What do we need to model changes in global biodiversity

Jorge Soberon, Department of Ecology and Evolutionary Biology and Biodiversity Institute

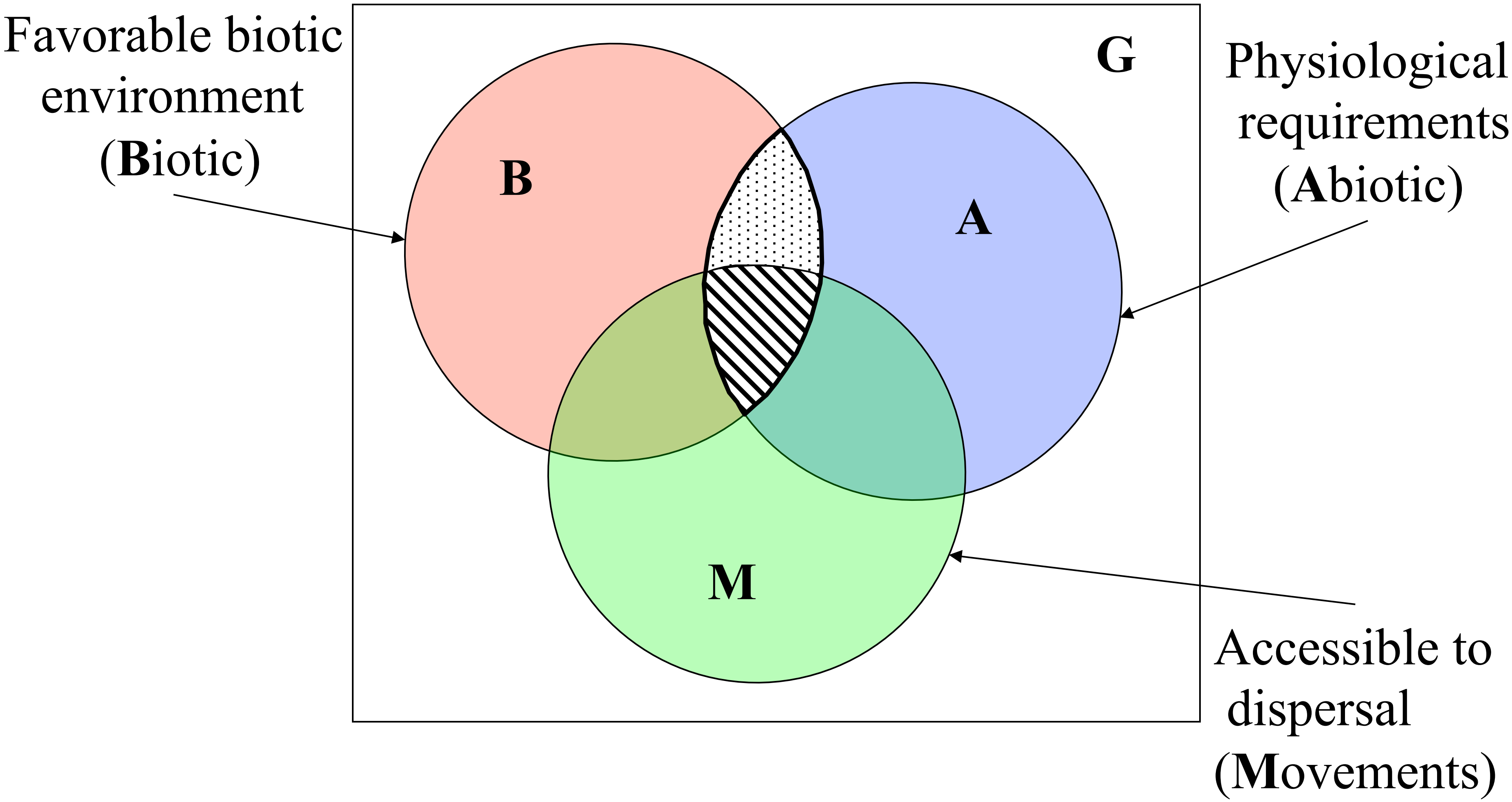
Biodiversity…

- All manifestations of life on earth
- It is about "points of view"
- Ecosystem view
- Taxonomic view
- Phylogenetics view
- Morphologic view…

Species view

- Question is: how climate change drives “biodiversity” = aggregate of species.
- Biodiversity as “a group of species”
- This can be modeled using specimen-based data to estimate something called the niche, which is essentially a description of tolerance to extreme conditions and preferences for optimal ones.

The area of distribution



“Niche Modeling”

- It is used to model climate change all the time. Hundreds of papers
- Requires simple and very abundant data, but these databases are out there
  - Climate (Petabytes)
  - Occurrences (Terabytes)
- Software (about 20 methods, R packages, free programs…)

The Condor 108:778–791
© The Cooper Ornithological Society 2006

CLIMATE CHAN
DIVERSITY BASED

Natural History Museu

MAR

Niches, models, and climate change: Ass
the assumptions and uncertainties

John A. Wiens[a,1], Diana Stralberg[a], Dennis Jongsomjit[a], Christine A. Howell[a], and Mark A. Sny

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Sciences, University of California, 1156 High Street, Santa Cruz, CA 95064

predict the
ions

Future projections for Mexican
faunas under global climate
change scenarios

wnsend Peterson*, Miguel A. Ortega-Huerta†, Jeremy Bartley
Sánchez-Cordero§, Jorge Sob
R. B. Stockwell¶, Robert H. Buddemeie

Global Change Biology (2006) 12, 2272–2281,

The ability of climate env
effect of climate change on

ROBERT J. HIJMANS*[1] and CATHERINE H. GR
*Museum of Vertebrate Zoology, University of California, 3101 Valle
†Department of Ecology and Evolution, Stony Brook University, 636

Birds track their Grinnellian niche throug
of climate change

Morgan W. Tingley[a,b,1], William B. Monahan[c], Steven R. Beissinger[a,b], and Craig Moritz[b,d]

Departments of [a]Environmental Science, Policy, and Management and [d]Integrative Biology, and [b]Museum of Vertebrate Zoology, University o
Berkeley, CA 94720; and [c]Audubon California, 4225 Hollis Street, Emeryville, CA 94608

Accepted 1 September 20

Validation of species–climate impact models under
climate change

MIGUEL B. ARAÚJO*†, RICHARD G. PEARSON*‡, WILFRIED THUILLER§ and
MARKUS ERHARD¶

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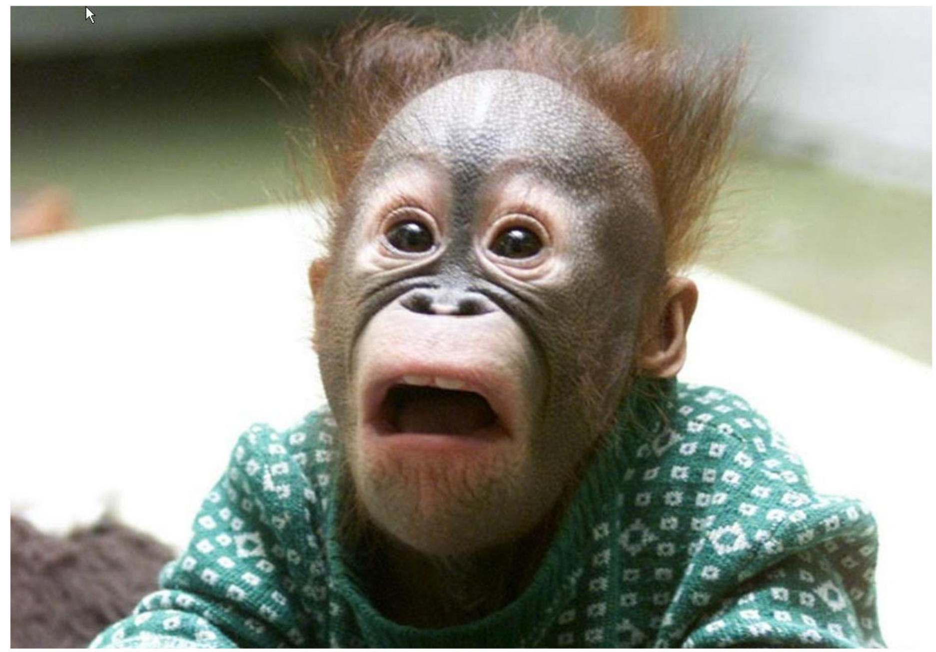
Research Group, Kirstenbosch Research Centre, South African National Biodiversity Institute, Private Bag x7, Claremont 7735,
Cape Town, South Africa, ¶Institute for Meteorology and Climate Research, Forschungszentrum Karlsruhe, Postfach 3640, 76021
Karlsruhe, Germany

Partitioning and mapping uncertainties in ensembles of forecasts
species turnover under climate change

José Alexandre F. Diniz-Filho, Luis Mauricio Bini, Thiago Fernando Rangel,
Rafael D. Loyola, Christian Hof, David Nogués-Bravo and Miguel B. Araújo

However….

- Current ENM is correlational
- It is static
- It ignores interactions
- It ignores history
- It ignores evolution
- It is coarse-grained (no habitat)

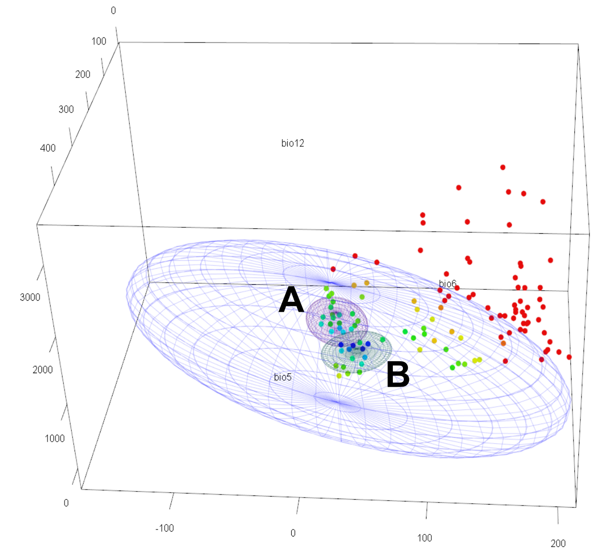


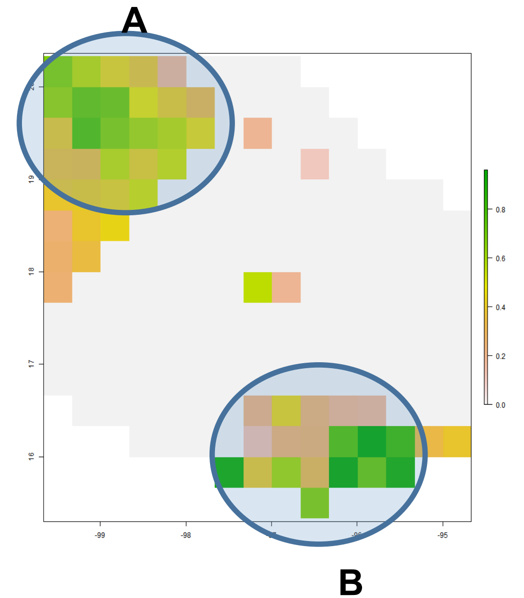
What a disaster!!

http://iheartHisto.com/post/50931794921/histology-look-a-like-23-skin-v-baby-orangutan

All is not lost

- We have a growing amount of data (iDigBio, GBIF, eBird, SANBI, CONABIO…)
- We have a much better theoretical understanding that ten years ago
- We have faster computers and better software
- We can keep improving on all the above



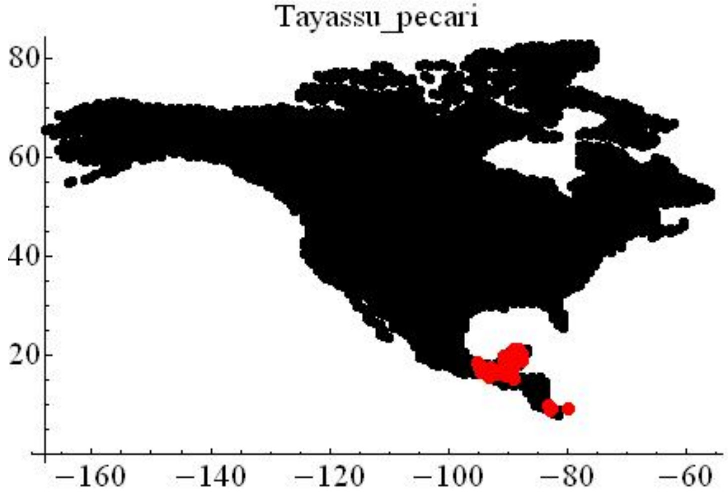


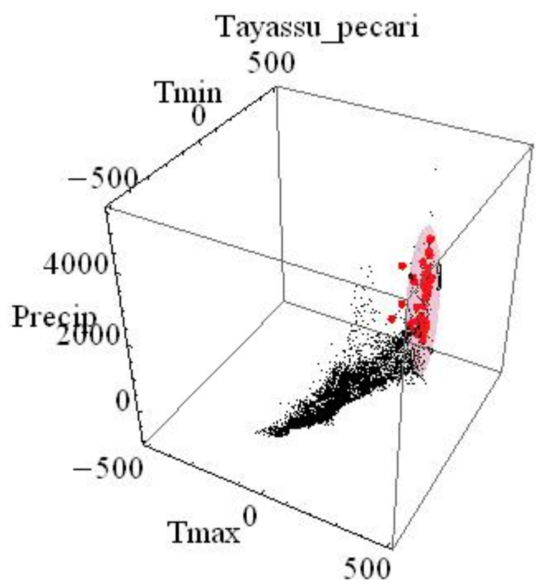
Some natural next steps

- First, the static models can be “forced” by climate
- This is based on “Hutchinson’s Duality”
- Assumes the world is entirely accessible
- And there are no interactions (Gleasonian Ecology)
- And there is no evolution (Kansas Model)

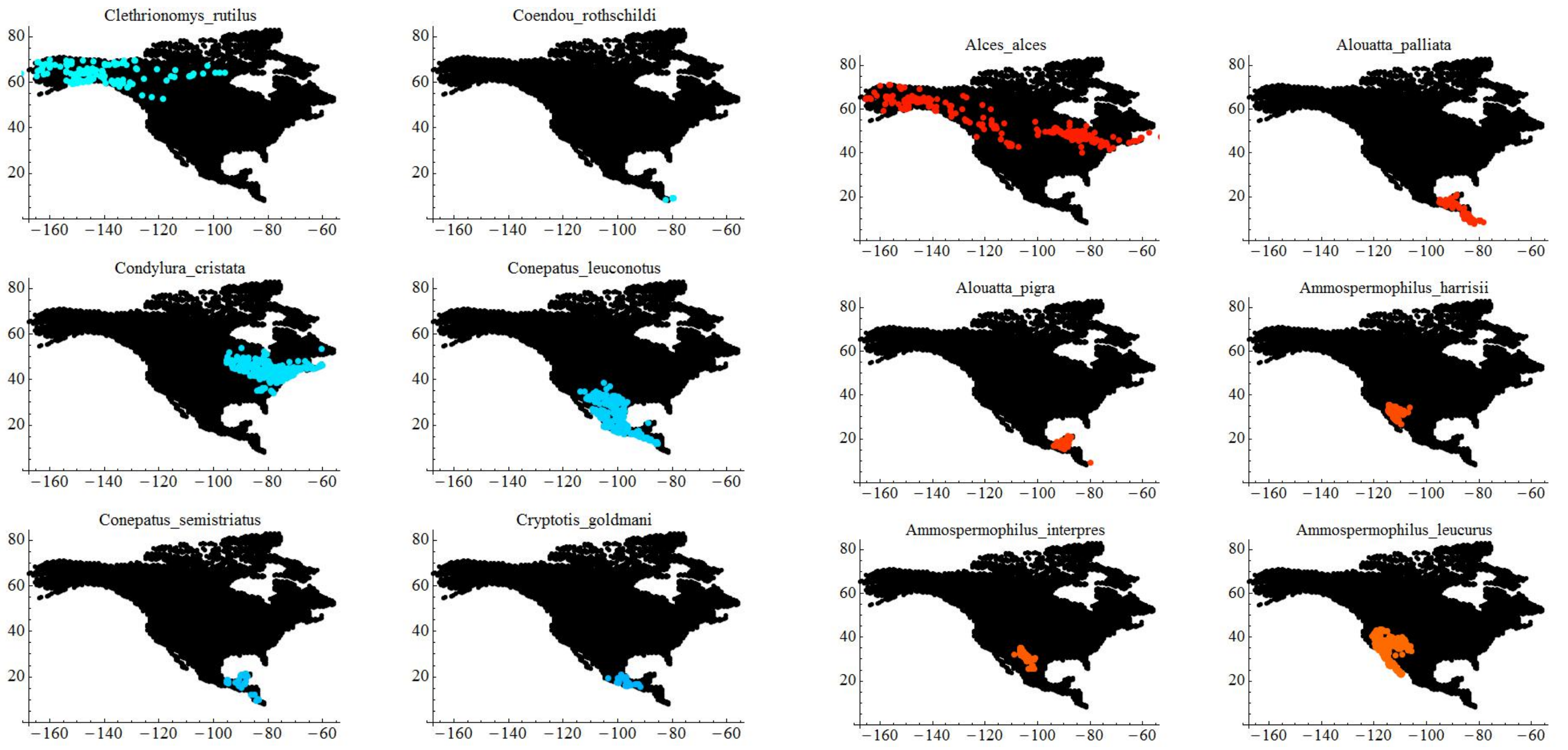
Hutchinson’s Duality

White-lipped peccary image from CONABIO’s image bank.



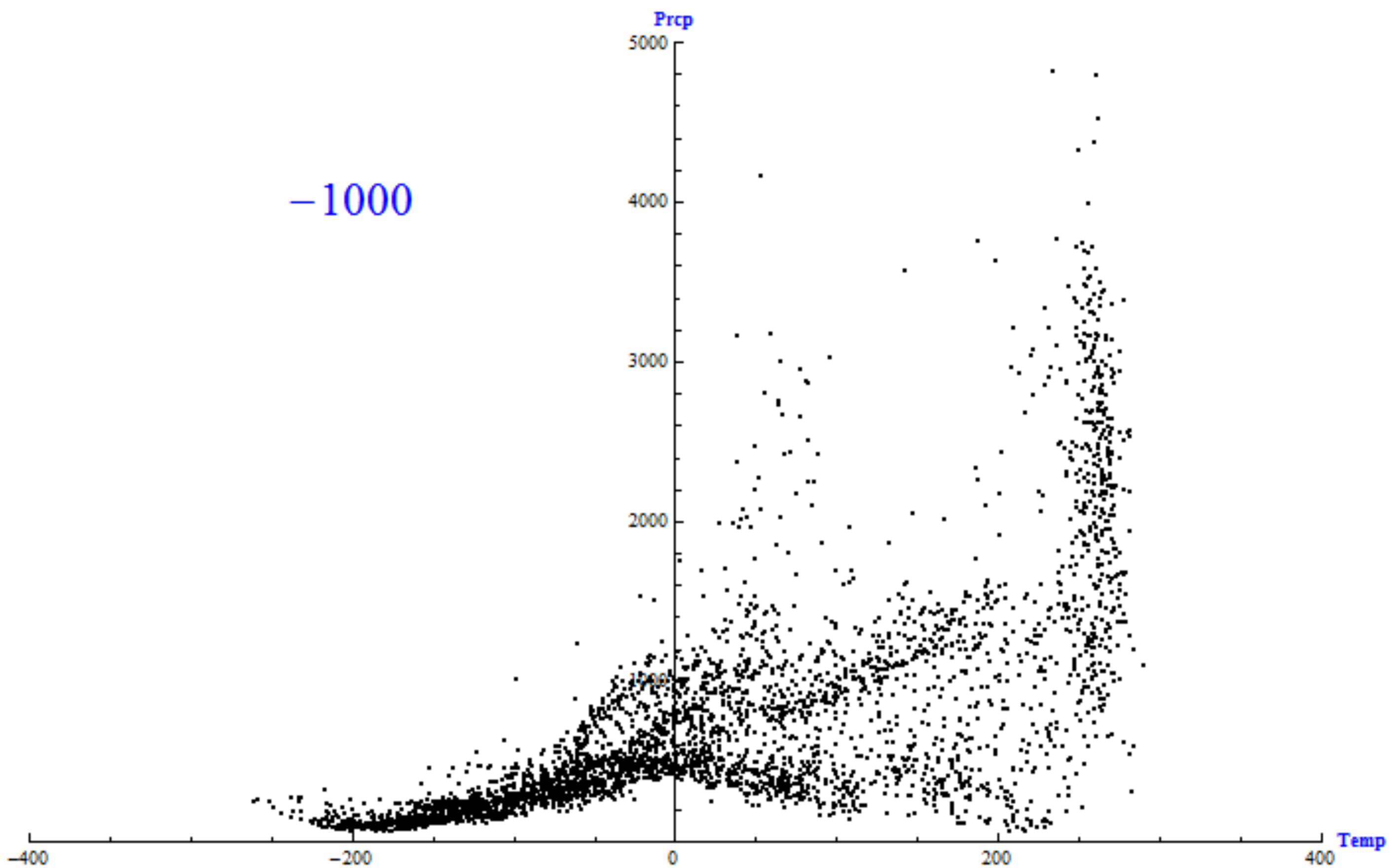


An example using ~10^5 occurrence data points, for the mammals of North America (lot of debugging)



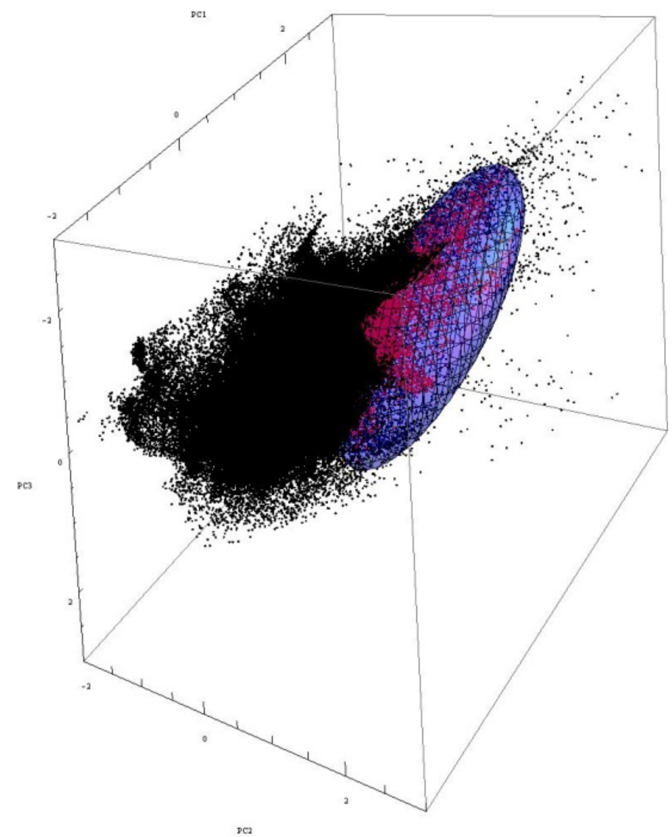
Soberon & Lira, in preparation

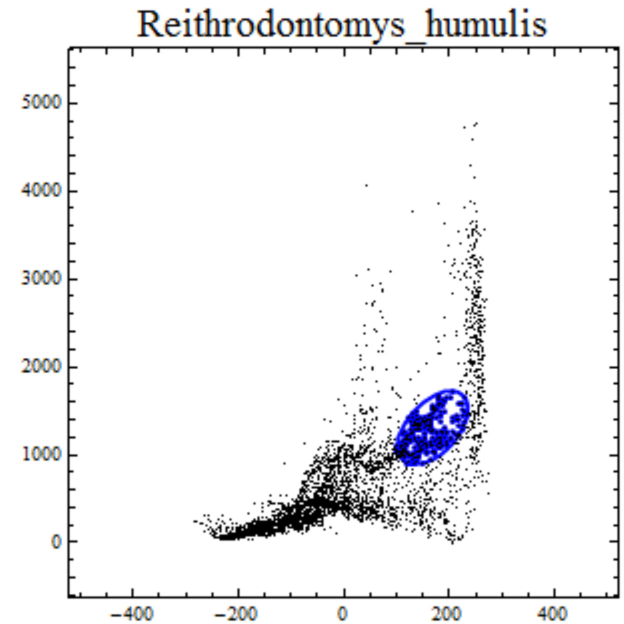
And GCMs for North America, present to 120,000 years BP (GCMs courtesy of Hadley, via Erin Saupe, formatted by Qiao & Osorio)



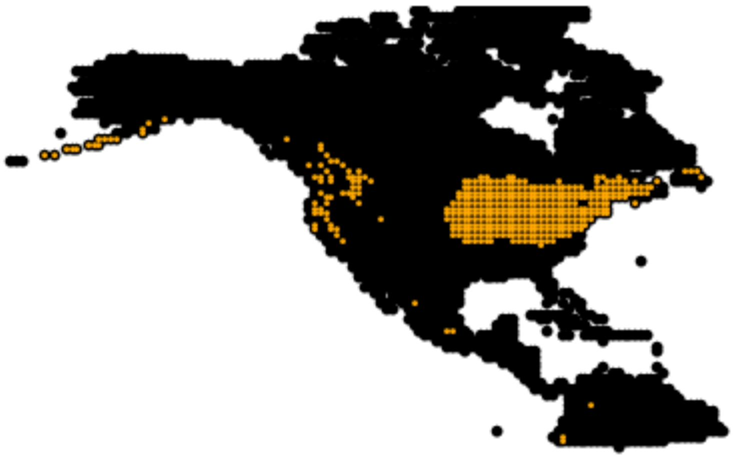
Somehow you estimate a niche

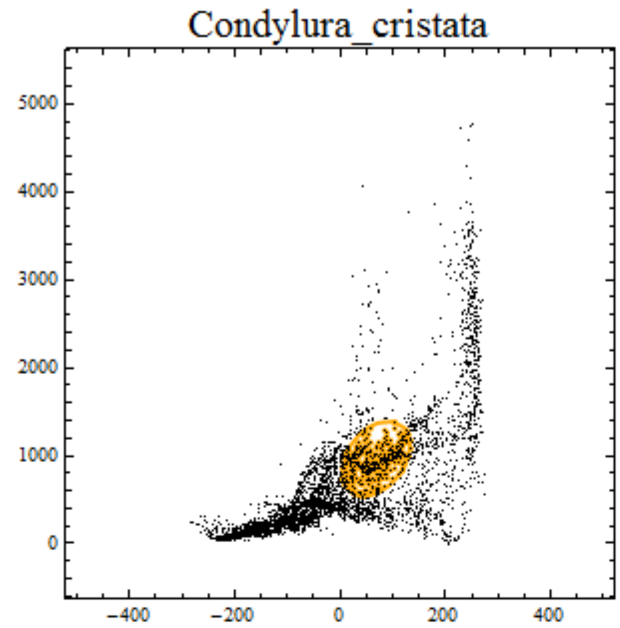
- Tons of software (Maxent, GAMs, GLIMs, BRUTO, OpenModeller…)
- Plenty of traps for the unwary (wrong names, poor or faulty georeference, wrong covariates, overfiting…)





Reithrodontomys humulis
Smithsonian NMNH

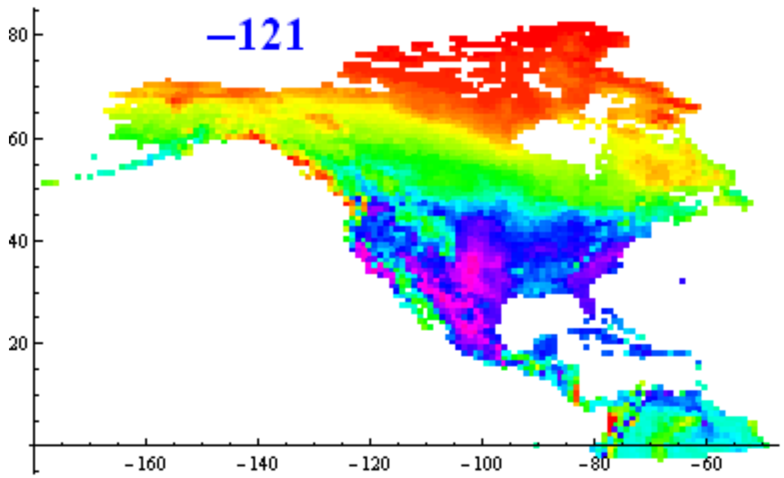


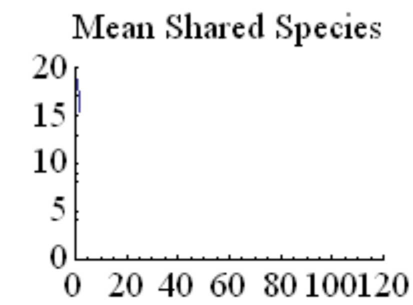


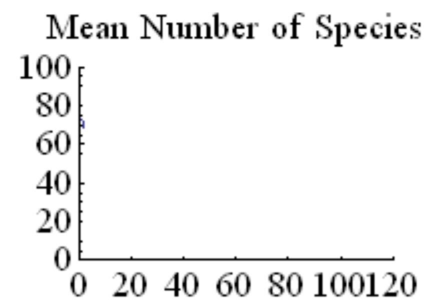
Condylura cristata
Smithsonian NMNH

Mammal potential numbers since Interglacial (120,000 BP)

Purple ~ 80
Blue ~ 70
Green ~ 60
Yellow ~ 50
Red ~ 40







The above is nice but it is simply a bunch of ENM projected using climate change.

How to add **M** and **B**?

The **A**, **B** and **M** circles. Autoecology, interactions, migration patterns, historical factors operating with different strenghts at different spatiotemporal scales.
There are equations (nasty) describing this.

Species

$$\frac{1}{x_i^j}\frac{dx_i^j}{dt} = r_i\,(\vec{e}^{\,j}) - \varphi_i^j(x_i^j;\vec{R}_i^j) + \psi^j(\vec{x};\mathbf{T})$$

Grid cell

Several antecedents

Journal of Biogeography (J. Biogeogr.) (2012)

SPECIAL ISSUE

How to understand species' niches and range dynamics: a demographic resea[rch] agenda for biogeography

Frank M. Schurr[1,2,3]*, Jörn Pagel[1,4], Juliano Sarmento Ca[bral] ... Groeneveld[6,7], Olga Bykova[8], Robert B. O'Hara[4], Flor... W. Daniel Kissling[9], H. Peter Linder[10], Guy F. M... Schröder[13,14], Alexander Singer[6] and Niklaus ...

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2010) **19**, 85–97

RESEARCH PAPER

Estimating demographic models for the range dynamics of plant species

Juliano S. Cabral* and Frank M. Schurr

SAUPE, Erin E., et al. "ASSESSING THE CONTRIBUTION OF ABIOTIC NICHES AND DISPERSAL LIMITATIONS TO SPECIATION AND EXTINCTION UNDER CLIMATE CHANGE USING SIMULATION STUDIES." *2014 GSA Annual Meeting in Vancouver, British Columbia*. 2014.

...10) **37**, 411–422

ORIGINAL ARTICLE

Integrating species distribution models and interacting particle systems to predict the spread of an invasive alien plant

M.G. Smolik[1], S. Dullinger[2,3]*, F. Essl[4], I. Kleinbauer[2], M. Leitner[1], J. Peterseil[4], L.-M. Stadler[1,5] and G. Vogl[1]

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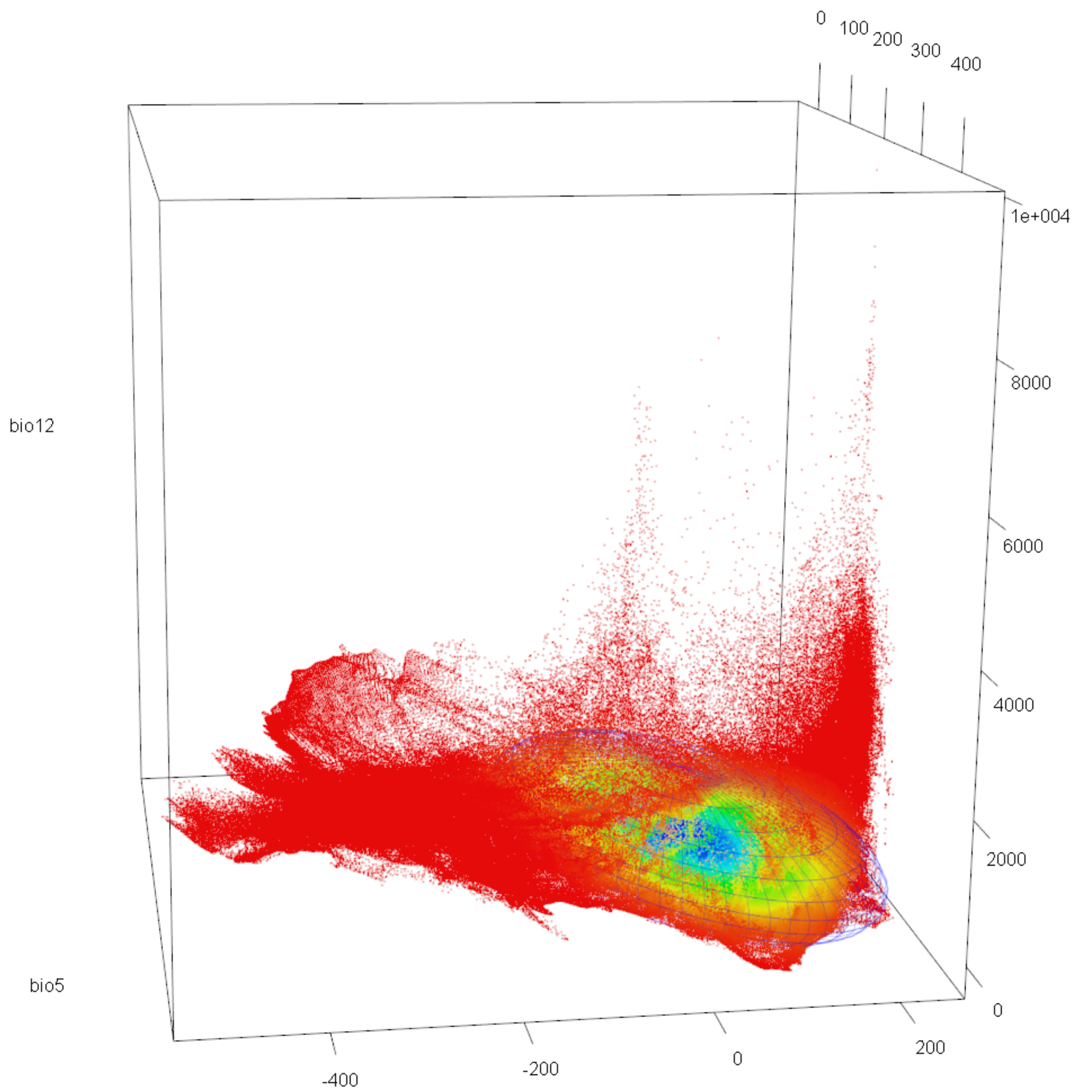
Subject Editors: Núria Roura-Pascual and...

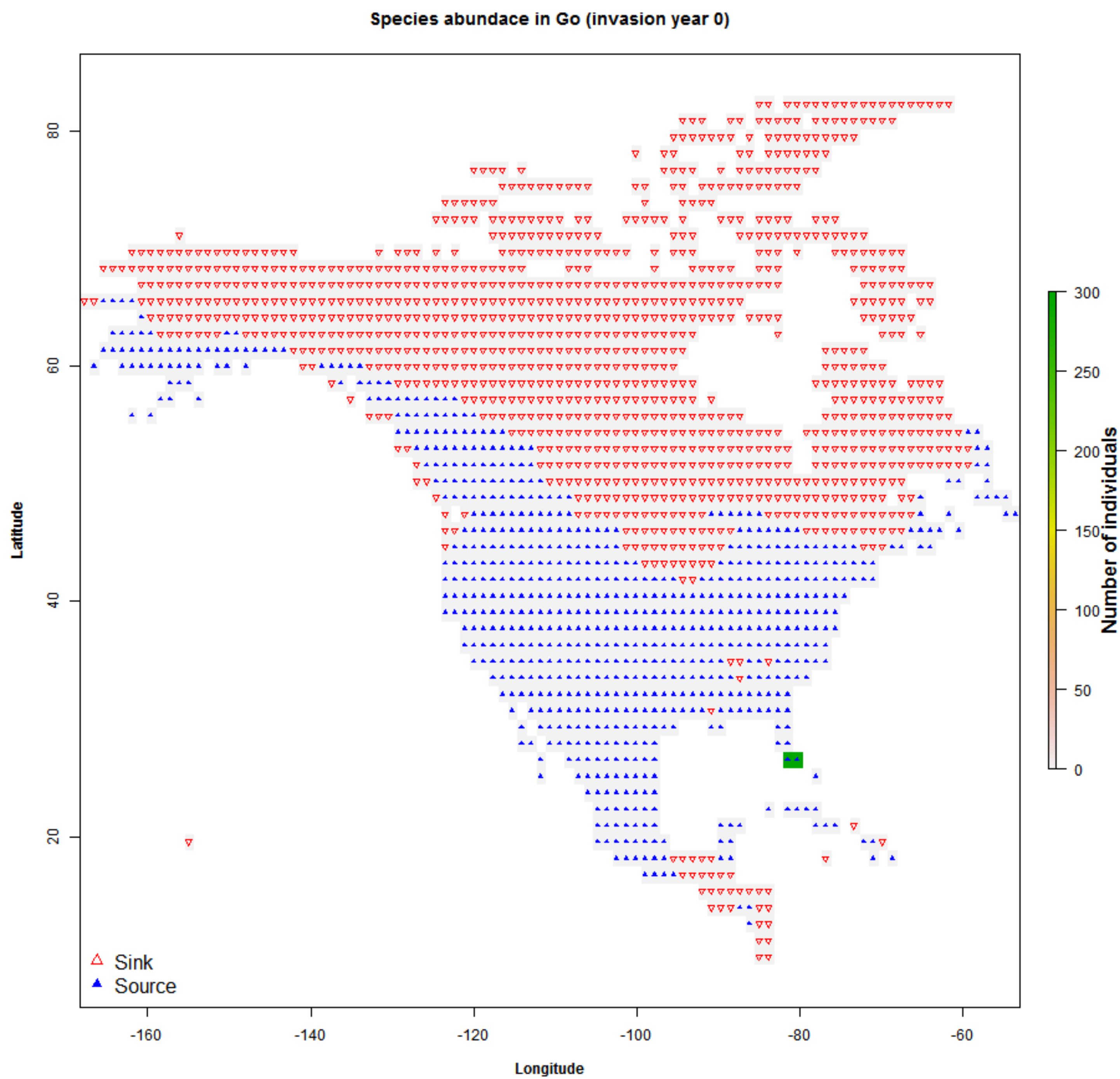
Niche and area of distribution modeling: a population ecology perspective

Jorge M. Soberón

J. M. Soberón (jsoberon@ku.edu), Museum of Natural History and Dept of Ecology and Evolutionary Biology, Univ. of Kansas, Dyche Hall 1345 Jayhawk Blvd., Lawrence, KS 66045, USA.

Niche of the Eurasian Collar Dove in the climatic space of the world





Species abundace in Go (invasion year 0)
Latitude
Longitude
80
60
40
20
-160
-140
-120
-100
-80
-60
Sink
Source
Number of individuals
300
250
200
150
100
50
0

To do the above…

- One needs to parameterize a complicated model.
- There are no databases comparable to GBIF's although things are changing (for demography,
- http://www.compadre-db.org http://www.compadre-db.org/Comadre/Home
- For movements, no public database (one in progress)

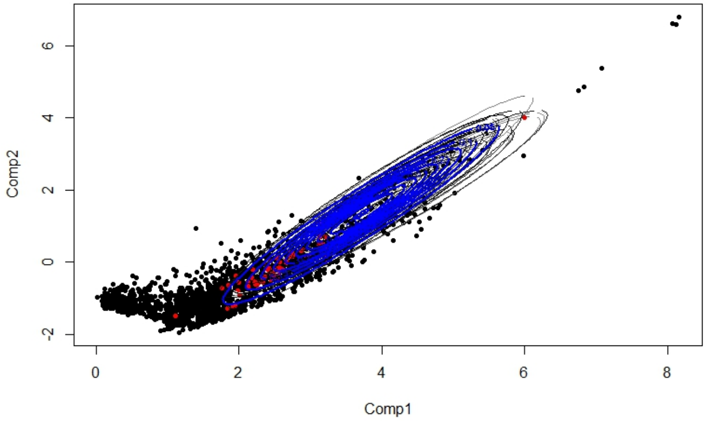
How to add evolution?

- Adaptation and speciation
- What evolves is the fundamental niche. We do not know too much about the fundamental
- Is it possible to estimate N_F?

Maybe some “lower bound”:

1. Postulating its shape
2. Considering **E**
3. Some *a priori* information

$$\mathcal{L}(\boldsymbol{\mu},\Sigma|\boldsymbol{D}) \propto \prod_{i=1}^{n}\left\{\frac{exp\left[-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right]}{\sum_{\boldsymbol{y}\epsilon\mathbf{E}(t;\,\boldsymbol{G})} exp\left[-\frac{1}{2}(\boldsymbol{y}-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{y}-\boldsymbol{\mu})\right]}\mathbf{1}\left(\boldsymbol{x}_i\epsilon\mathbf{E}(t;\,\boldsymbol{G})\right)\right\}^{w_i}$$

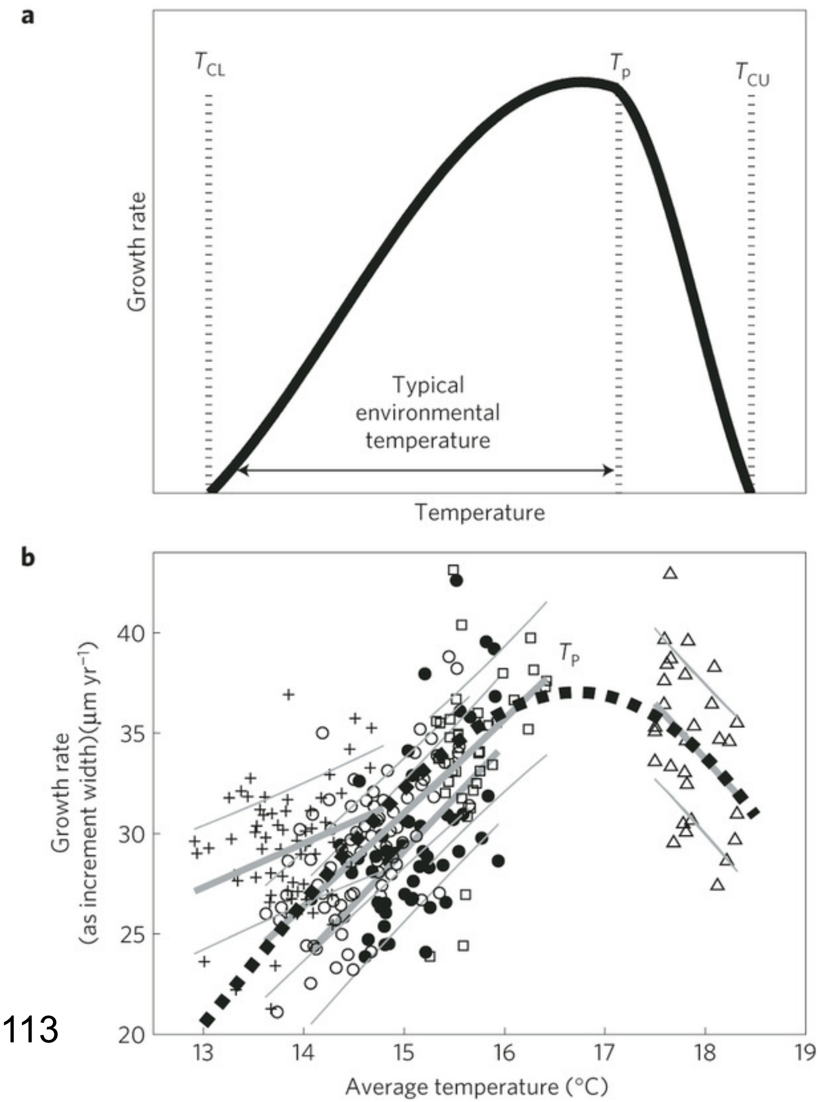


$$f\left(\boldsymbol{\mu},\Sigma\middle|\boldsymbol{D},\mathbf{E}(t;\,\boldsymbol{G})\right) \propto \mathcal{L}(\boldsymbol{\mu},\Sigma|\boldsymbol{D})g_1(\boldsymbol{\mu})g_2(\Sigma).$$

Christen, Jimenez & Soberon, in prep.

Where is the data for the priors?

- No databases of physiology.
- Most available data only for temperature
- A handful of literature on temperature & water stress.
- Huge data gap here



Neuheimer et al. 2011 Nature Climate Change 1:110-113

With that one can add adaptation and model the evolution of the $\mathbf{N}_{\mathrm{F}}$

$$\mathbf{G}(t+1) \leftarrow \mathbf{S}(t) \times \mathbf{M} \times \mathbf{G}(t)$$

$$\mathbf{S}(t) = f_1[\mathbf{N}_F(t), \mathbf{E}_g(t)]$$

$$\mathbf{N}_F(t+1) = \left[\mathbf{x}(t) - \boldsymbol{\mu}(t)\right]\mathbf{A}(t)\left[\mathbf{x}(t) - \boldsymbol{\mu}(t)\right]^T - 1$$

$$\boldsymbol{\mu}(t+1) = f_2[\mathbf{H}^2, \Phi(t), \boldsymbol{\mu}(t), \bar{\mathbf{X}}(t), \boldsymbol{\Sigma}_M, \boldsymbol{\Sigma}_S, \mathbf{n}(t)]$$

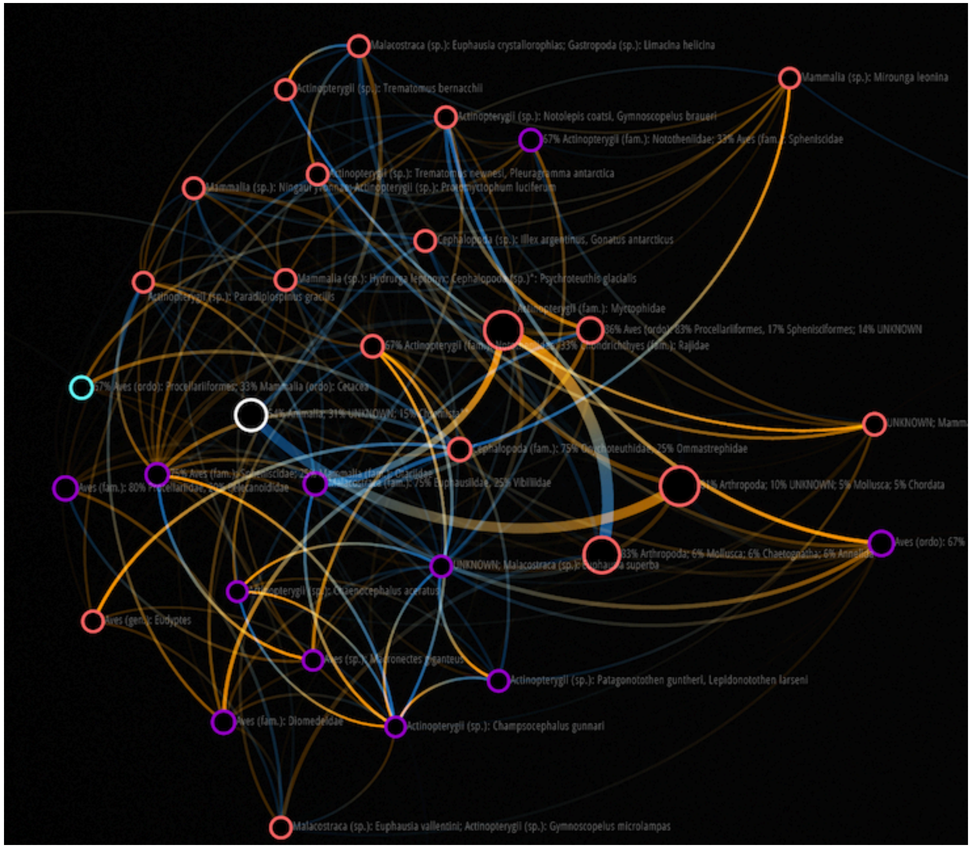
$$\mathbf{A}(t+1) = f_3\left[\mathbf{H}^2, \Phi(t), \boldsymbol{\mu}(t), \bar{\mathbf{X}}(t), \boldsymbol{\Sigma}_M, \boldsymbol{\Sigma}_S, \mathbf{n}(t)\right]$$

Soberon & Miller, in prep.

What about interactions? …

- Very little theory (Vandermeer, 1973; Pulliam, 2000; Soberon, 2010; Wisz et al., 2013; Godsoe et al. 2015)
- Very, very few data (review: Hargreaves et al. 2014)
- Some coming

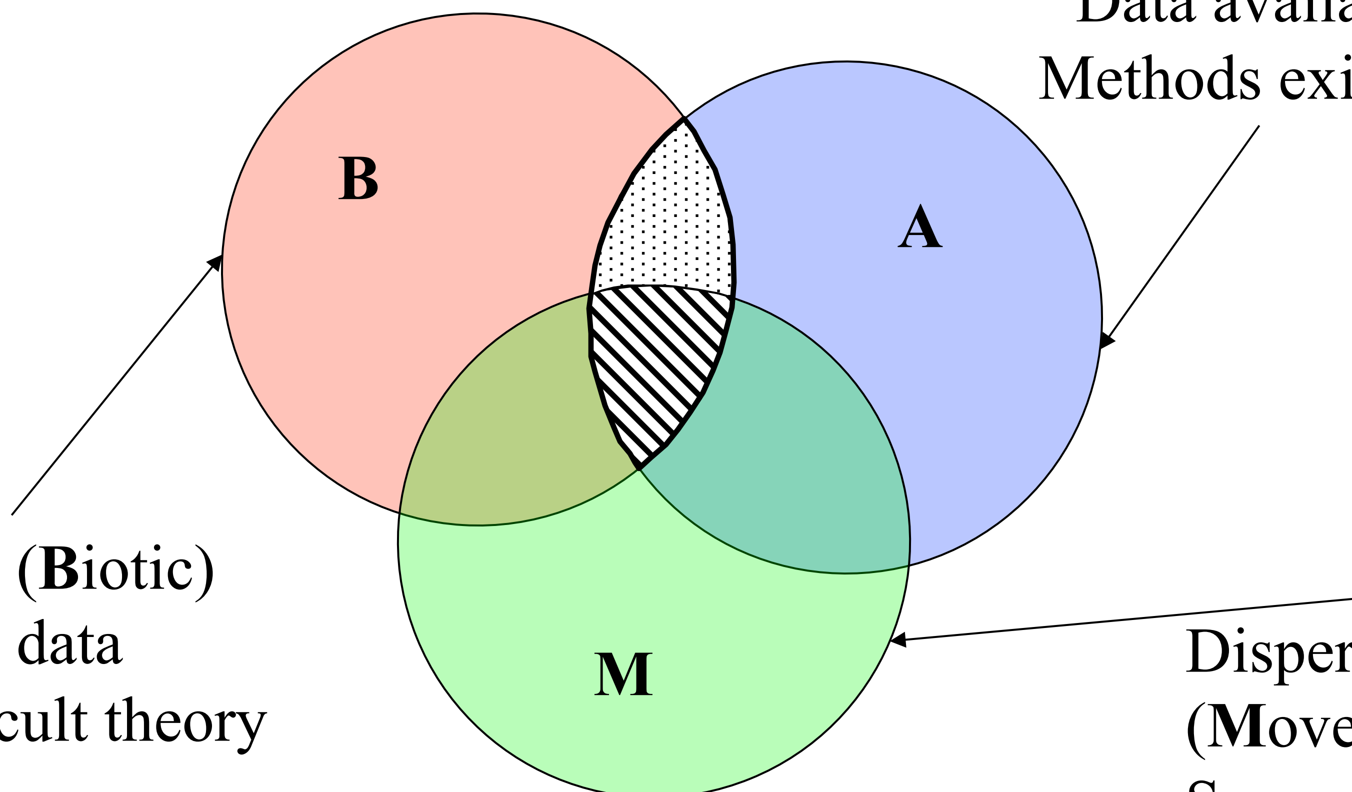
http://www.globalbioticinteractions.org/index.html



http://figshare.com/articles/Global_Biotic_Interactions_food_web_map/1297762

To summarize

The niche
(**A**biotic).
Data available
Methods existing



The niche (**B**iotic)
Very little data
Very difficult theory

Dispersal
(**M**ovements)
Some theory,
some data

Conclusions

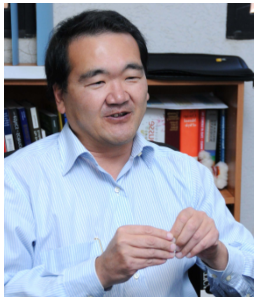
- In order to model distributions under climate change we need several things:

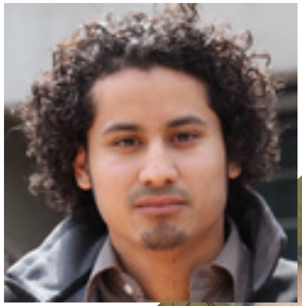
1. Models of the mechanisms (correlative models are bound to fail: they cannot be extrapolated reliably)
2. Data to parameterize such models. Preferably in open databases (DAK).
3. And data to test (paleodata, automated data capture)

- And software of course. The community is kind of on its way…

Thanks to…

- iDigBio
- Jeff Cavner, A. Christen, H. Arita, P. Rodriguez, A. Lira, F. Villalobos, coworkers in the biodiversity perspectives stuff
- A. T. Peterson, for endless conversations on this.
- And the money folks

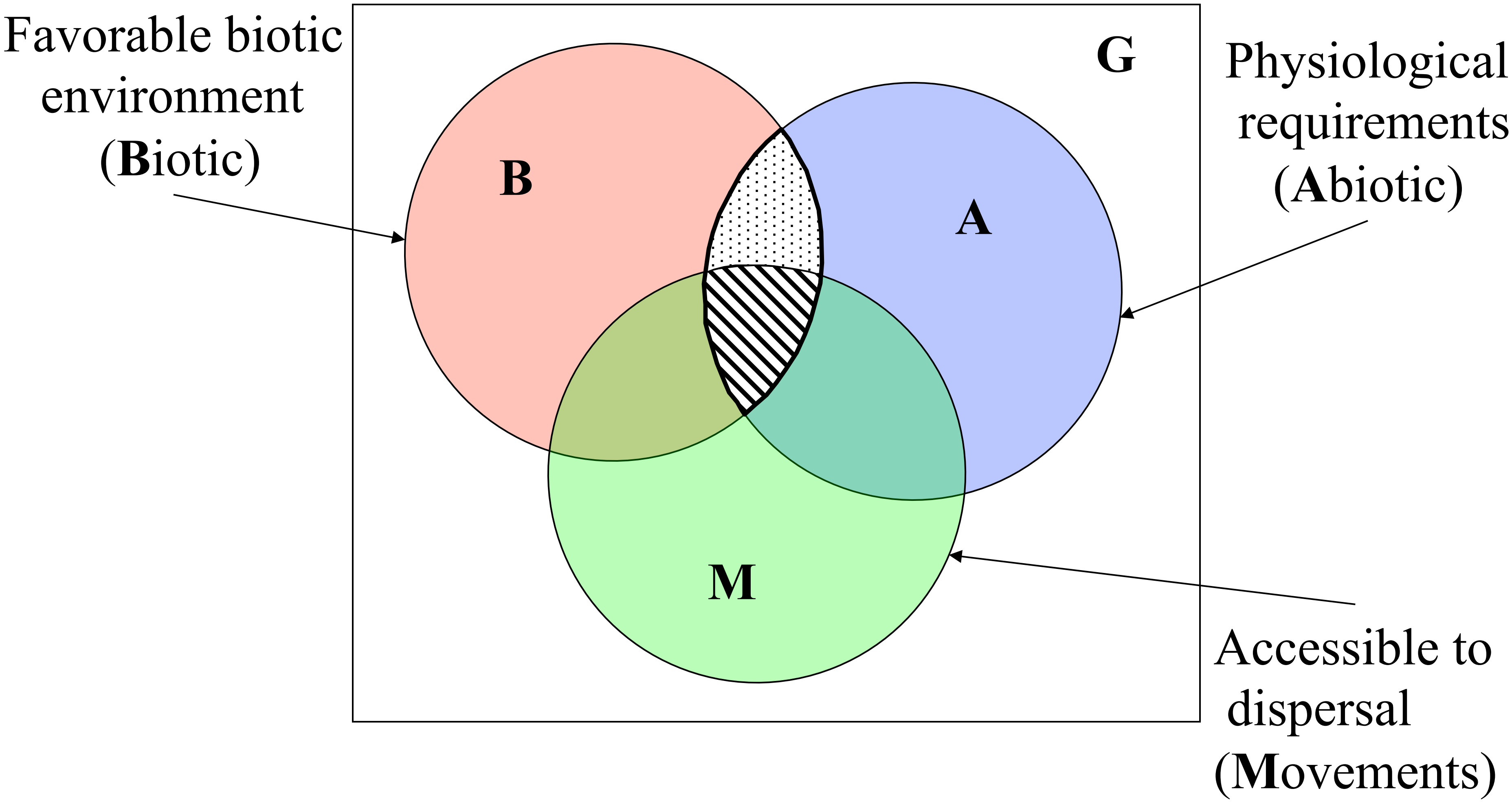




Conclusion

- But people keeps advancing our understanding, adding data, improving software
- We already can provide zero-order hypotheses about climate change using occurrence data
- Soon our hypotheses will include first, second and maybe even third order effect.

The area of distribution



The A,B and M circles

A

- **A** refers to the "Fundamental Niche"
- Physiological requirements
- Non-reactive variables. Uncoupled

B

- **B** refers to interactions
- Biotic requirements and impacts. Resource consumption, interactions, competitors, predators...
- Variables interactive, dynamically coupled

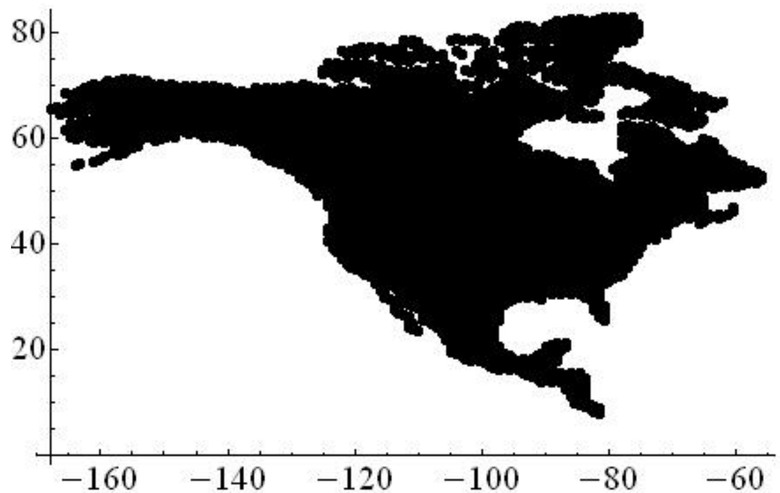
M

- **M** refers to dispersal and other movements
- Begs the question of initial conditions

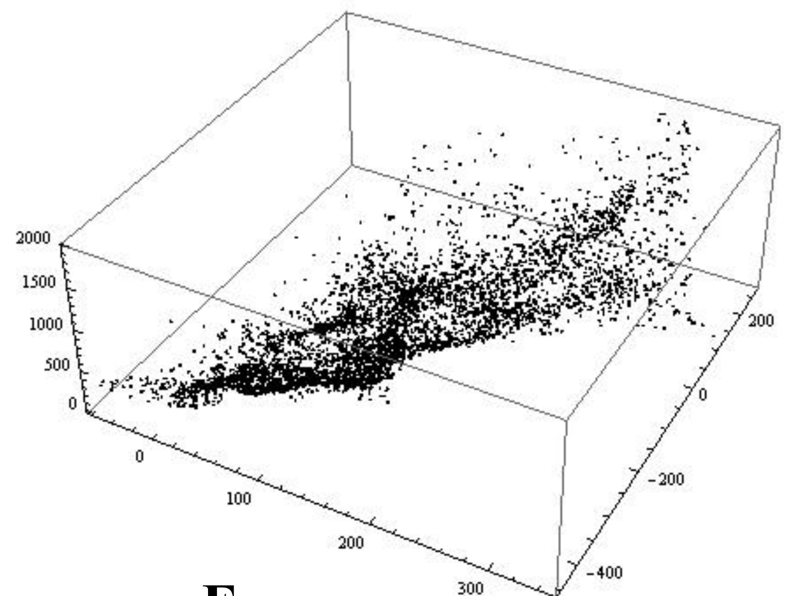
Hutchinson's Duality

To every cell in **G** one can establish a correspondence to its environments, and viceversa:

Generally speaking, |**G**| = |**E**|, but in a continuous space some regions in **E** are dense and others very sparse

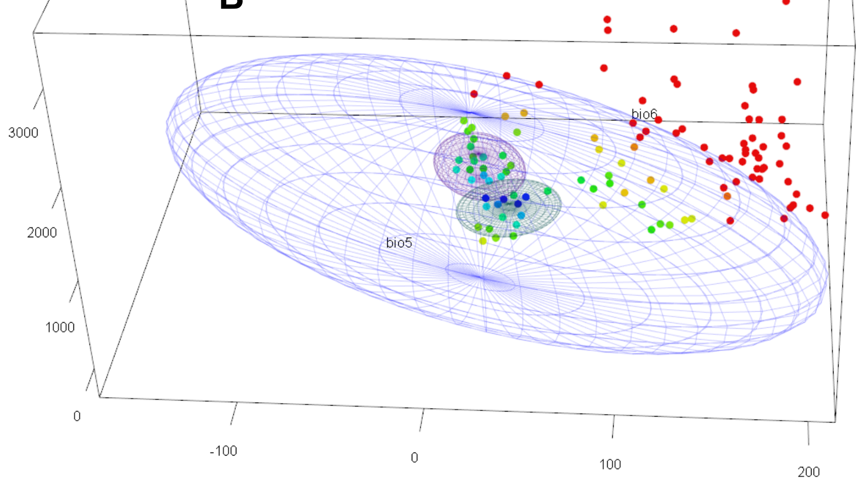


G space

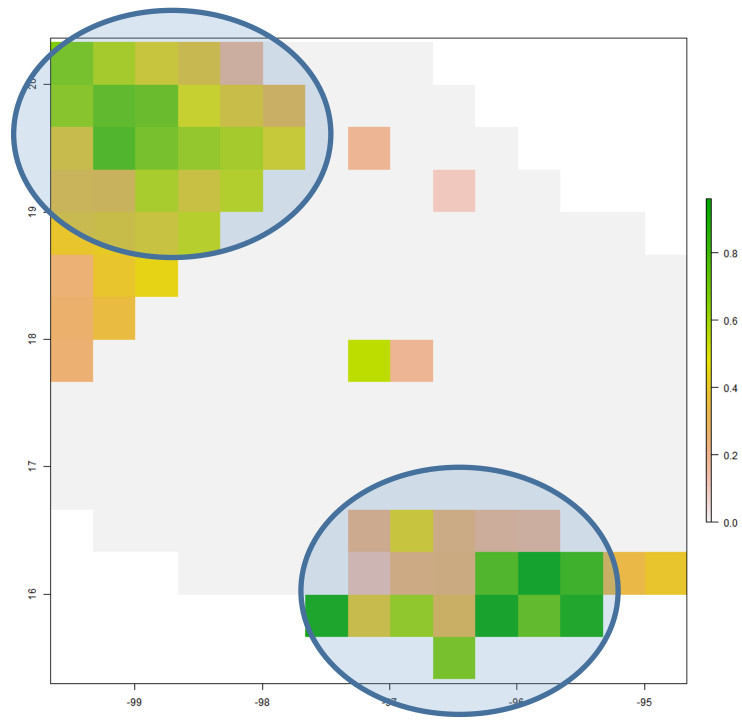


E space

Peterson et al, 2011

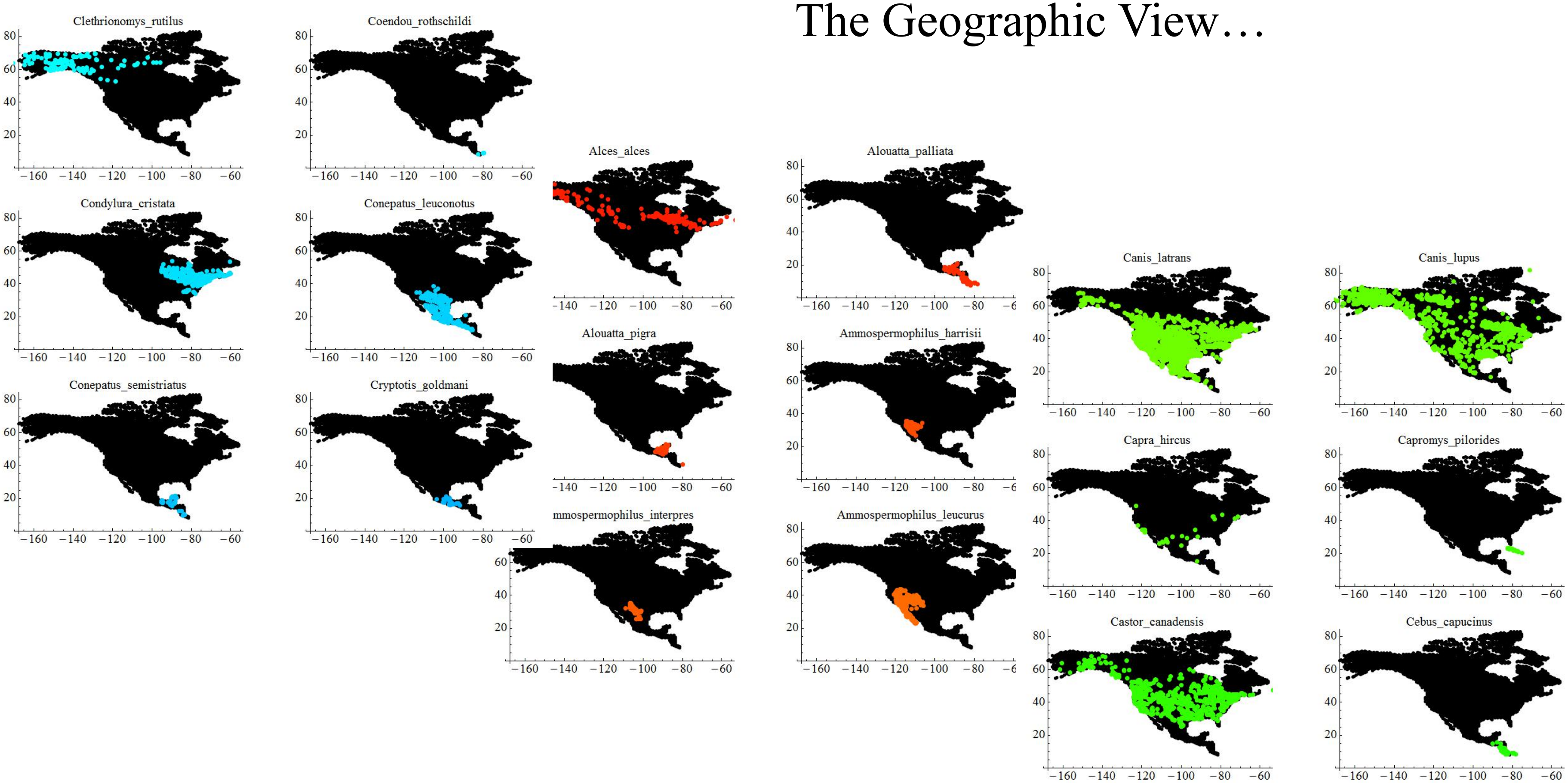

3000
2000
1000
0
-100
0
100
200
bio6
bio5

A


20
19
18
17
16
-99
-98
-95
0.8
0.6
0.4
0.2
0.0

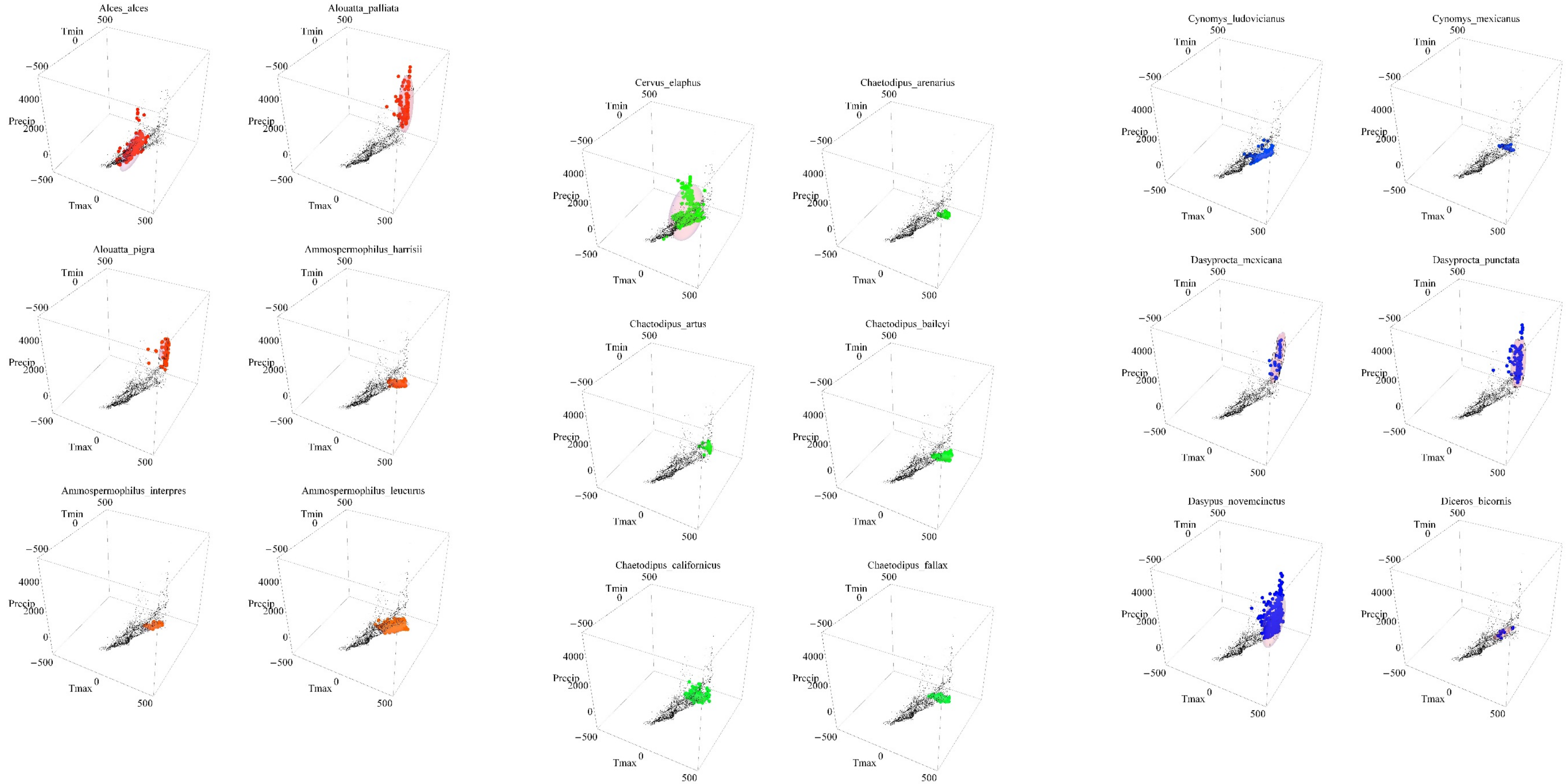
B

The Geographic View…



Soberon & Lira, in preparation

And the niche view

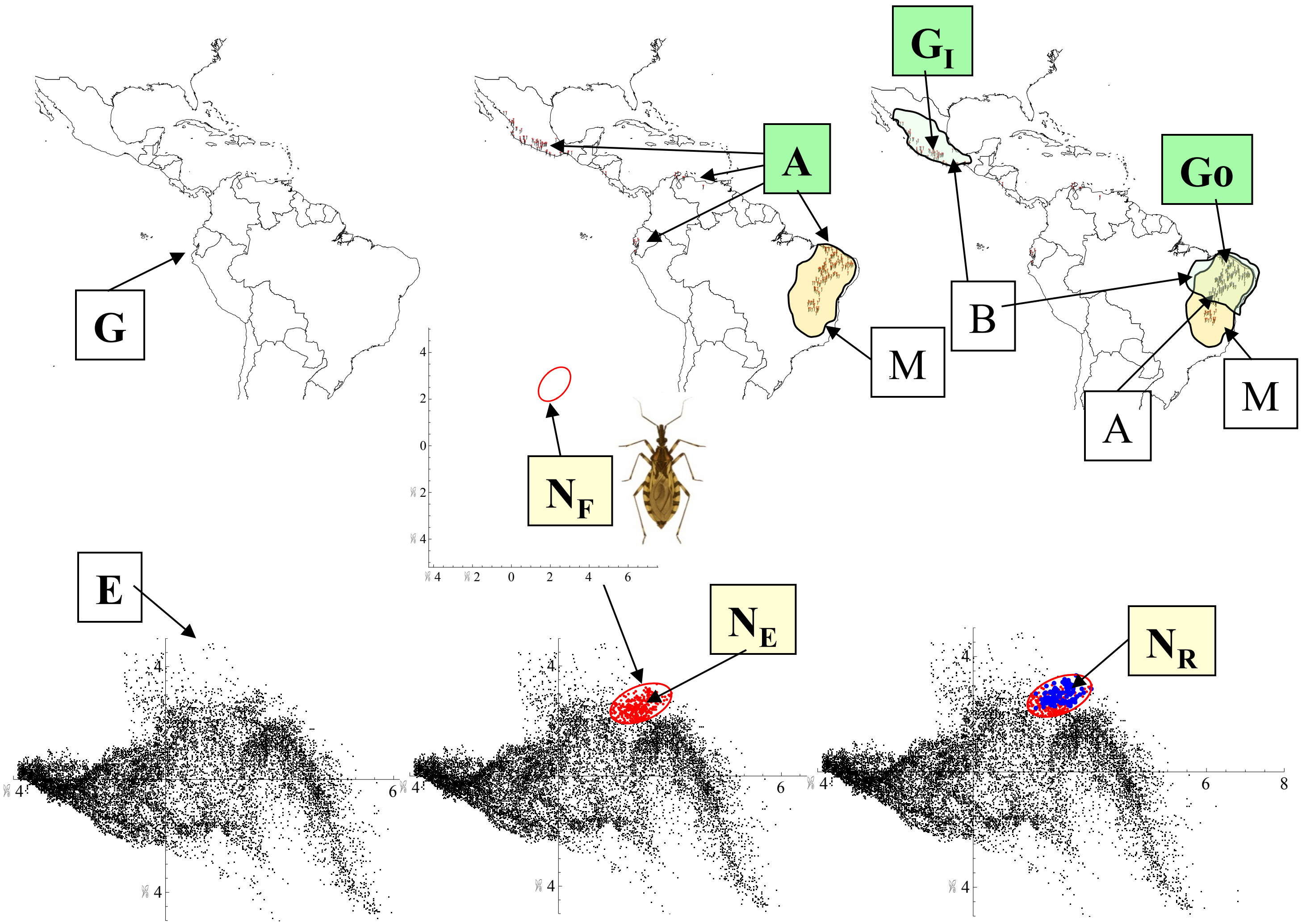


III. Hutchinson's Inequalities

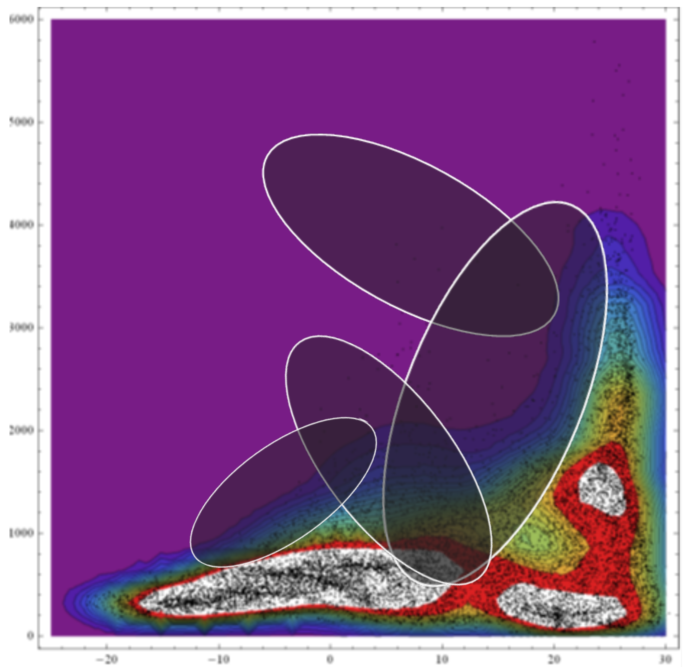
$$\mathbf{N}_F \supseteq \mathbf{N}^*(t,G) = \mathbf{N}_F \cap \mathbf{E}(t,\mathbf{G}) \supseteq \mathbf{N}_R(t,\mathbf{G})$$

Fundamental Existing Realized

- Fundamental: Physiology
- Existing: actual climate
- Realized: what is available where the species can be observed
    - Every ecologist (almost: see Pulliam, 2000) assumes that the fundamental niche is "larger" than the realized.
    - Hutchinson others (Colwell and Futuyma) hinted at the "existing niche" (Jackson & Overpeck, 2000).
    - These inequalities set the limits to niche modelling, what ultimately limits ranges, and hints to a substantial role of environmental change

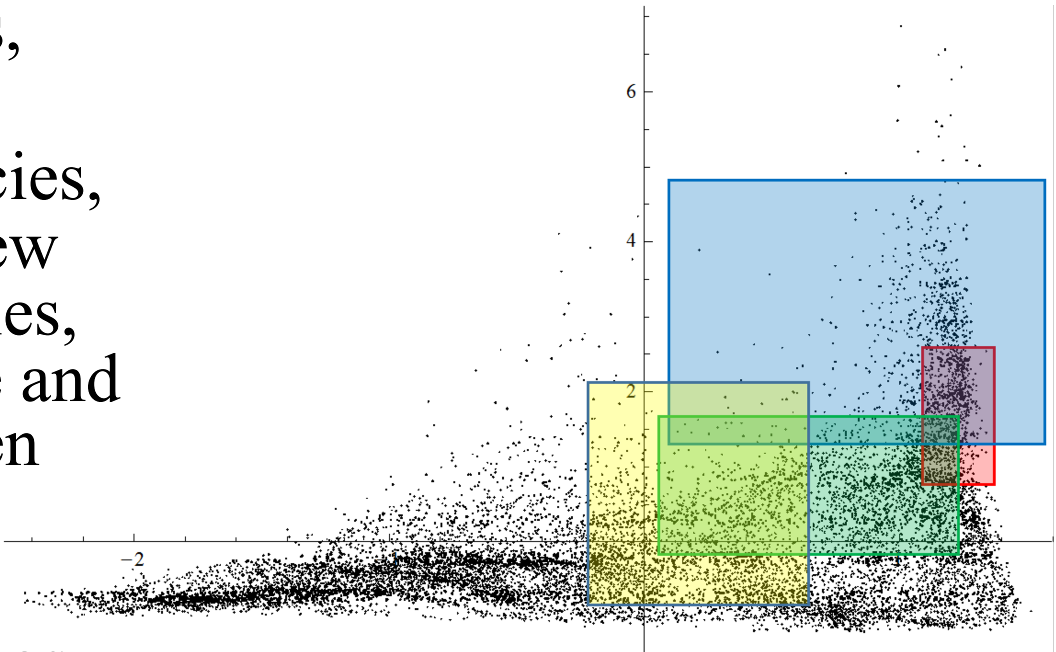

G
A
M
G_I
Go
B
A
M
N_F
E
N_E
N_R

To test Hutchinson's Inequalities one needs to know the fundamental niche



Data for the Fundamental Niches, courtesy of the United Nations

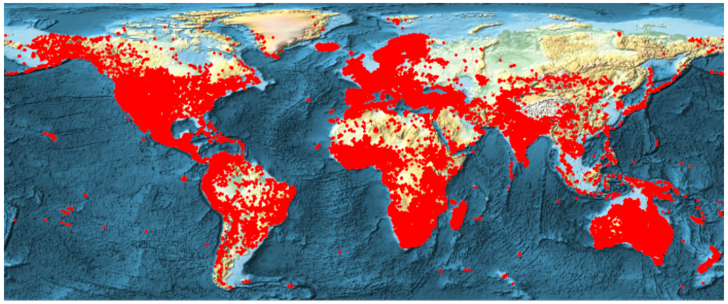
- 1710 species, mostly trees, cultivars, weeds, and medicinal plants
- For each of these species, extreme limits for a few environmental variables, including temperature and precipitation have been obtained
- These extremes allow approximating the N_F as 2D "boxes"

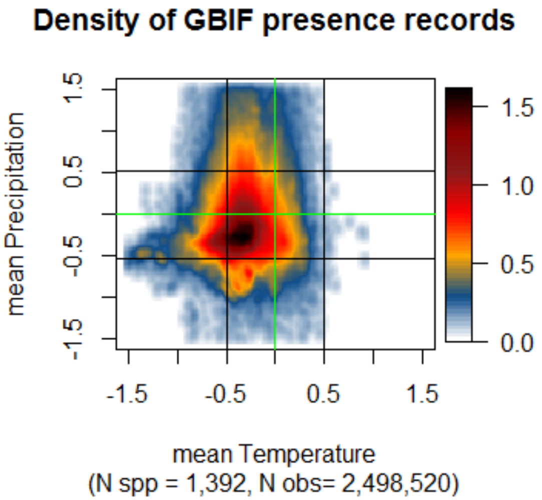


Data for the Realized Niches

- From GBIF, we extracted 2,498,081, non-redundant, non-inconsistent records. The environments in these points represent the realized niches
- Essentially, most points are inside the N_Fs (~70%).
- Which means that Hutchinson's inequalities are basically valid for the FAO dataset.

Soberon & Arroyo, submitted





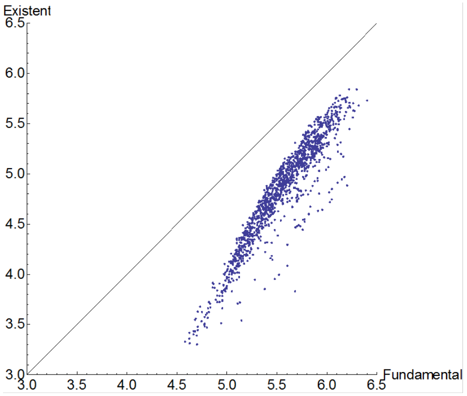
Some consequences

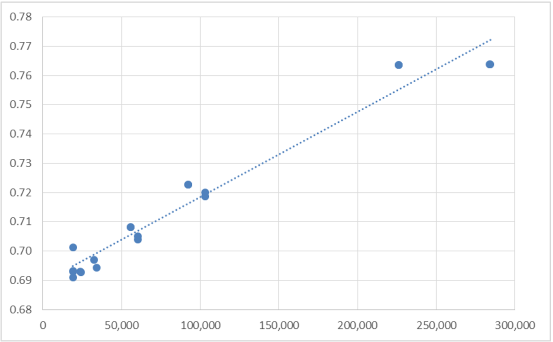
$$\mathbf{N}_F \supseteq \mathbf{N}^*(\mathrm{t}, \mathbf{G})$$

This relationship is very much a matter of definition, but studying how much bigger than N* is N_F is an empirical question, and a very interesting one since it determines how much room there is for a niche to change without evolving.

$$\mathbf{N}_F \supseteq \mathbf{N}_R(\mathrm{t}, \mathbf{G})$$

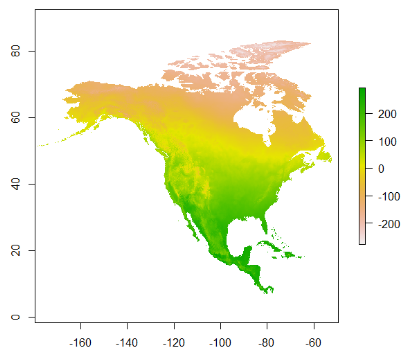
For the FAO data, an overwhelming majority of species fulfill the relationship. This means that for such species, natural or anthropogenic facilitation is the exception.



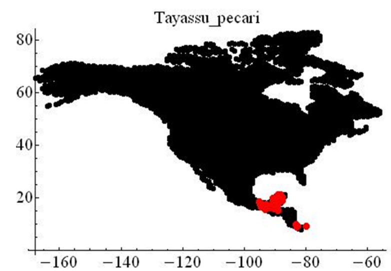


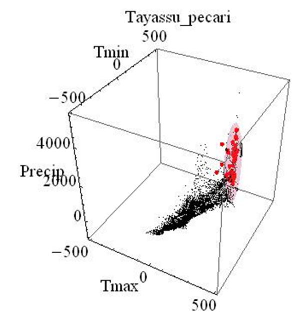
So, we have building blocks:

What variables to use (scenopoetic), with Petabytes of data



Operations between niche and geography (niches to areas and viceversa), with Terabytes of data





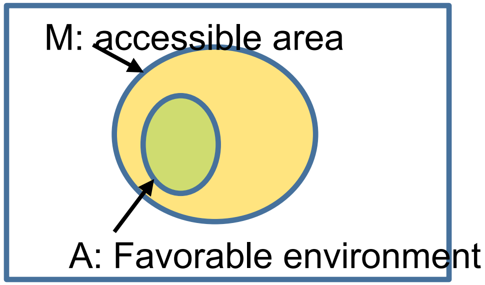
Consistent relationships among the major concepts (N_F, N* and N_R)

$$\mathbf{N}_F \supseteq \mathbf{N}^*(t,G) = \mathbf{N}_F \cap \mathbf{E}(t,\mathbf{G}) \supseteq \mathbf{N}_R(t,\mathbf{G})$$

But some assumptions are also required

- Gleasonian Ecology (no interactions)
- Hutchinson World (all geography available)
- Kansas Model (no evolution)

$$\alpha_{i,j} \approx 0; \alpha_{j,i} \approx 0 \forall i \neq j$$



$$\frac{\partial \boldsymbol{\mu}}{\partial t} = 0; \frac{\partial \boldsymbol{\Sigma}}{\partial t} = 0$$

Two more assumptions:

1. Fundamental niches are convex shapes
2. Environmental space can be represented by continuous kernels

Their product is a measure of how much an environment both exists and it is suitable to a given species $E(t,\vec{\nu})N_F(\vec{\nu})$