The what, how, why of SDMs/ENMs

Bob Muscarella
Sapienza University, Roma
June 9-11

THE NICHE-RELATIONSHIPS OF THE CALIFORNIA THRASHER.[1]

BY JOSEPH GRINNELL.

THE California Thrasher (*Toxostoma redivivum*) is one of the several distinct bird types which characterize the so-called "Californian Fauna." Its range is notably restricted, even more so than that of the Wren-Tit. Only at the south does the California

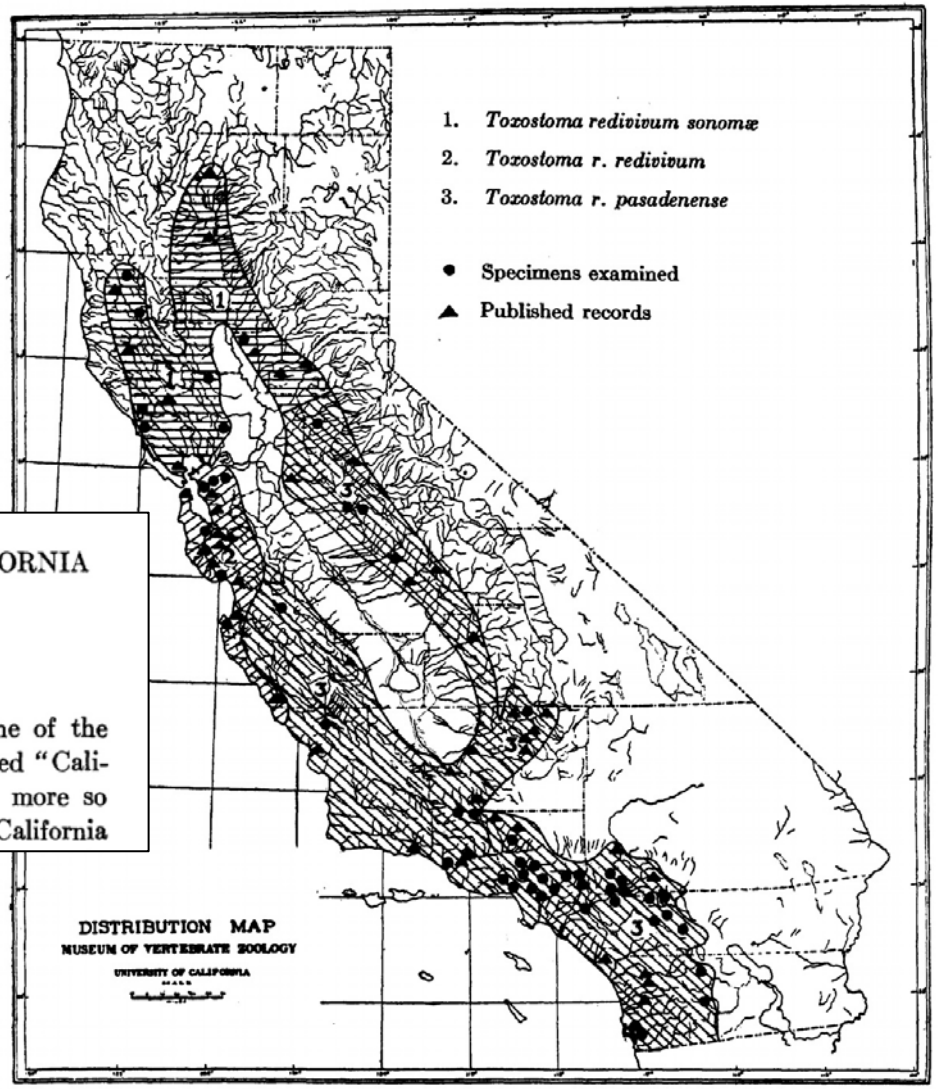

Figure 1.

Grinnell (1917) doi:10.2307/4072271

The what, how, why of SDMs/ENMs

What:

- Models that describe the distribution of species across space or environmental gradients

How:

- Develop statistical relationships between environmental conditions and locations where a species is present (and, in some cases, absent)

Why:

- Address fundamental questions of ecology / evolution
- Understand the potential exposure of species to environmental change
- Develop solutions for applied problems in conservation, restoration, agriculture, forestry, *etc.*

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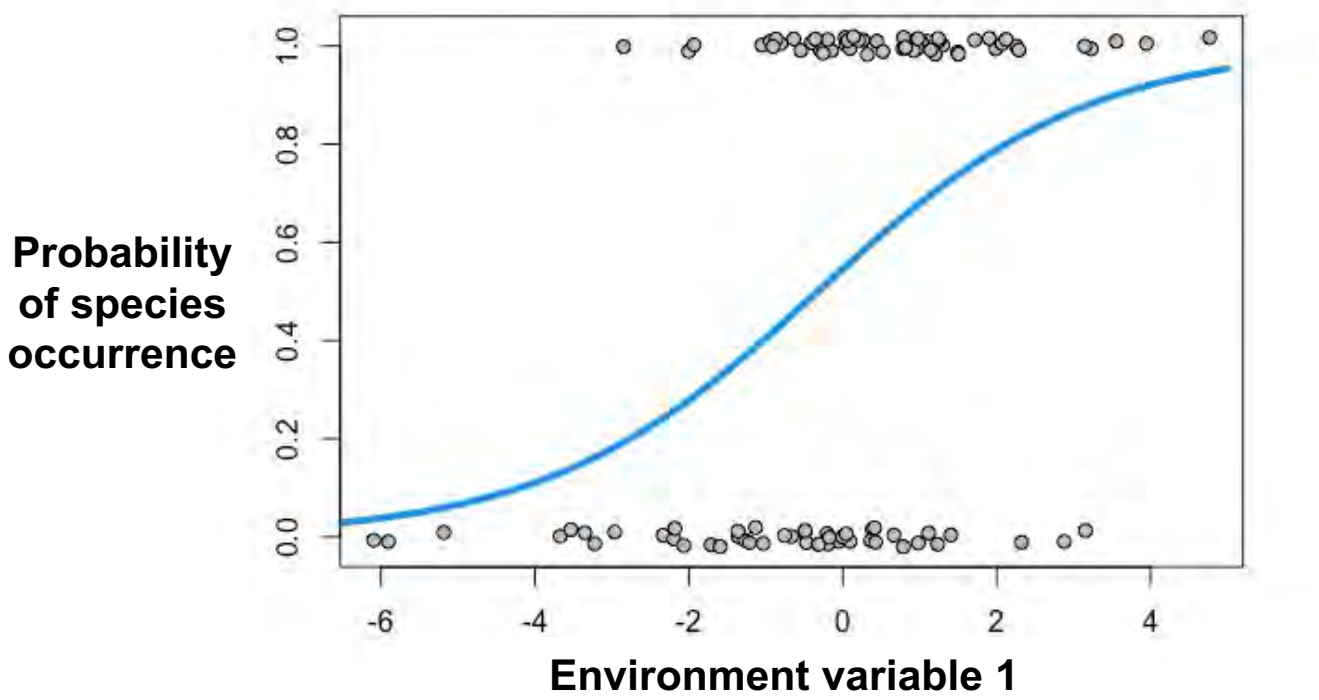
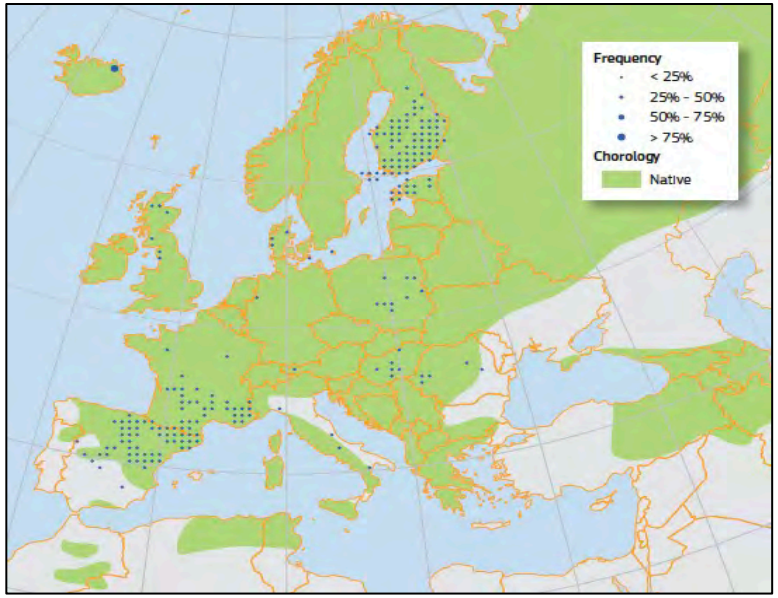
What:

- Models that describe the distribution of species across space or environmental gradients

  ENMs (Ecological or Environmental niche models) focus on environmental space

  SDMs (Species distribution models) focus on geographic space





The what, how, why of SDMs/ENMs

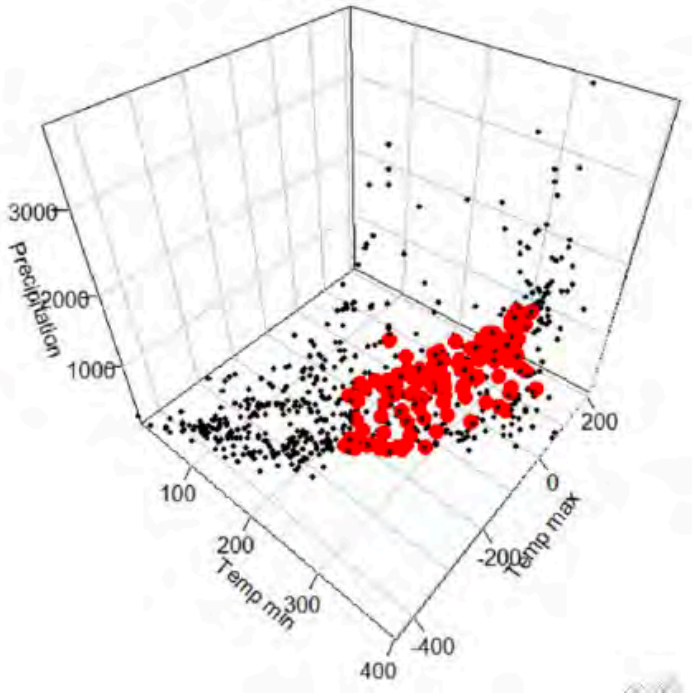
What:

- Models that describe the distribution of species across space or environmental gradients

  Environmental and geographic space

G space

E space



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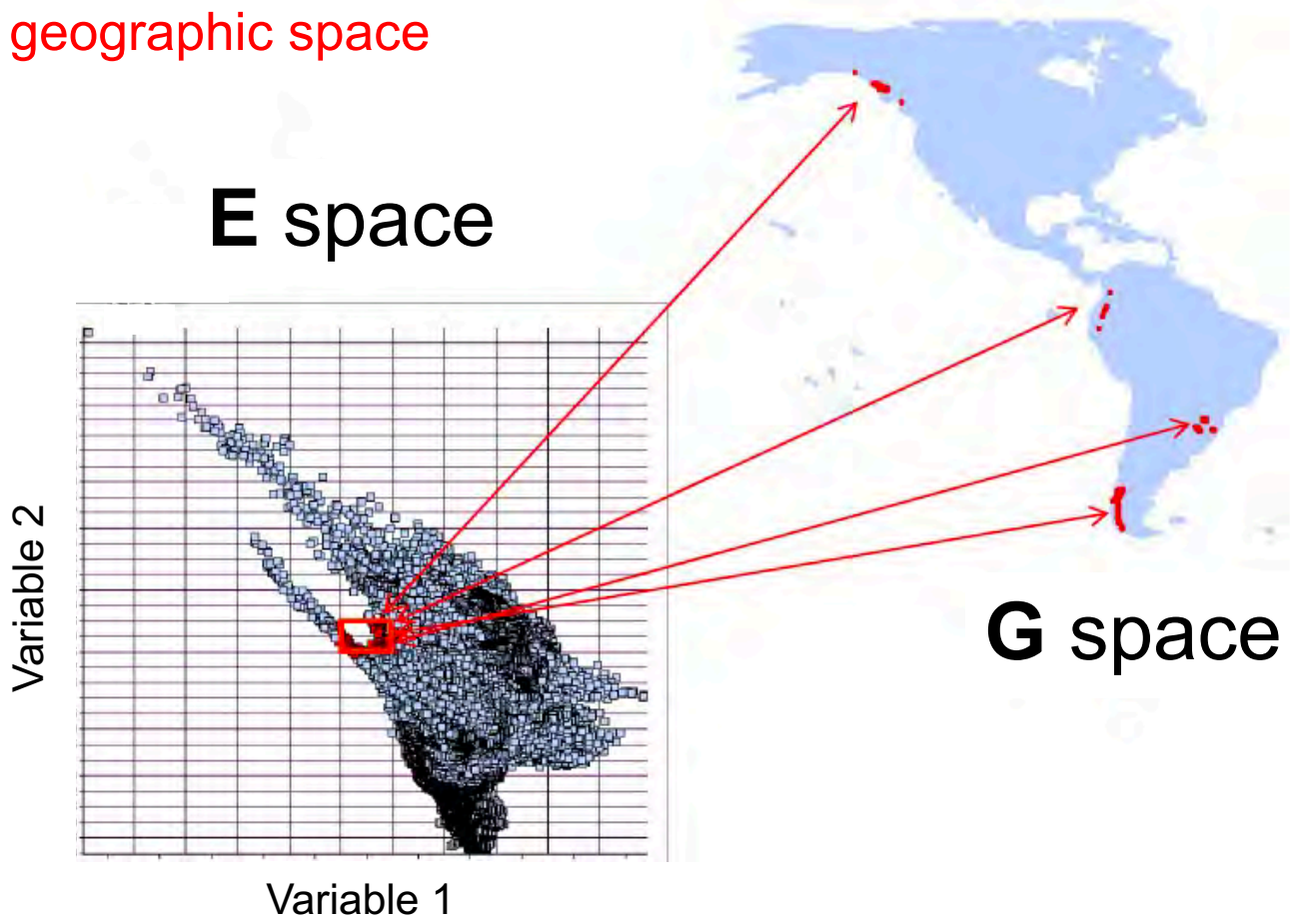
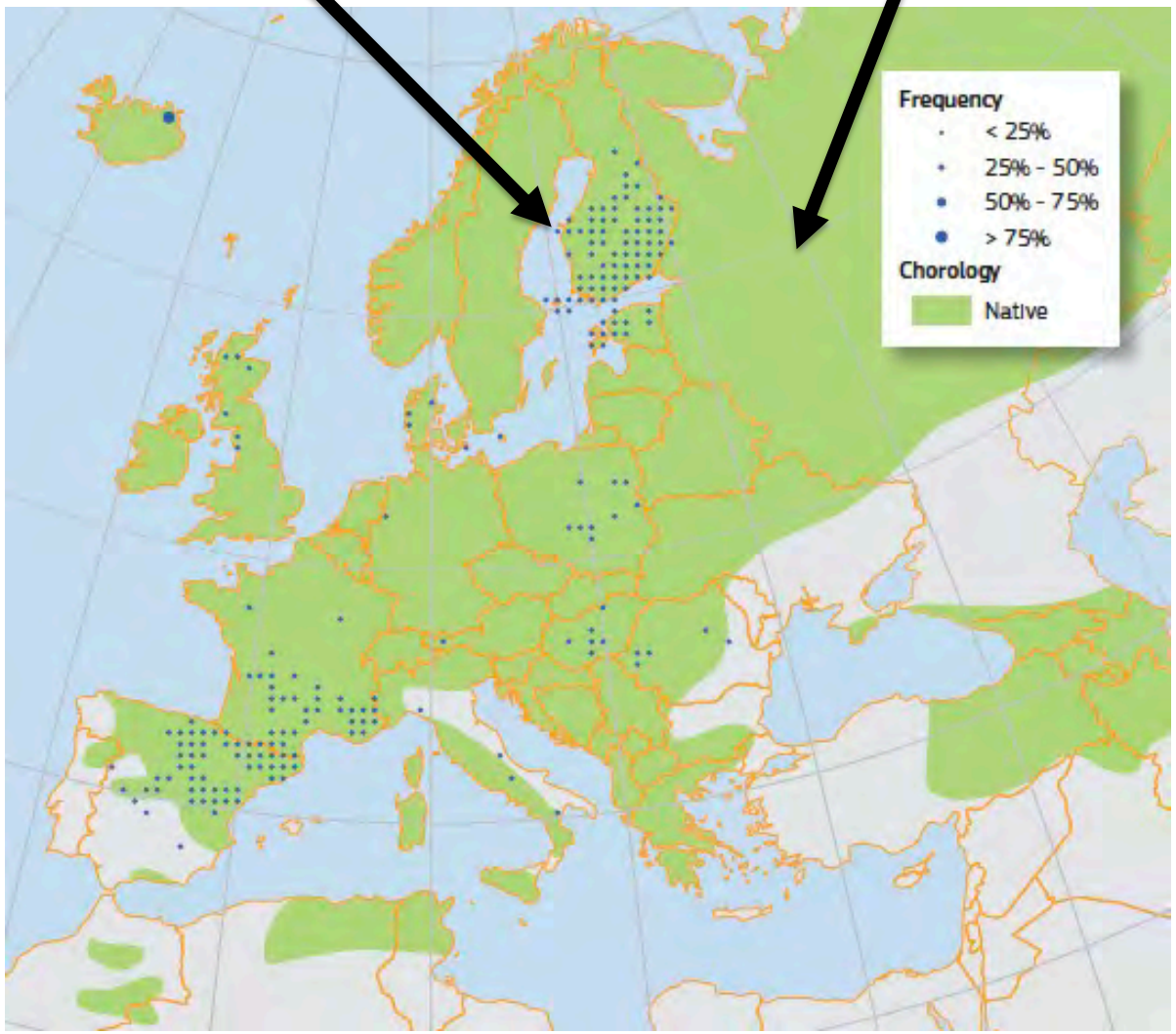


Occurrences

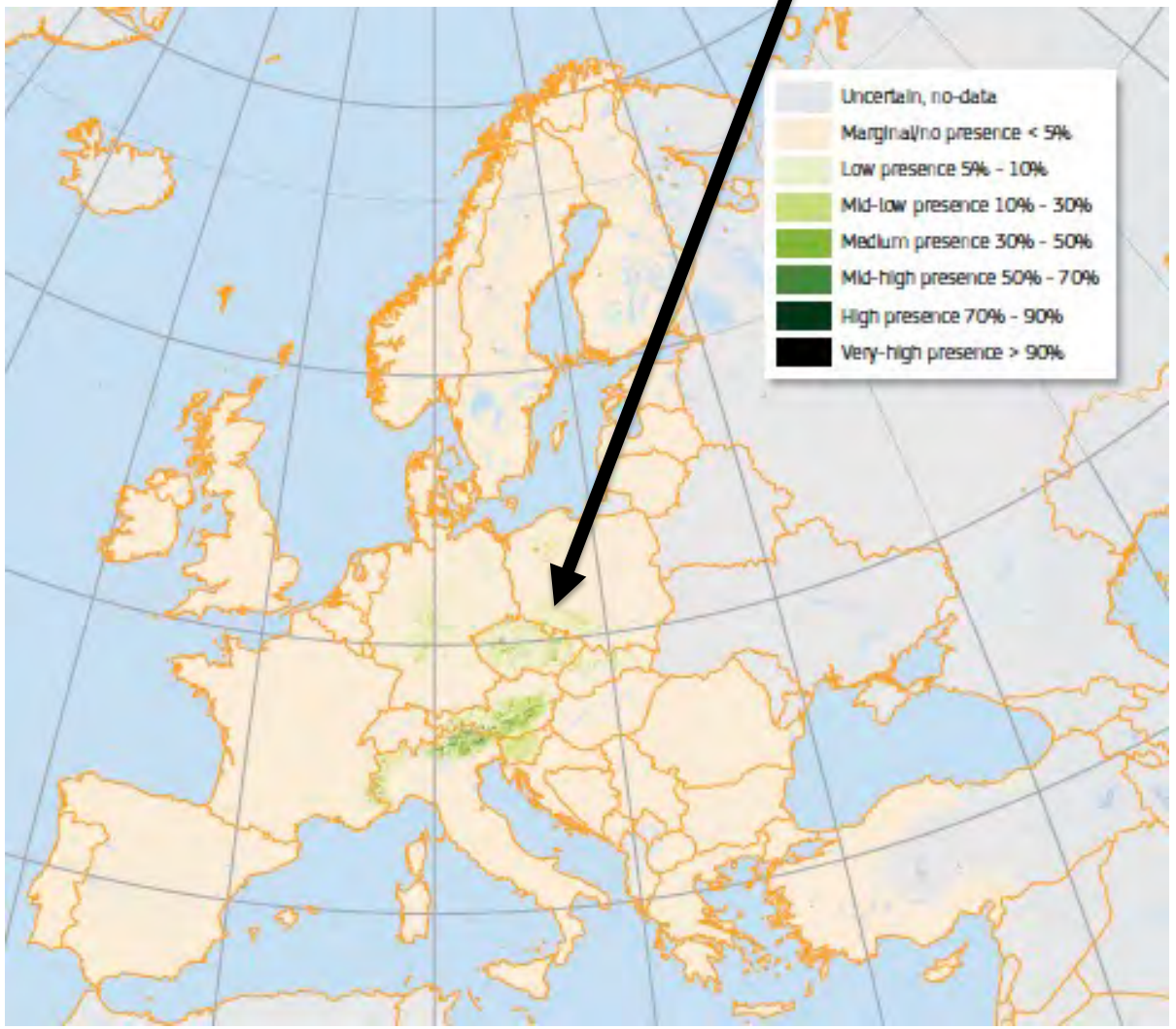
Geographic distribution

“Probability of occurrence”

Juniperus communis

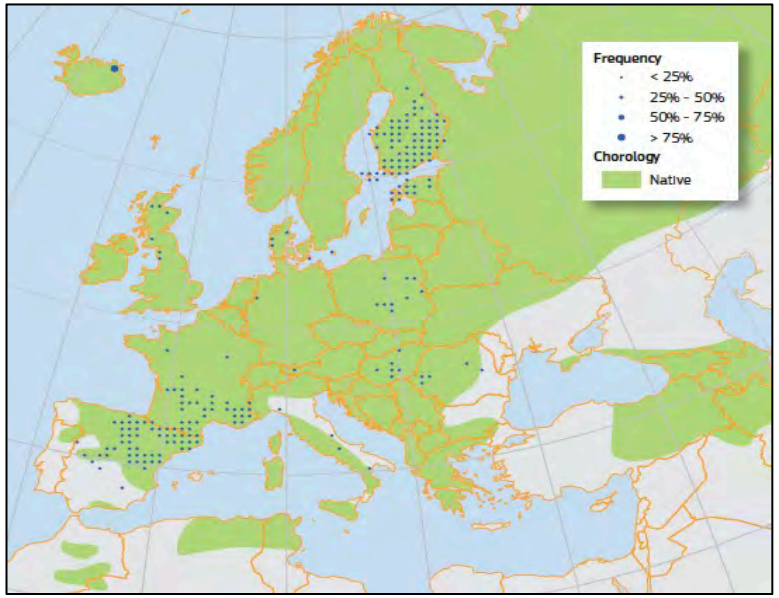


Larix decidua

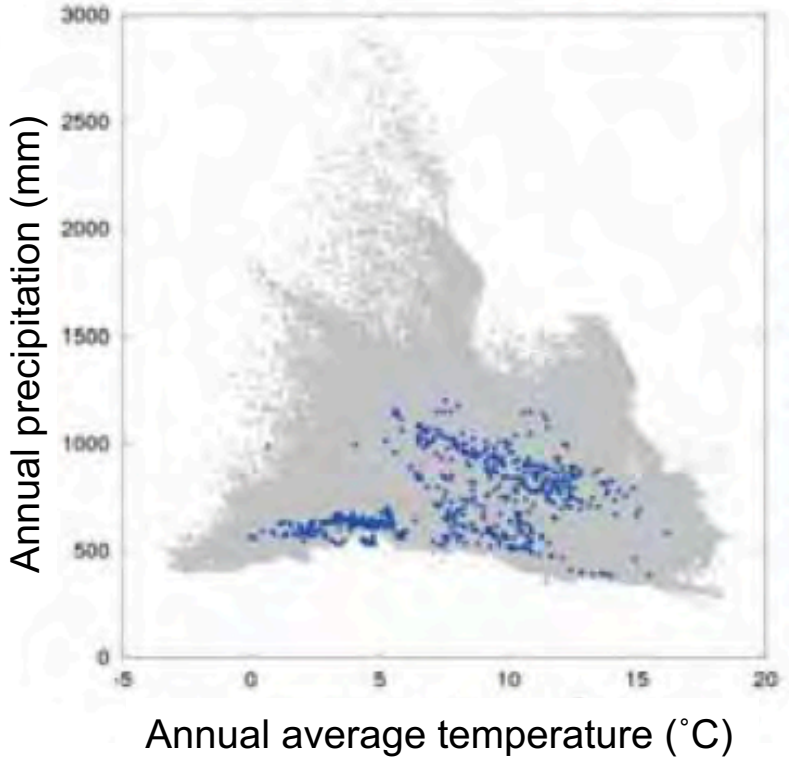


Juniperus communis

Distribution in ‘**geographic space**’



Distribution in ‘**environmental space**’



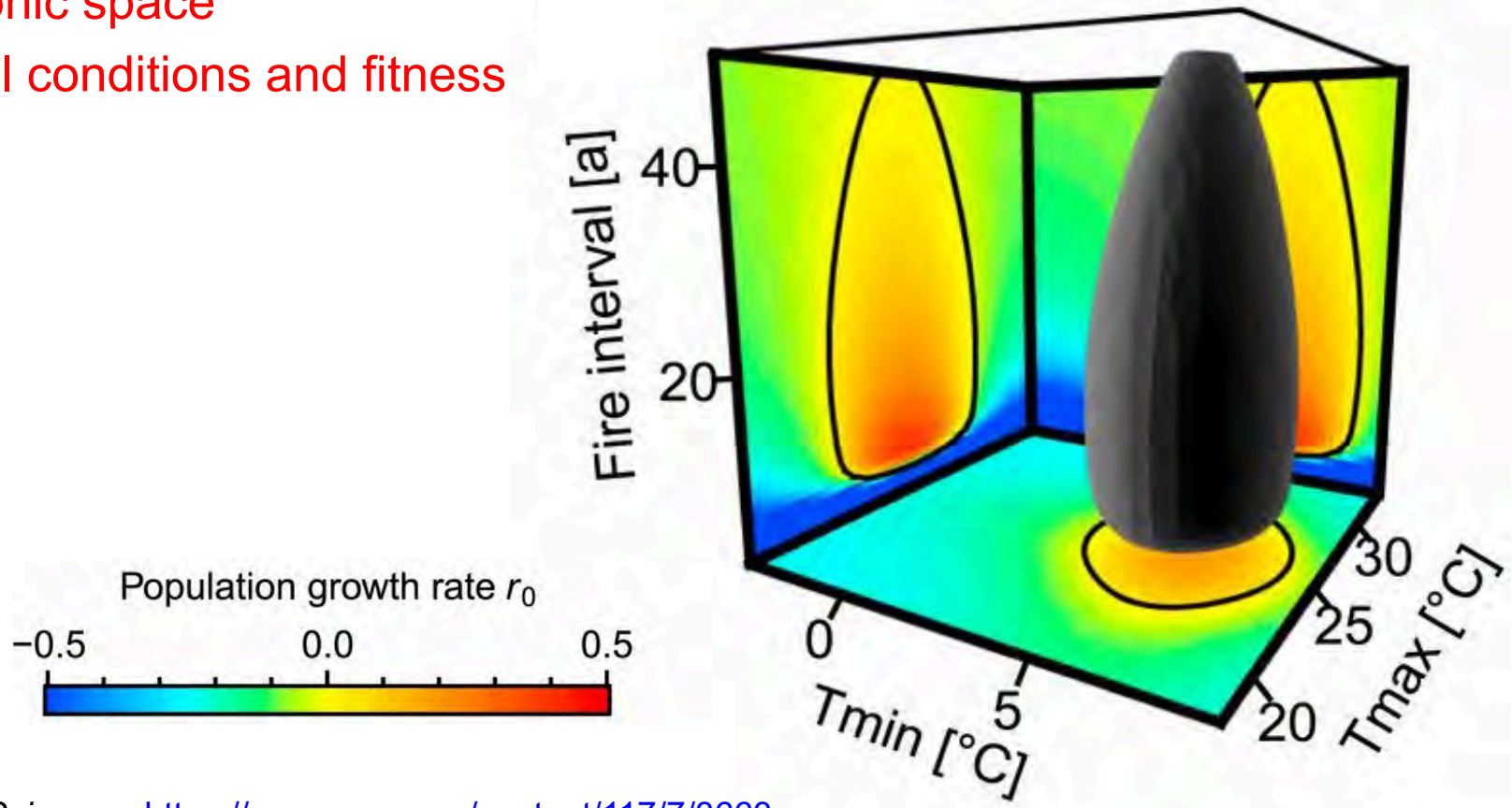
The what, how, why of SDMs/ENMs

What:

- Models that describe the distribution of species across space or environmental gradients

  Environmental and geographic space

  Link between environmental conditions and fitness



Pagel et al. (2020) *Proc. of the National Academy of Sciences*. https://www.pnas.org/content/117/7/3663

The what, how, why of SDMs/ENMs

What:

- Models that describe the distribution of species across space or environmental gradients

How:

- Develop statistical relationships between environmental conditions and locations where a species is present (and, in some cases, absent)

The what, how, why of SDMs/ENMs

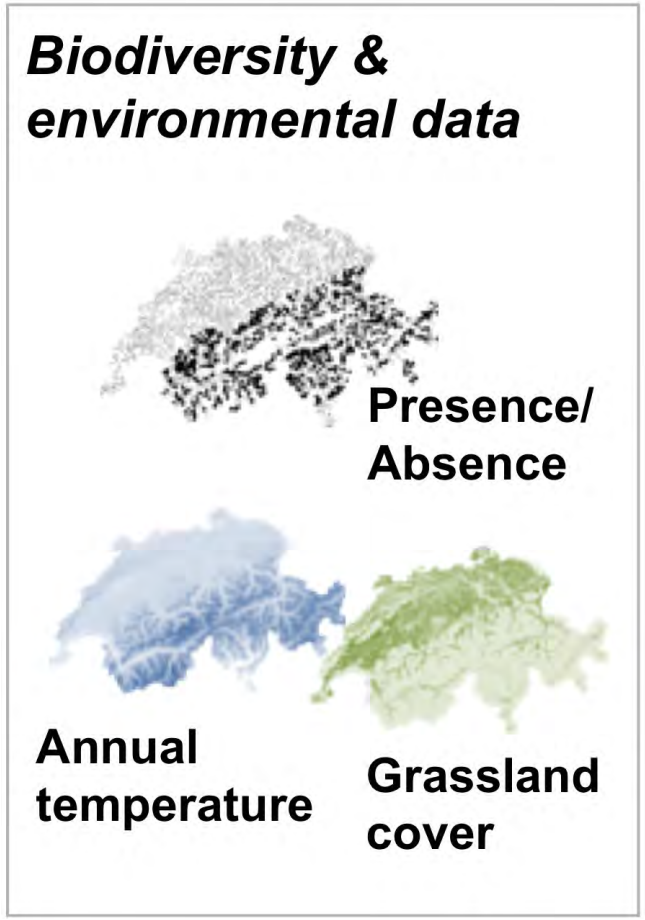
What:

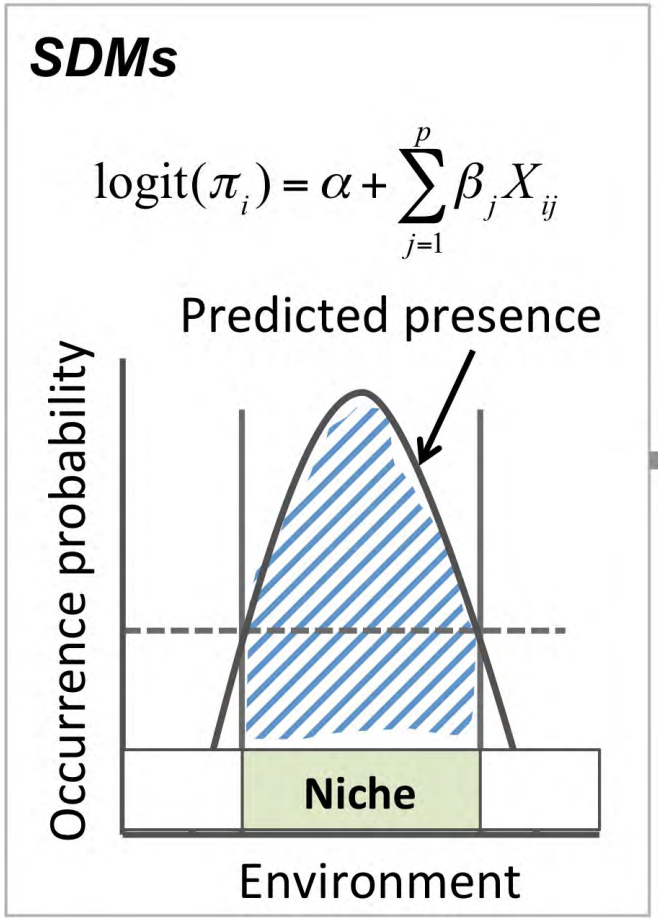
- Models that describe the distribution of species across space or environmental gradients

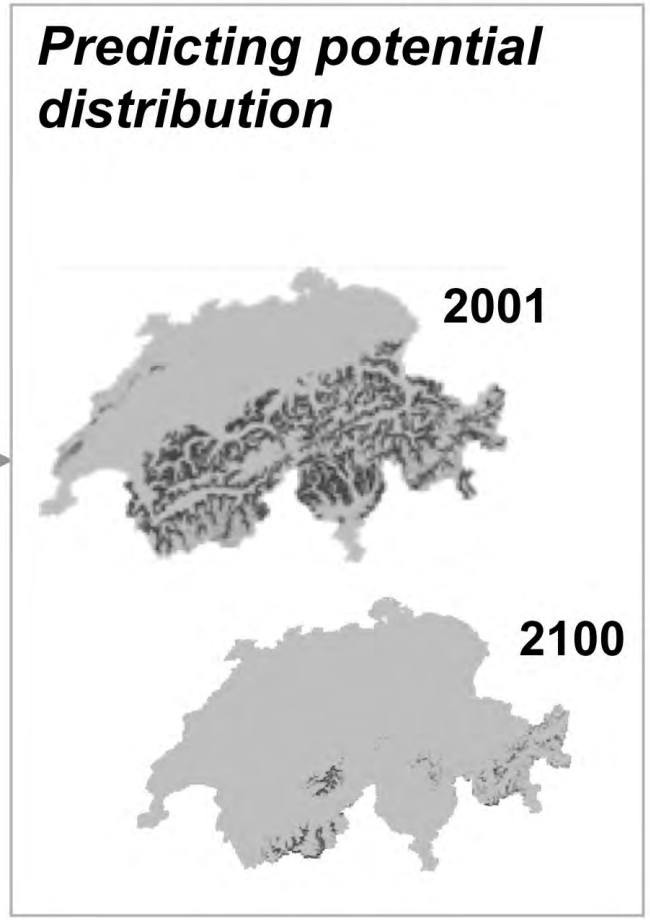
How:

- Develop statistical relationships between environmental conditions and locations where a species is present (and, in some cases, absent)
  - Correlative vs. Mechanistic
  - Presence-absence vs. presence-only

Correlative SDMs/ENMs

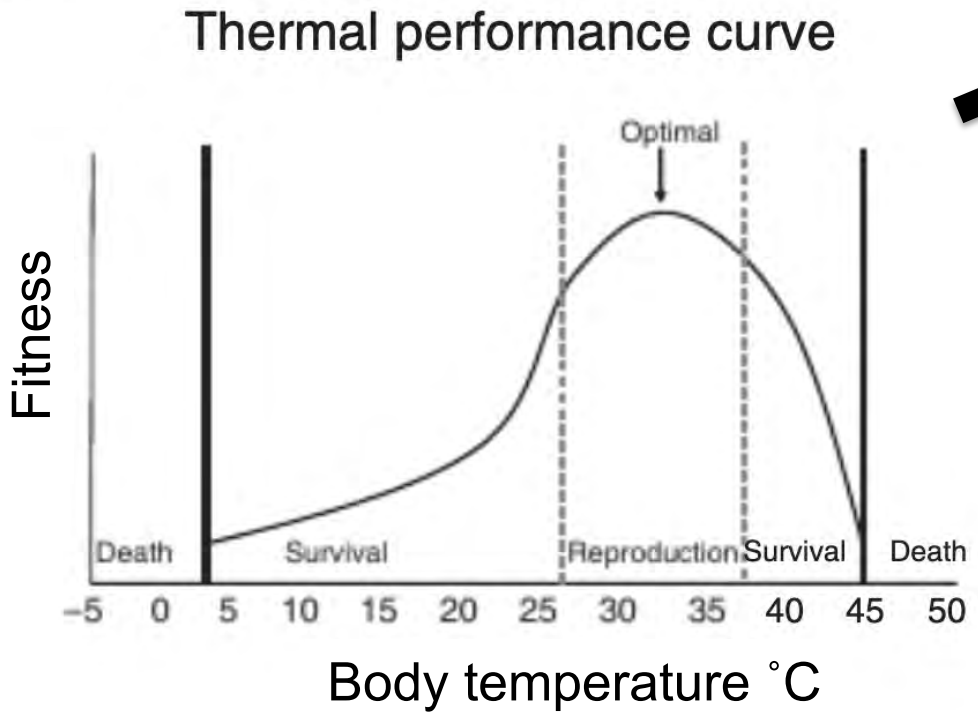


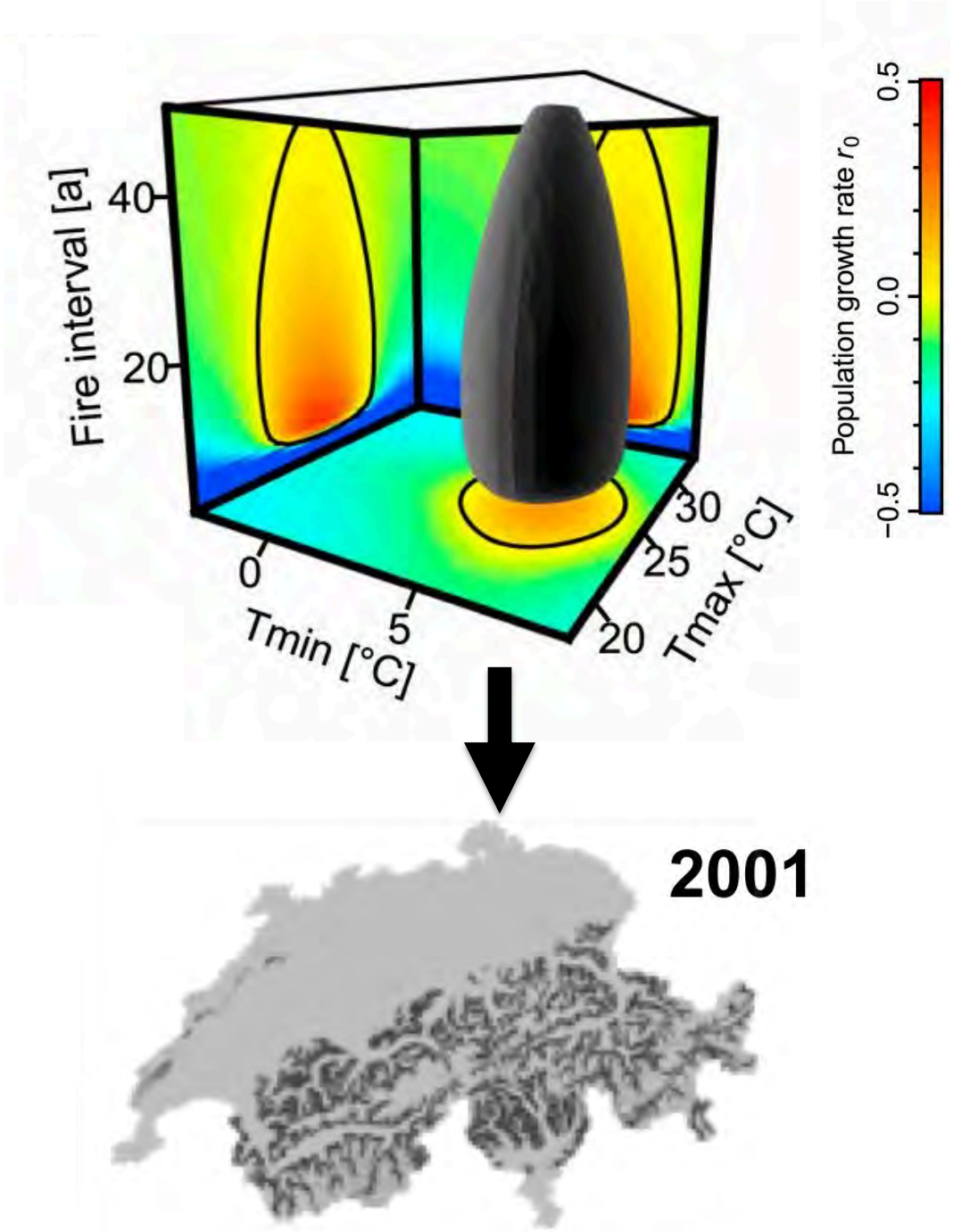




https://damariszurell.github.io/SDM-Intro/

Mechanistic SDMs/ENMs





Kearney and Porter (2009) *Ecology letters* 12 4: 334-50.

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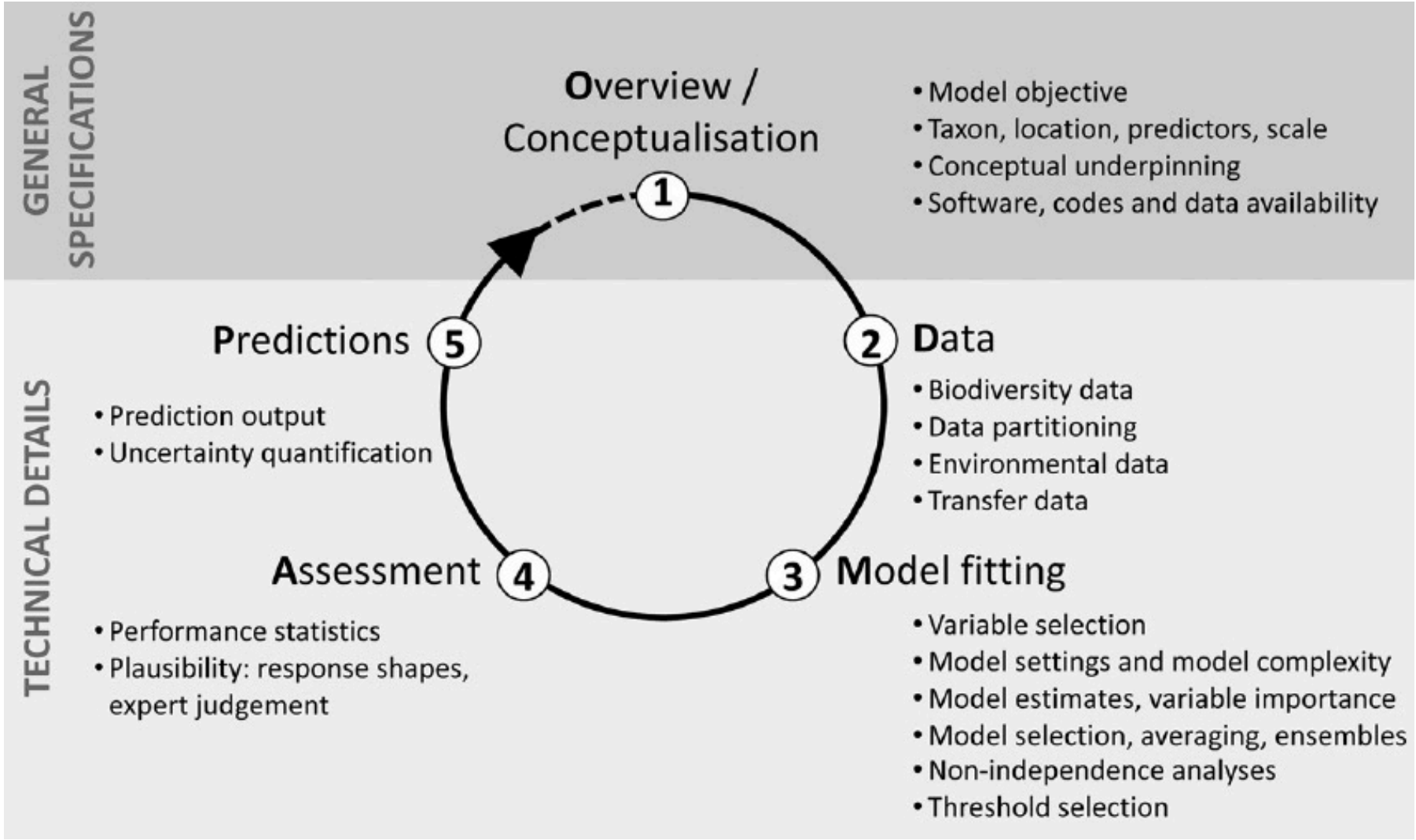
SDM / ENM workflow



Zurell *et al.* (2020) A standard protocol for reporting species distribution models. *Ecography,* **43,** 1261-1277.

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- Models that describe the distribution of species across spatial or environmental gradients

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- Develop statistical relationships between environmental conditions and locations where a species is present (and, in some cases, absent)*

Why:

- Understanding / prediction
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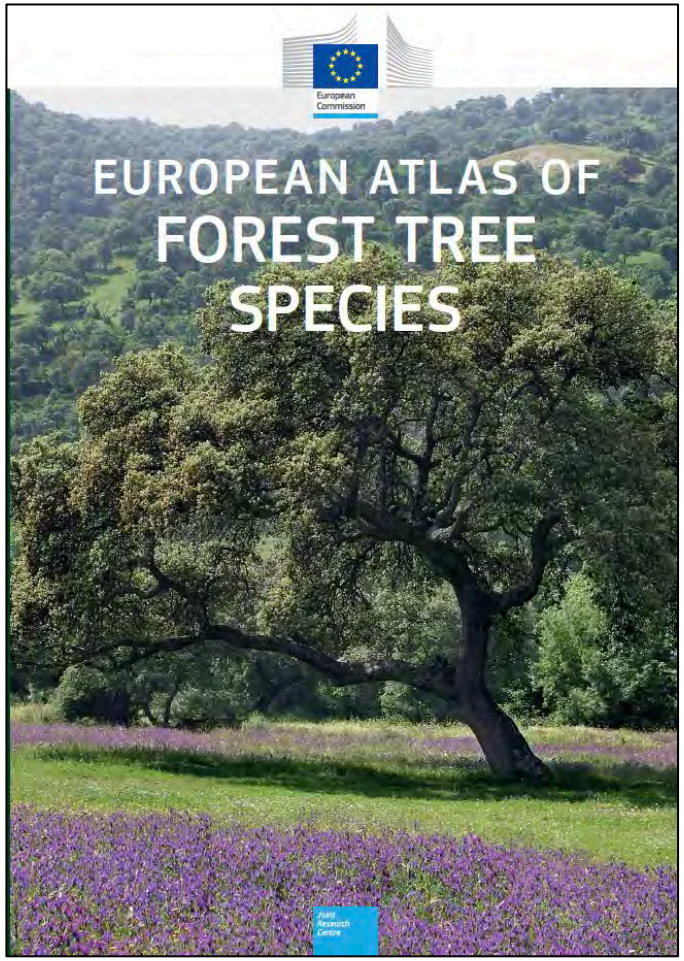

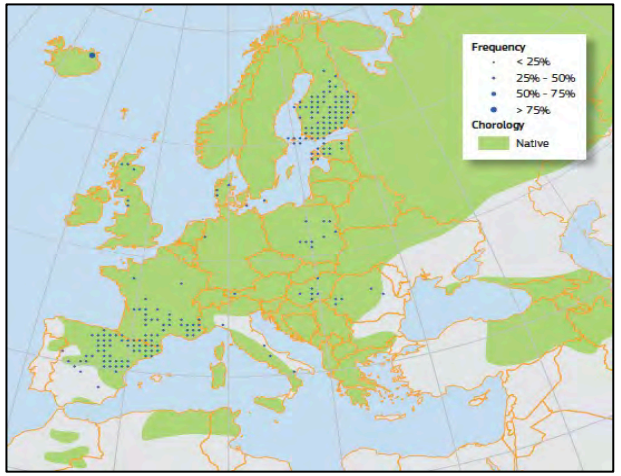

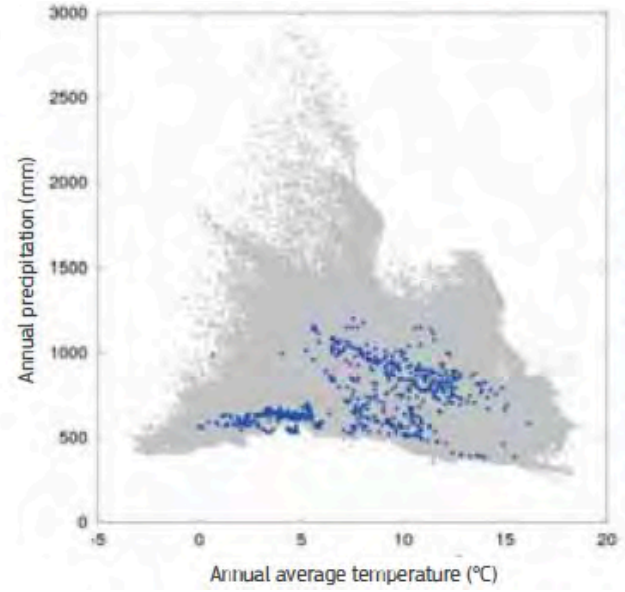

Who is where?

Common kingfisher (*Alcedo atthis*)

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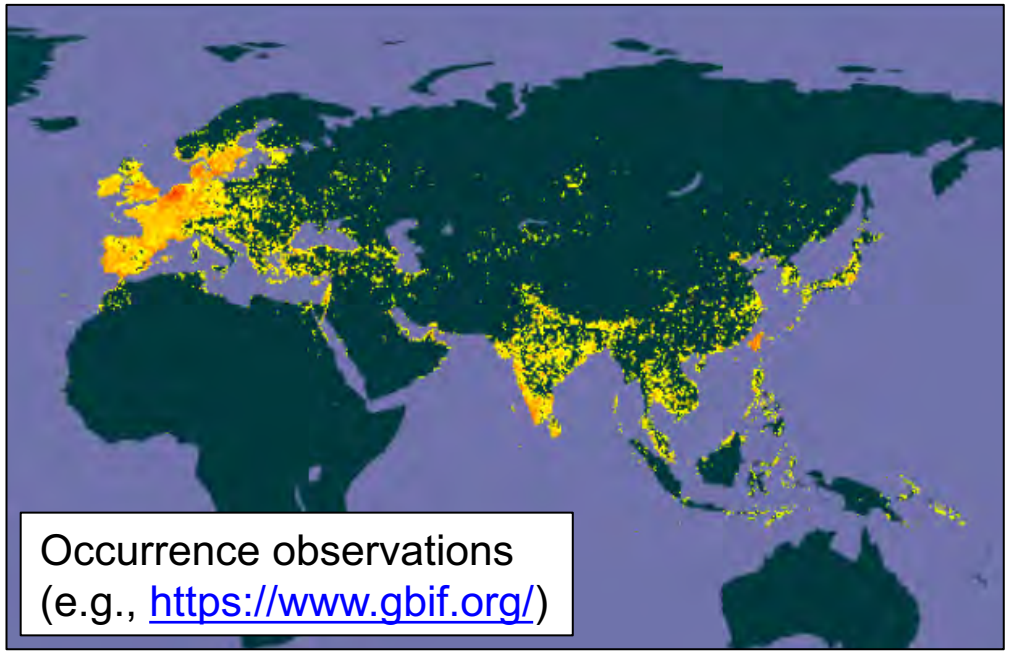
Photo: Shantanu Kuveskar



Occurrence observations
(e.g., https://www.gbif.org/)

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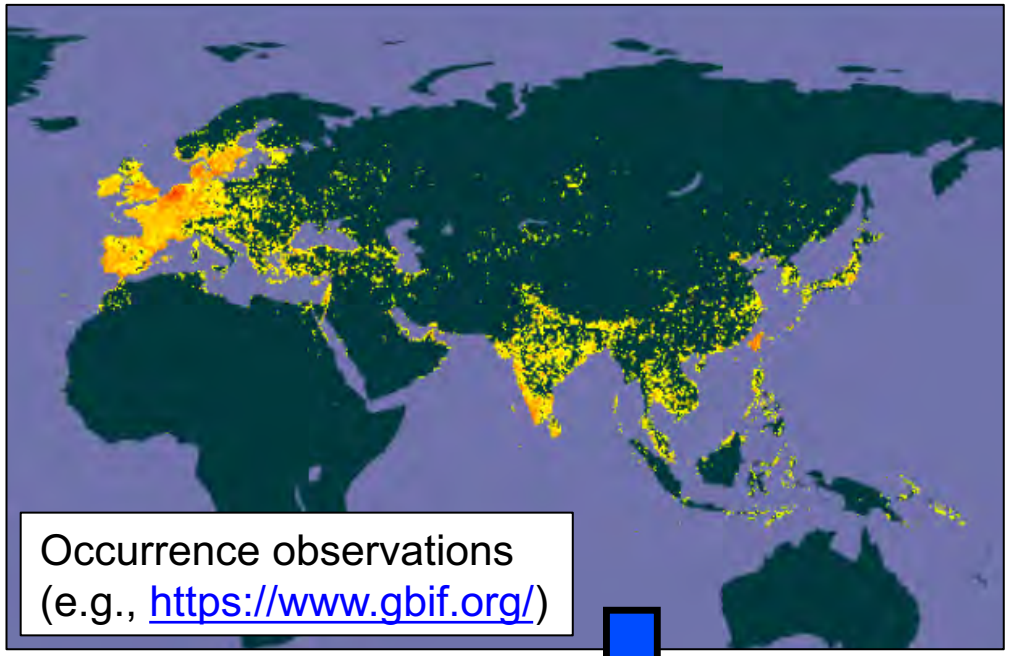
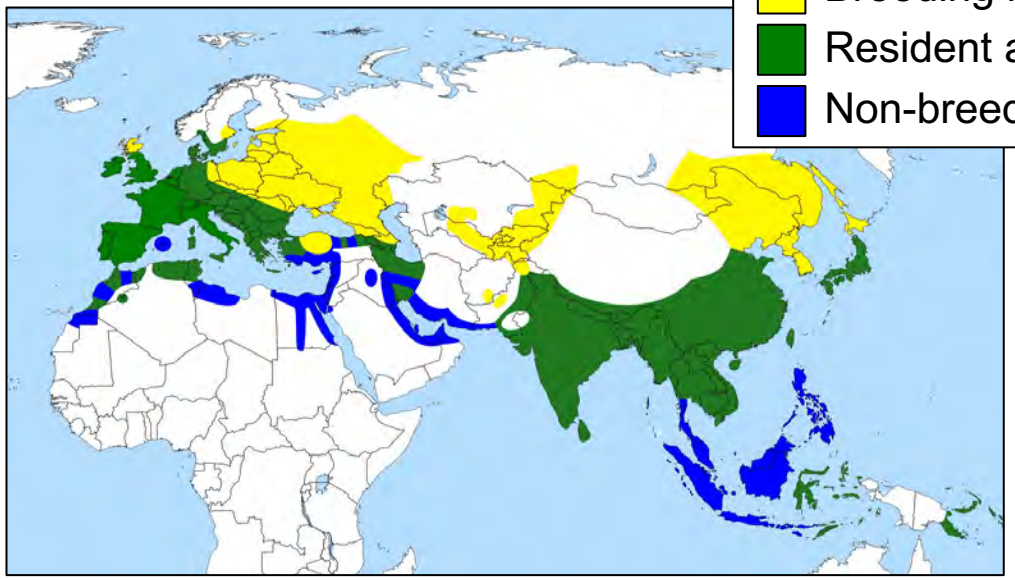


Occurrence observations
(e.g., https://www.gbif.org/)

Range map



Breeding range
Resident all year-round
Non-breeding range

Who is where?

Species observations

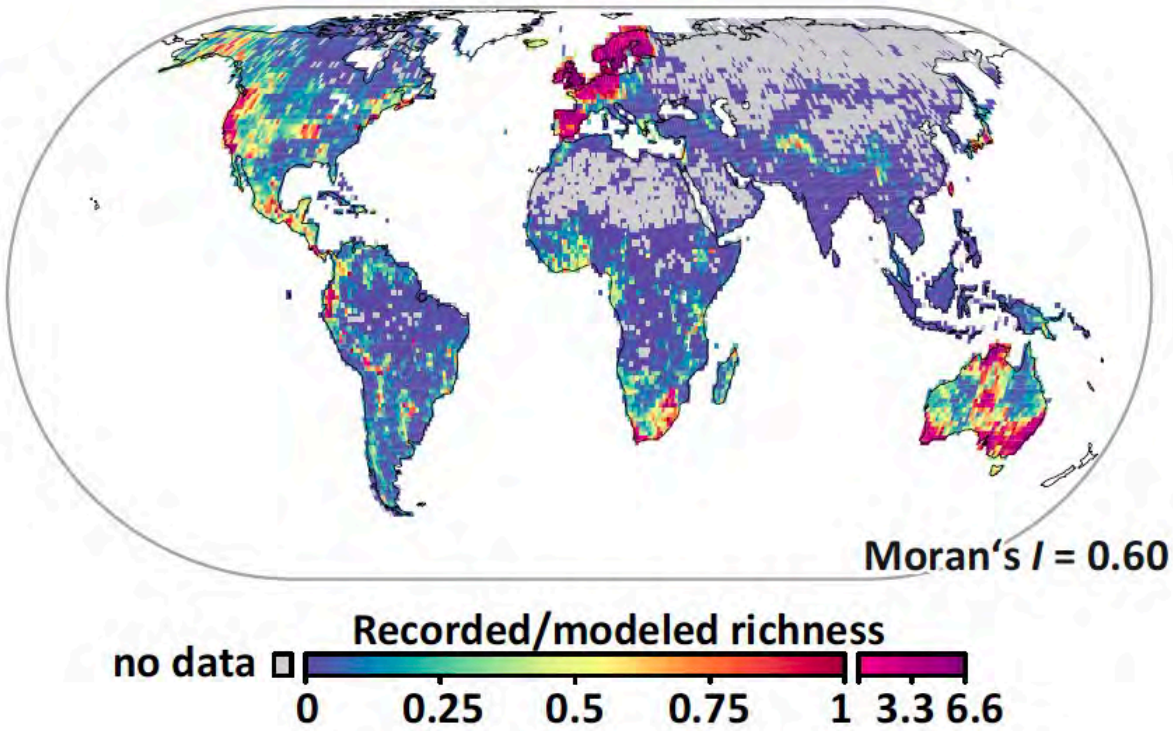
- Checklists
- Other studies
- Herbarium collections
- Other biological collections
- Citizen science

Dataset	Link
ArtPortalen (Sweden)	https://www.artportalen.se/
Biodiversity Information Serving Our Nation (BISON)	https://bison.usgs.gov/
BioTime	http://biotime.st-andrews.ac.uk/home.php
Botanical Information and Ecology Network (BIEN)	http://bien.nceas.ucsb.edu/bien/
eBird	https://ebird.org/home
ForestGEO	https://forestgeo.si.edu/
ForestPlots.net	https://www.forestplots.net/
Global Biodiversity Information Facility (GBIF)	https://www.gbif.org/
iNaturalist	https://www.inaturalist.org/
International Union for the Conservation of Nature (IUCN) Redlist	http://www.iucnredlist.org/
Neotoma	https://www.neotomadb.org/
Paleobiology Database	https://paleobiodb.org/#/
PalmTraits	https://datadryad.org/stash/dataset/doi:10.5061/dryad.ts45225
Phylacine	https://datadryad.org/stash/dataset/doi:10.5061/dryad.bp26v20
USGS Breeding Bird Survey	http://www.pwrc.usgs.gov/BBS/
VertNet	http://vertnet.org/

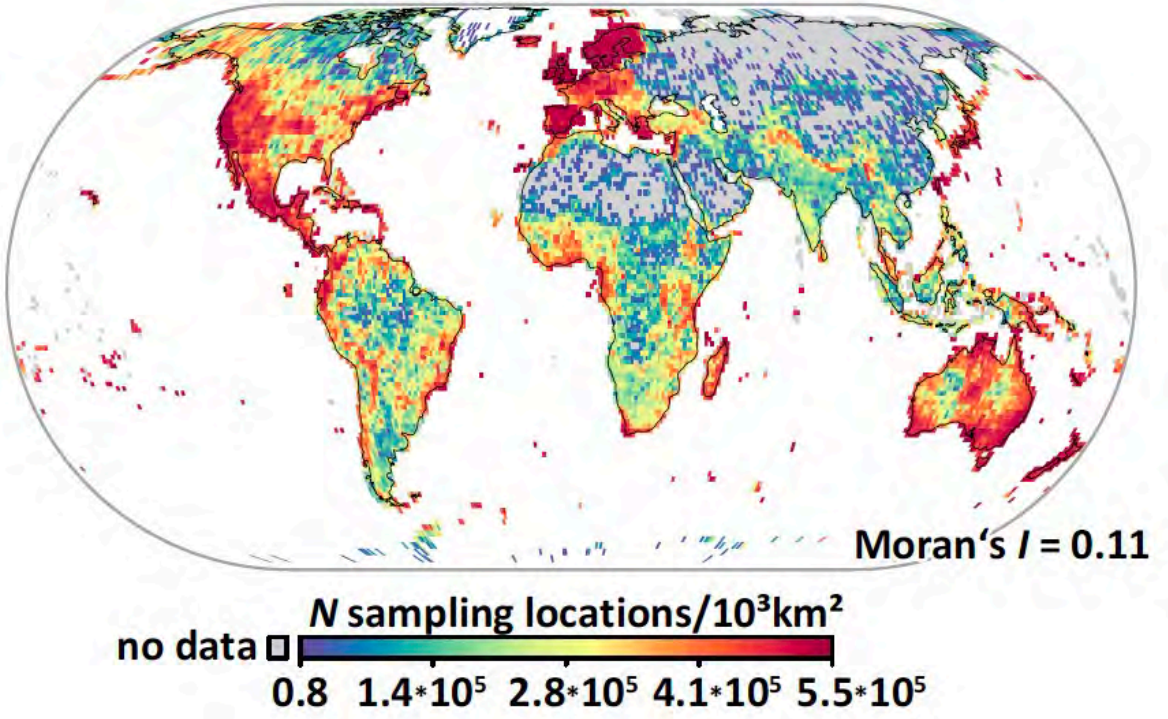
Who is where?

Occurrence records are biased / incomplete samples in terms of taxonomy, geography, and time

Taxonomic Coverage



Geographic Coverage



Meyer *et al.* (2016) Multidimensional biases, gaps and uncertainties in global plant occurrence information. Ecology Letters, 19: 992-1006. doi:10.1111/ele.12624

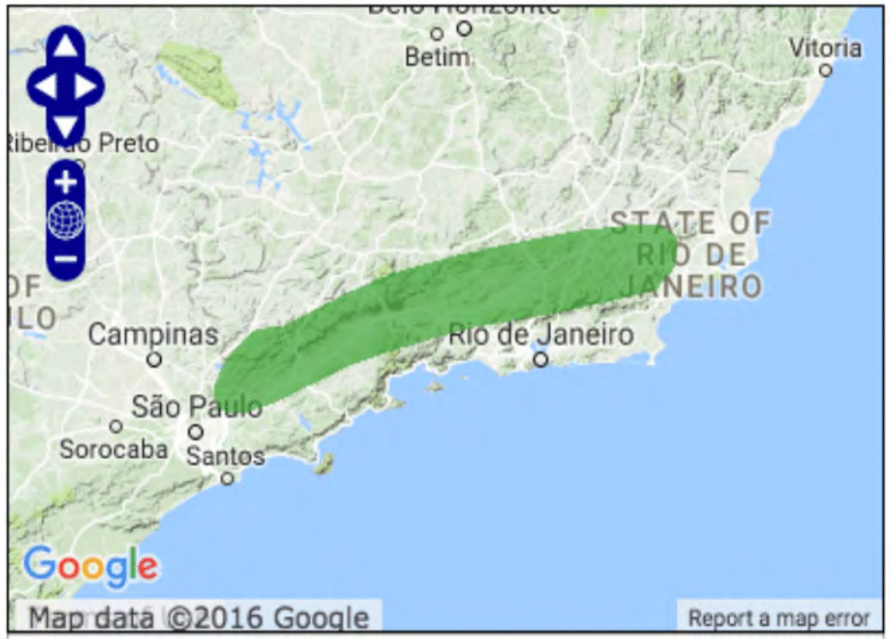
Understanding distributions is critical for conservation

NT Black-and-gold Cotinga *Tijuca atra*

Justification
This species is classified as Near Threatened because it is suspected to be declining moderately rapidly owing to habitat loss.

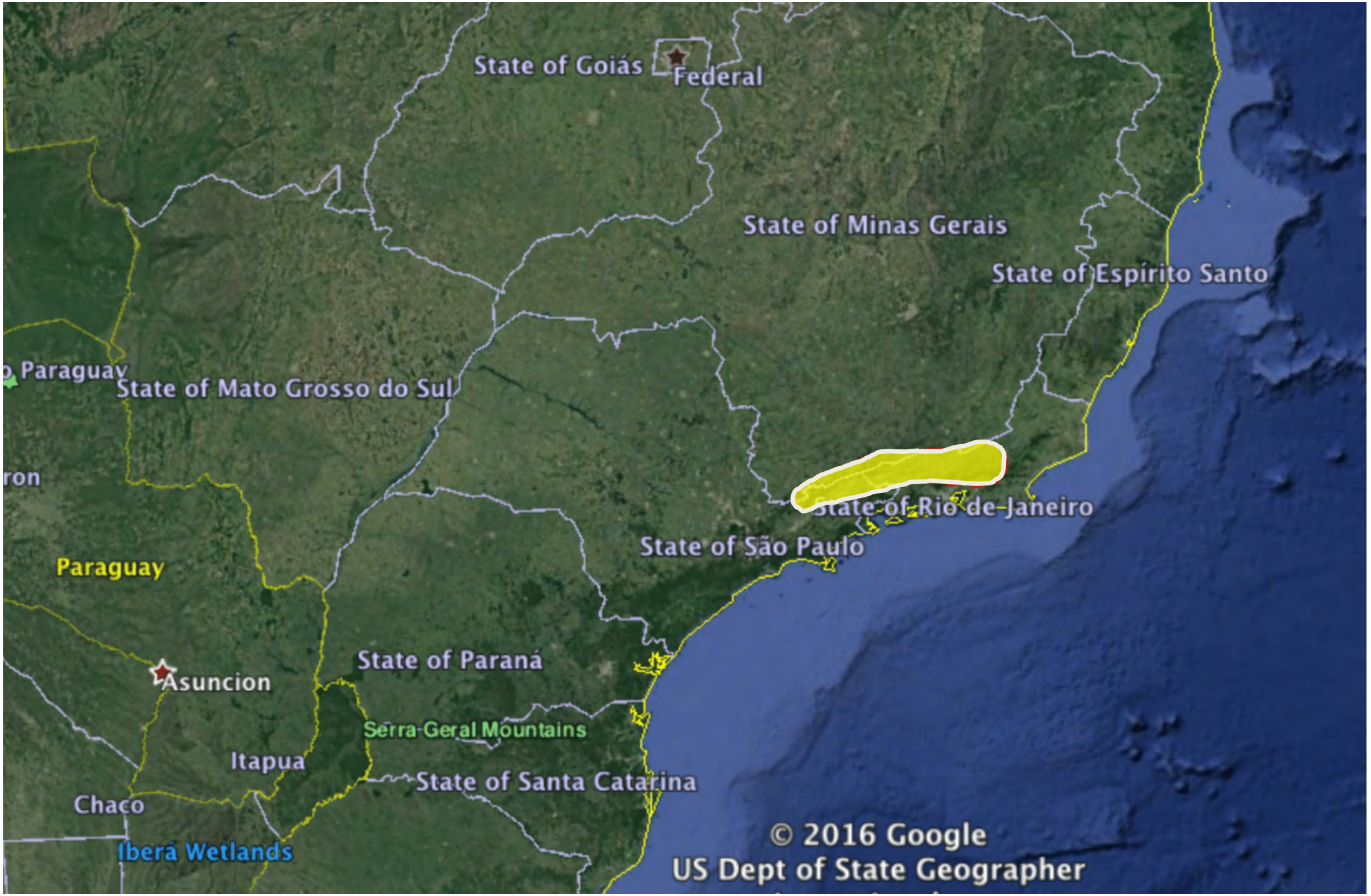
Taxonomic source(s)
SACC. 2006. A classification of the bird species of South America. Available at: #http://www.museum.lsu.edu/~Remsen/SACCBaseline.html#.

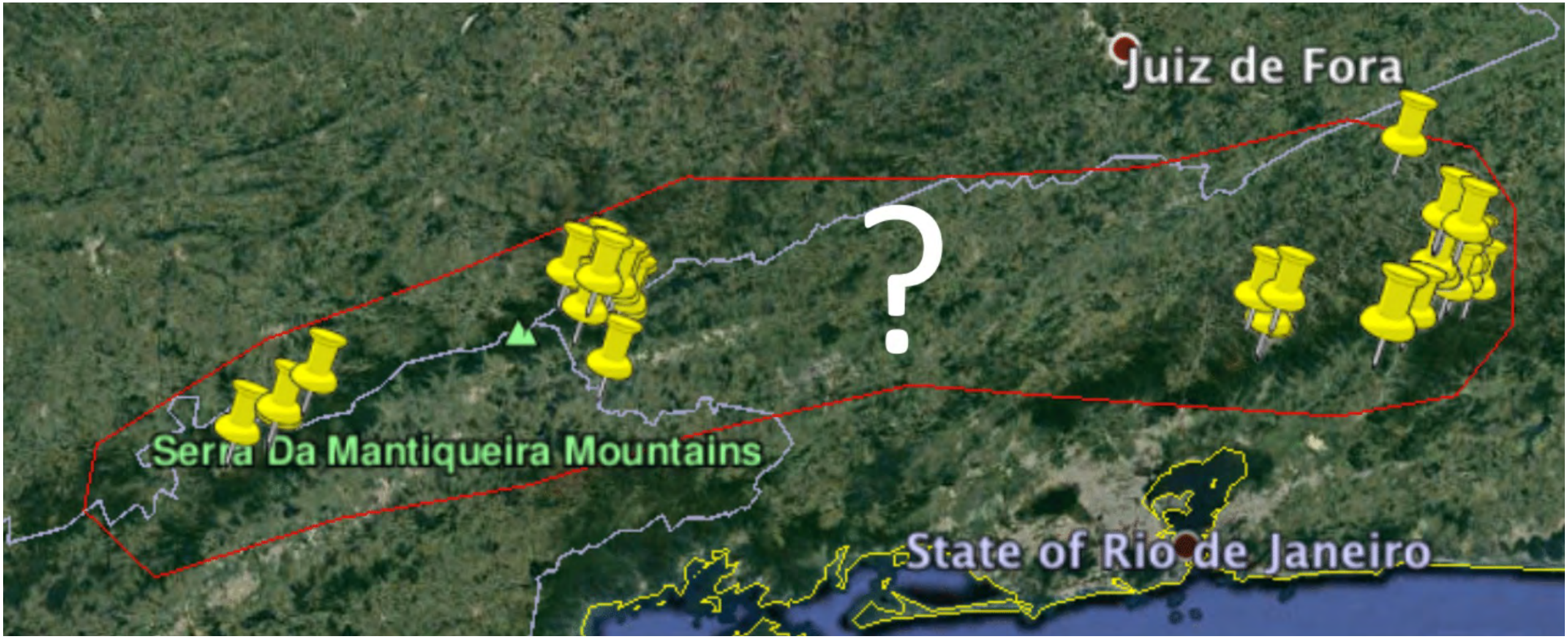
Distribution and population
Tijuca atra occurs in Rio de Janeiro, extreme east São Paulo and adjacent south Minas Gerais, south-east **Brazil** (Ridgely and Tudor 1994, Parker *et al.* 1996). Despite this highly restricted range, habitat destruction of its montane Atlantic forest has been much less extensive than in adjacent lowland areas (Stattersfield *et al.* 1998). As a consequence, it is numerous in the upper reaches of Itatiaia and Serra dos Órgãos national parks, and locally fairly common in the canopy and middle levels of montane forest elsewhere within its range (Ridgely and Tudor 1994).

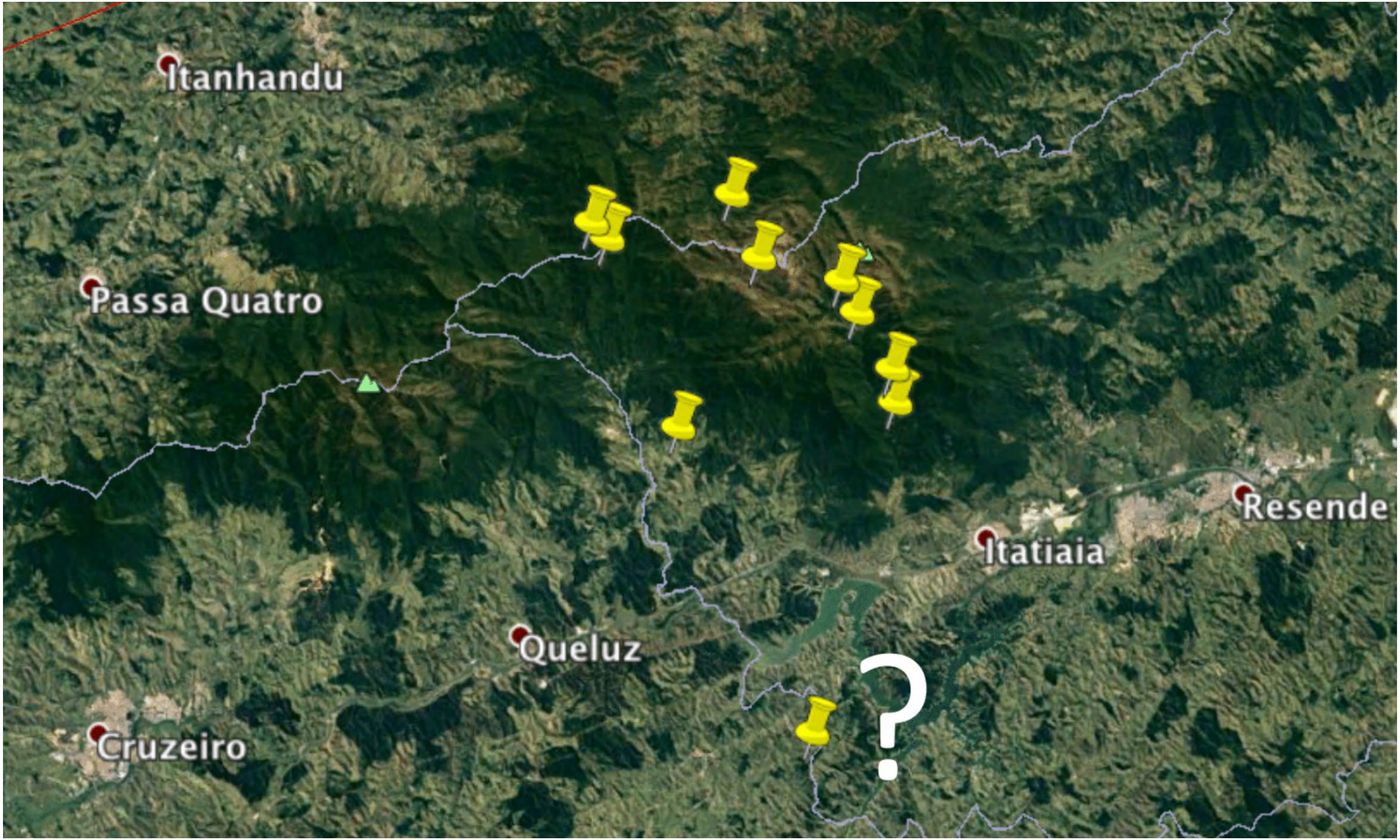


Population justification
The global population size has not been quantified, but this species is described as 'uncommon' (Stotz et al. 1996).

© 2016 Google
US Dept of State Geographer
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google ear


State of Goiás
Federal
State of Minas Gerais
State of Espírito Santo
Paraguay
State of Mato Grosso do Sul
State of Rio de Janeiro
State of São Paulo
Paraguay
State of Paraná
Asuncion
Serra Geral Mountains
Itapua
State of Santa Catarina
Chaco
Iberá Wetlands
© 2016 Google
US Dept of State Geographer


Juiz de Fora
?
Serra Da Mantiqueira Mountains
State of Rio de Janeiro

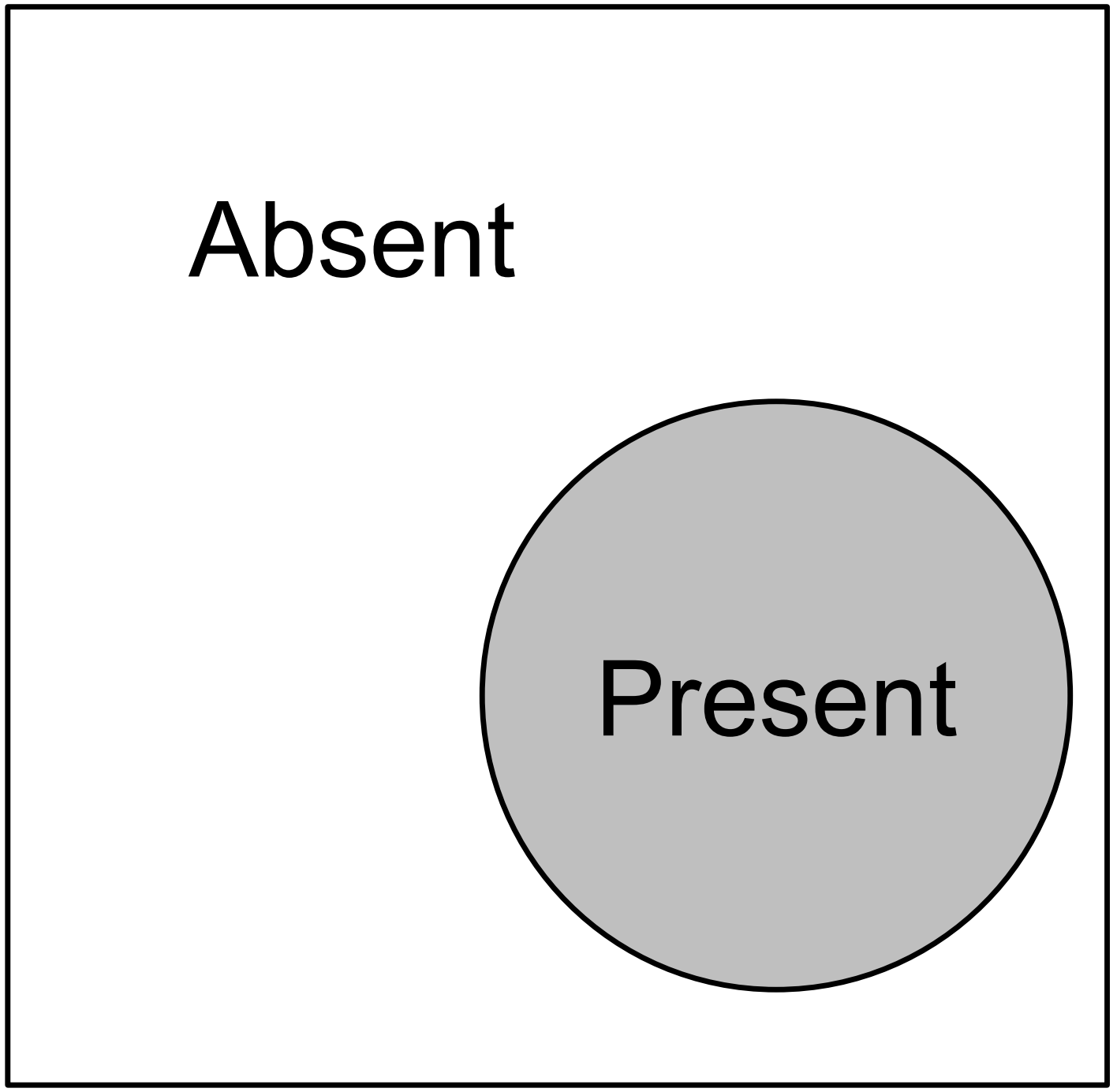

Itanhandu
Passa Quatro
Resende
Itatiaia
Queluz
Cruzeiro
?

Challenges to understand distributions

- Observations are biased in taxonomy, space, and time
- Incomplete knowledge of species distributions
- Errors and uncertainties in available data
- Scale-dependency of all range mapping phenomena
- In reality, “species” and “distributions” are not homogeneous entities

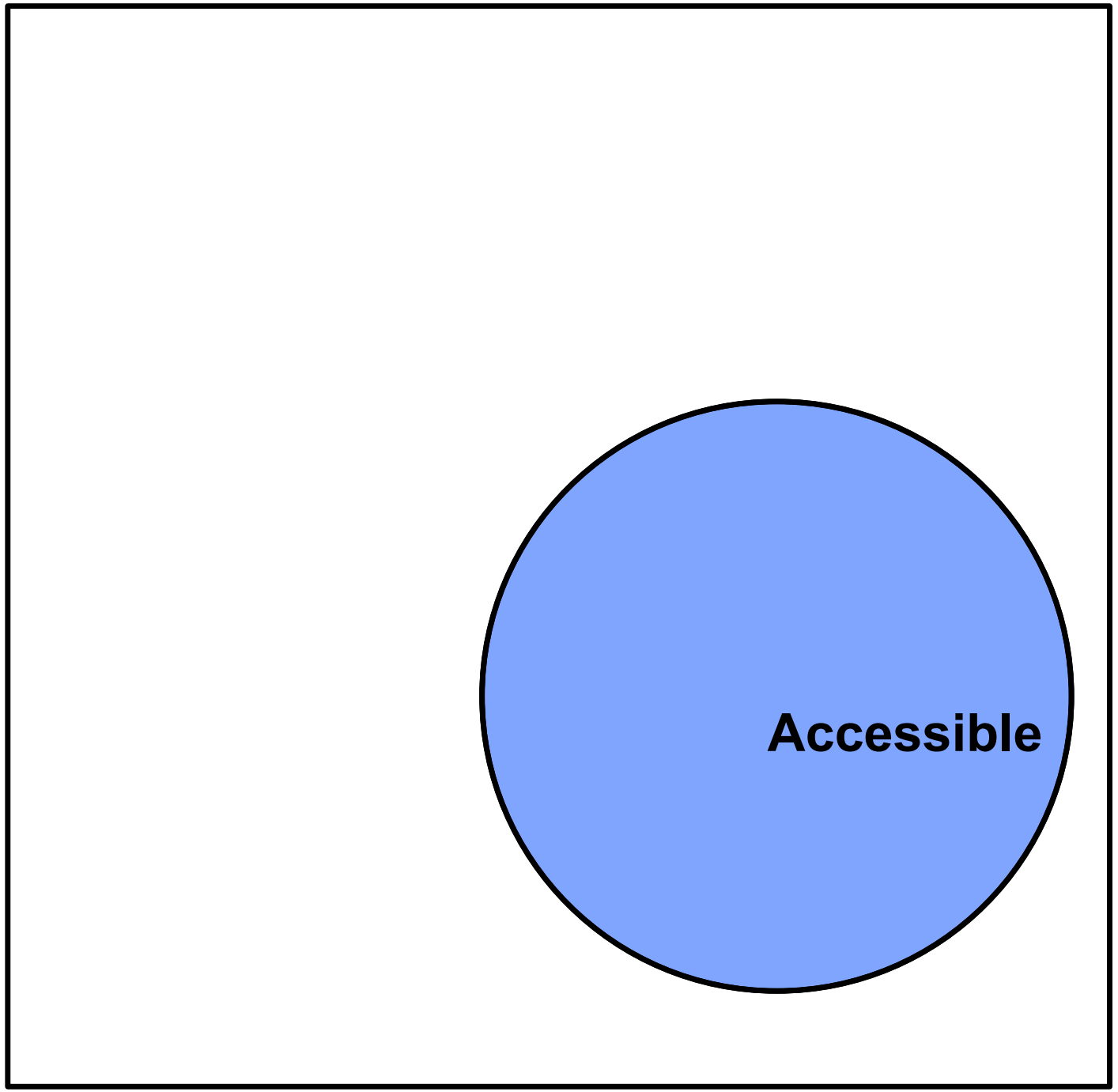
Who is where?

And why?



Who is where?
And why?

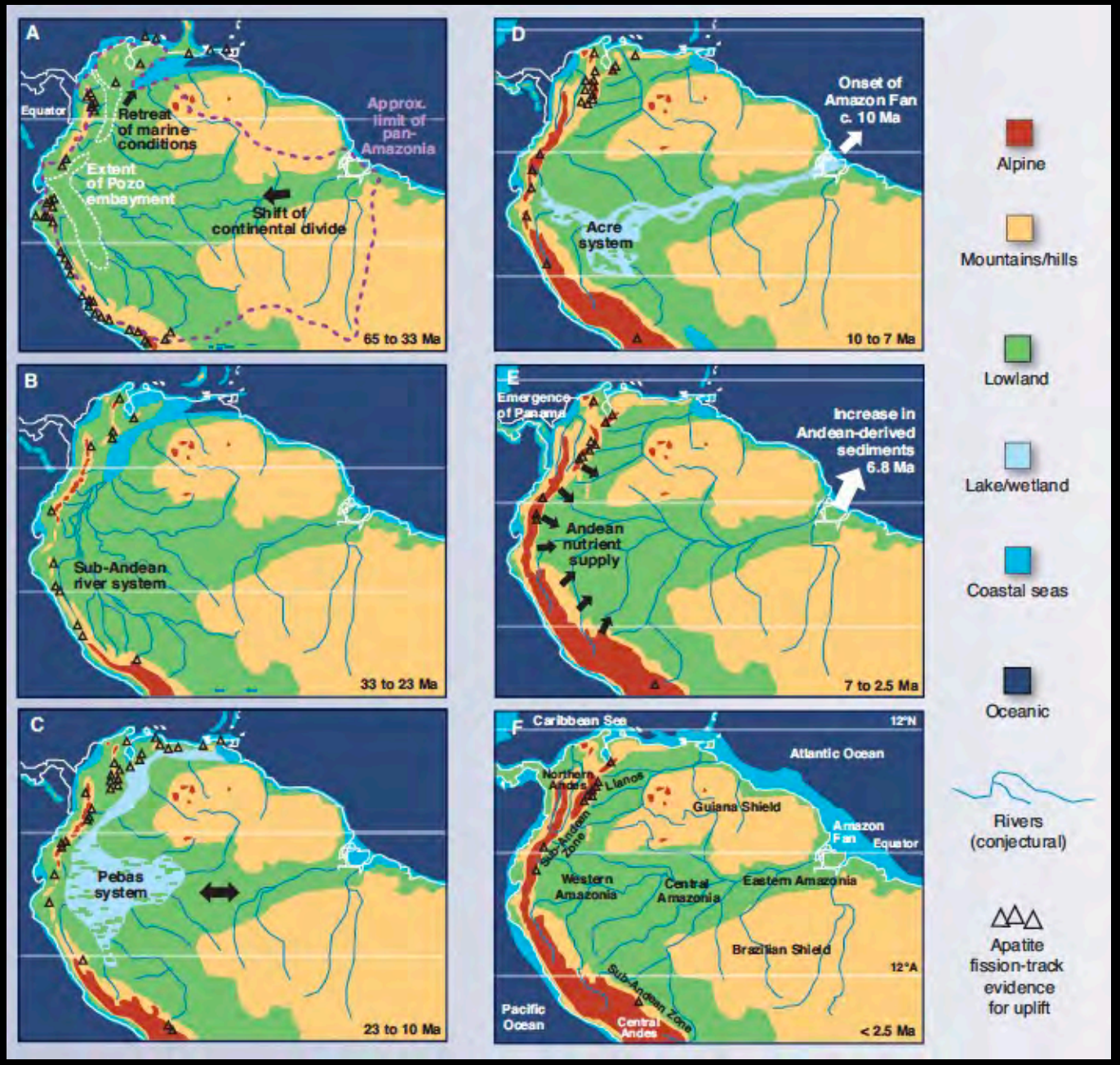
- Accessible (movement)
  - Short-term movement
  - Long-term dispersal
  - Geographic barriers



Organisms move

(in different ways and at different rates!)

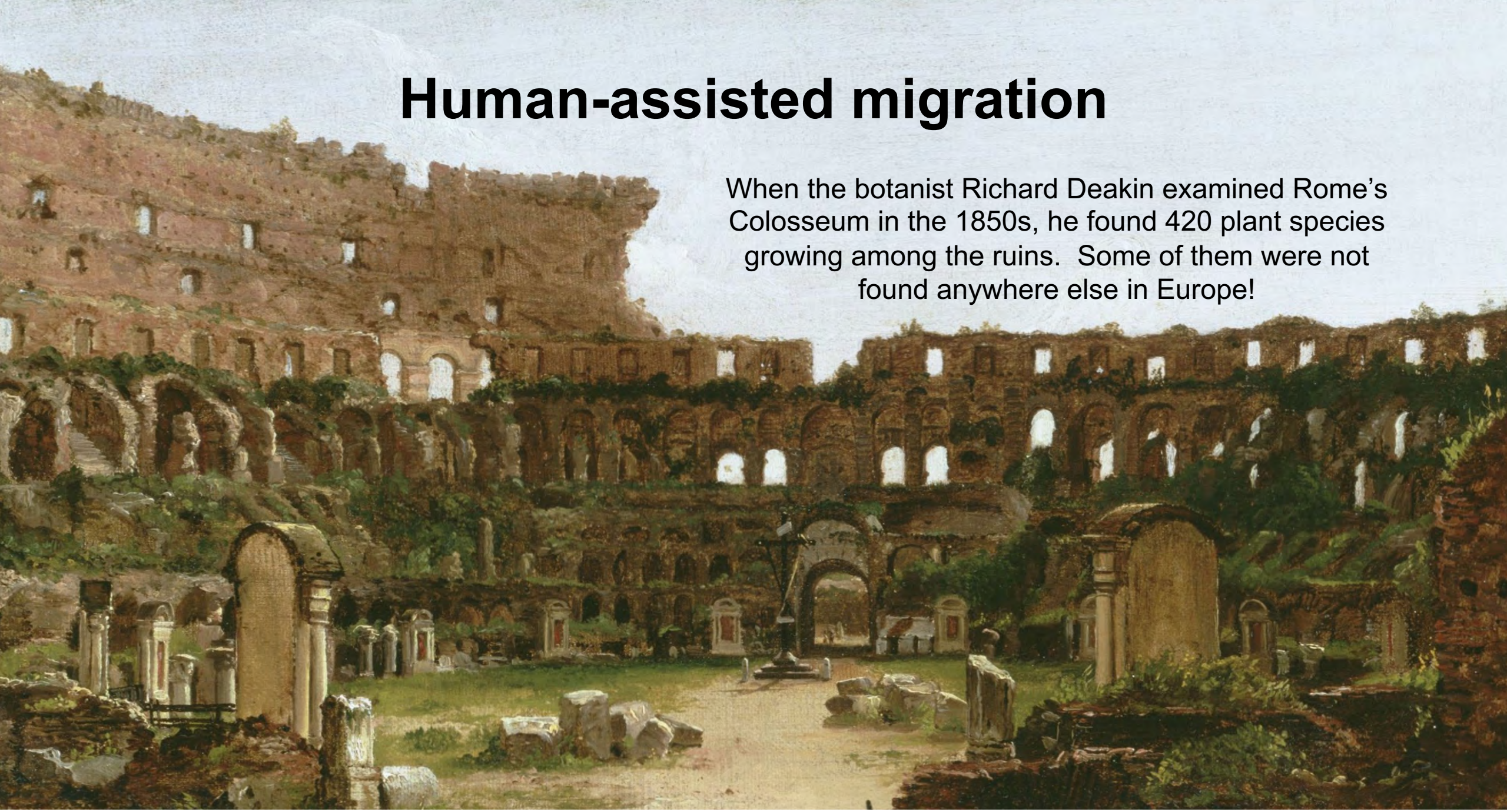
Geology happens



Hoorn *et* al. (2010) Amazonia Through Time: Andean Uplift, Climate Change, Landscape Evolution, and Biodiversity. *Science 12*: 927-931.

Human-assisted migration

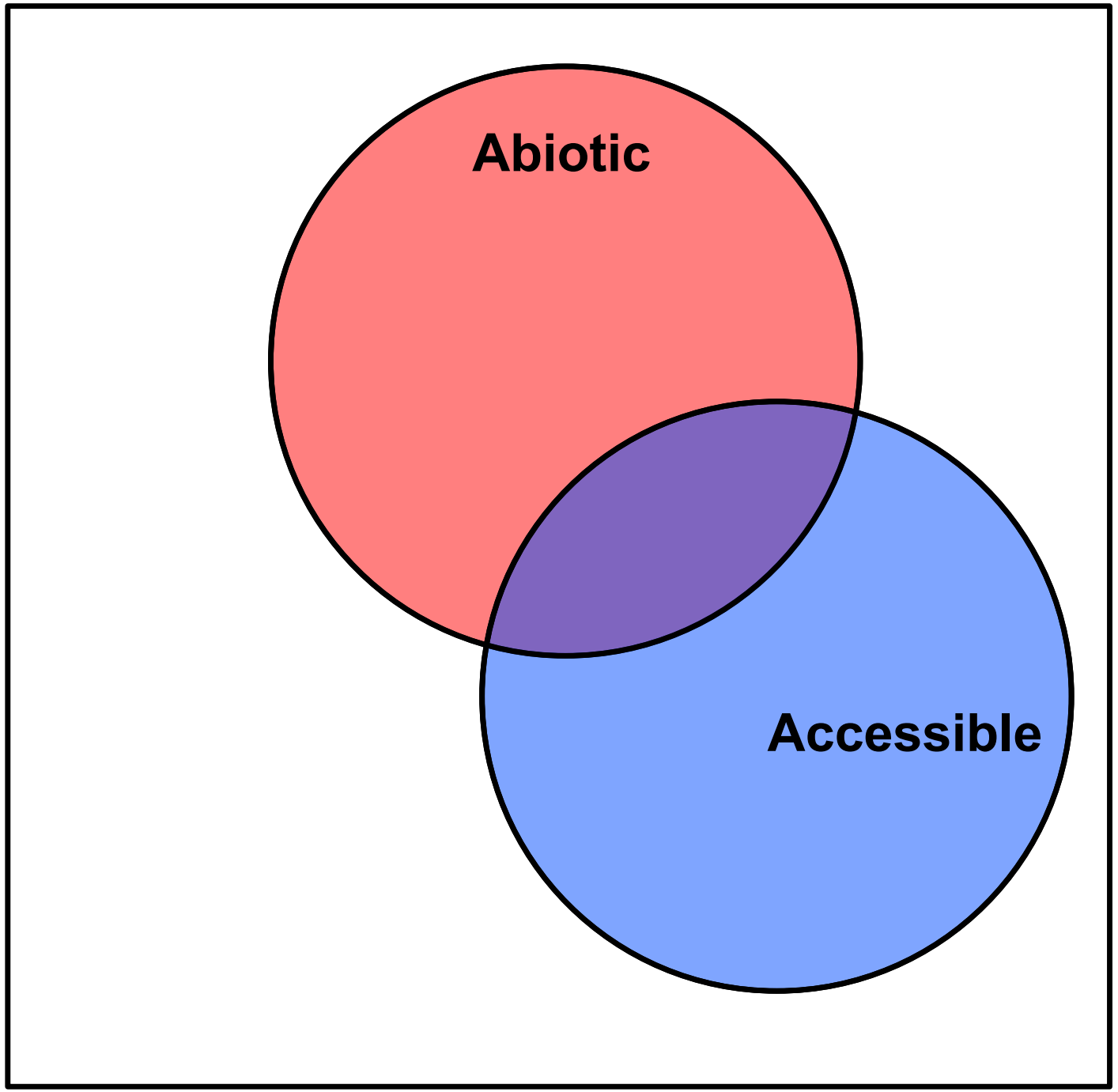
When the botanist Richard Deakin examined Rome's Colosseum in the 1850s, he found 420 plant species growing among the ruins. Some of them were not found anywhere else in Europe!



https://www.theatlantic.com/science/archive/2017/12/romes-colosseum-garden/547535/#:~:text=When%20the%20botanist%20Richard%20Deakin,and%2056%20varieties%20of%20grass.

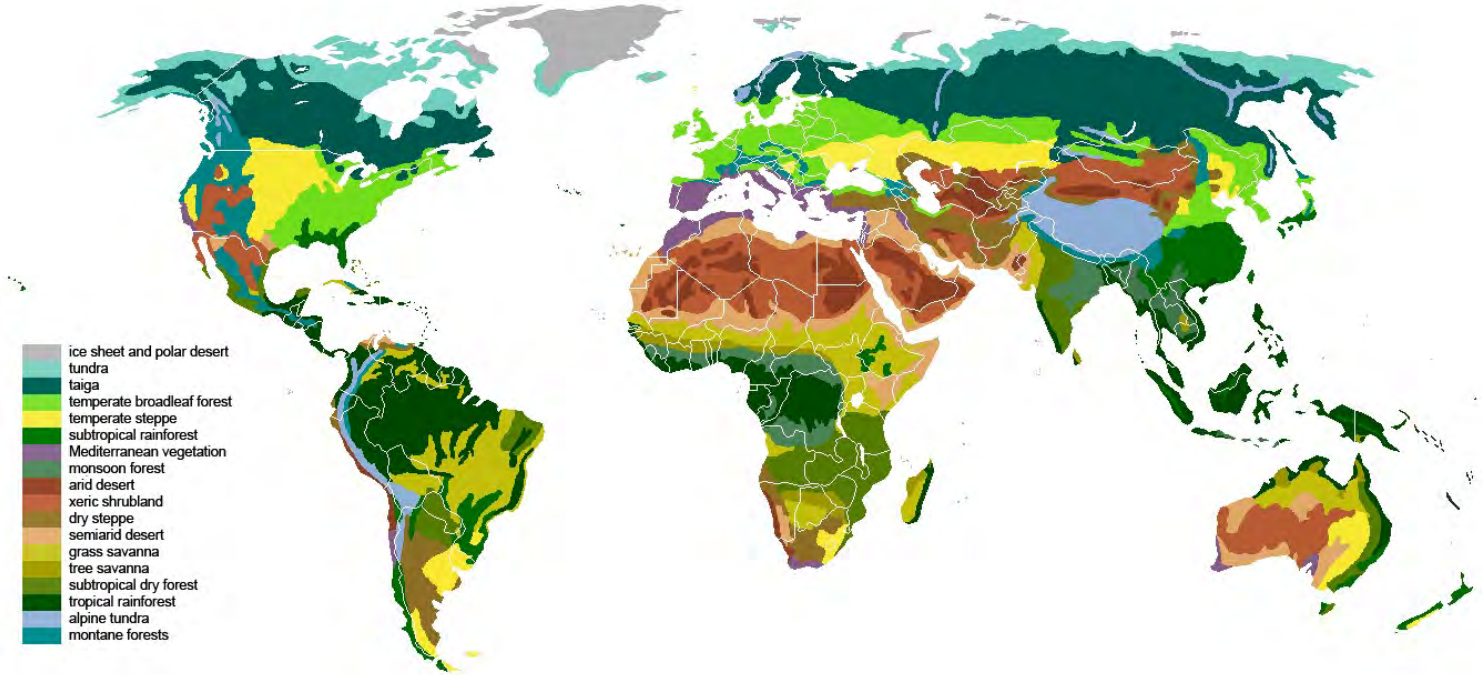
Who is where?
And why?

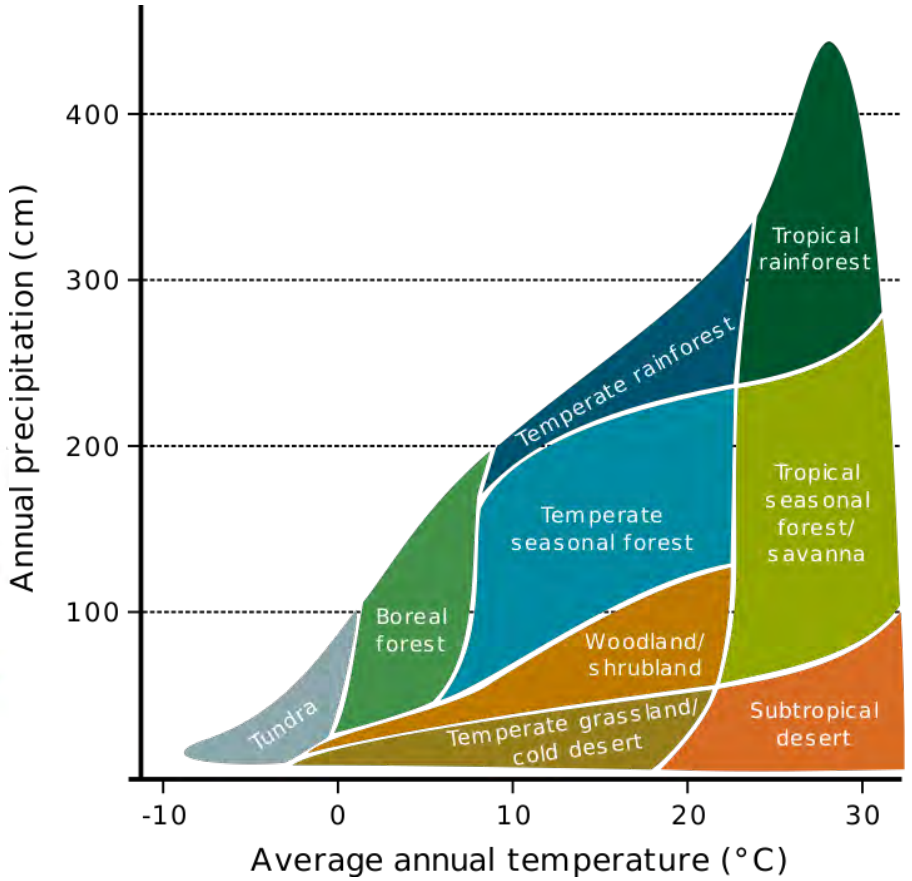
- Accessible (movement)
- Physiological tolerance (abiotic)
  - Climate
  - Soil / water chemistry
  - Nutrients



Biomes of Earth

Distributions of biomes are largely explained by mean annual rainfall and temperature





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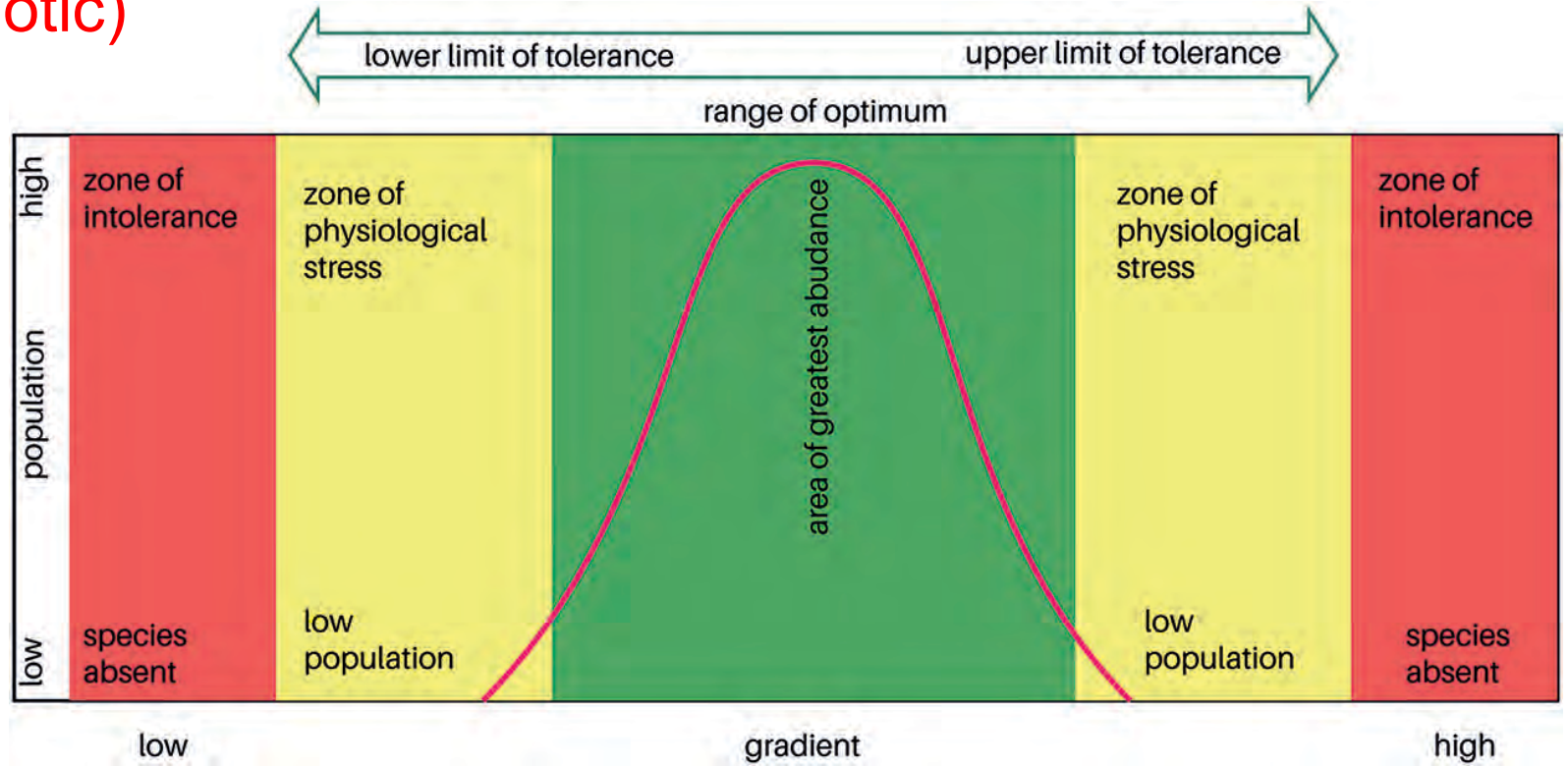

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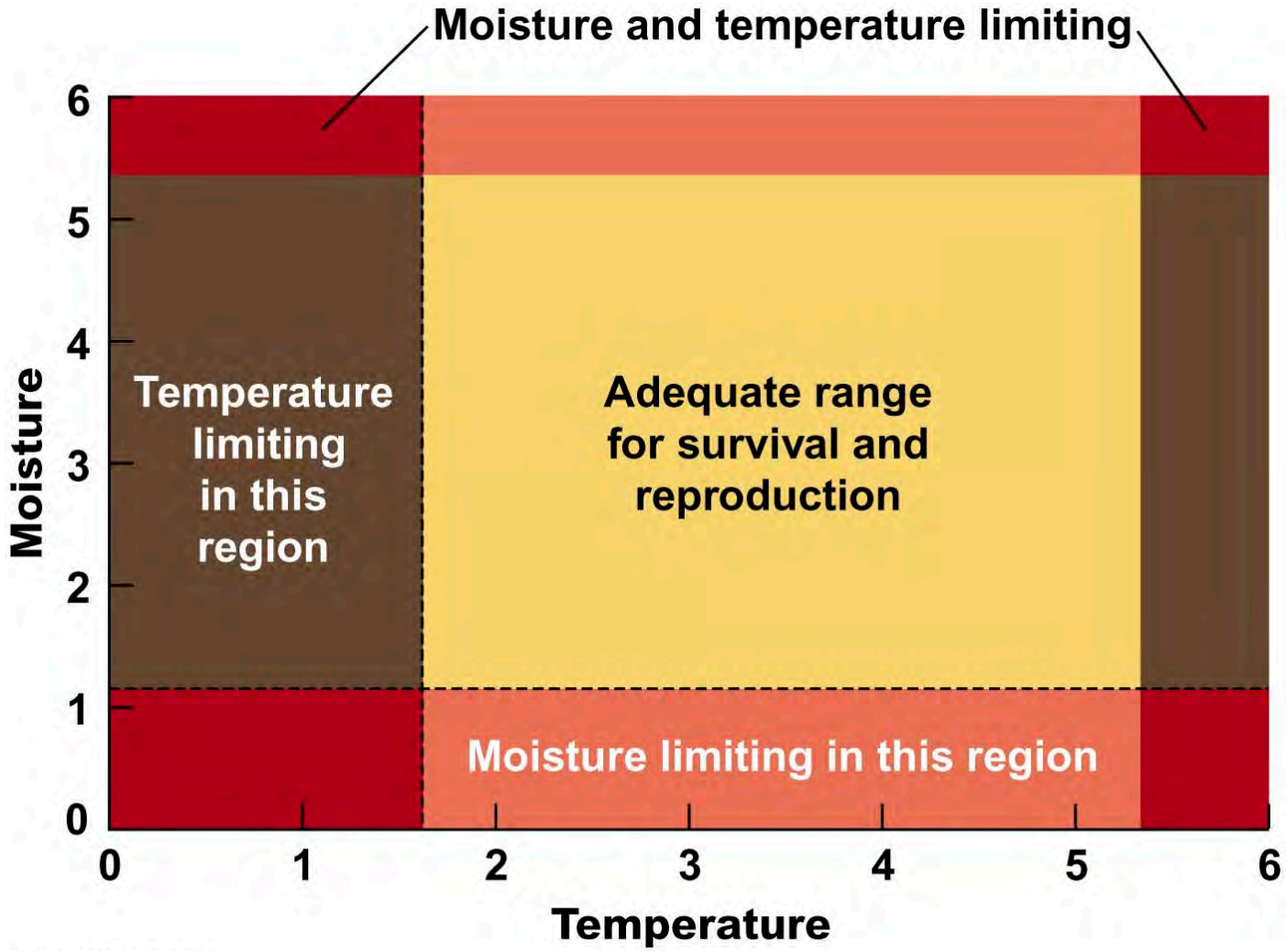
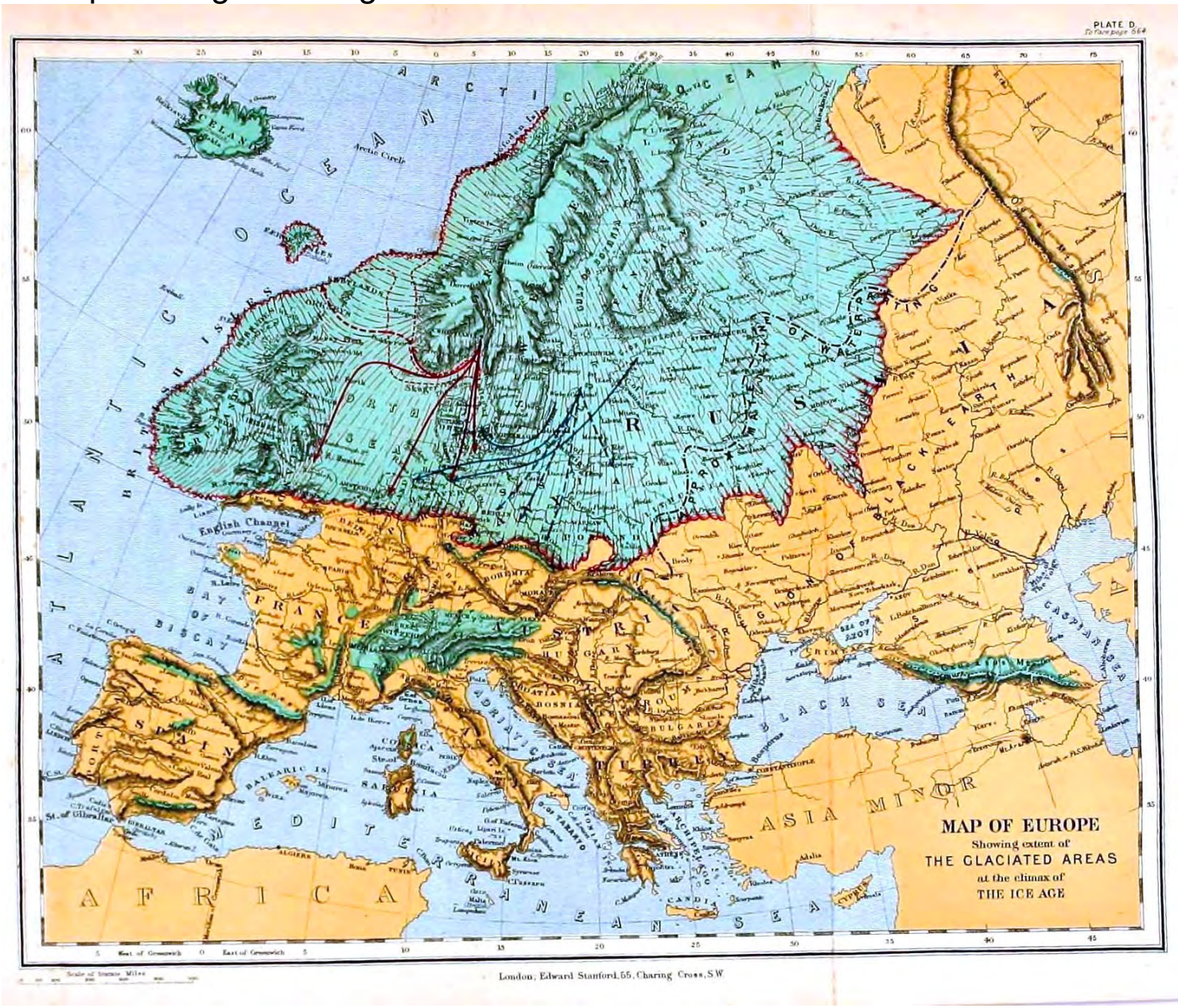


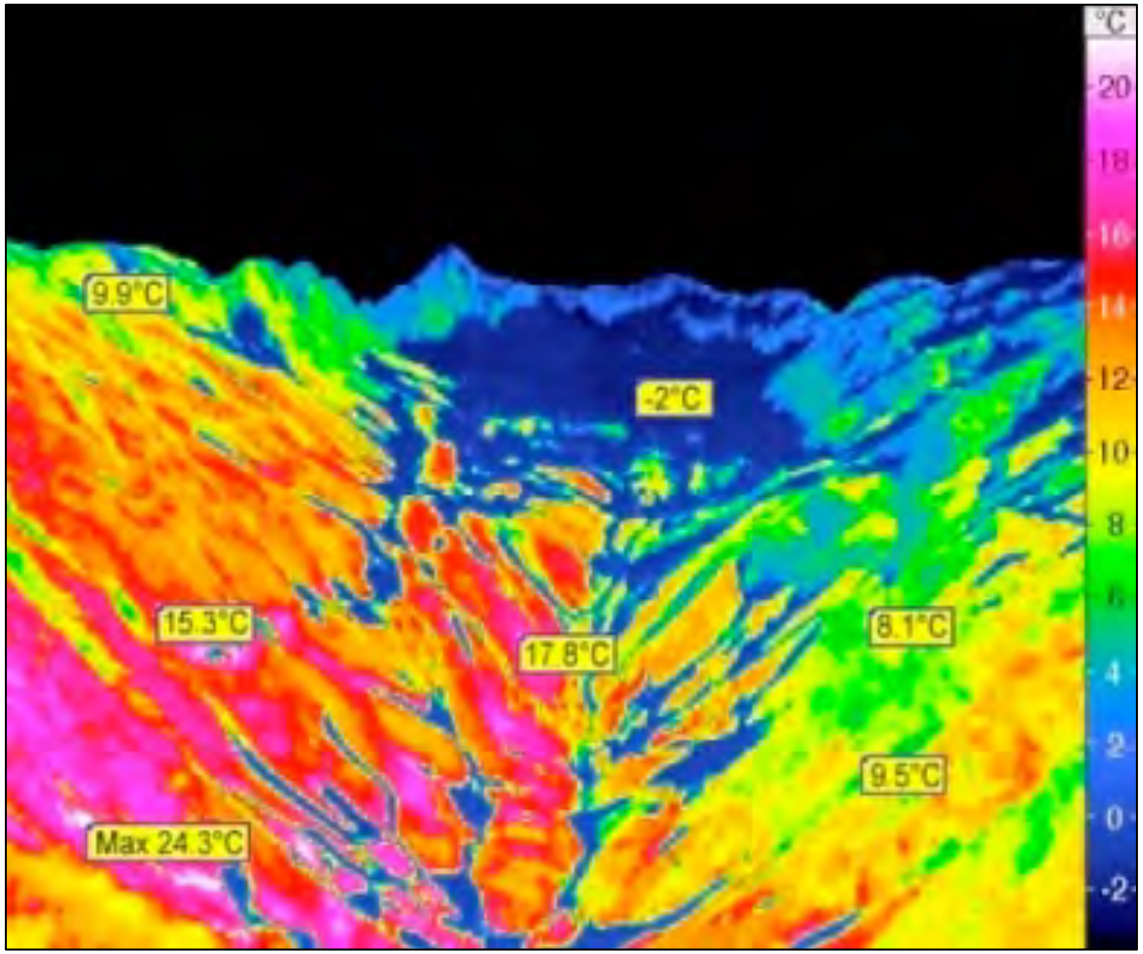
Who is where?
And why?

Megafauna in Spain during last glacial maximum

Europe during the last glacial maximum

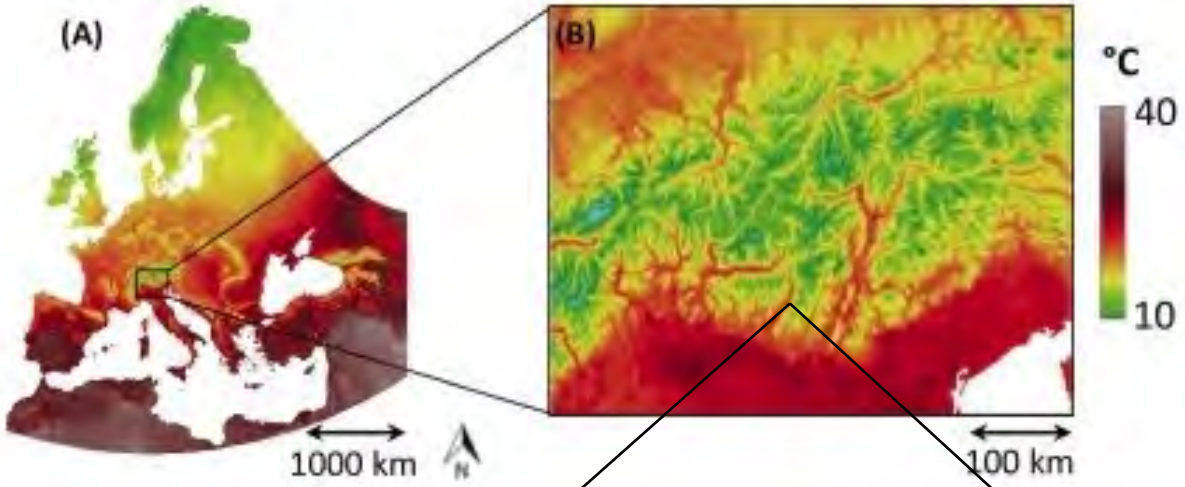


Microclimate matters

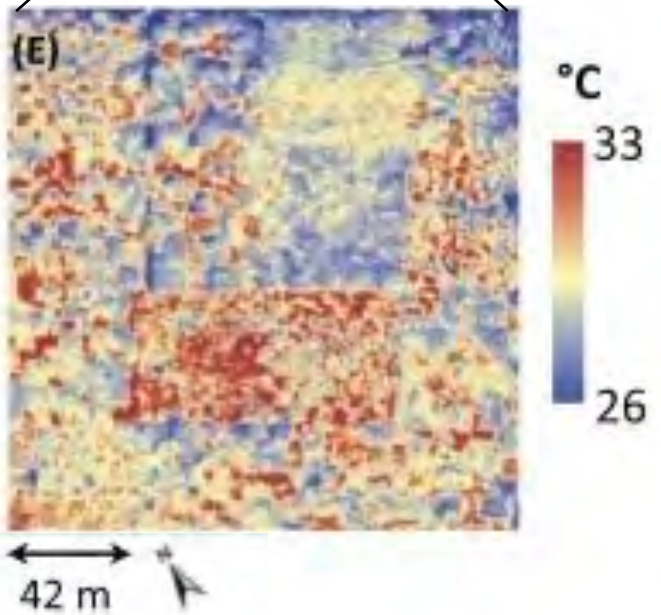


C. Körner

Satellite-based land surface temperature



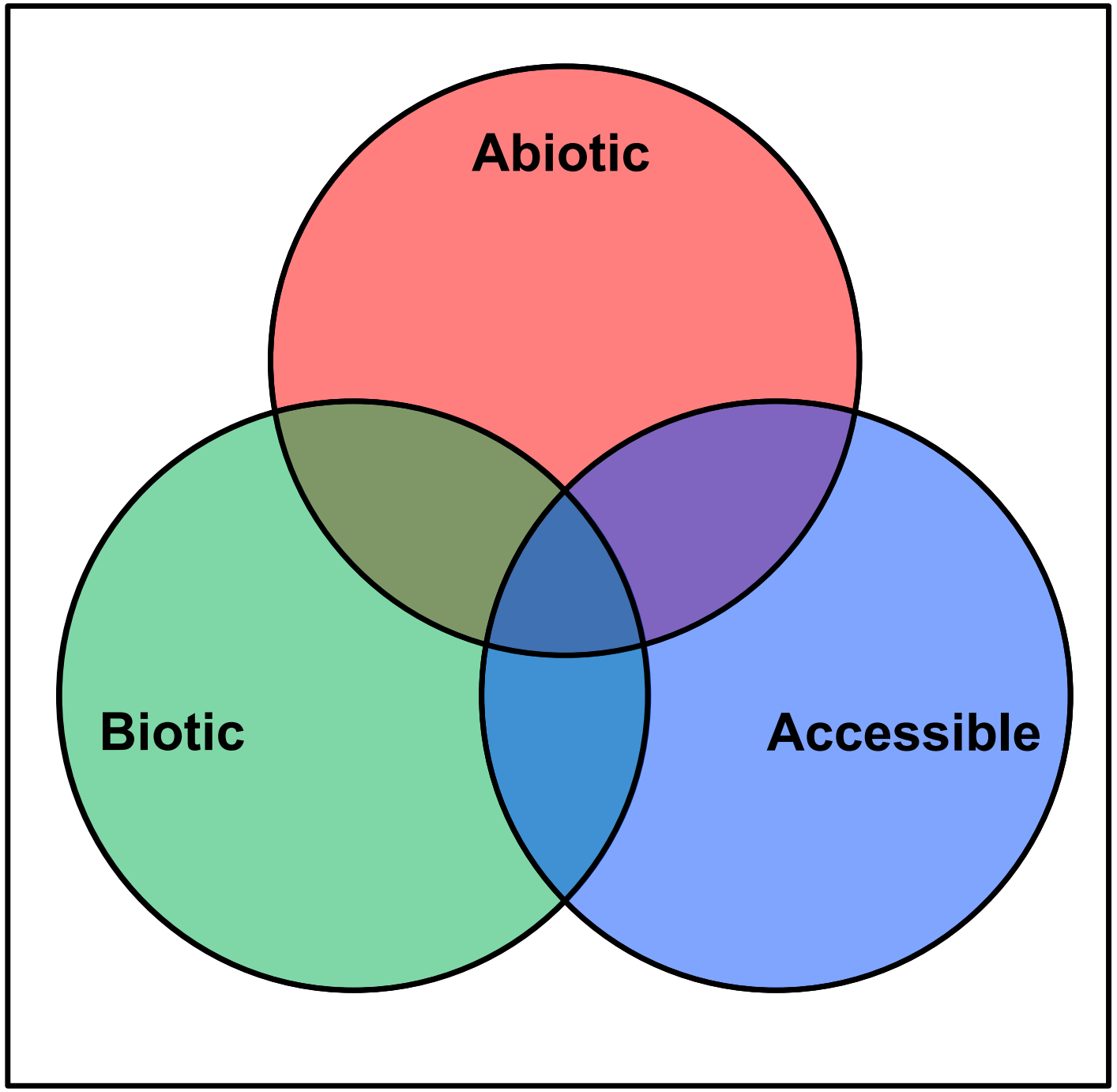
UAV-based remote sensing



Zellweger et al. (2019) Advances in Microclimate Ecology Arising from Remote Sensing. *Trends in Ecology & Evolution* 34: 327-341.

Who is where?
And why?

- Accessible (movement)
- Physiological tolerance (abiotic)
- **Biotic interactions**
  - Competition
  - Predators / Prey
  - Parasites
  - Mutualists
    - Pollinators
    - Soil symbionts
    - Facilitators
    - Dispersal



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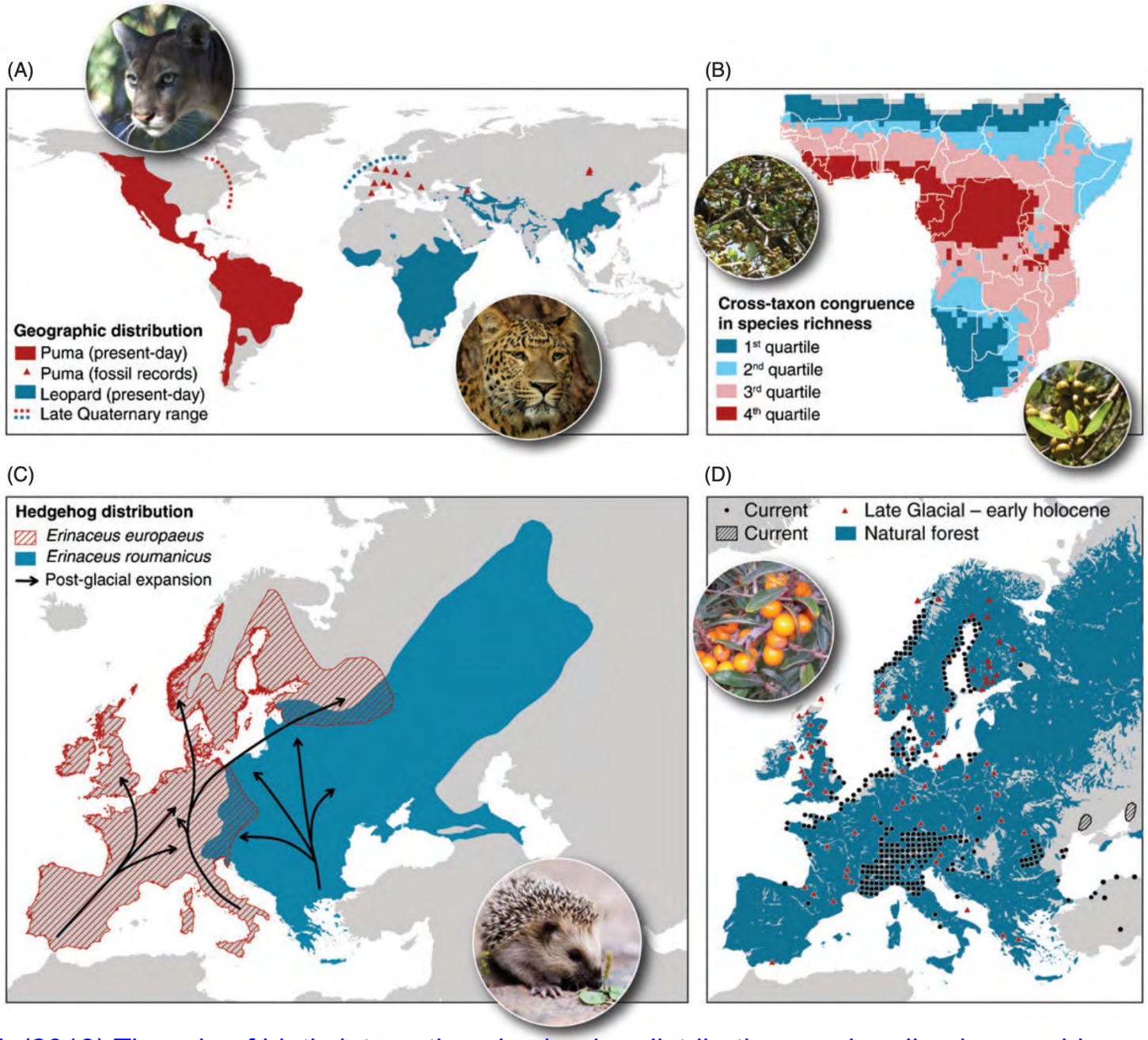
Biotic interactions can affect distributions



Wisz et al. (2013) The role of biotic interactions in shaping distributions and realised assemblages of species: implications for species distribution modelling. *Biological Reviews* 88: 15-30.

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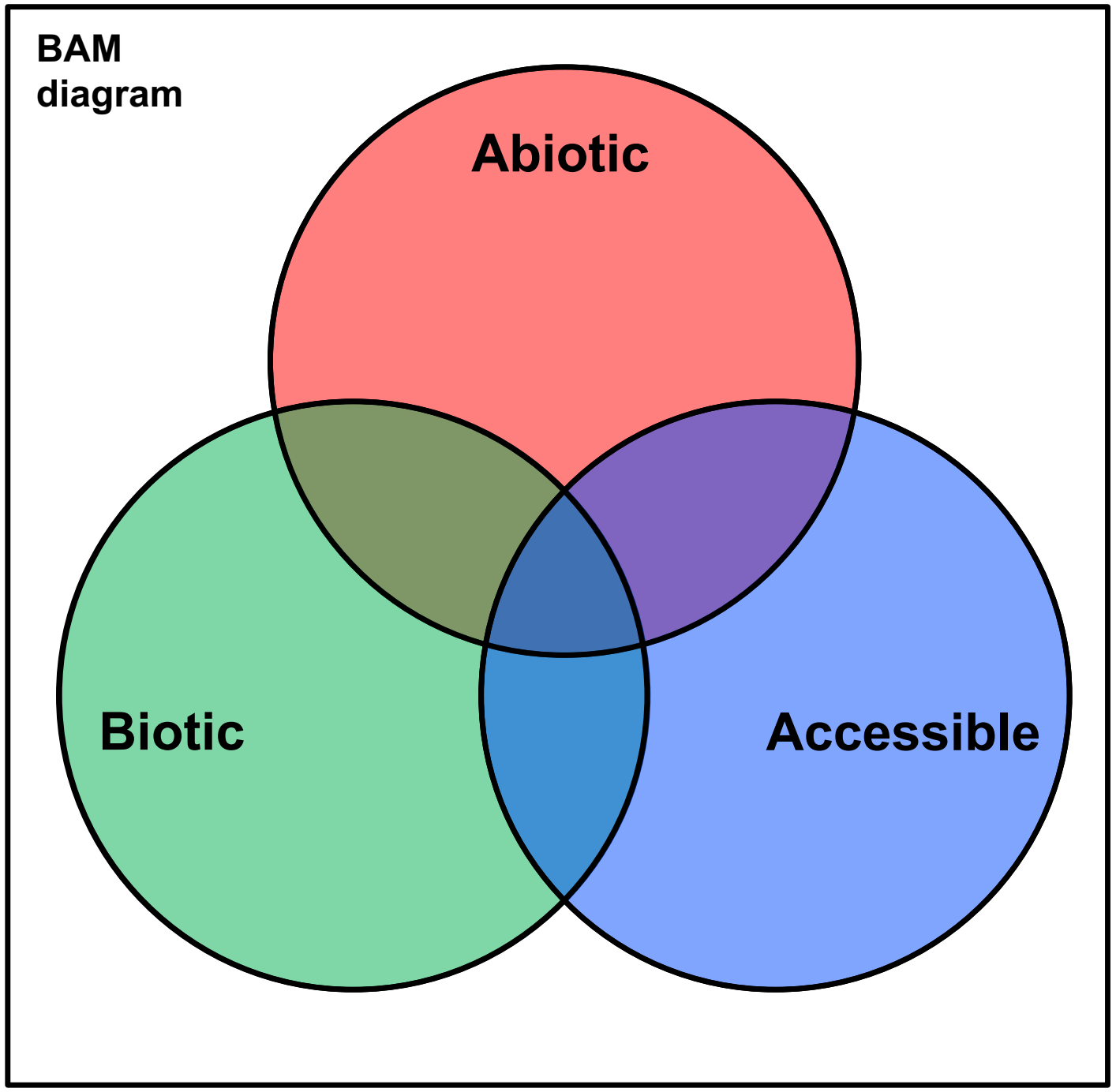

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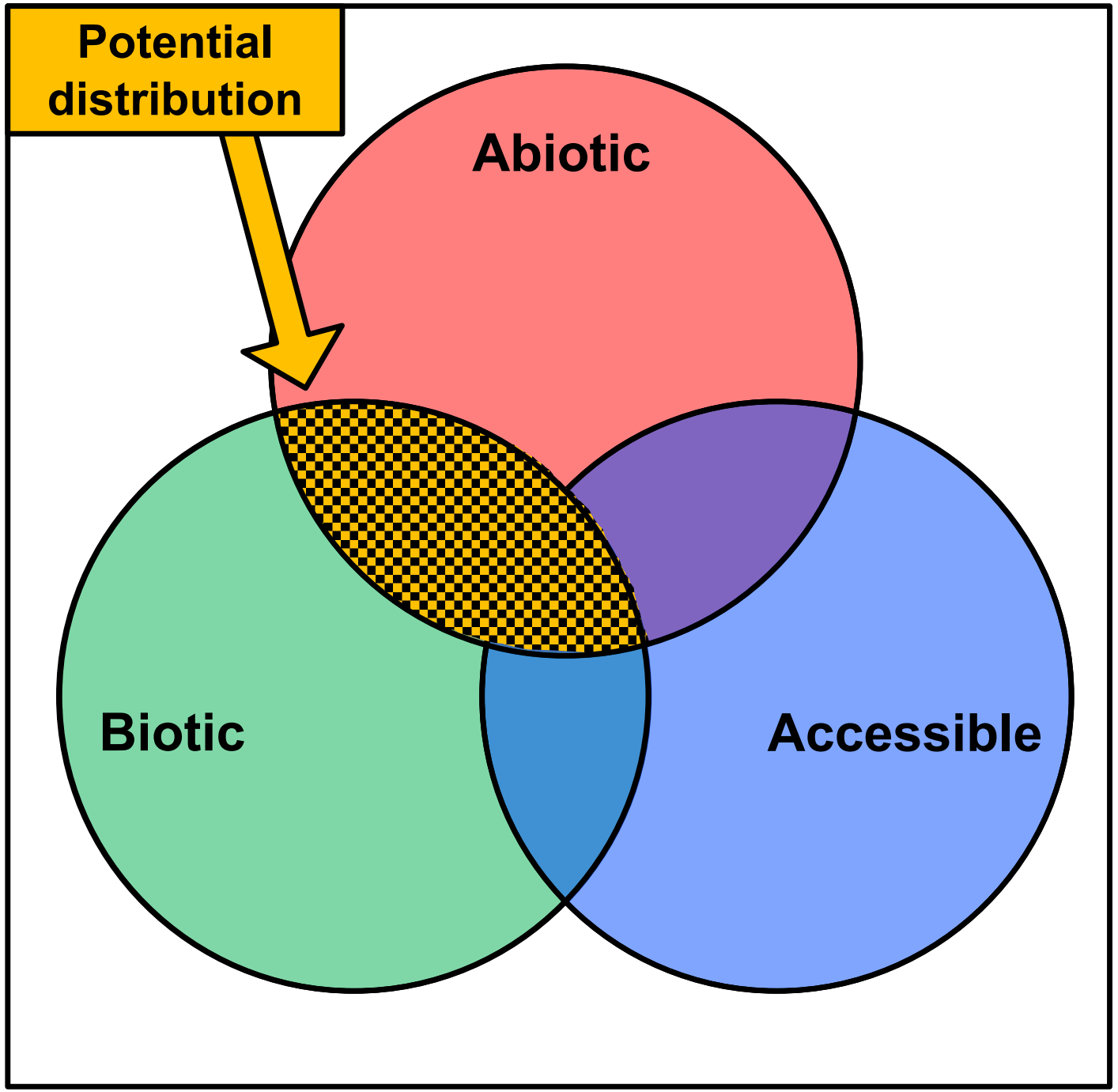
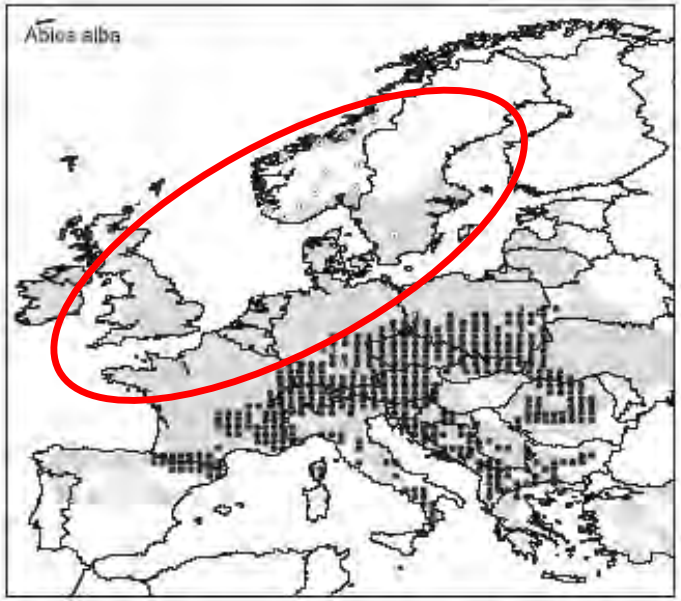
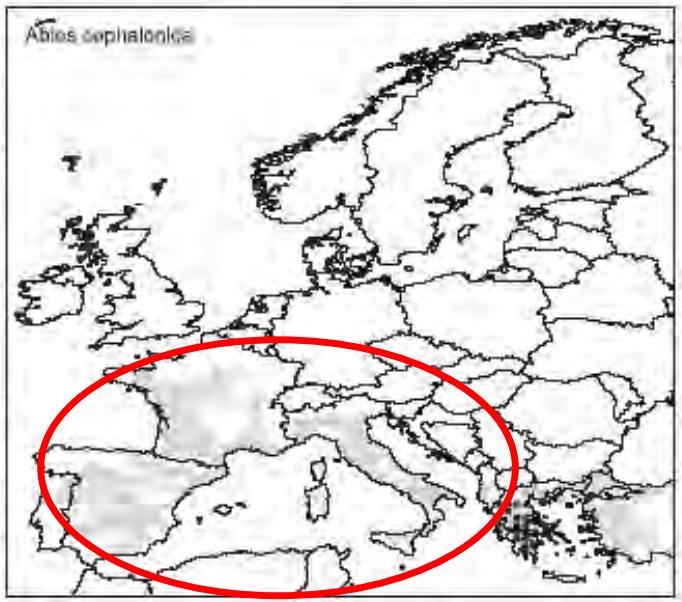
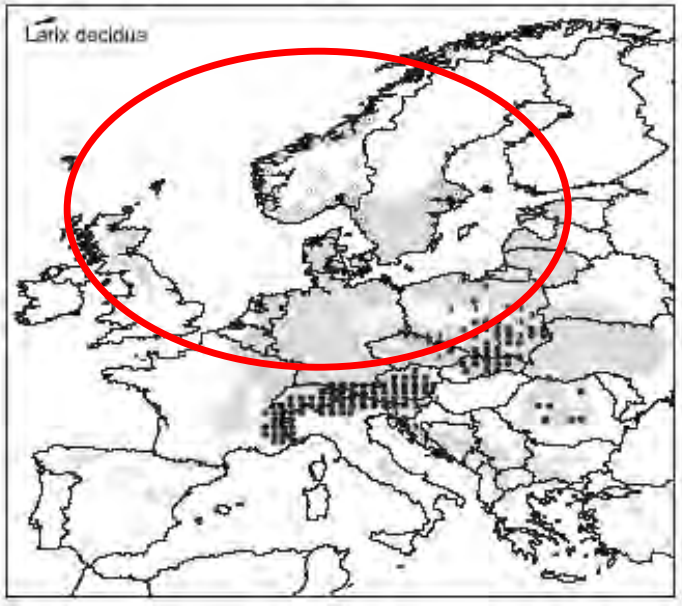
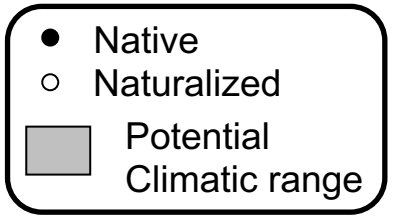


Limited filling of the potential range in European tree species









Svenning & Skov (2004) *Ecology Letters.* Limited filling of the potential range in European tree species

Who is where?
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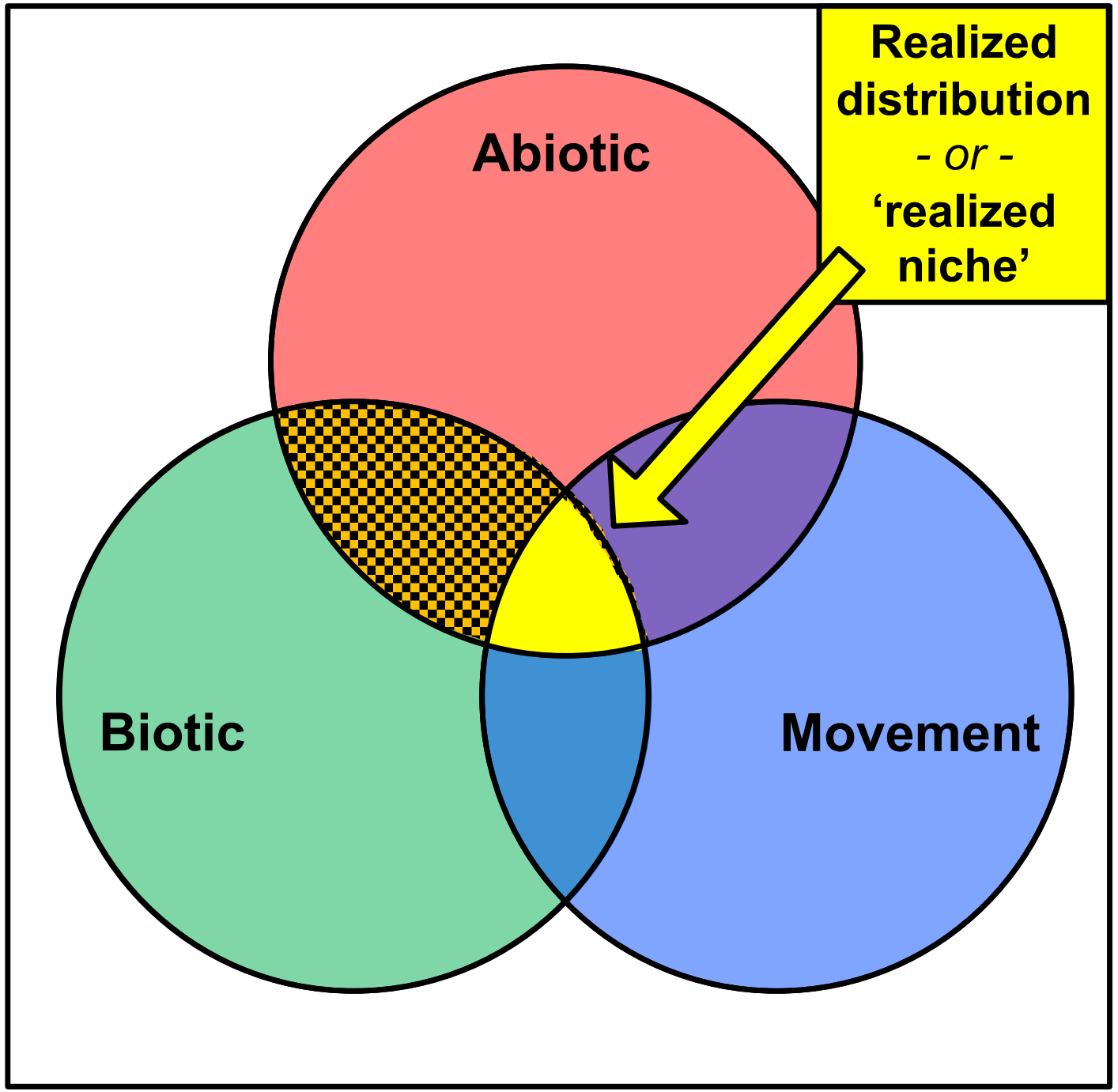
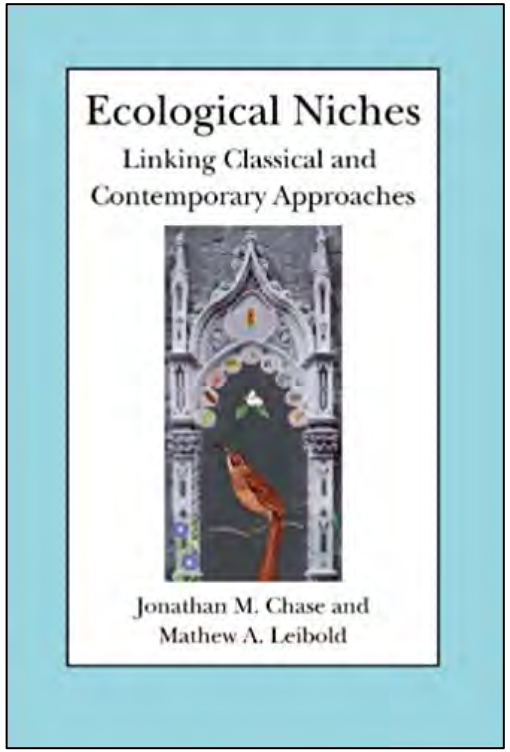
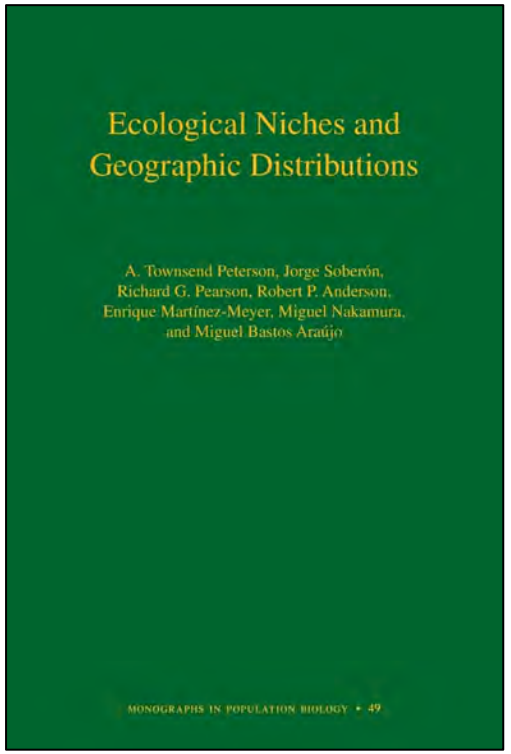


The Ecological Niche

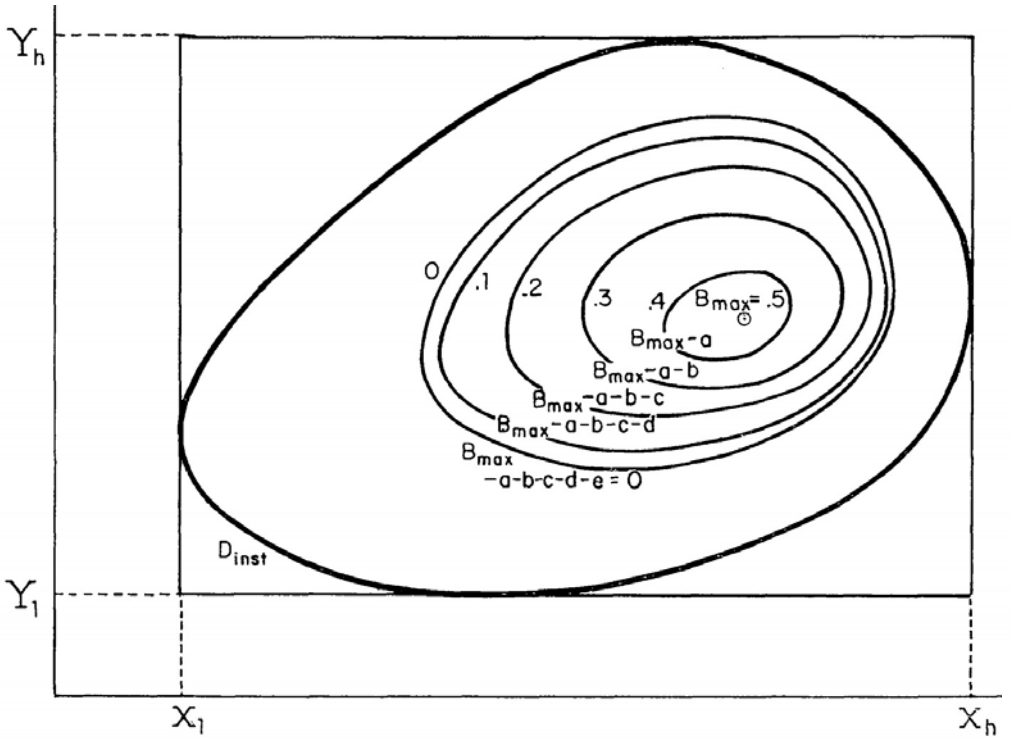
- Broadly defined as the conditions where a species can exist (*spatial, temporal, behavioral, etc.*)
- Multivariate and complex, (*e.g.*, life stages, above / below-ground, etc.)
- The ecological niche is a *scientific construction* – NOT a specific place
- Multiple definitions and hotly debated!

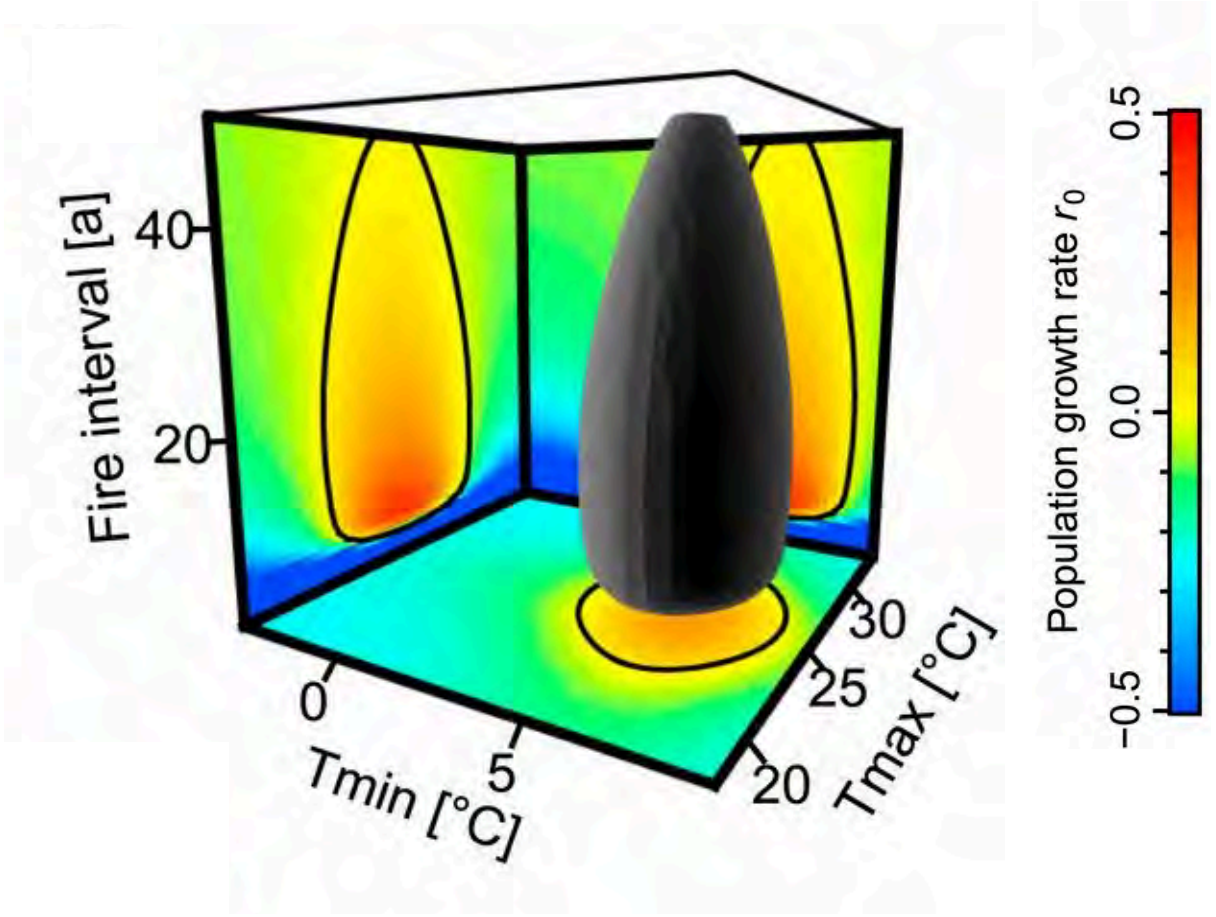




The Ecological Niche as a *fitness landscape*

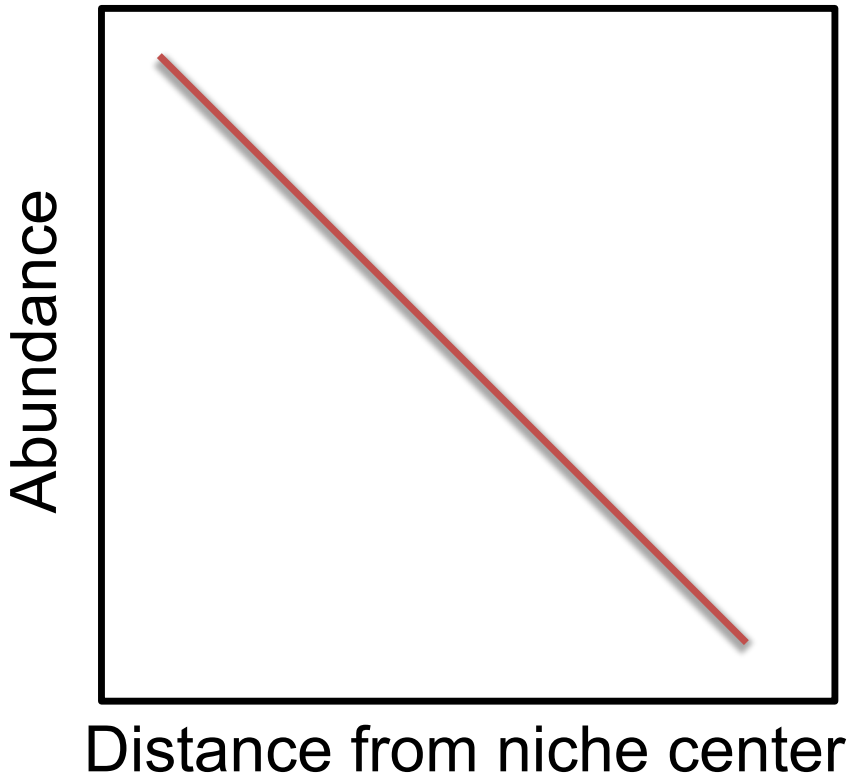
- Maguire (1973) proposed niches should have a structure measured in fitness



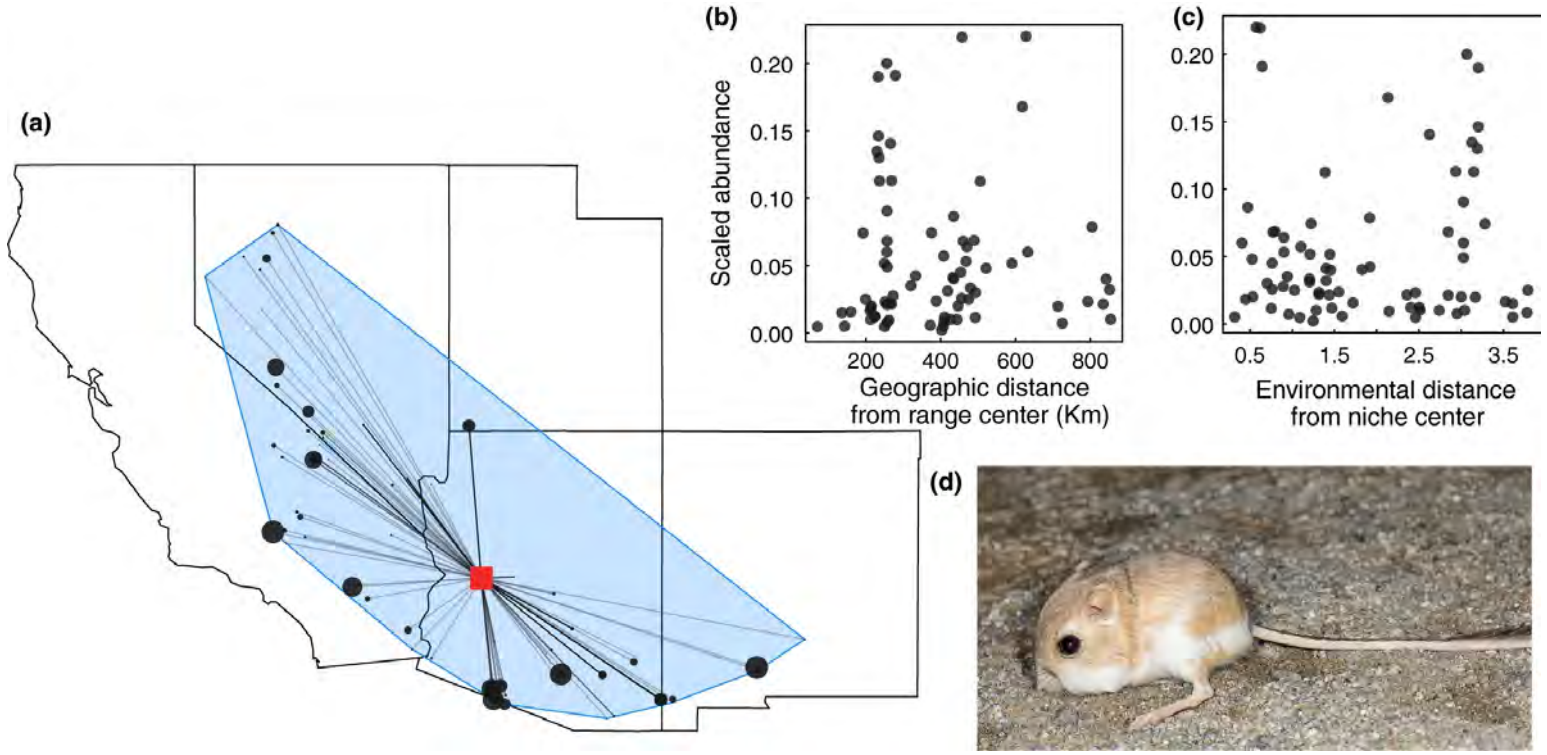


Maguire (1973) *The American Naturalist*. http://www.jstor.org/stable/2459795
Pagel et al. (2020) *Proc. of the National Academy of Sciences*. https://www.pnas.org/content/117/7/3663

The ‘Abundant Center’ Hypothesis



For >1,400 species of birds, trees, mammals, fishes:



Dallas et al. (2017) Species are not most abundant in the centre of their geographic range or climatic niche. *Ecology Letters*. 10.1111/ele.12860

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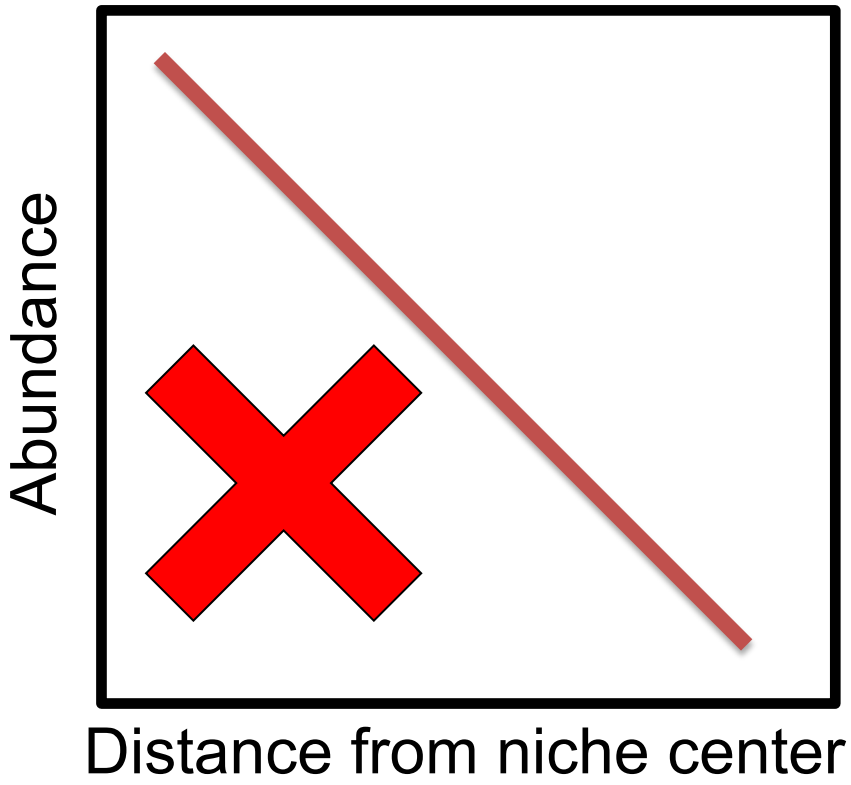

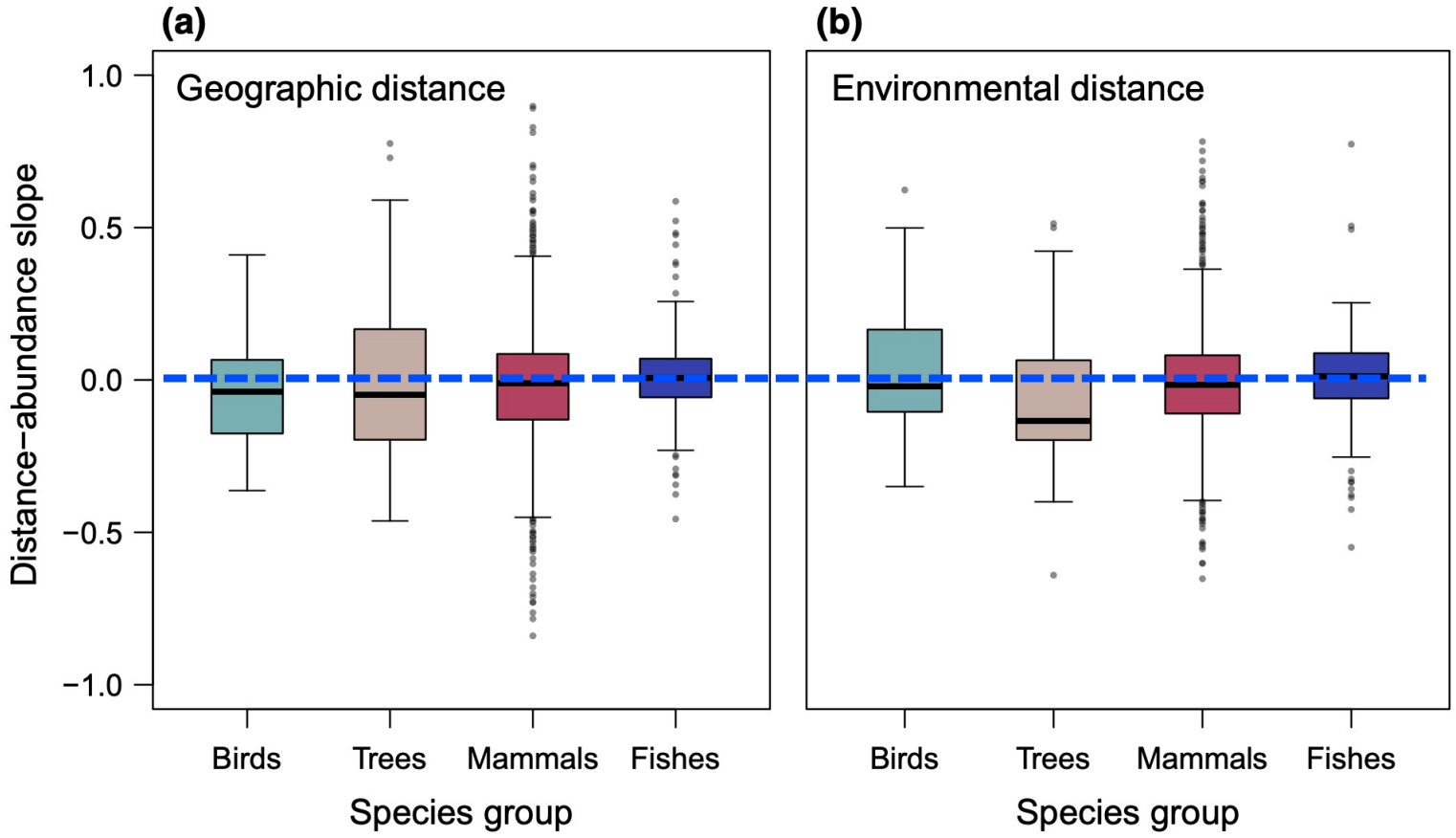

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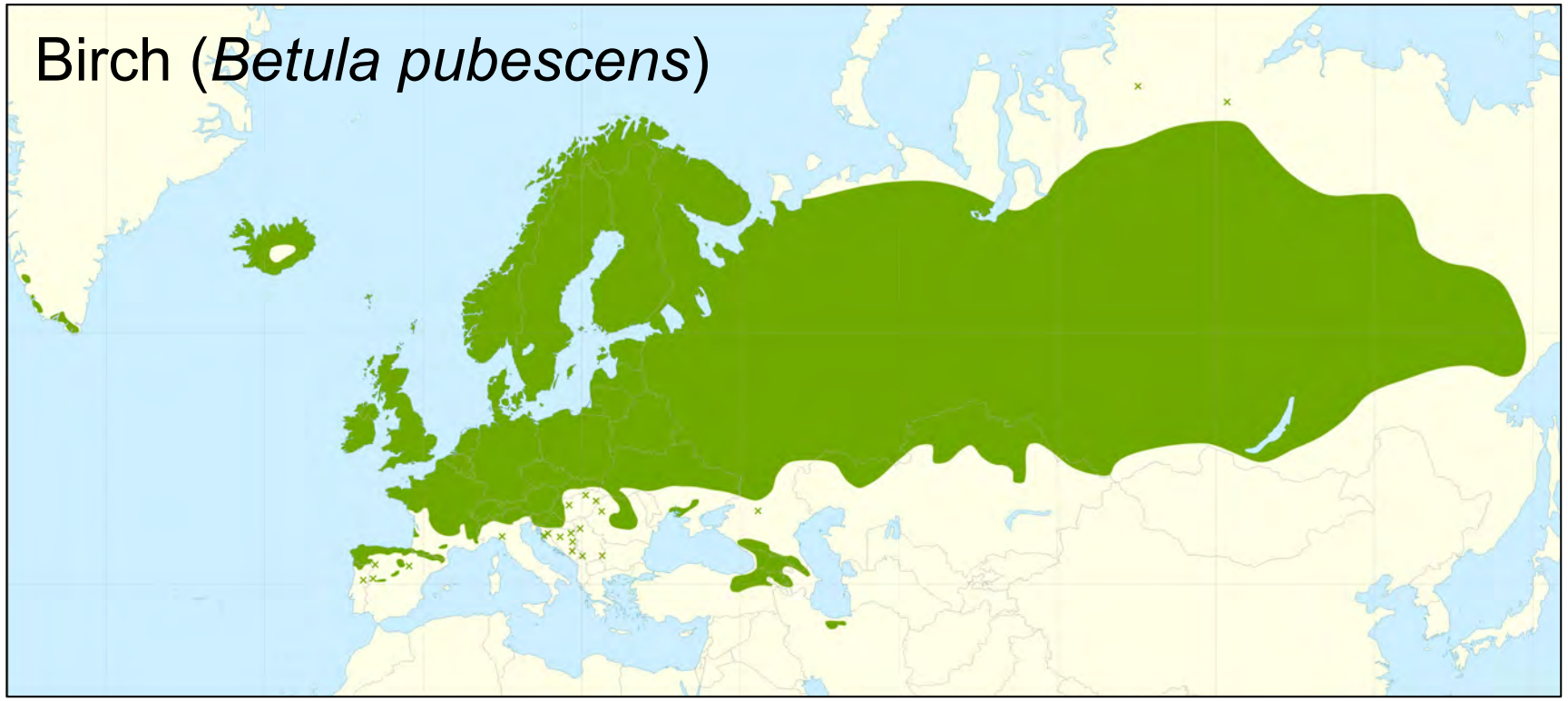
Birch (*Betula pubescens*)



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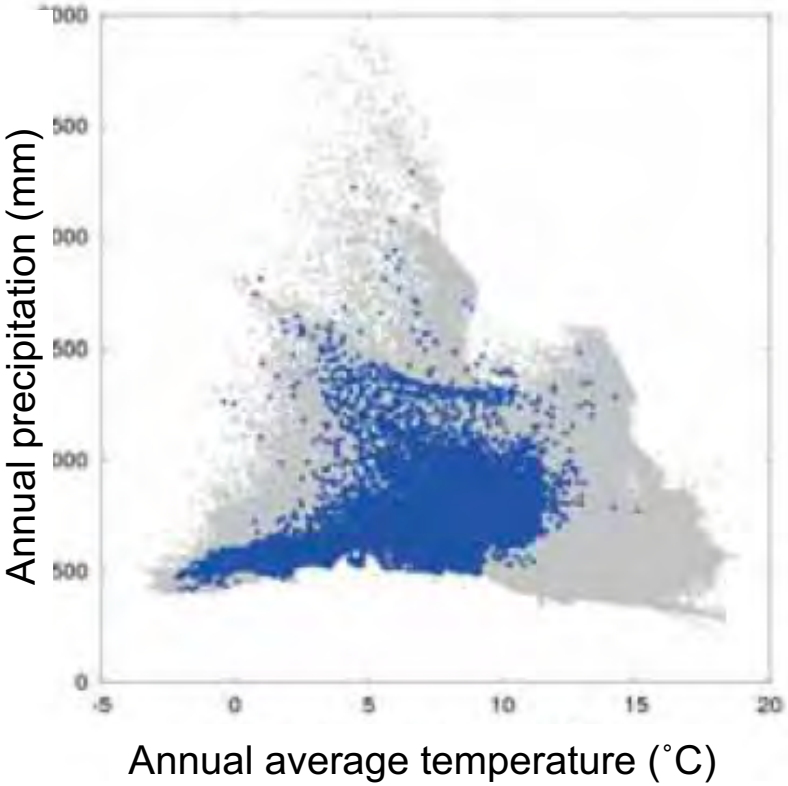

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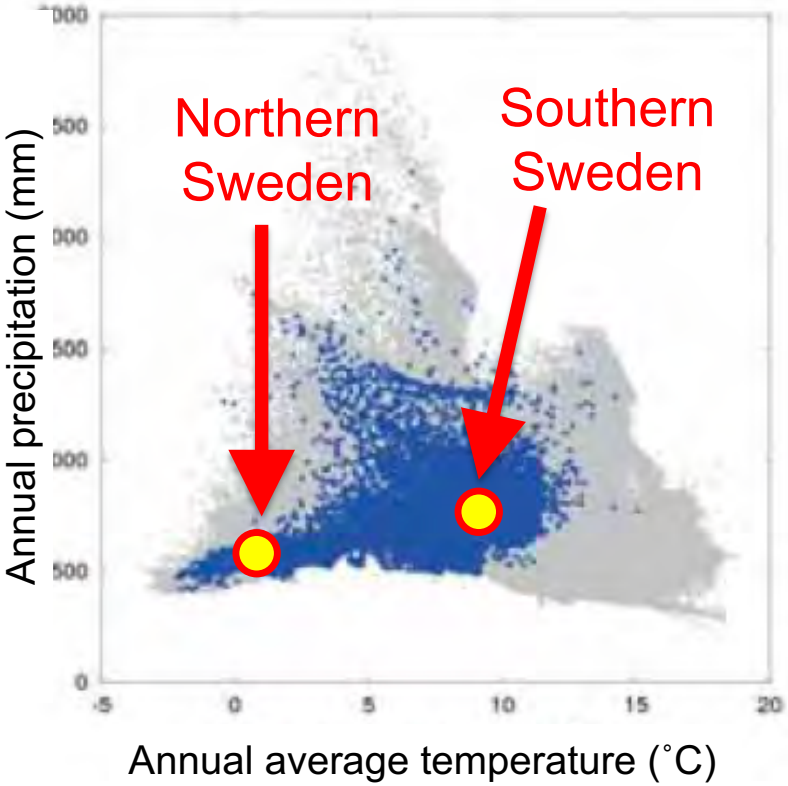


Intraspecific variation and ecotypes

Turesson's birches

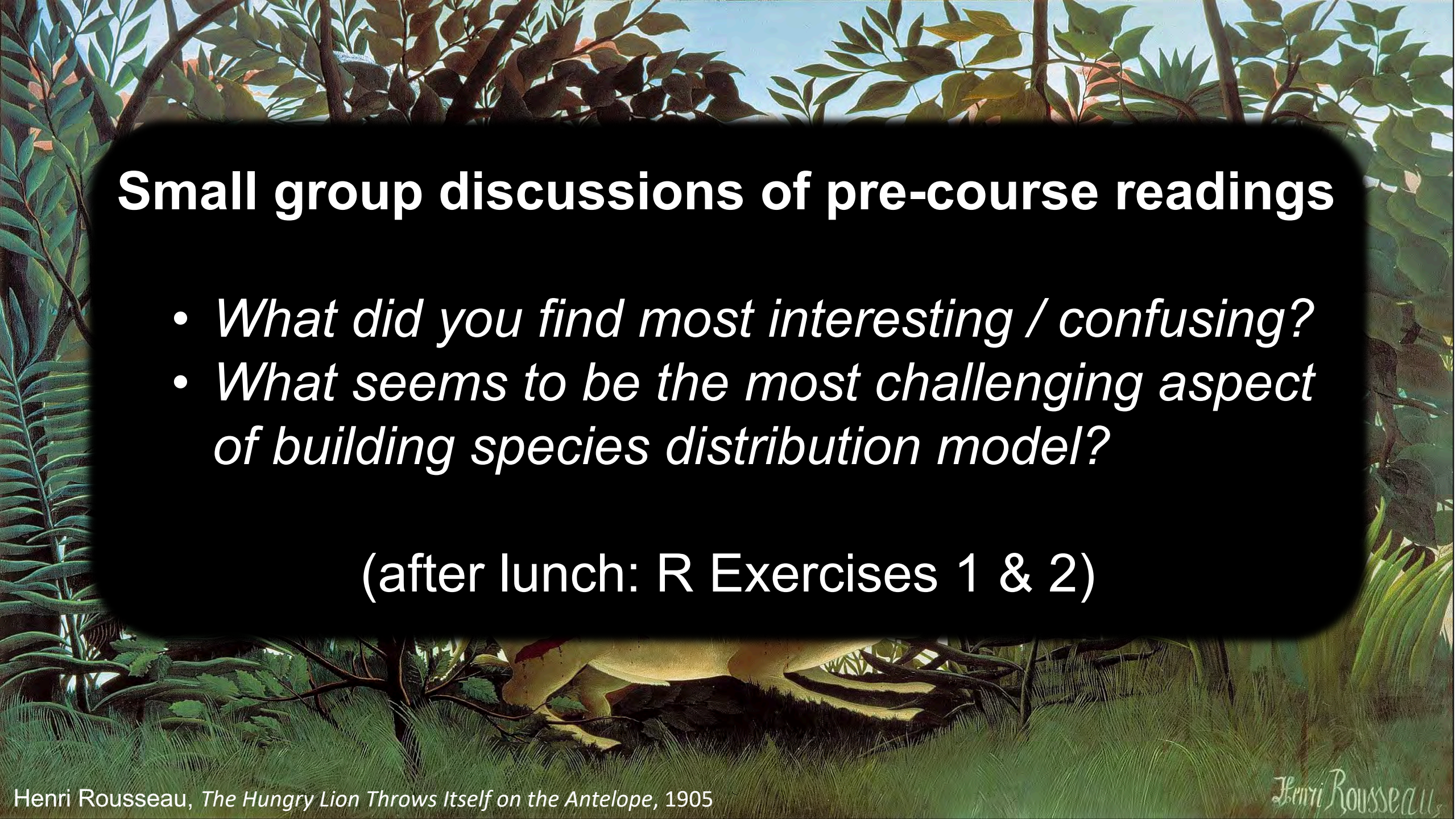
Göte Turesson
(1892 – 1970)

Summary

- Species distributions + niches are scale-dependent and estimated from imperfect data
- Species distributions + niches are governed by a combination of accessibility, abiotic conditions, and biotic interactions
- Species distributions + niches are dynamic and change in space / time
- Abundance + fitness vary in complex ways across a species' distribution + niche

Questions?

Henri Rousseau, *The Hungry Lion Throws Itself on the Antelope*, 1905



Small group discussions of pre-course readings

- *What did you find most interesting / confusing?*
- *What seems to be the most challenging aspect of building species distribution model?*

(after lunch: R Exercises 1 & 2)

Henri Rousseau, *The Hungry Lion Throws Itself on the Antelope*, 1905