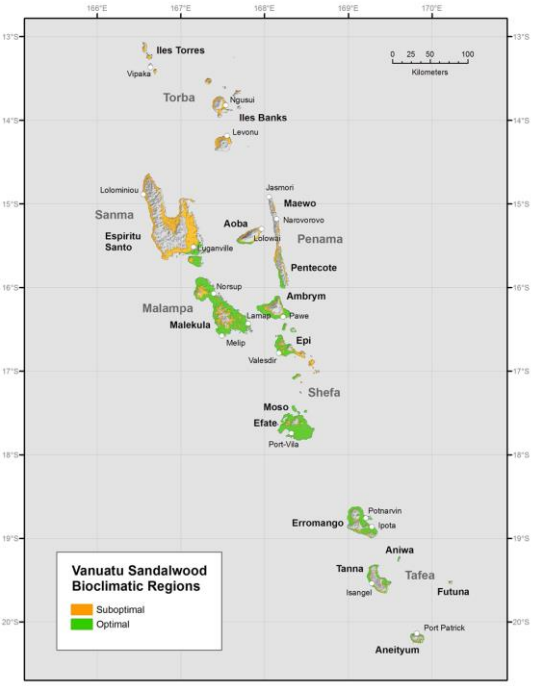
Session 7:
GIS applications, Evolutionary Biology

Outline:

1. Review and brief overview of some applications to Evolutionary Biology
2. Case study: Guiding field surveys, species discovery
3. Case study: Range expansions
4. Case study: Evolutionary Processes

1

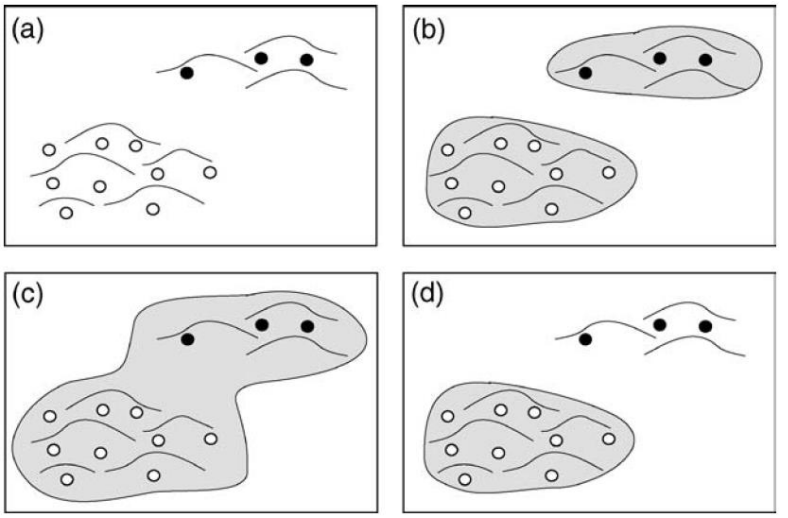
GIS as a cartographic tool



(J. Silverman)

2

Ecological niche models for species delimitation



Wiens & Graham 2005 *Ann Rev Ecol Evol Syst*

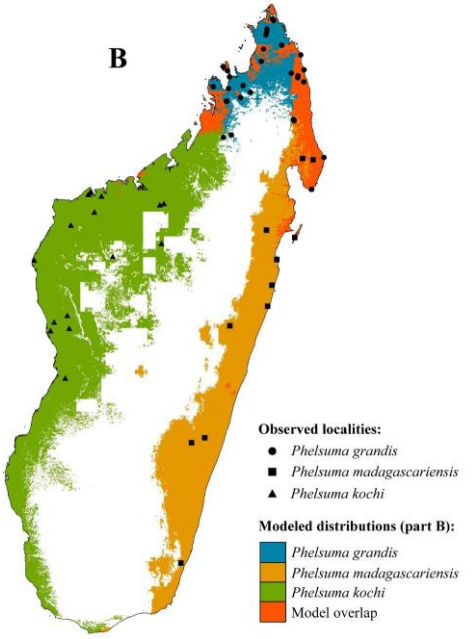
3

Species Delimitation Example: *Phelsuma madagascariensis* subspecies

Phelsuma madagascariensis grandis

Phelsuma madagascariensis kochi

Phelsuma madagascariensis madagascariensis



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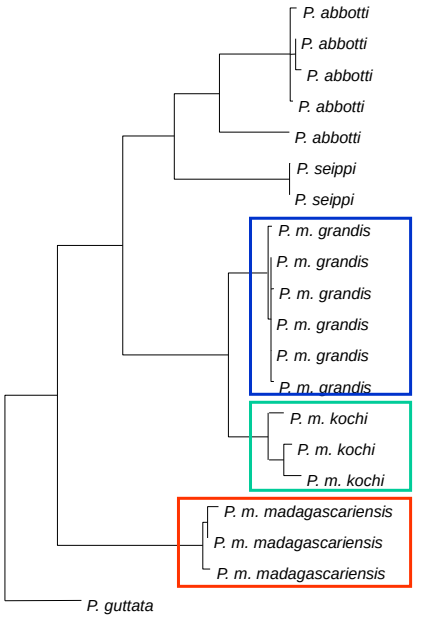


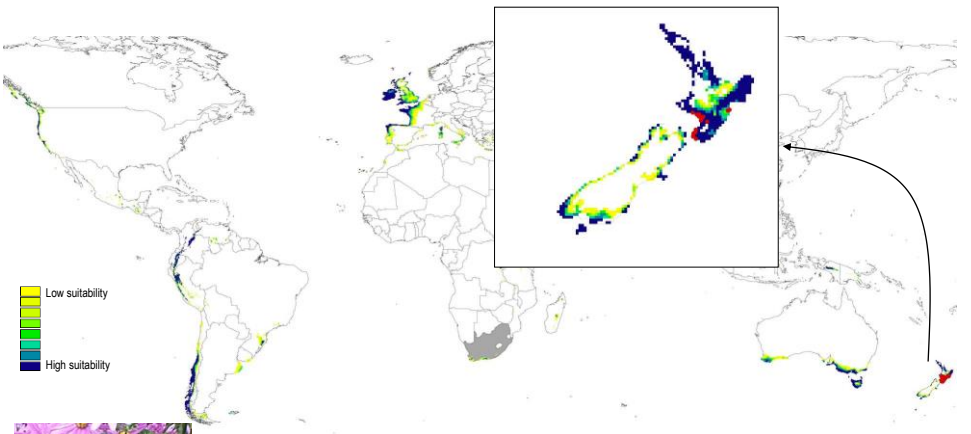
Phelsuma madagascariensis 'subspecies' are **paraphyletic!**

=> 3 subspecies elevated to species rank

Raxworthy et al. *Systematic Biology* **56**:907-923

5

Niche-based modeling of species' invasion potential



Senecio glastifolius (Asteraceae)

Thuiller et al. 2006 *Global Change Biology*

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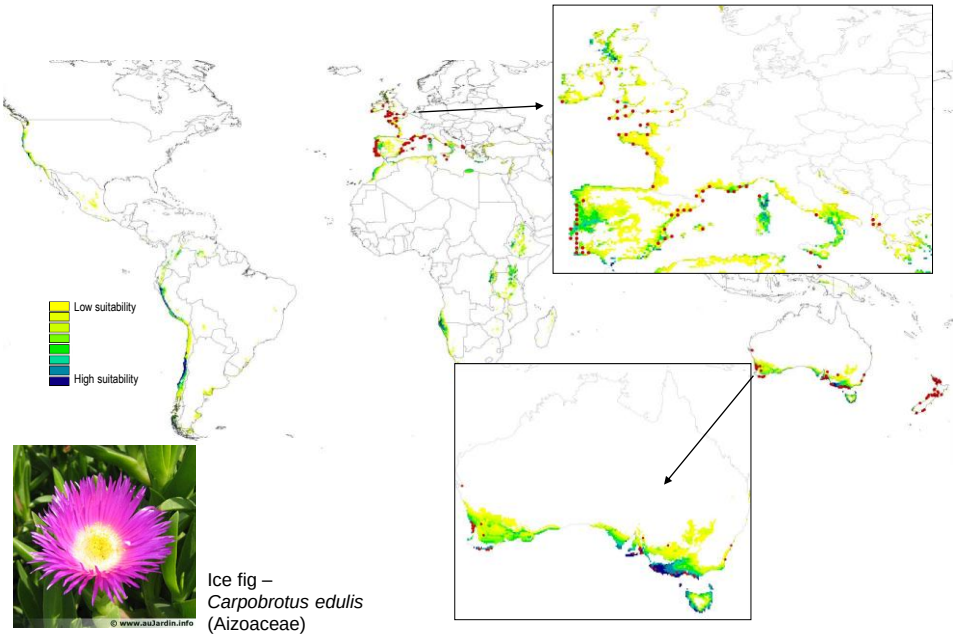
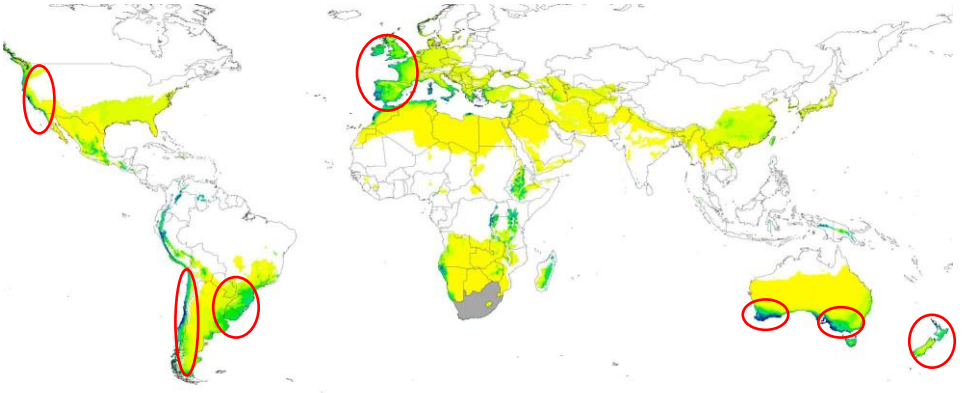


Ice fig –
Carpobrotus edulis
(Aizoaceae)

Thuiller et al. 2006 *Global Change Biology*

7

Mapping risk of invasibility

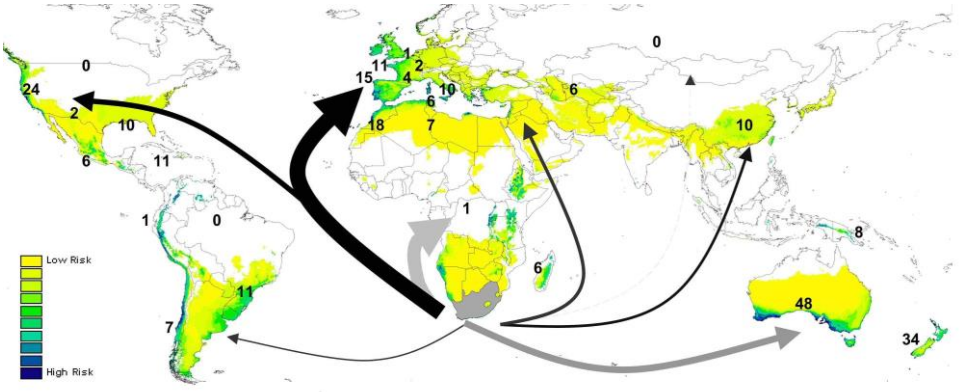


Sum of probability surfaces for 96 taxa, rescaled to a range of 0–1

Thuiller et al. 2006 *Global Change Biology*

8

Mapping risk: incorporating propagule pressure



Arrows indicate propagule pressure increase in thickness with increasing tourism, and range from grey to black with increasing trade in live plant products. Numbers indicate the number of South African plant species recorded as invasive

Thuiller et al. 2006 *Global Change Biology*

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Other interesting recent examples

- Chiarenza et al. 2019 - SDMs show that Maastrichtian North American dinosaur diversity decline is not due to a climatically-driven decrease in habitability but probably a product of sampling bias in the fossil record.

- Hallfors et al. 2016 – Using SDMs to predict local adaptation

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Case study:
Guiding AMNH herpetological surveys in Madagascar

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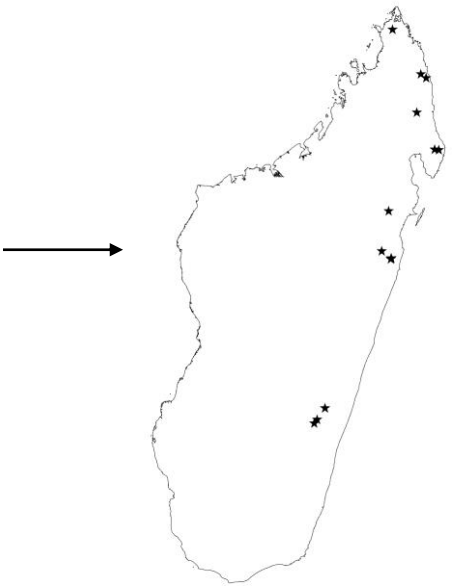
Species' occurrence records (vector point data)



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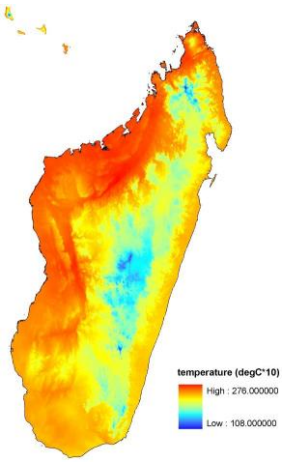
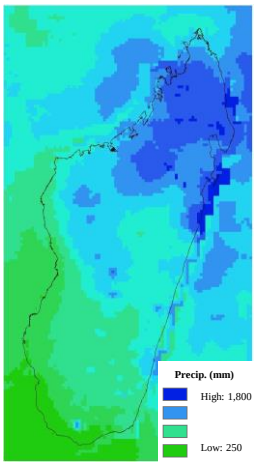
Environmental layers (raster data)



Mean annual temperature
Source: WorldClim



Mean annual precipitation
Source: NOAA FEWS

Aspect: East-West
Source: USGS Hydro1k

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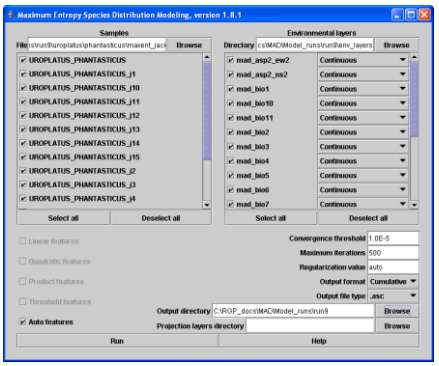
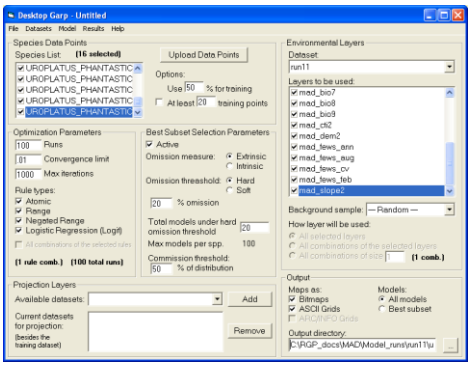
Ecological niche models



Maximum Entropy (Maxent)
Phillips et al. in press. *Ec. Mod.*
www.cs.princeton.edu/~schapire/maxent/



GARP
Stockwell and Peters 1999 *Int. J. GIS*
http://www.lifemapper.org/desktopgarp/

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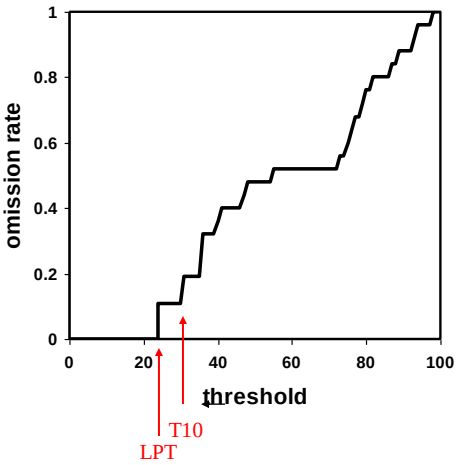
Selecting decision thresholds



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Model evaluation with small numbers of presence-only records

A niche-based distribution model should:

1. Successfully predict a high proportion of test localities
2. Not predict as suitable such a large proportion of the study area as to make the model statistically indistinguishable from a random prediction

Species	Locality sample size
U. malahelo	4
undescribed	5
undescribed	6
U. malama	6
U. guentheri	7
U. lineatus	10
U. ebenaui	11
U. henkeli	13
undescribed	13
U. fimbriatus	15
U. phantasticus	15
U. sameiti	16
U. sikorae	23

=> Use jackknife approach (Pearson et al. 2007 *J. Biogeog.*)

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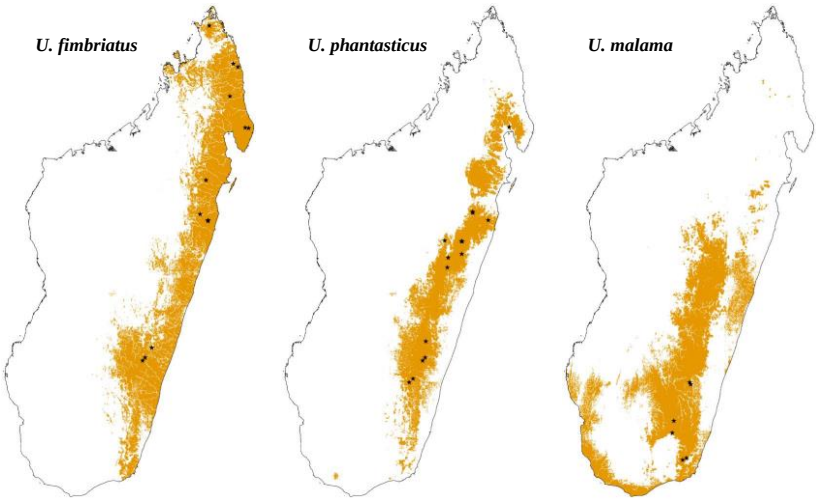
Results: Niche model predictions



Example modeled distributions, using Maxent and applying a decision threshold of 10

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Results: Jackknife evaluation

Species	Locality sample size	Maxent (t10)		GARP (t1)	
		Successes	*p*-value	Successes	*p*-value
U. malahelo	4	2	0.0481	0	1.0
undescribed	5	5	4.72e-09	2	1.00e-04
undescribed	6	5	2.53e-05	2	0.0092
U. malama	6	6	2.71e-05	1	0.0227
U. guentheri	7	7	2.04e-05	2	0.0019
U. lineatus	10	10	1.32e-06	6	1.38e-06
U. ebenaui	11	10	1.57e-08	11	1.02e-07
U. henkeli	13	10	1.76e-04	9	1.50e-04
undescribed	13	10	1.97e-06	9	8.35e-09
U. fimbriatus	15	13	2.09e-07	11	2.22e-07
U. phantasticus	15	13	5.31e-09	12	1.28e-08
U. sameiti	16	15	8.57e-10	13	4.28e-08
U. sikorae	23	21	1.45e-10	18	1.05e-06

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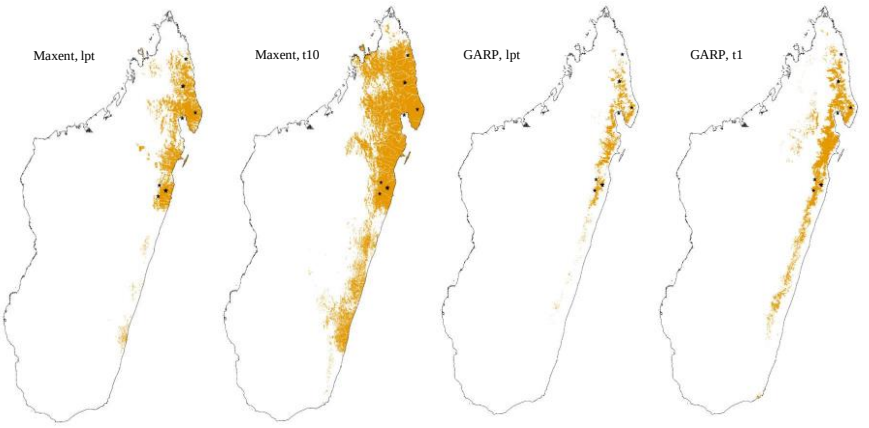
Results: comparison of modeling methods and thresholds



Modeled distributions for *U. lineatus* using both algorithms and two decision thresholds

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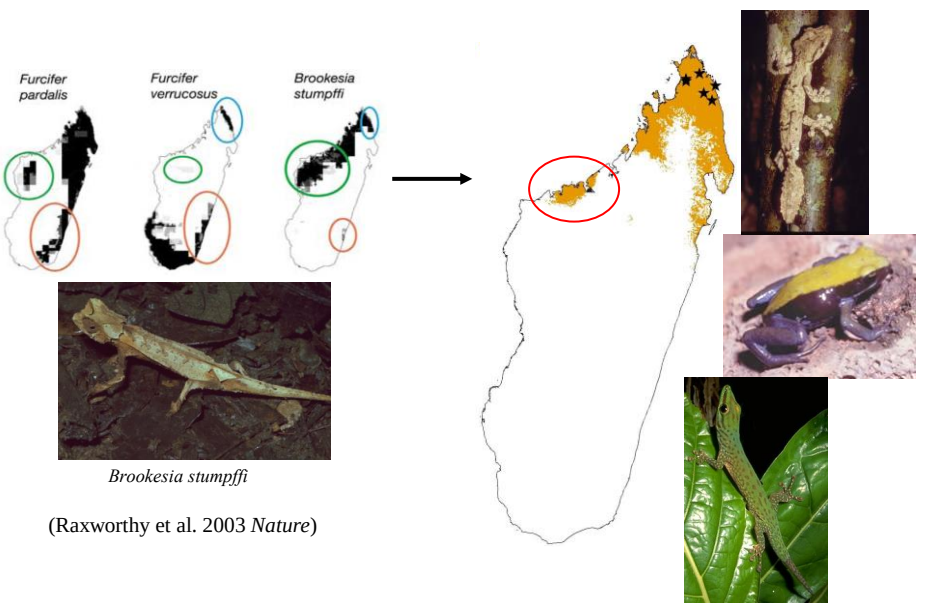
Application of models to guide field surveys in Madagascar



Brookesia stumpffi

(Raxworthy et al. 2003 *Nature*)

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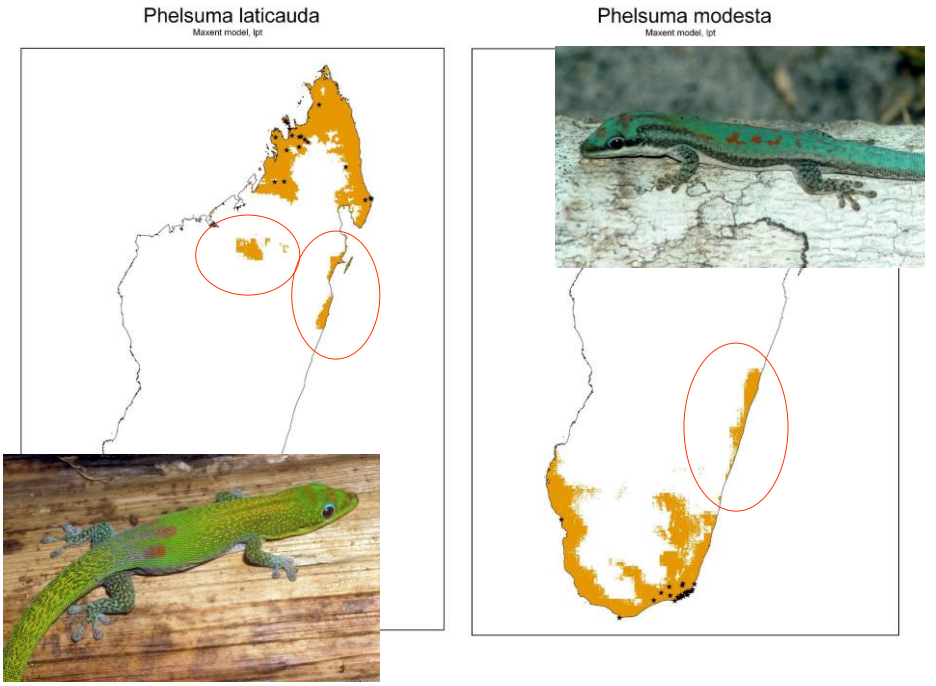

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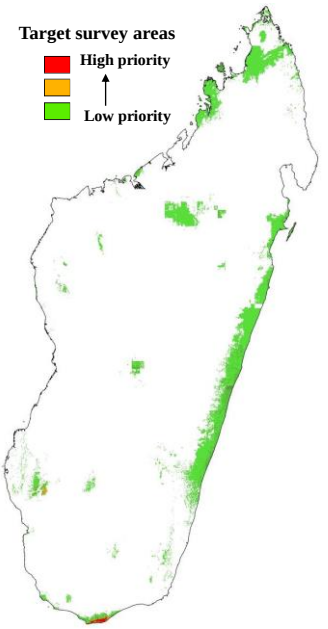
GIS overlay of predictions for multiple species

Chameleons (*Brookesia* & *Chamaeleo*)

Day geckos (*Phelsuma*)



Leaf-tailed geckos (*Uroplatus*)

(Pearson et al. 2007 *J. Biogeography*)

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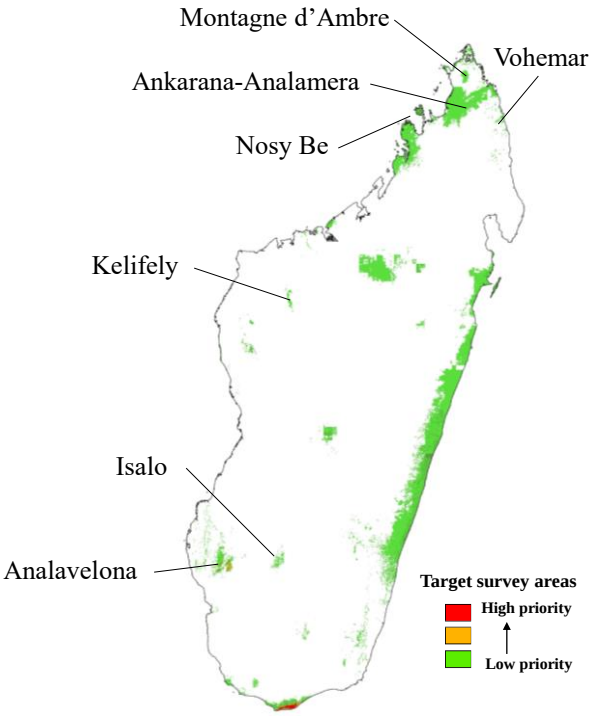
Overlay map correctly identifies well-known areas of local endemism



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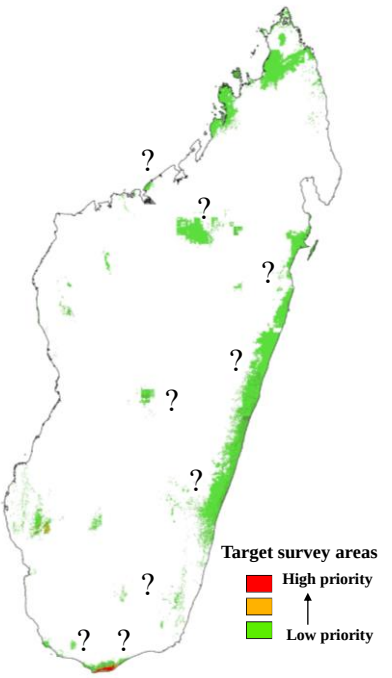
But other areas were poorly studied, and subjected to survey 2006-2009



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Results: New Species of *Calumma* chameleon

Calumma sp. 1

Calumma sp. 2

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Results: New Species of *Oplurus, Liophidium*

Oplurus sp.

Liophidium sp.

and others…

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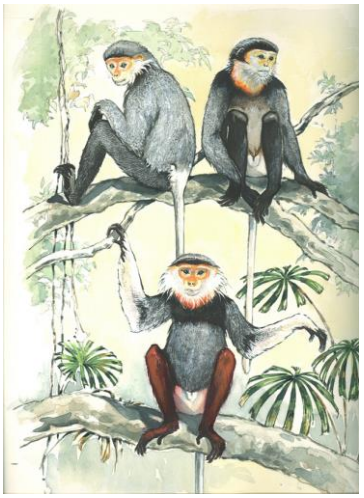
Doucs (*Pygathrix*)



Joyce A. Powzyk

Douc complex

Kevin Koy/CBC-AMNH

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Range Expansion Discovery: Grey-shanked Doucs

WWF

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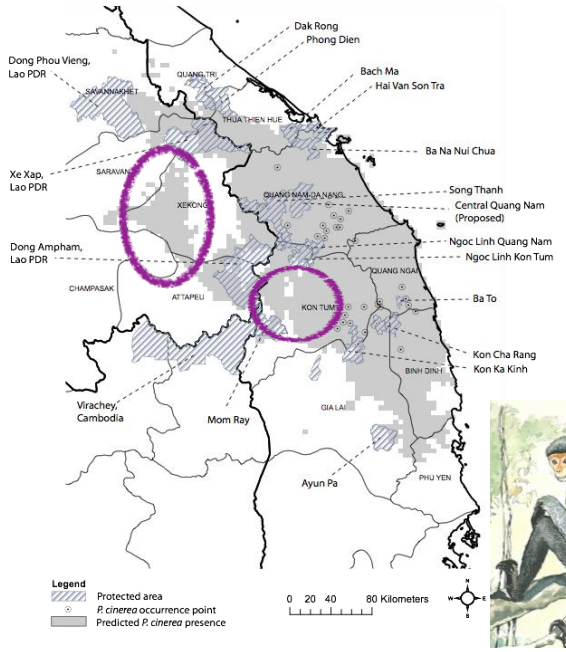

- Identifying areas with long-term conservation value
- Identifying areas where species could be - to direct surveys, monitoring

Grey-shanked douc
Pygathrix cinerea
MaxEnt model 2012

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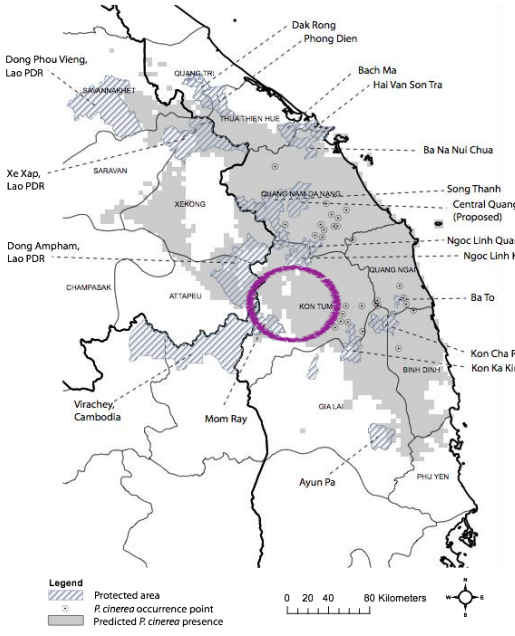

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Ecological niche evolution and speciation processes

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Acknowledgements

- Co-authors: Eleanor Sterling, Richard Pearson, Chris Raxworthy, Matt Dusch



- Also: Y. Wyner, A. Yoder, R. DeSalle, J. Tinsman, and the New York Regional Species Distribution Modeling discussion group for valuable discussion
- This project was partly funded by the U.S. National Science Foundation (DEB 0423286, DEB 0641023, CHE 1313908).

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Can Niches Evolve?
Ecological Niche ~~Evolution~~ Differences

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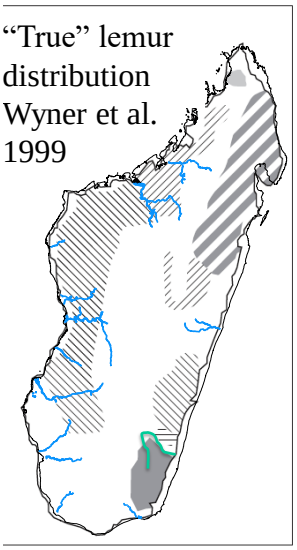
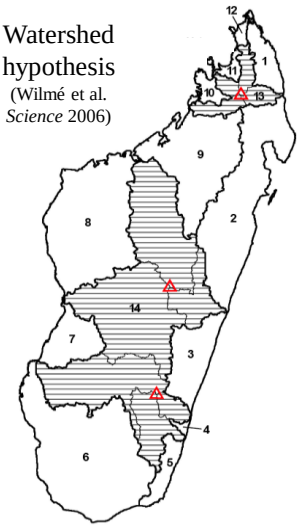
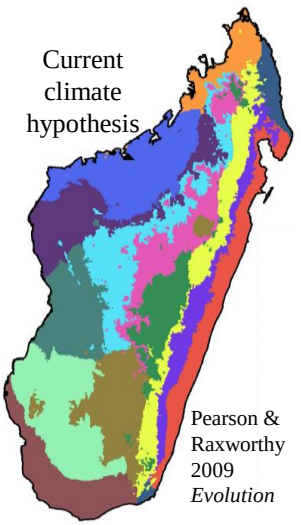
Hypotheses for endemism







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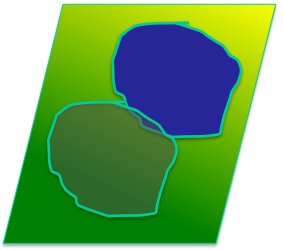
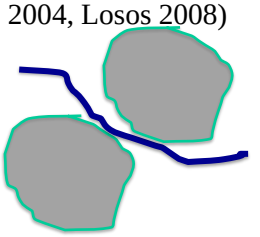
Case Studies

- Built ecological niche models (ENMs) for lemurs (*Eulemur)* in Madagascar
- Test sister taxa for :
  - niche divergence; niche conservatism, or null

Parapatric ecological speciation



Allopatric speciation (e.g. Wiens et al. 2004, Losos 2008)



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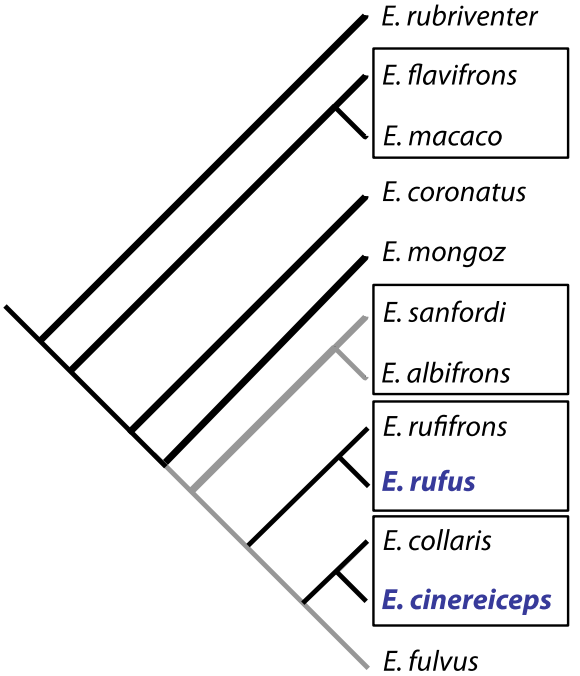

Eulemur Sister taxa

- Tree based on:
  - Horvath *et al.* 2008
  - Gudde *et al.* 2013
  - Johnson *et al.* 2008
  - Pastorini *et al.* 2003
  - Wyner *et al.* 1999

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MaxEnt ENMs (Phillips et al. 2006)

Climate Variables at 30 arc-second resolution
(Hijmans et al. 2005 *WorldClim)*

Lemurs:
Isothermality
Temp annual range
Temp seasonality
Min temp coldest month
Precip driest quarter
Precip coldest quarter

Correlations among variables $r<0.67$

Blair *et al. J. Evolutionary Biology* 2013

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MaxEnt ENMs (Phillips et al. 2006)

- Lemur distribution data from Wilmé *et al.* (2006)
  - Corrected with more recent survey data
  - 10-86 records per species
- Regularization = 1
- 4-fold cross-validation

- All models showed strong predictive ability
  - AUC values all >0.85, most >0.90

Blair *et al. J. Evolutionary Biology* 2013

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Testing for Niche Divergence and Conservatism:

ENMTools (Warren *et al.* 2008, 2010)

1. Measure overlap (Schoener's *D* and Hellinger's *I*, 0->1)
2. Background Test

- Better statistical rigor to infer niche conservatism or divergence than previous methods - null model and test of significance

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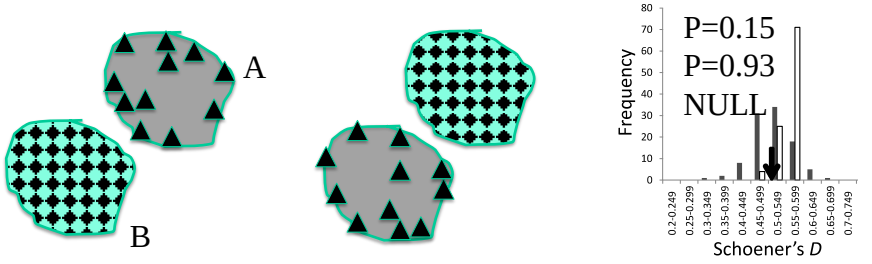
Testing for Niche Divergence and Conservatism:

ENMTools (Warren *et al.* 2008, 2010)

1. Measure overlap (Schoener's *D* and Hellinger's *I*, 0->1)
2. Background Test



X 100 ENMs X 100 ENMs

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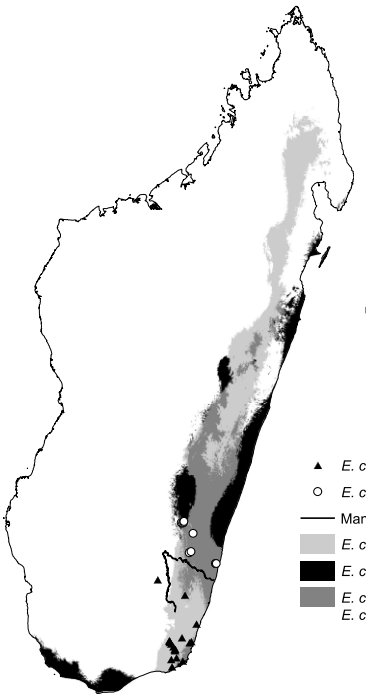
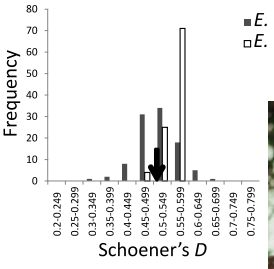
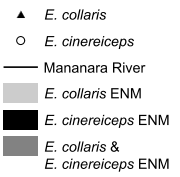
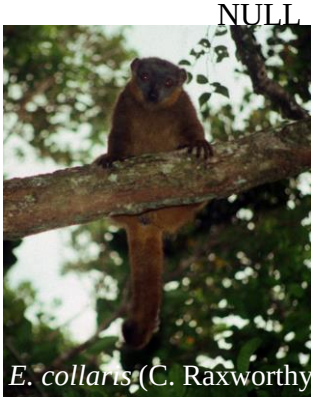


E. collaris – E. cinereiceps



E. collaris to *E. cinereiceps* P=0.07
E. cinereiceps to *E. collaris* P=0.92
NULL




E. collaris (C. Raxworthy

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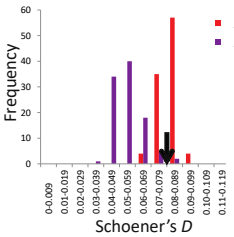
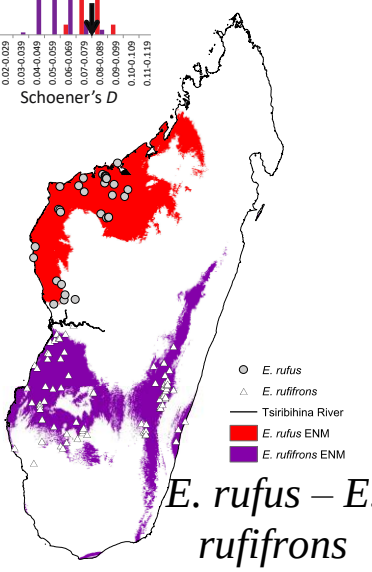
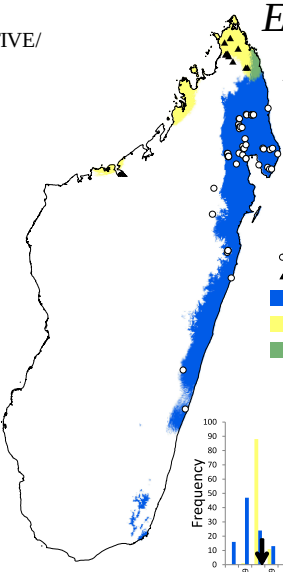


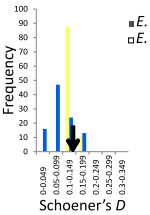
E. rufus to *E. rufifrons* P=0.78
E. rufifrons to *E. rufus* P=0.03
CONSERVATIVE/
NULL



E. rufus – E. rufifrons

E. albifrons – E. sanfordi





E. sanfordi to *E. albifrons*
E. albifrons to *E. sanfordi*
P=0.45
P=0.44
NULL

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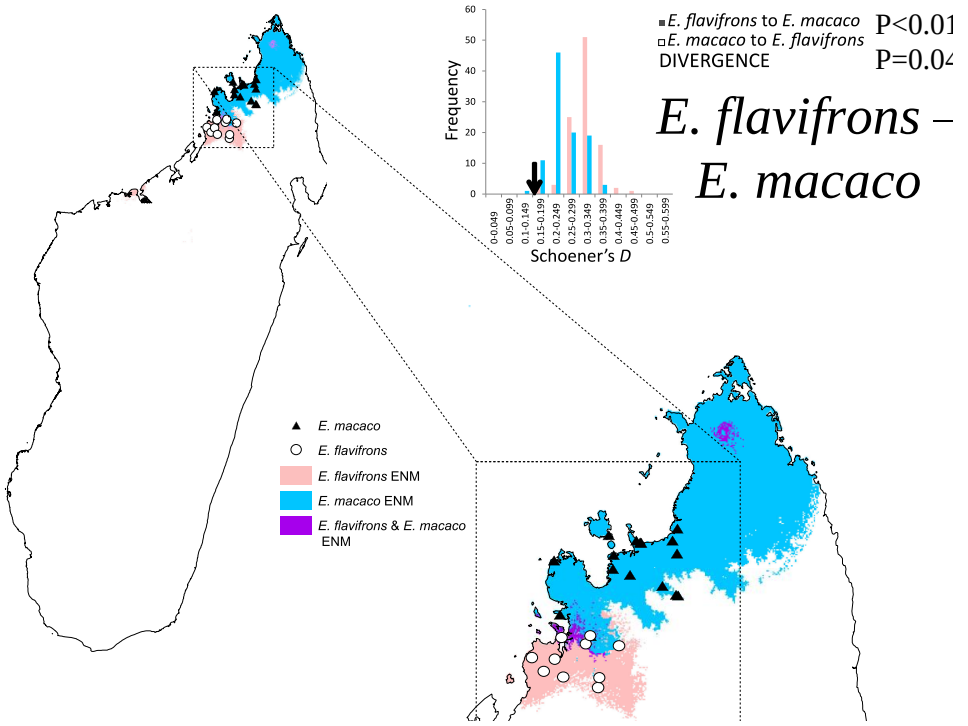

E. flavifrons – *E. macaco*

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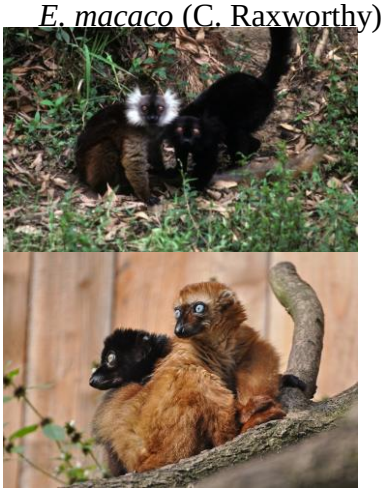
E. flavifrons (CR) – *E. macaco* (VU)

- Elevated to species in 2008
- No natural barrier
- Precipitation ecotone
- Possible hybrid zones*
- Also: morphological differences that might facilitate assortative mating

E. macaco (C. Raxworthy)



E. flavifrons (flickr)

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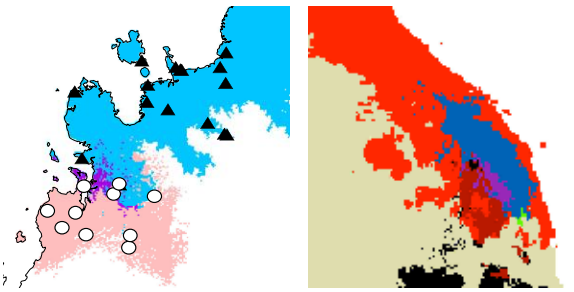
Hybrid zones

- Secondary contact or primary speciation process?
  - ENMs are a useful tool



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Conclusions and Future Work

- Multiple divergence processes
  - Landscapes facilitate speciation through both population isolation and ecotone adaptation
- Conservation efforts should focus on ecotones and incorporate river barriers into planning as a means to maintain evolutionary processes
- Future work:
  - Landscape genomics along ecotones
  - Projecting ENMs to the past and into the future
  - Adding other environmental data (land cover) to ENMs
  - Look across many other taxonomic groups

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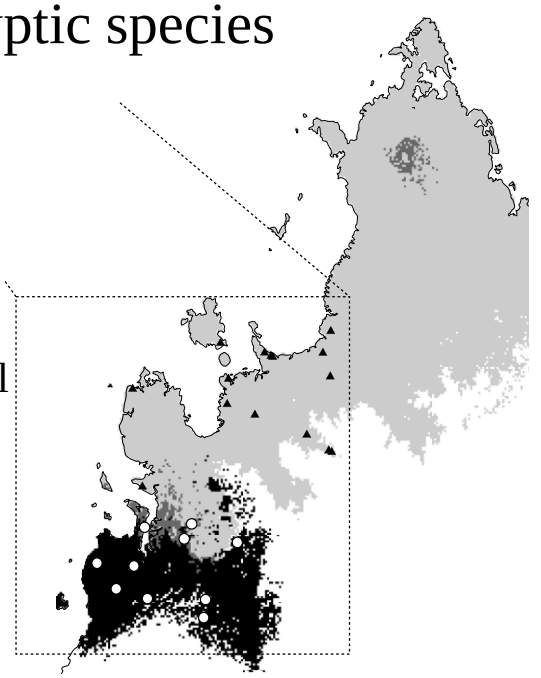
Cryptic species

- Identity test (ENMTools)
- Non-equivalent niches
- Lack of ecological exchangeability



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ENMTools: pros and cons

- Pros:
  - Null model for statistical significance
- Cons: *(Pyron et al. 2015 Biological Reviews)*
  - Relatively easy to reject null hypothesis
  - Brownian motion appropriate?
  - Weird results sometimes (not sensitive to gradients, depends on scale, background, fit)
  - Carries over uncertainty of Maxent model algorithm (can be difficult to incorporate model tuning)
- Alternative approach: Broenniman et al. 2011

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