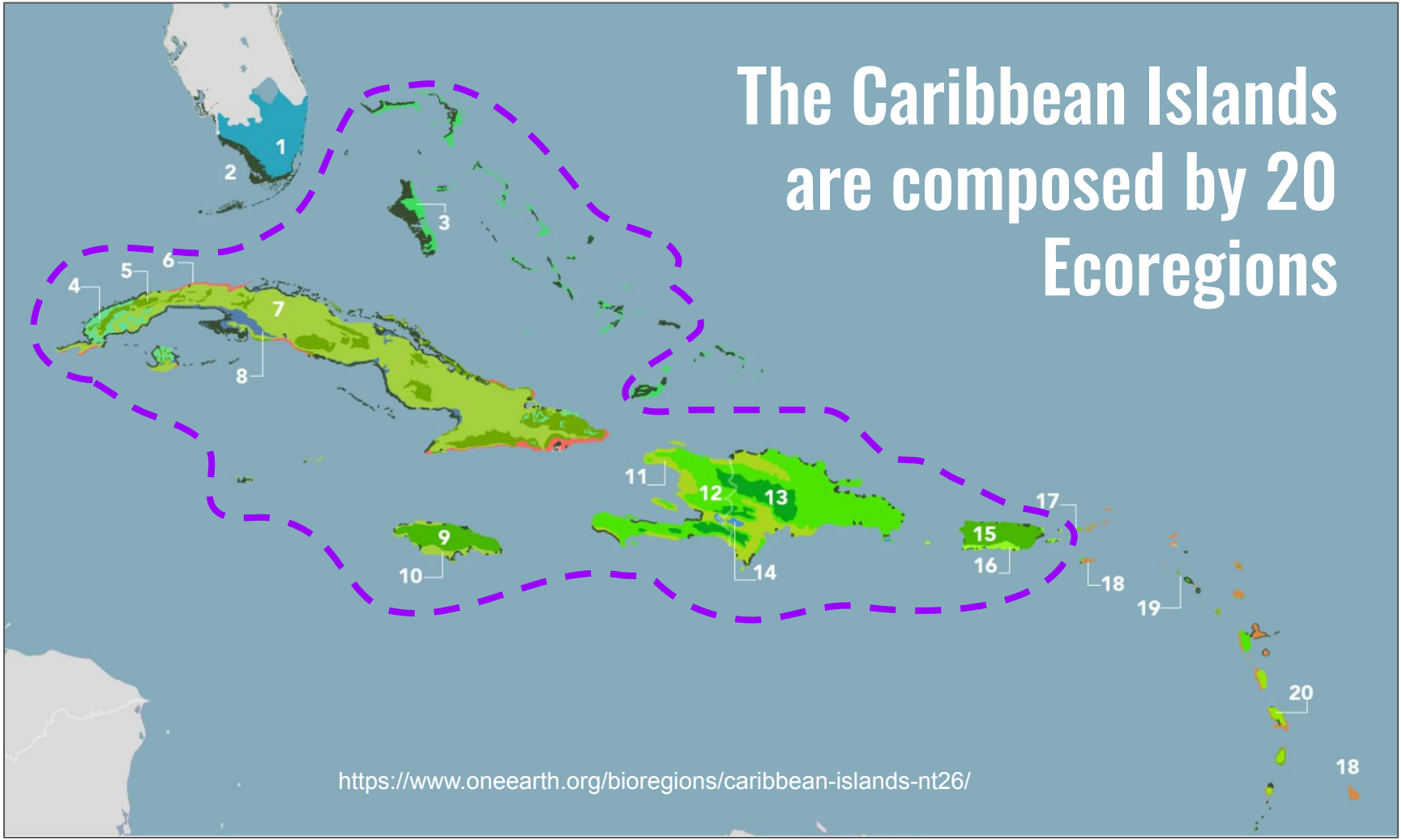
Re-evaluation of the taxonomic status of Caribbean Eptesicus



We merged the six recognized subspecies throughout the Caribbean into *Eptesicus dutertreus*

- *E. f. dutertreus* (Cuba) Gervais, 1837
- *E. f. bahamensis* (the Bahamas) Miller, 1897
- *E. f. wetmorei* (Puerto Rico) Jackson, 1916
- *E. f. hispaniolae* (Hispaniola) Miller, 1918
- *E. f. lynni* (Jamaica) Shamel, 1945
- *E. f. petersoni* (Isla de la Juventud) Silva-Taboada, 1974

Recent discussions: Yi & Latch (2022a); Yi & Latch (2022b); Ramírez-Chaves et al. 2023; Cláudio et al. 2023; Mônico & Soto-Centeno 2024; Yi et al. 2024


The Caribbean Islands are composed by 20 Ecoregions
1
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19
20
18
https://www.oneearth.org/bioregions/caribbean-islands-nt26/

How the intraspecific phenotypic variation is structured across *Eptesicus dutertreus* range?

Considering the **Caribbean islands heterogeneity**, and that there is **many examples of wide range speciation in the region** 

In which traits the variation is more evident?

Does the morphological variation fits into the phylogenetic data?

Are the results from Supervisioned & Unsupervised Machine learning concordant?

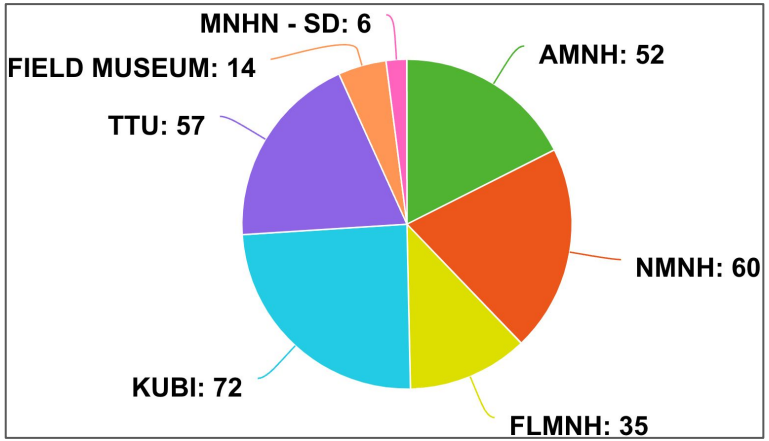
Are the Holotypes good lineages representatives?

How many groups exist, under the morphological perspective?

Is there sexual dimorphism?

Analyzing the biggest dataset for *Eptesicus dutertreus* morphological data ever done

The Bahamas = **120**
Cuba + Isla de la Juventud = **46**
Jamaica = **25**
Hispaniola = **26**
Puerto Rico = **69**

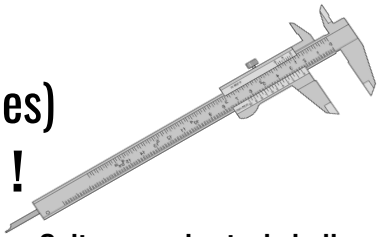


Museum collections

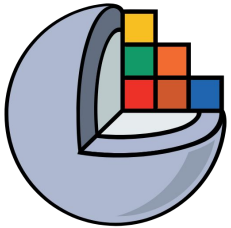
Linear measurements from 16 craniodental characters

Total = **286** specimens (including ALL holotypes)

! 98% of the available material in the United States !



Caliper or physical skulls



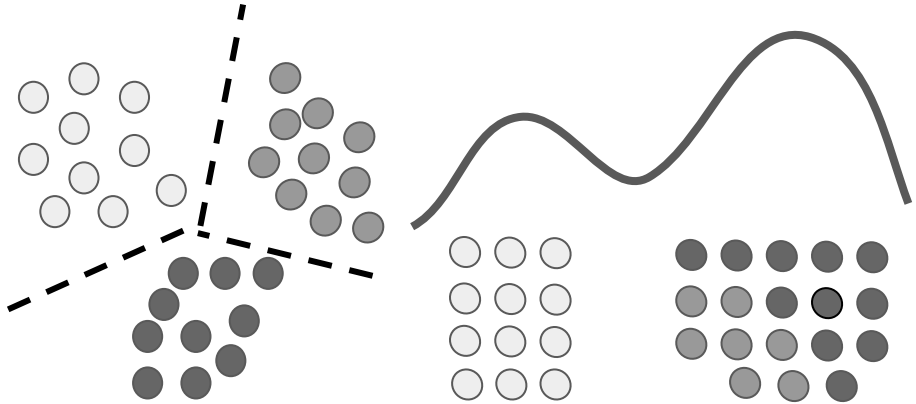
For CT-SCAN data
3D Slicer

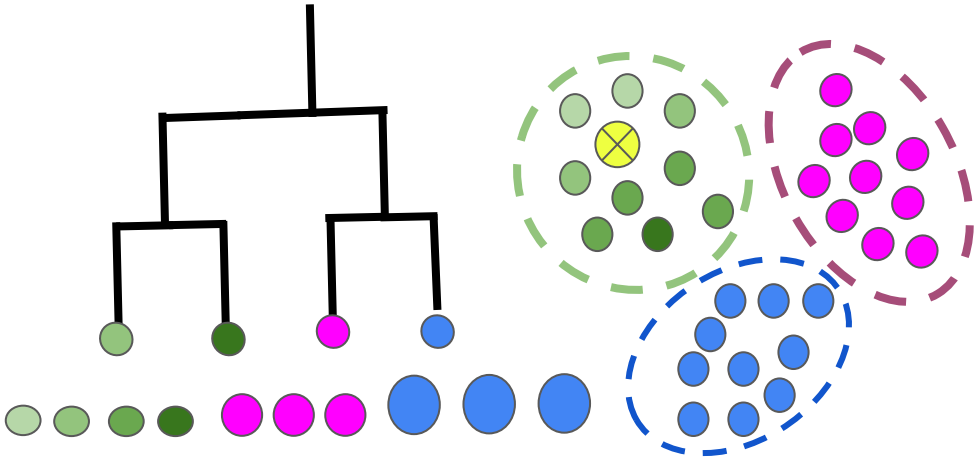
For Pictures
ImageJ

Combining methods to reduce bias

Unsupervised machine learning

Supervised machine learning & Hypotheses testing

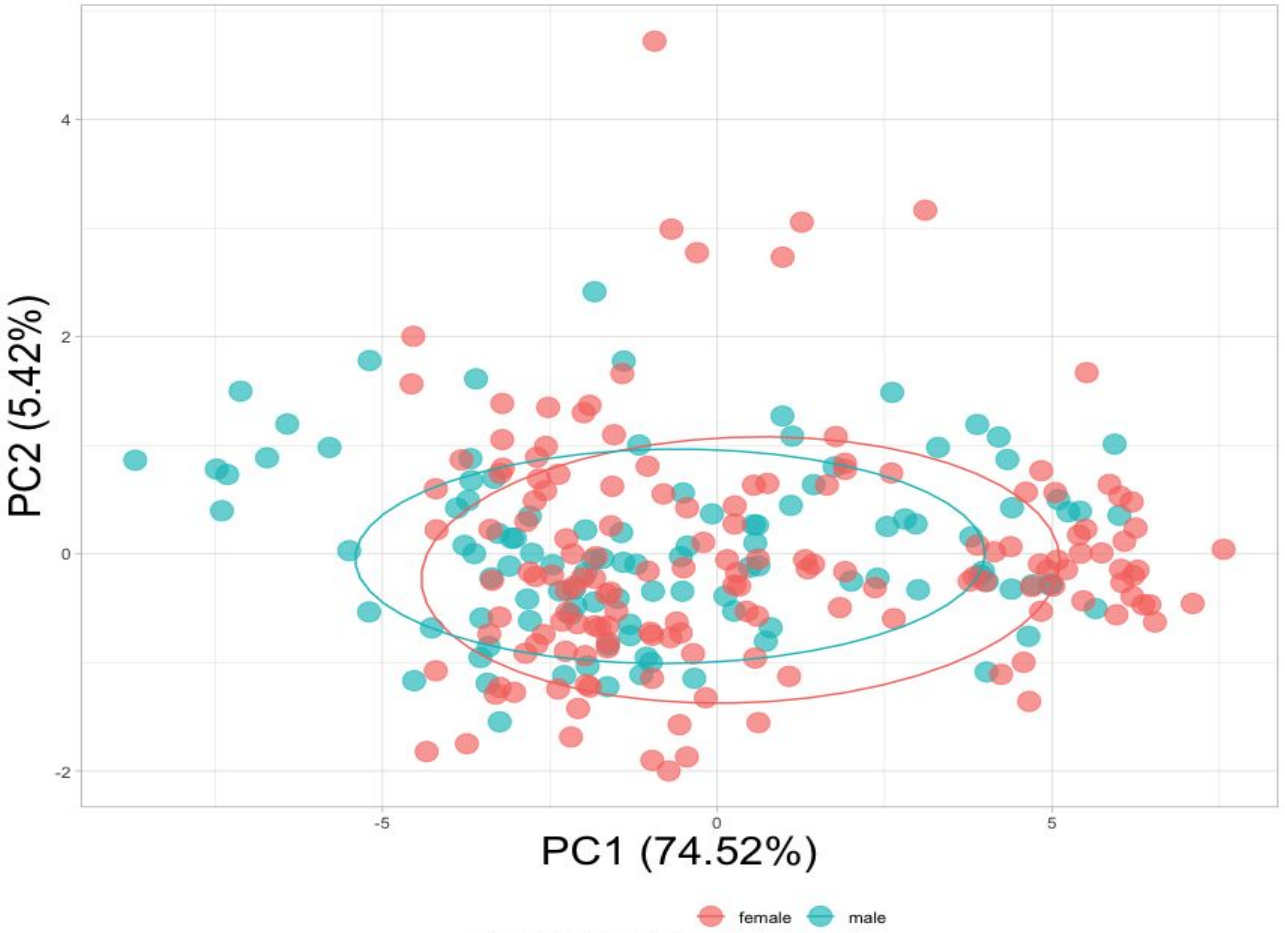




Clustering with unlabelled data

Classification based in labelled data
& More analyses

Sex analyses on *Eptesicus dutertreus* showed no significant sexual dimorphism



Is there sexual dimorphism?

Females are slightly bigger than males

(this pattern was already observed for other Vespertilionidae species)

Island lineages have different craniofacial relationships

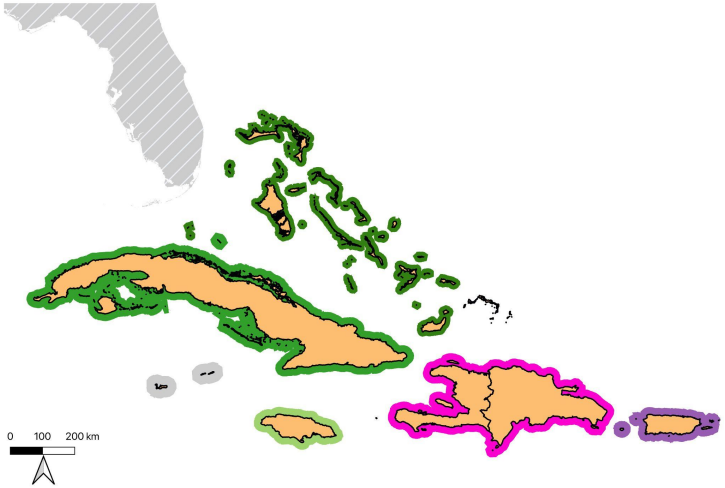
Are the results from Supervisioned & Unsupervised Machine learning concordant?

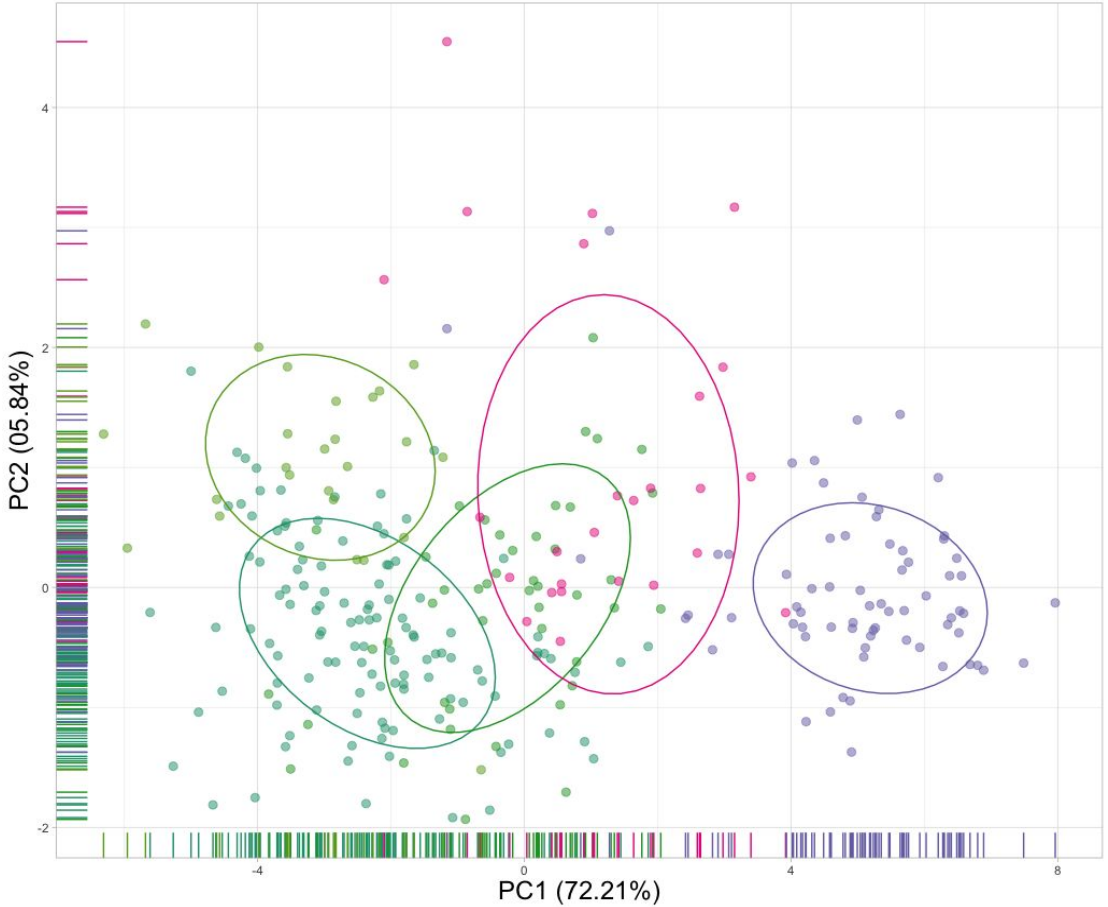
Principal Component Analysis (PCA)

Cluster without labels/IDs to maximize variance

Linear Discriminant Analysis (LDA)

Considers labels/IDs to maximize group differences





Island lineages have different craniofacial relationships

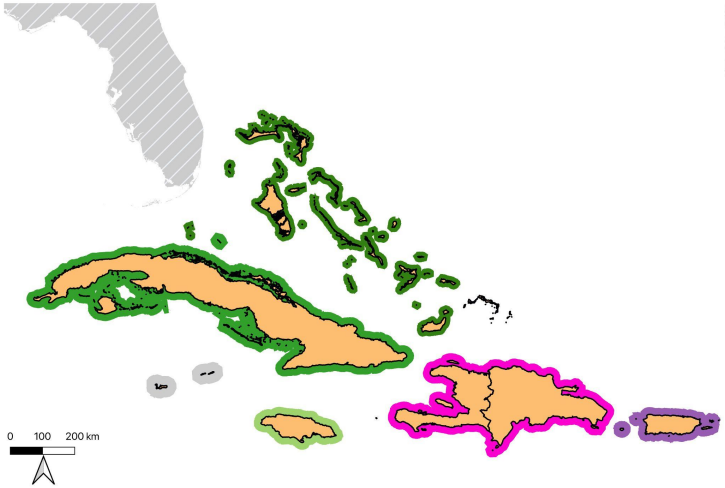
Are the results from Supervisioned & Unsupervised Machine learning concordant?

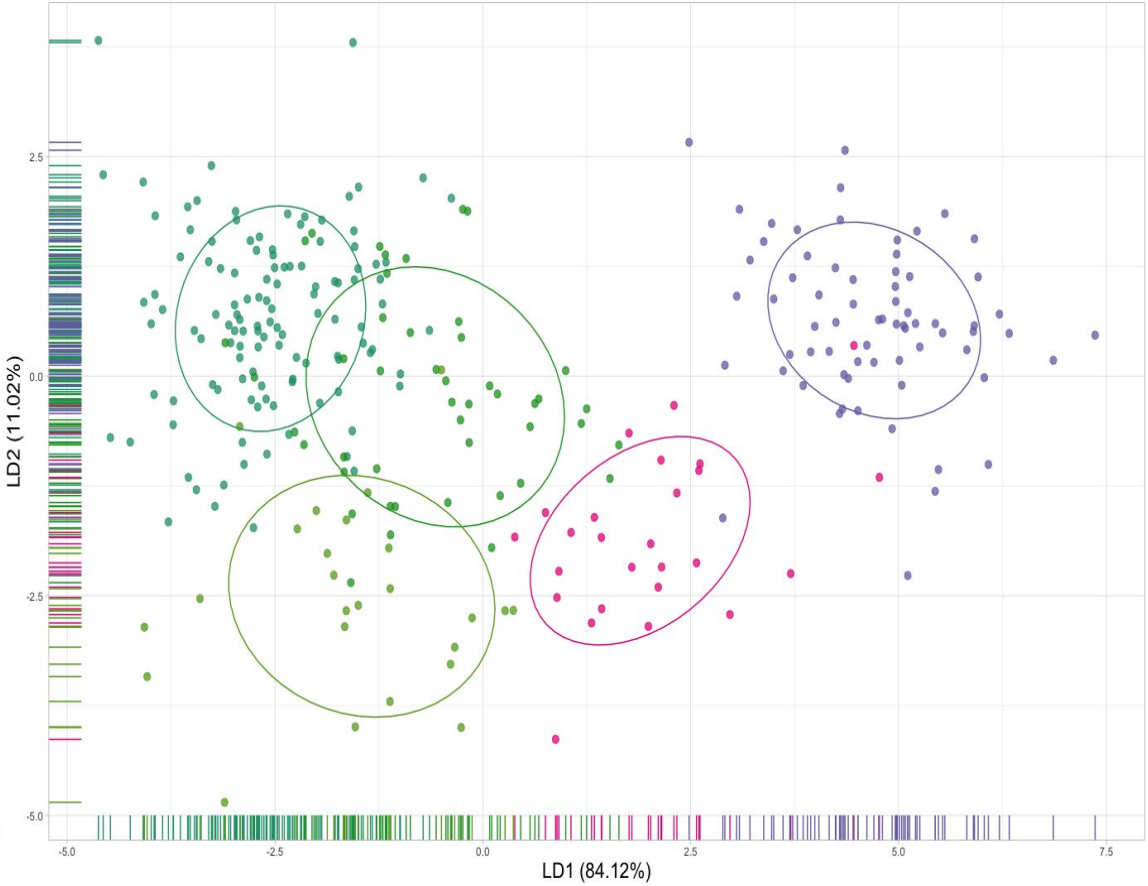
Principal Component Analysis (PCA)

Cluster without labels/IDs to maximize variance

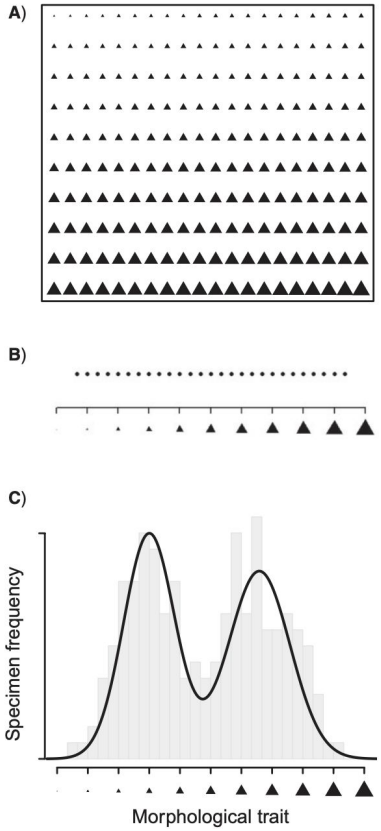
Linear Discriminant Analysis (LDA)

Considers labels/IDs to maximize group differences





Phenotypes density plots suggest cryptic morphological diversity

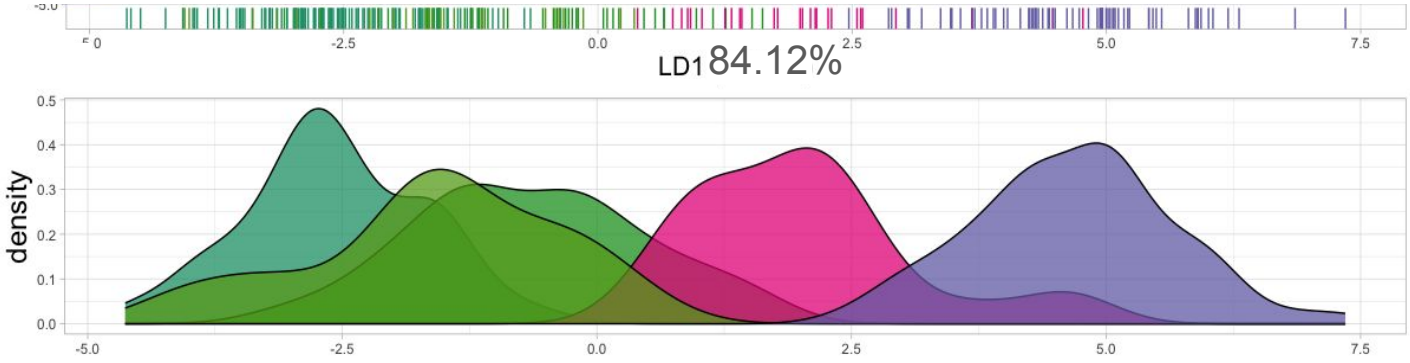


Cadena et al. 2018

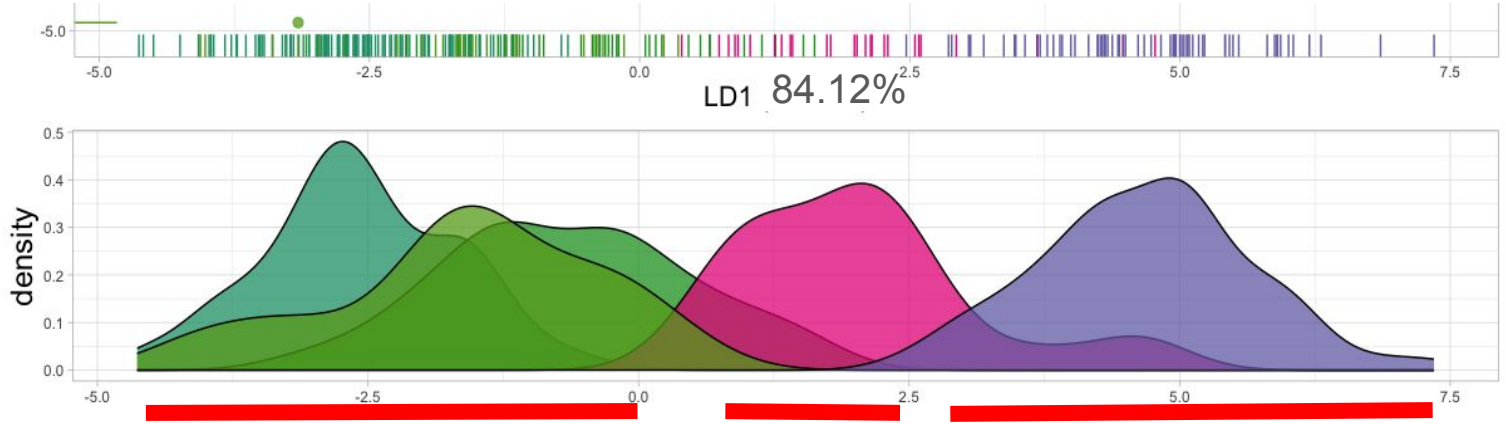
How many groups exist, under the morphological perspective?

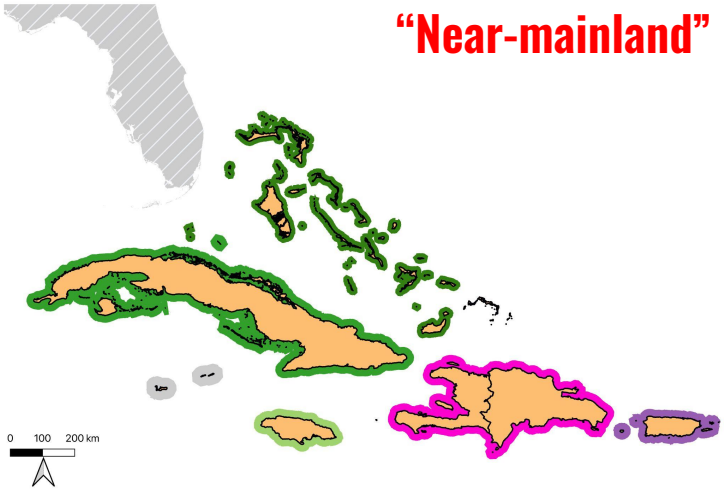
Normal Mixed Models / Gaussian Mixture Models

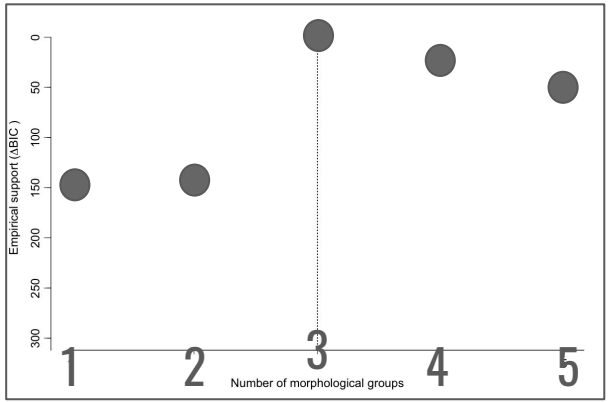
- Machine learning approach that does not consider labels or IDs
- Uses all 16 characters, not only 3 or 4 most responsive
- Determine many normal distributions exist within the samples



Non-labeled Normal Mixture Models analysis suggests 3 morphological groups

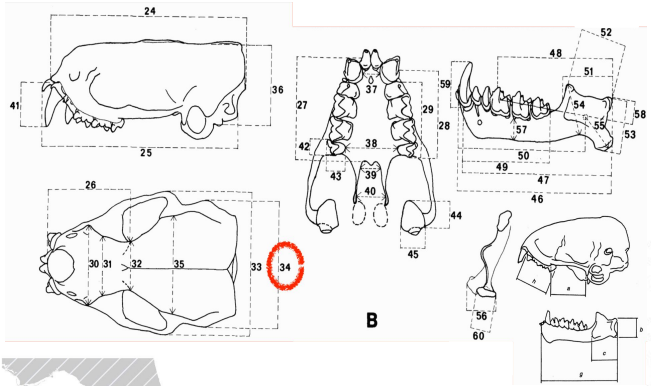


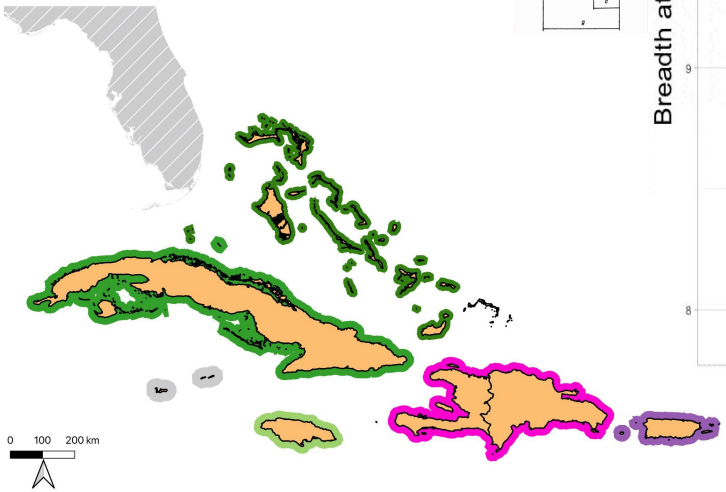




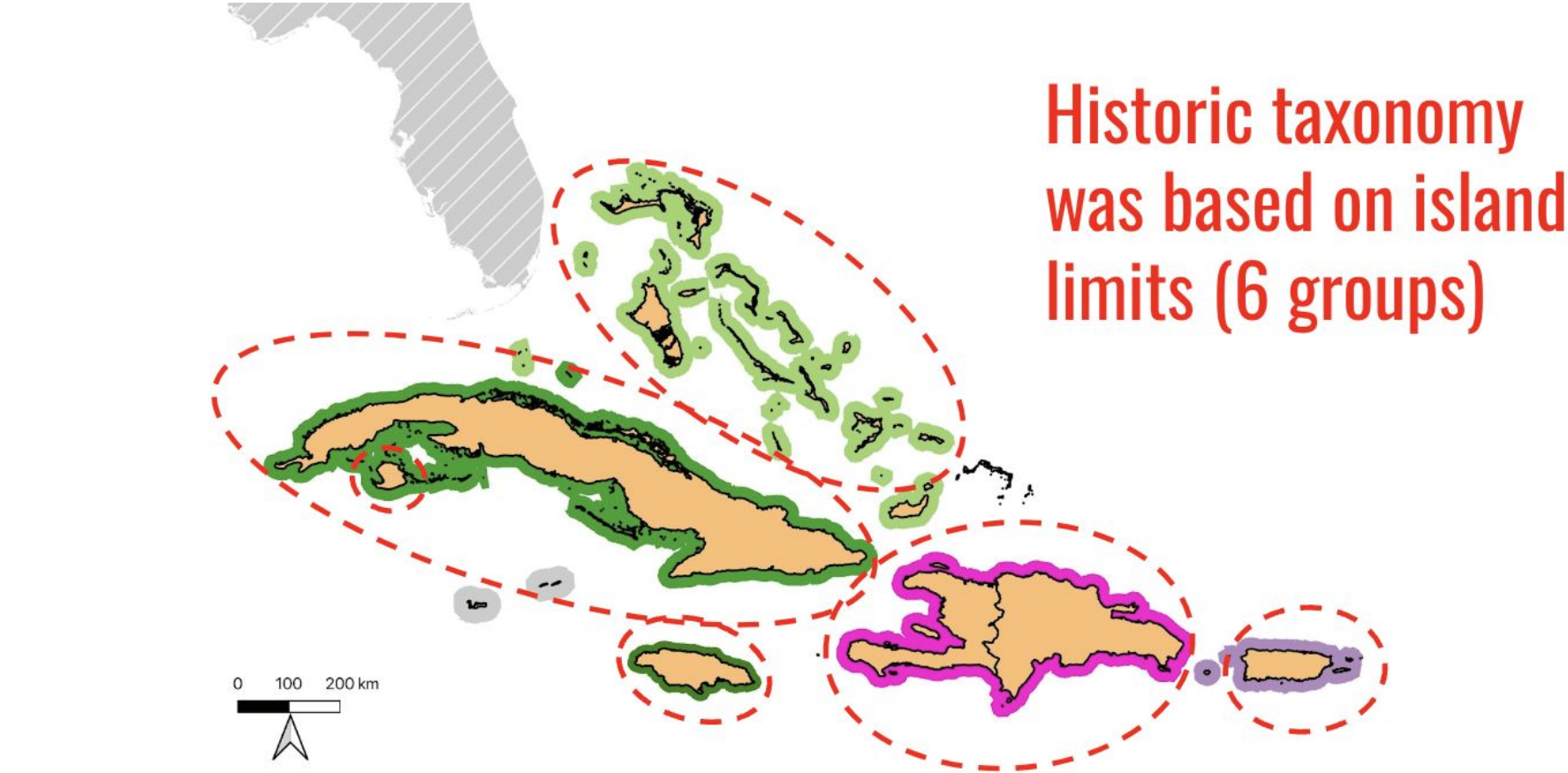
Although the support for 3, 4 or 5 morpho-groups is quite similar, there is more support for this scenario than for a single & homogeneous group

Summary statistics from the 16 craniodental characters spotlight a morphological gradient across geographic distribution

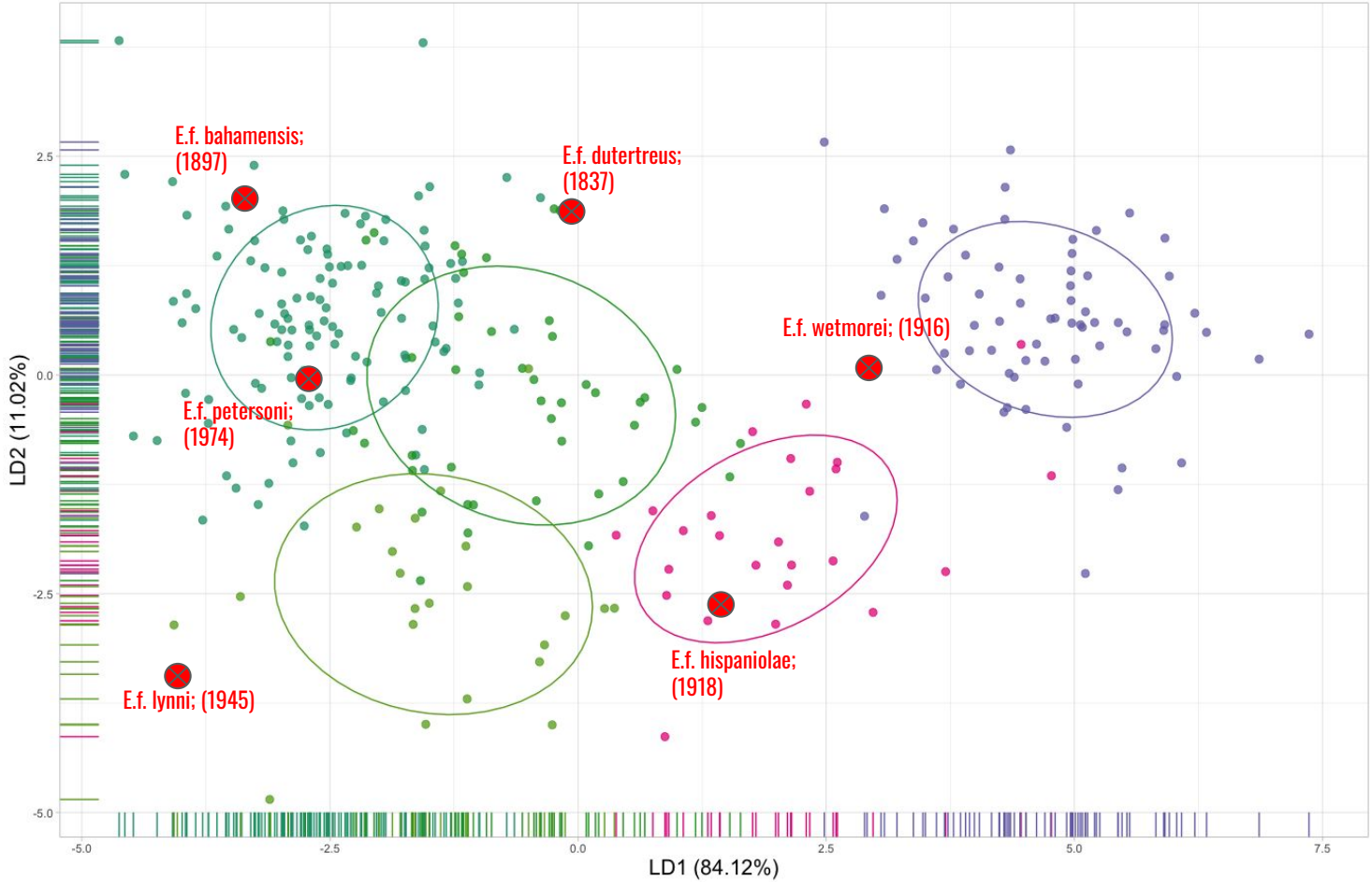




New discoveries discord with original morpho-based taxonomy



ID tests on Holotypes showed low representativity for most groups

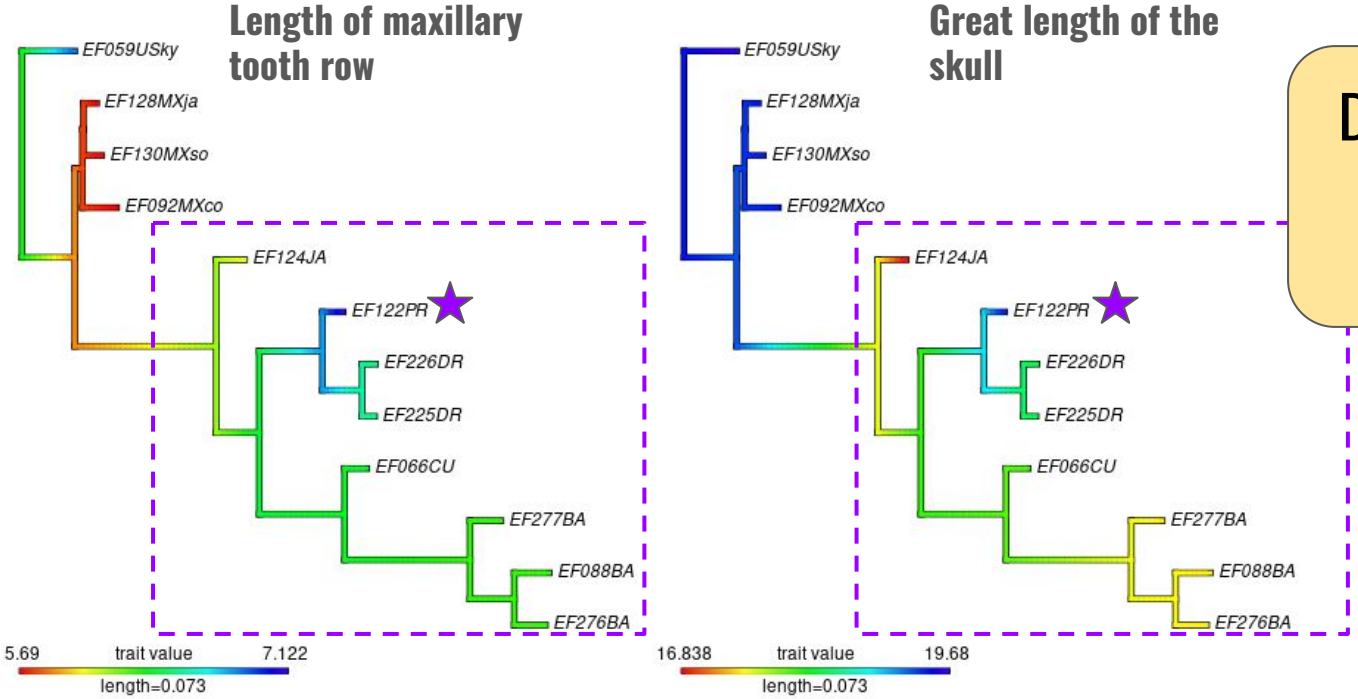


Are the Holotypes good lineages representatives?

Taxonomy of the groups was historically built on morphological traits, but 5 out of 6 holotypes lied outside the 95% confidence interval

Signals of speciation are more evident in isolated lineages

We used the continuous characters together with the nuclear data to model the morphological gradient



Does the morphological variation fits into the phylogenetic data?

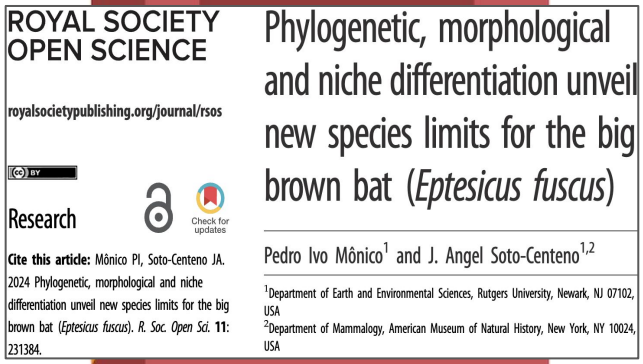
For more info on Consistency index, retention index and parsimony

This research generated new evidence of morphological speciation across the *Eptesicus dutertreus* lineages.

1) We uncovered and described the morphological gradient across *Eptesicus dutertreus* range
2) We found statistical support for at least 3 distinct morpho-groups.
3) The morphological gradient seems related to the geographical isolation of lineages
4) Most of holotypes are overestimating or underestimating lineages diversity

Our results suggest that **the current Diversity & Taxonomy of *Eptesicus dutertreus* is underestimated.**

2024



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Research

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Phylogenetic, morphological and niche differentiation unveil new species limits for the big brown bat (*Eptesicus fuscus*)

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2025

2nd semester

Exploring species diversity & factors that are driving it

2026

1st semester

Reconstructing the species evolutionary history across time

+

Taxonomic review

Thank you!

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GBatNet

& to everyone that directly or indirectly helped in the project!

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