# Putting process on the map: why ecological gradients are important for preserving biodiversity

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# Biodiversity Hotspots






# Two limitations of hotspots

1) may fail to capture regions important in generating or maintaining adaptive variation

2) may fail to take into account climatic change

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are needed to see this picture.

# Why preserve gradients?

1) Natural Selection along gradients is a powerful driver of adaptive variation

2) Given climate change preserving them may offer a bet hedging approach

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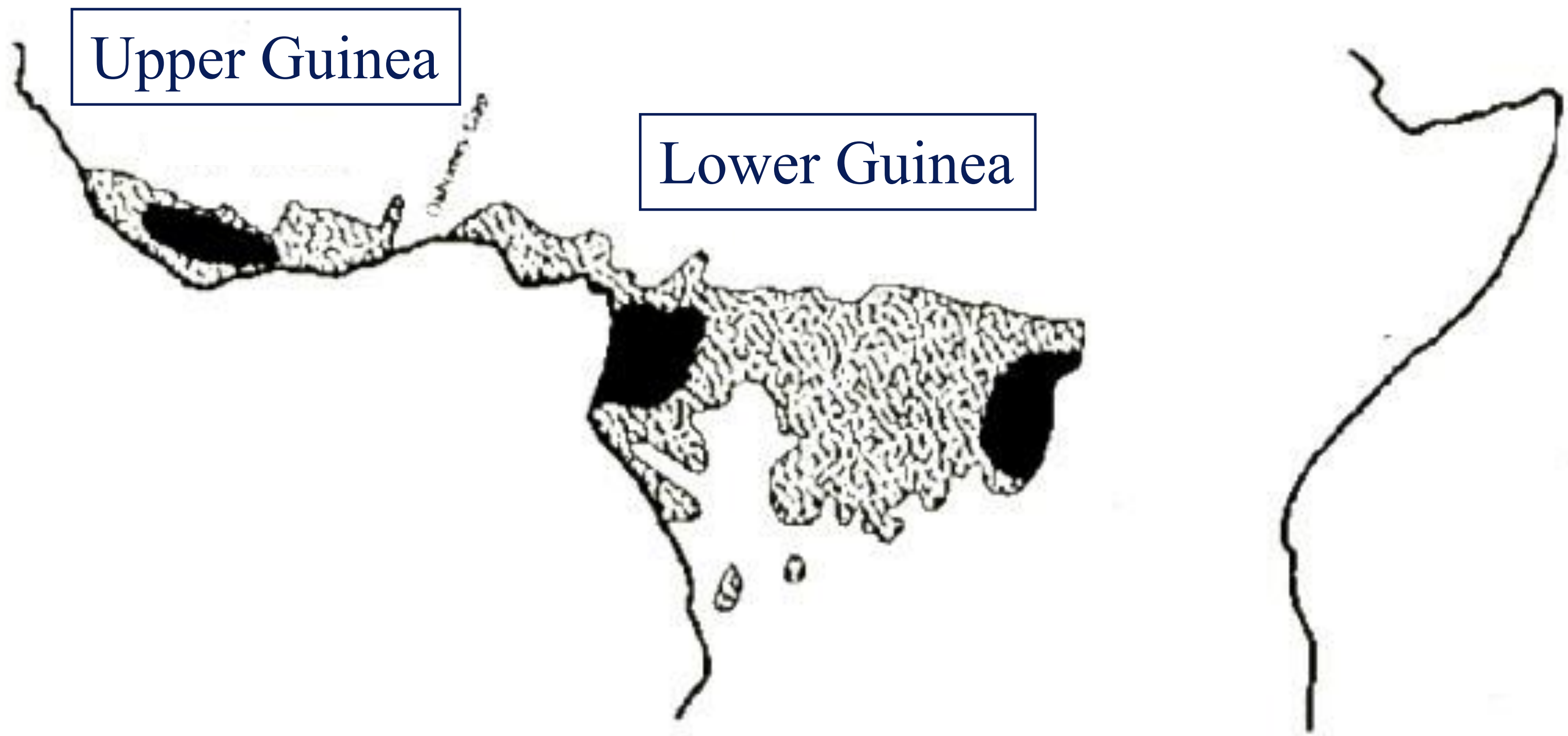
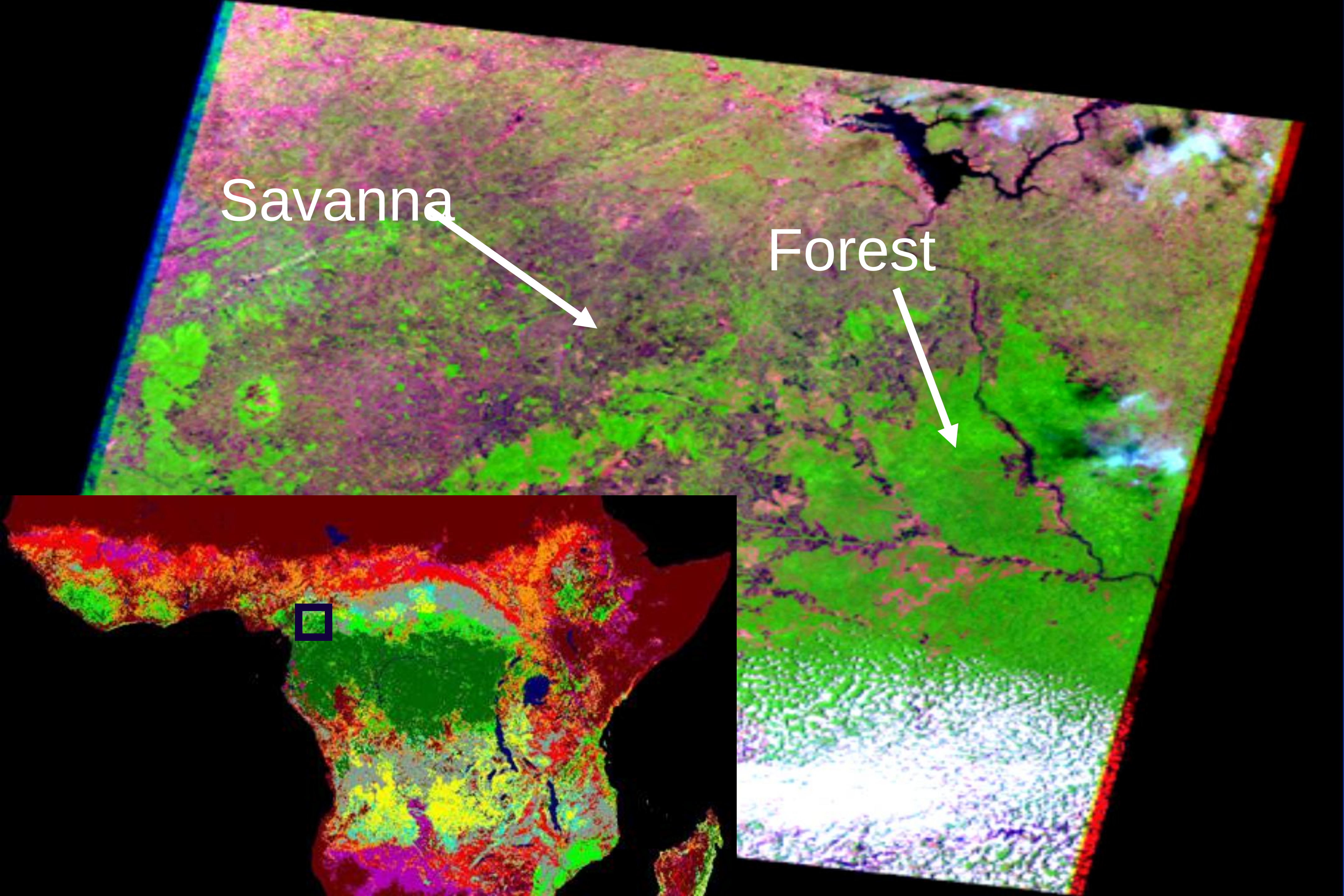
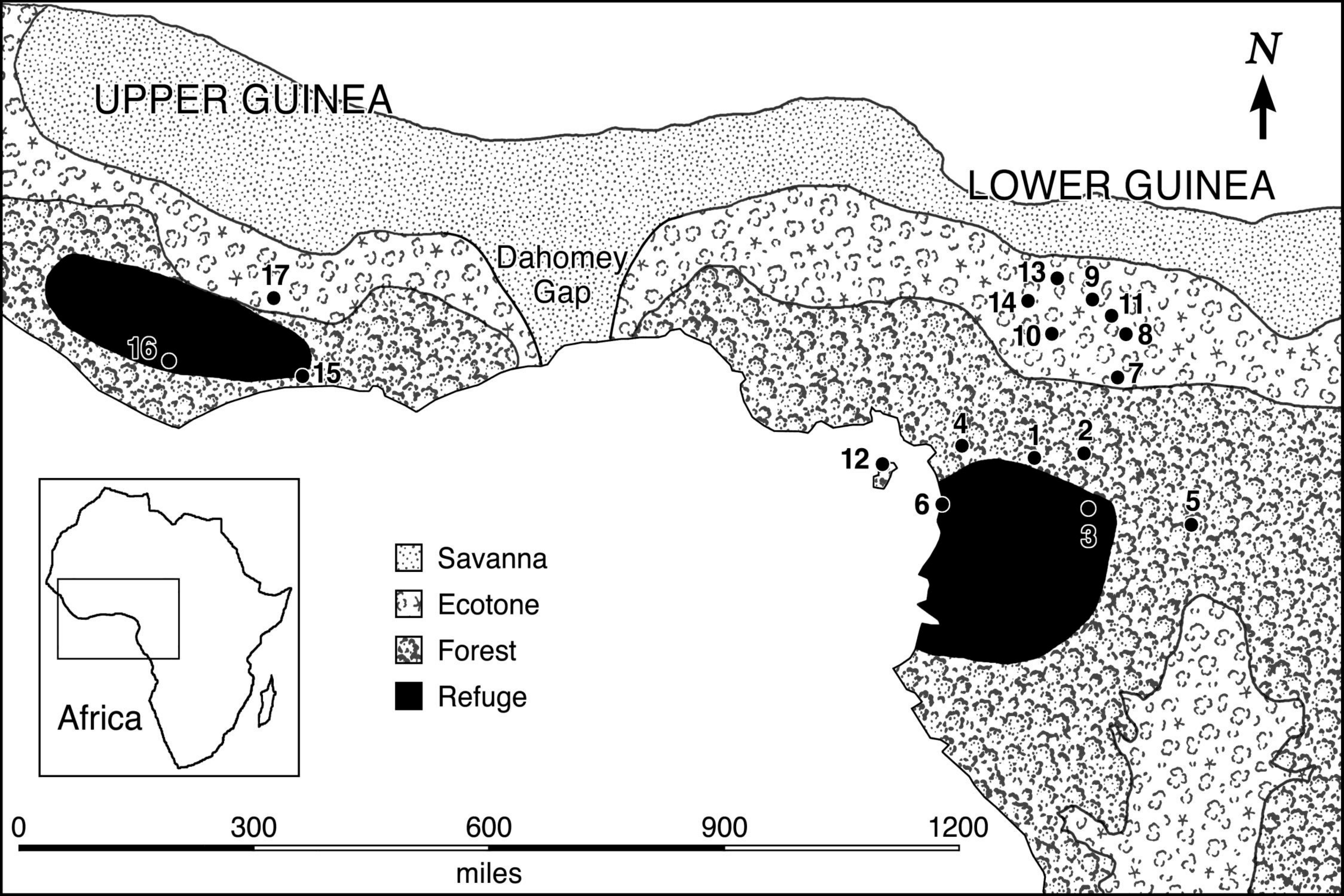
# Present distribution of rainforest (stipple) and postulated locations of refuges (black)

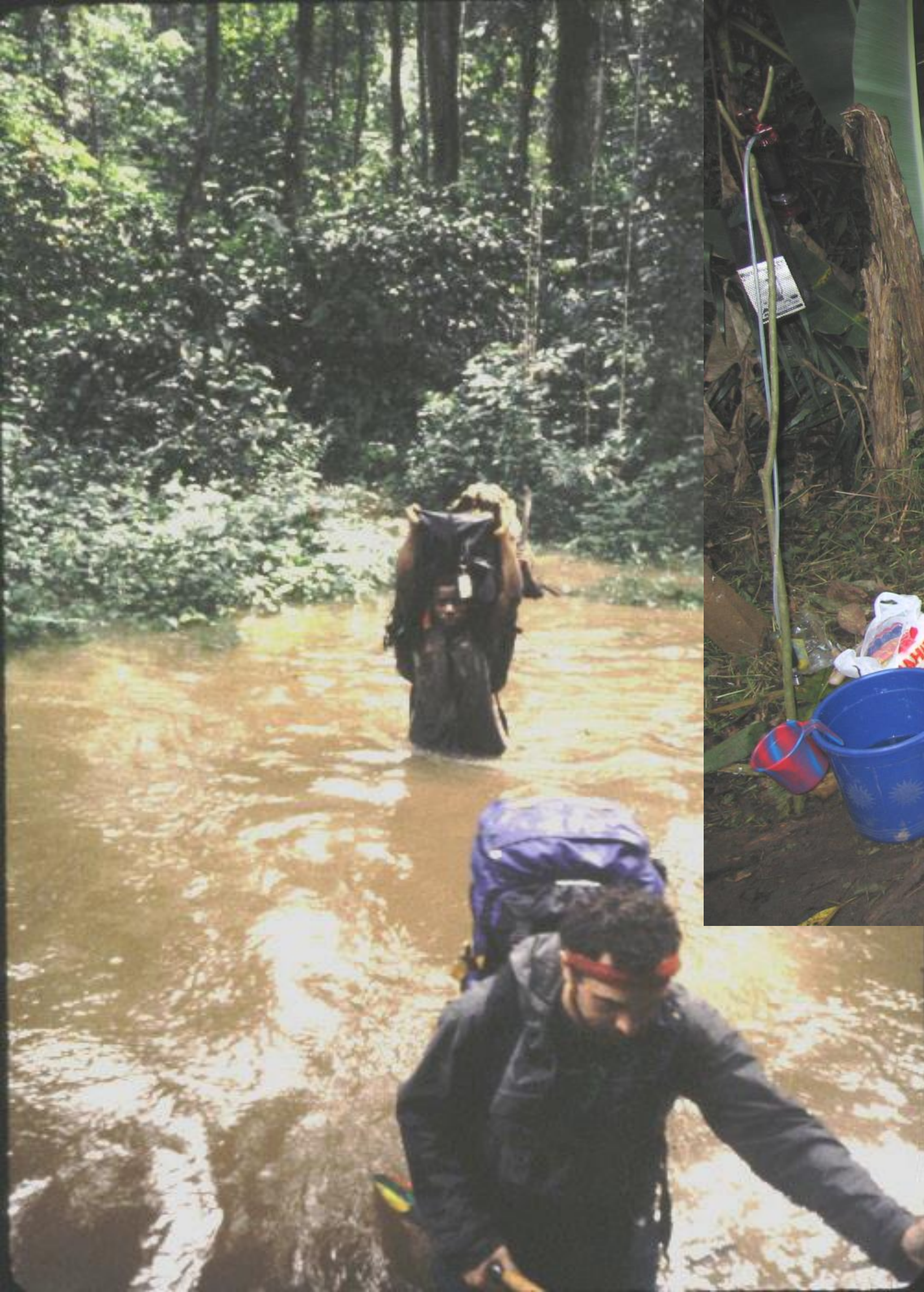
(from Mayr and O'Hara 1986)




Savanna
Forest



UPPER GUINEA
LOWER GUINEA
N
Dahomey
Gap
17
16
15
13
9
14
11
10
8
7
4
1
2
12
6
3
5
Africa
Savanna
Ecotone
Forest
Refuge
0
300
600
900
1200
miles

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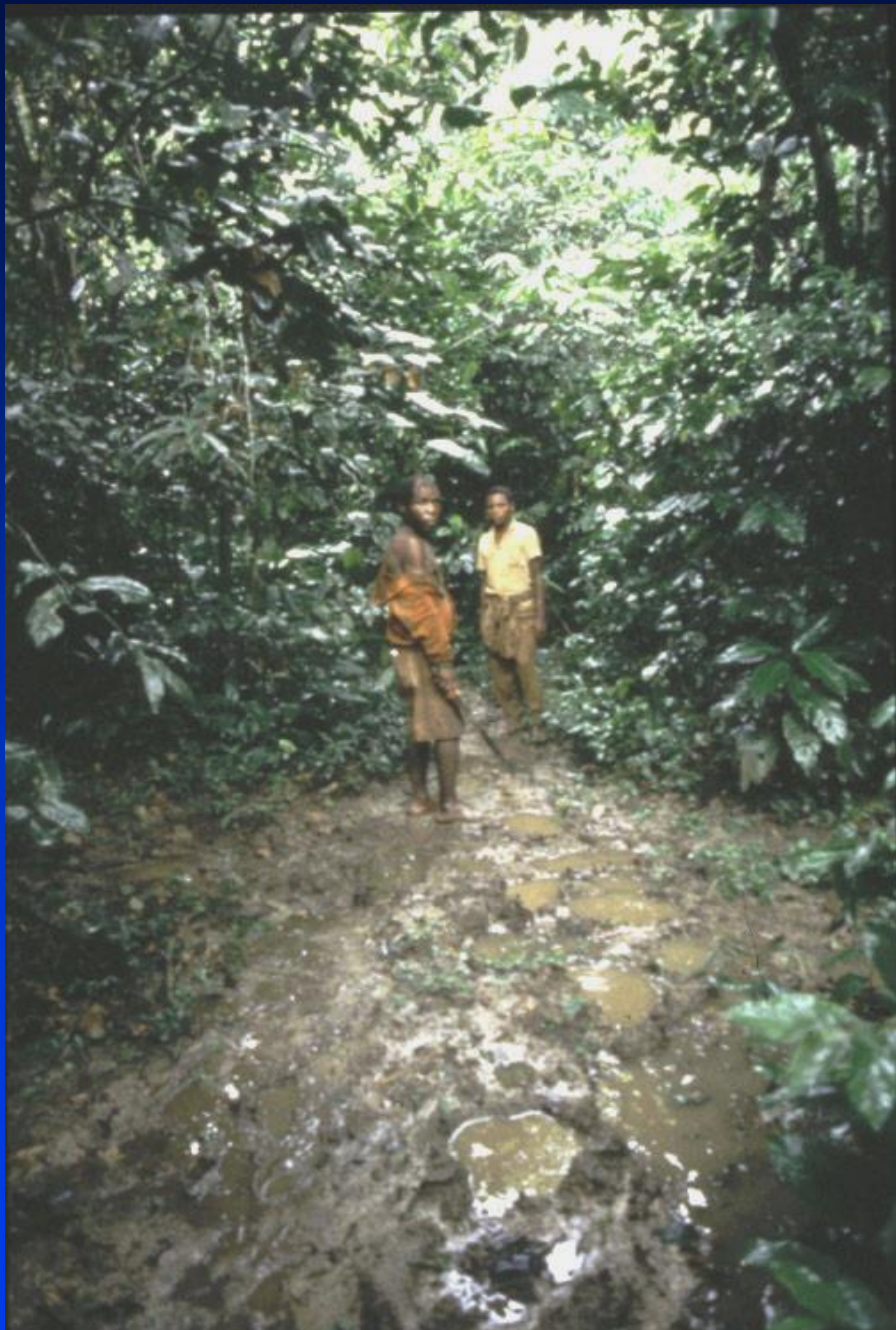

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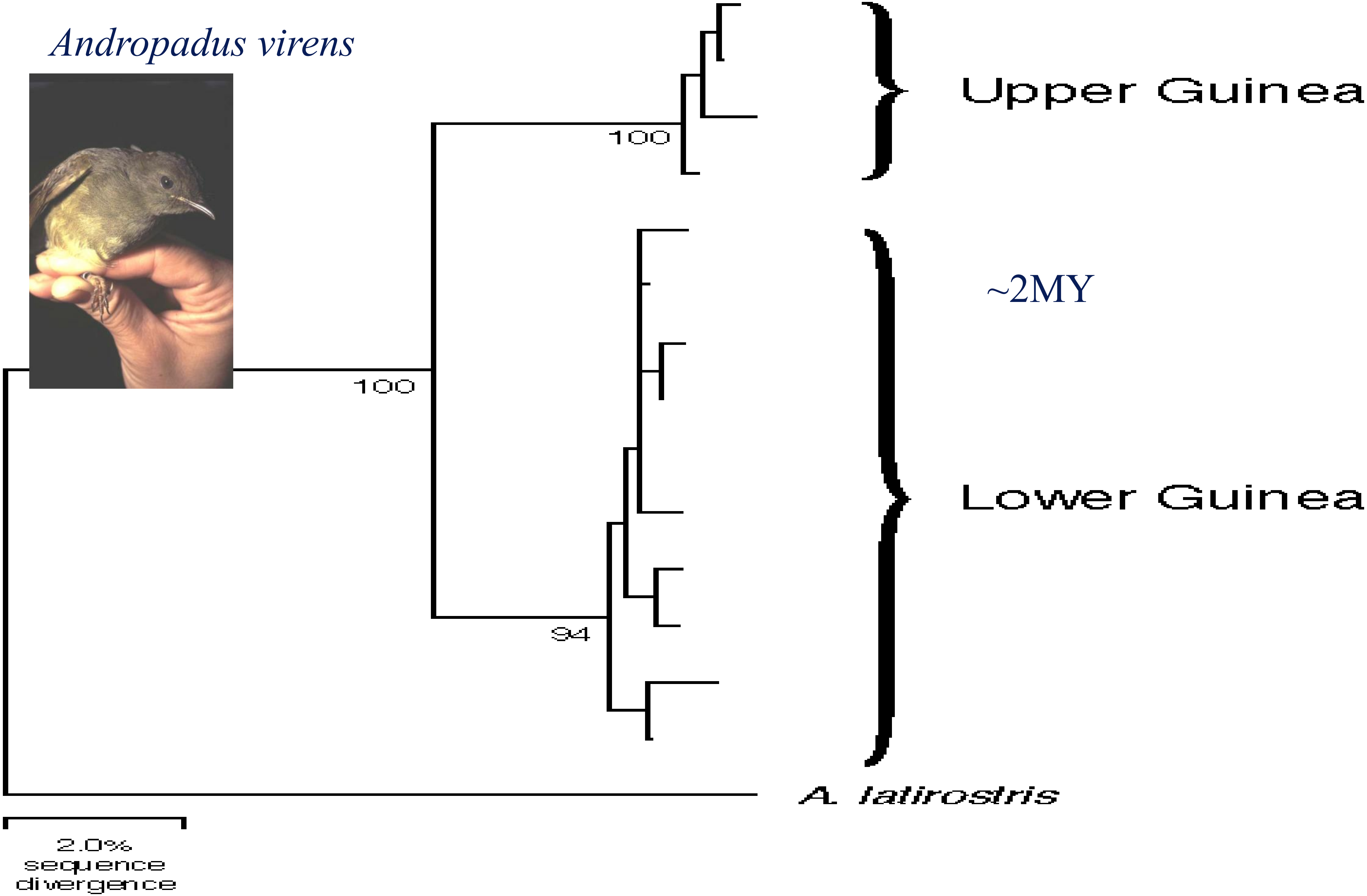
Little Greenbul

*Andropadus virens*

*Andropadus virens*



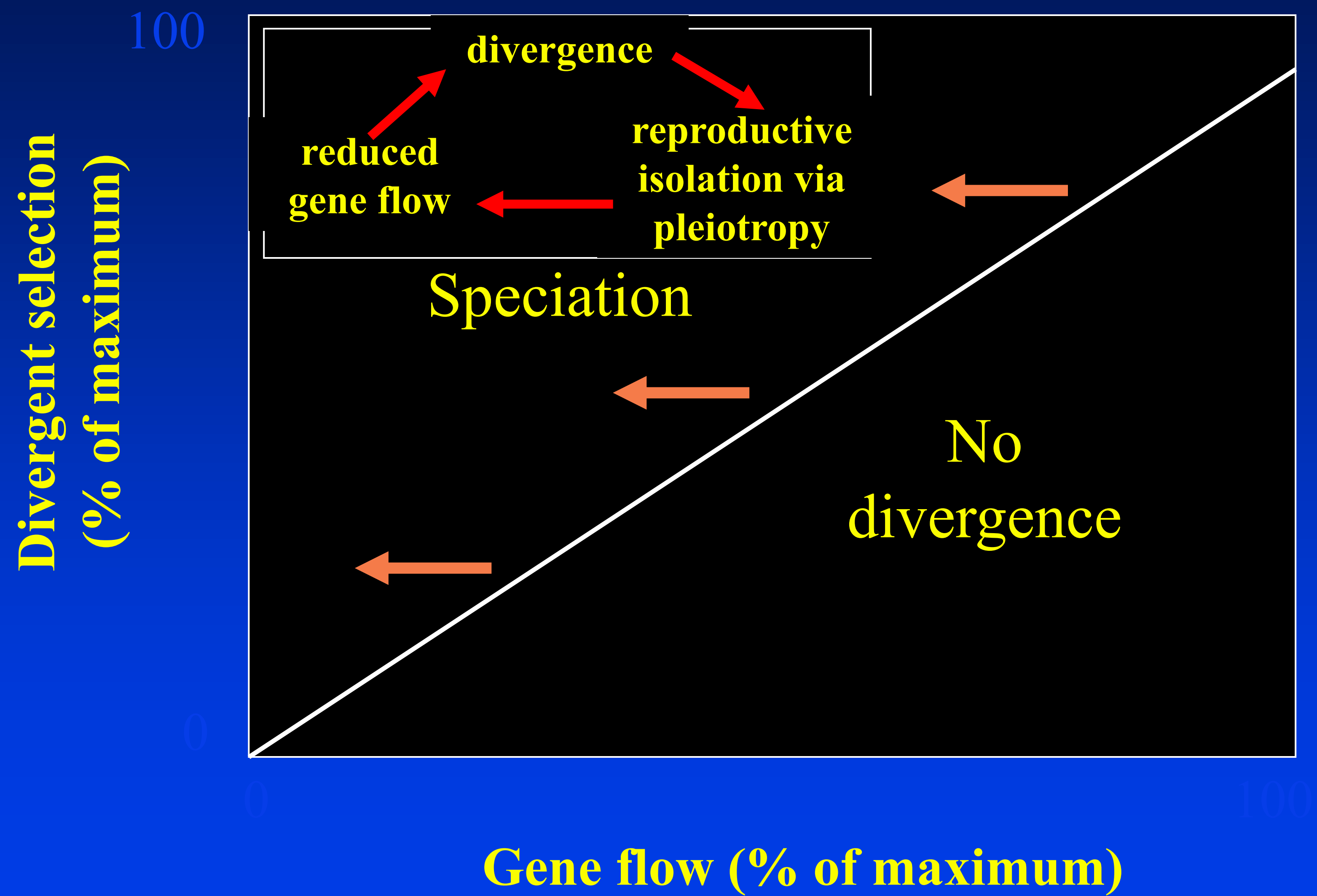
Two way MANOVA between region (upper and lower guinea) and habitat (forest vs. ecotone)

Adult Males

| Character | Whole Model<br>*P* | Habitat<br>*P* | Region<br>*P* |
|---|---|---|---|
| Mass (g) | **0.0001** | **0.0001** | **0.01** |
| Wing length (mm) | **0.0001** | **0.0001** | 0.35 |
| Tail length | **0.001** | **0.0001** | 0.41 |
| Tarsus length | **0.0001** | **0.0001** | 0.29 |
| Upper mandible l. | **0.01** | 0.49 | **0.002** |
| Bill depth | **0.06** | **0.022** | 0.64 |

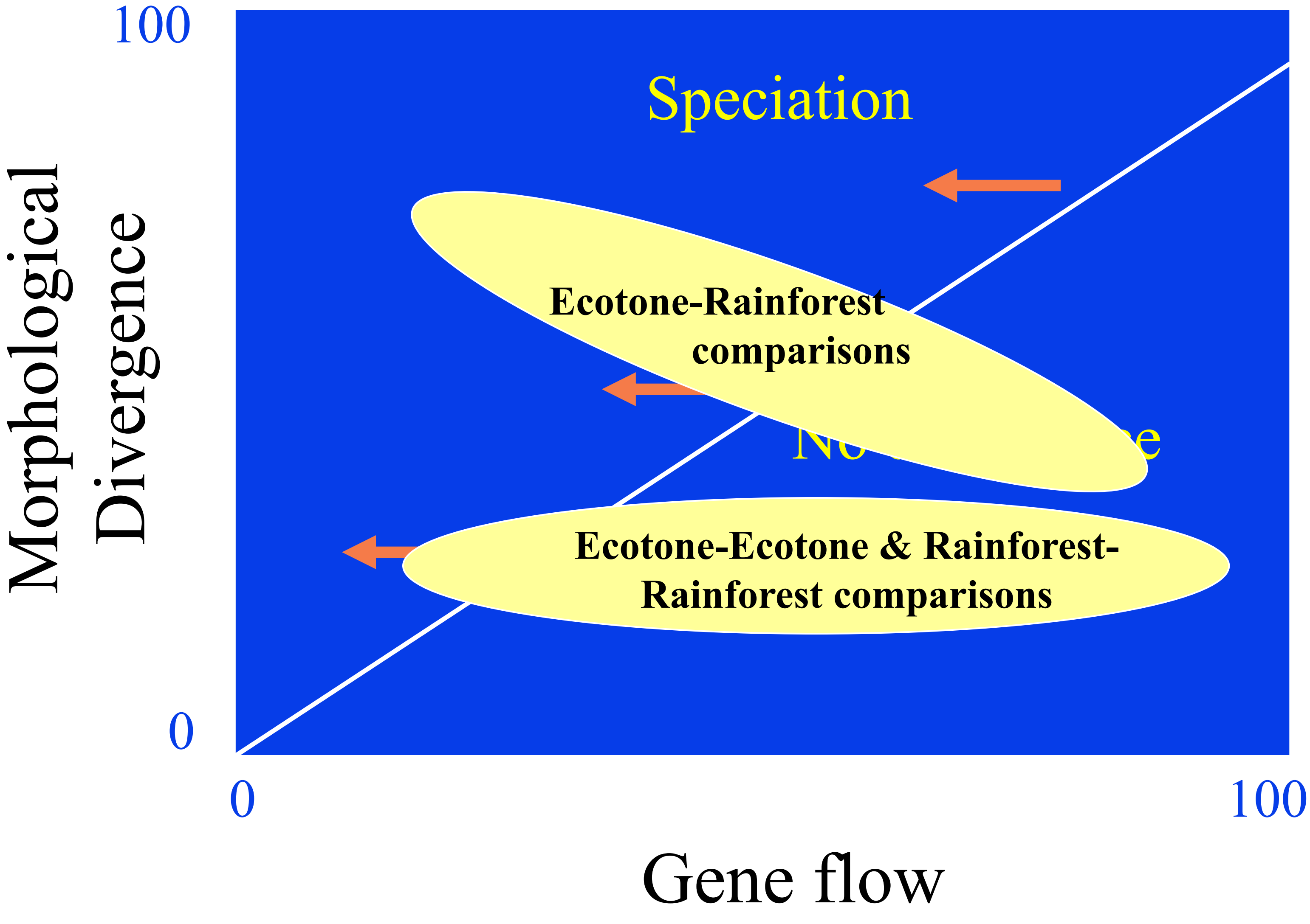
Smith et al. 2005 J. Evol. Bio.

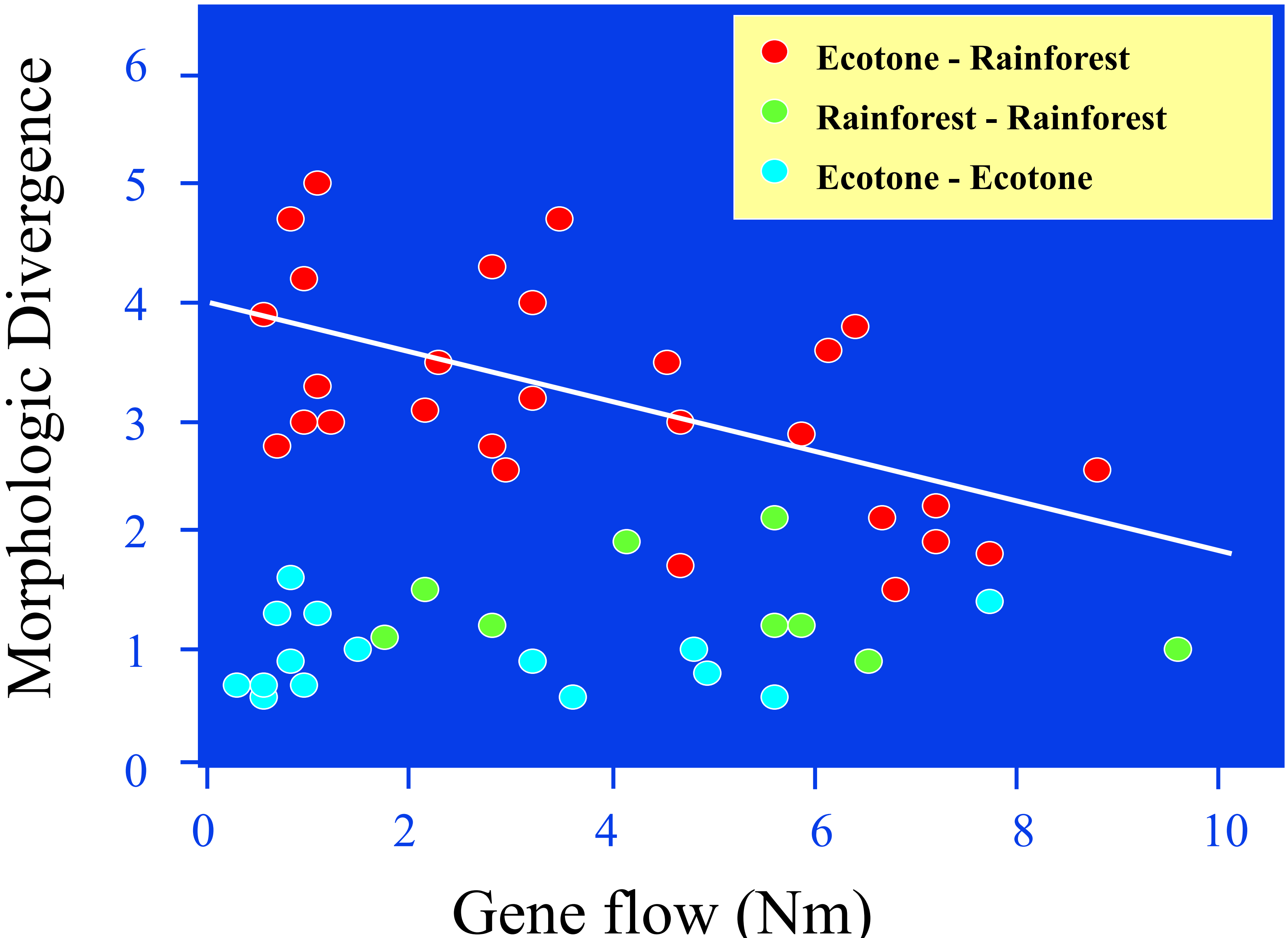
# Divergence-with-gene-flow model of speciation




(Rice & Hostert: Evolution 1993)

# Divergence-with-gene-flow in little greenbuls





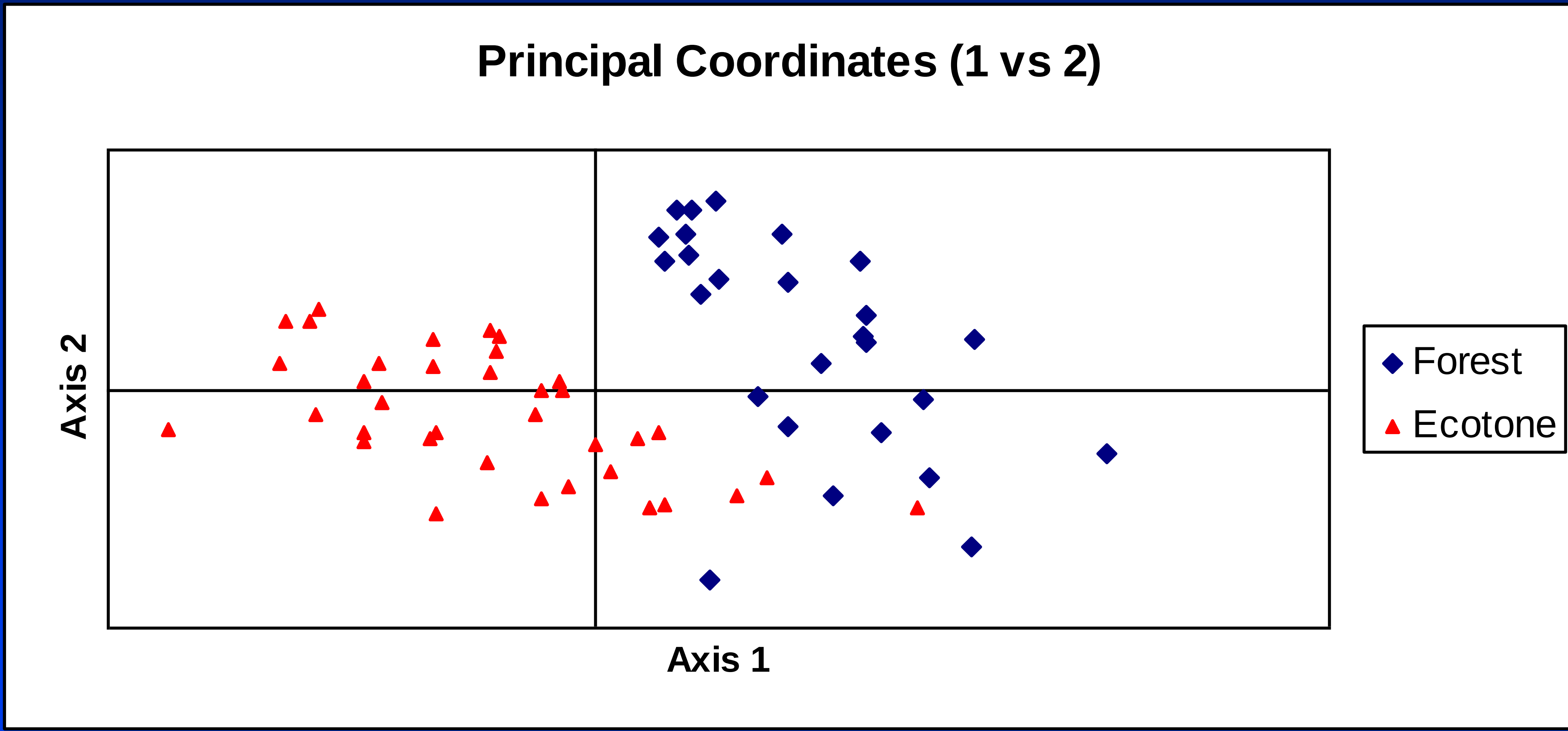

(Smith et al. Science 1997)

Evidence of morphological divergence and divergence with gene flow

What is the evidence for genetic divergence and reproductive isolation?

# Principal Coordinates Analysis of AFLP Markers

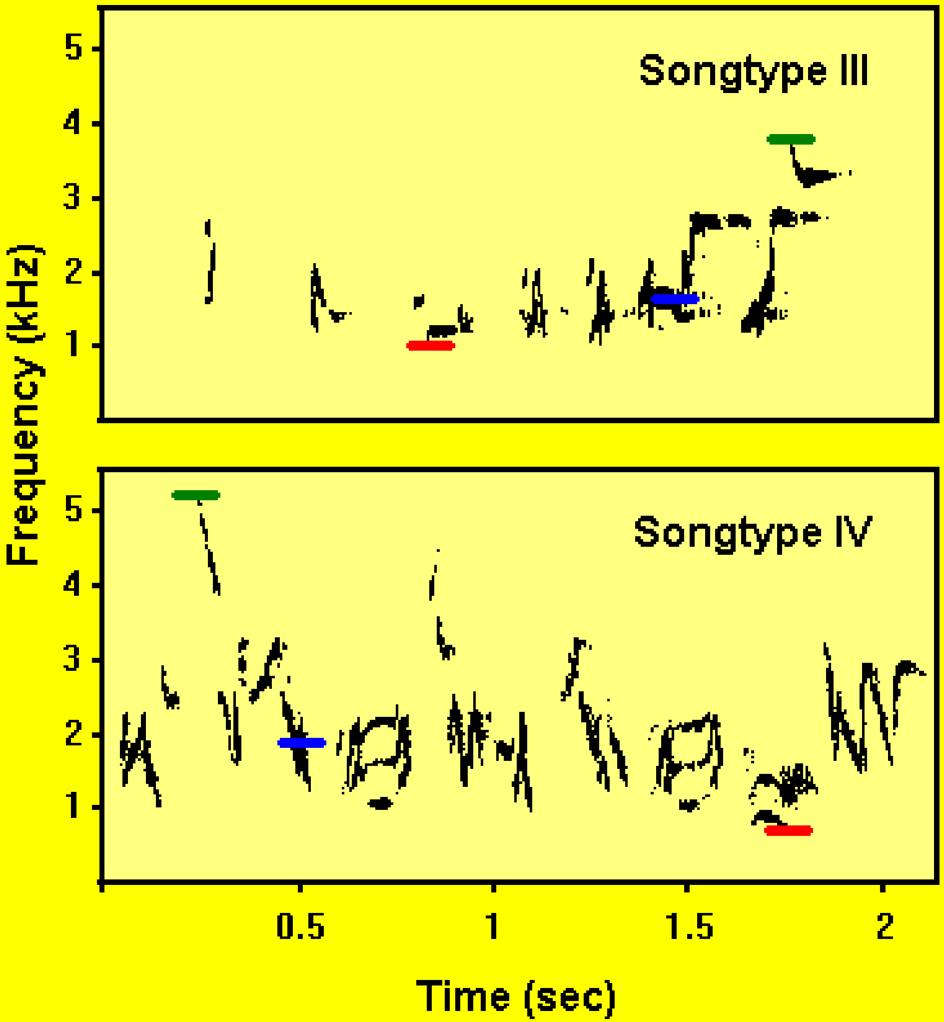
75 individuals
4 Forest sites; 5 Ecotone sites
210 markers (c9 + c13)



# Breeding activity of *Andropadus virens* by habitat and period

| Habitat | June-July | Jan-Feb |
|---|---|---|
| ECOTONE | - | + |
| FOREST | + | - |

# Acoustic Divergence




**Songtype III**

| | Rainforest | Ecotone | F | P | |
|---|---|---|---|---|---|
| Fmax | 3669 | 3385 | 44.65 | <0.001 | ** |
| Fpeak | 2069 | 2093 | 0.002 | NS | |
| Fmin | 1009 | 1036 | 19.67 | <0.001 | ** |
| Delrate | 7.8 | 6.6 | 49.27 | <0.001 | ** |

**Songtype IV**

| | Rainforest | Ecotone | F | P | |
|---|---|---|---|---|---|
| Fmax | 5086 | 5206 | 4.10 | NS | |
| Fpeak | 2398 | 2318 | 4.48 | NS | |
| Fmin | 904 | 957 | 37.18 | <0.001 | ** |
| Delrate | 8.6 | 8.6 | 0.27 | NS | |

Slabbekoorn and Smith 2002 Evolution

# Evidence for reproductive divergence?

Prezygotic isolating barriers

- ✓ 1) Habitat forest vs. ecotone
- ✓ 2) Temporal differ in breeding time
- ✓ 3) Behavioral differences in song

# Agents of Natural Selection?

- Food?
- Disease?
- Habitat structure?
- Predation?


Black-bellied Seedcracker *Pyrenestes ostrinus*
Large and small morph in the forest

# SEED HARDNESS

| Morph specializing | Species | Maximum Fracture Force (N) | Diameter (mm) |
|---|---|---|---|
| | | Mean $\pm$ SE | Mean $\pm$ SE |
| small | Soft sedge (*Scleria goossensii*) | 12.3 $\pm$ 2.0 | 2.92 $\pm$ 0.44 |
| large | Hard sedge (*S. verrucosa*) | 146.9 $\pm$ 2.0 | 3.26 $\pm$ 0.02 |


# Third bill morph in ecotone

$F_{st} = 0.005$ (ns) between mega and other morphs

Smith 1997 Ibis

# SEED HARDNESS

| Morph | Species | Maximum Fracture Force (N) | Diameter (mm) |
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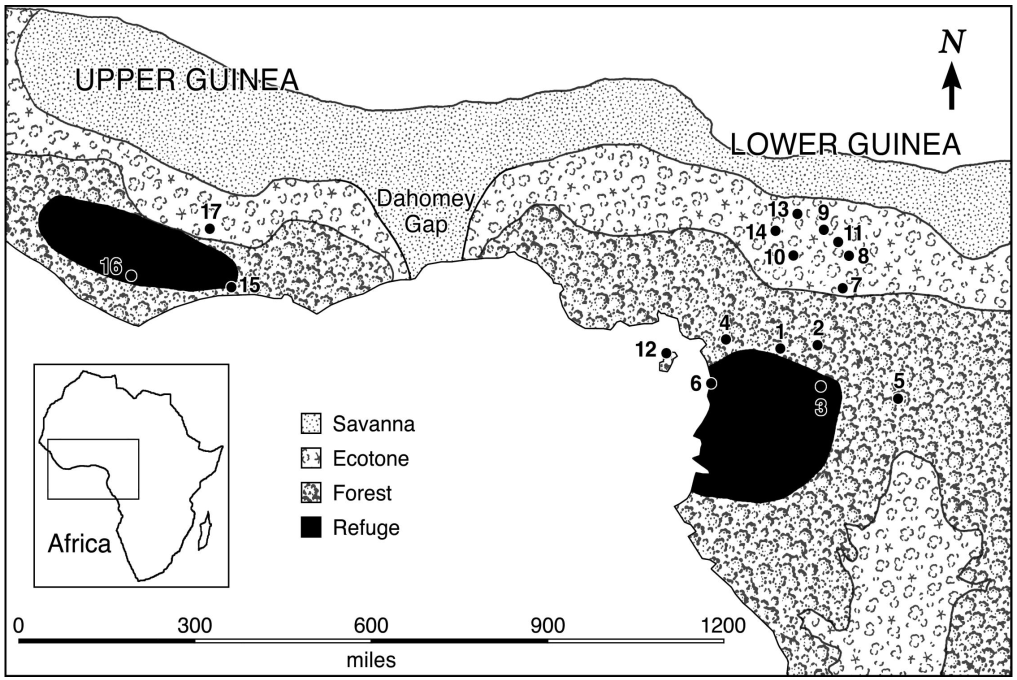
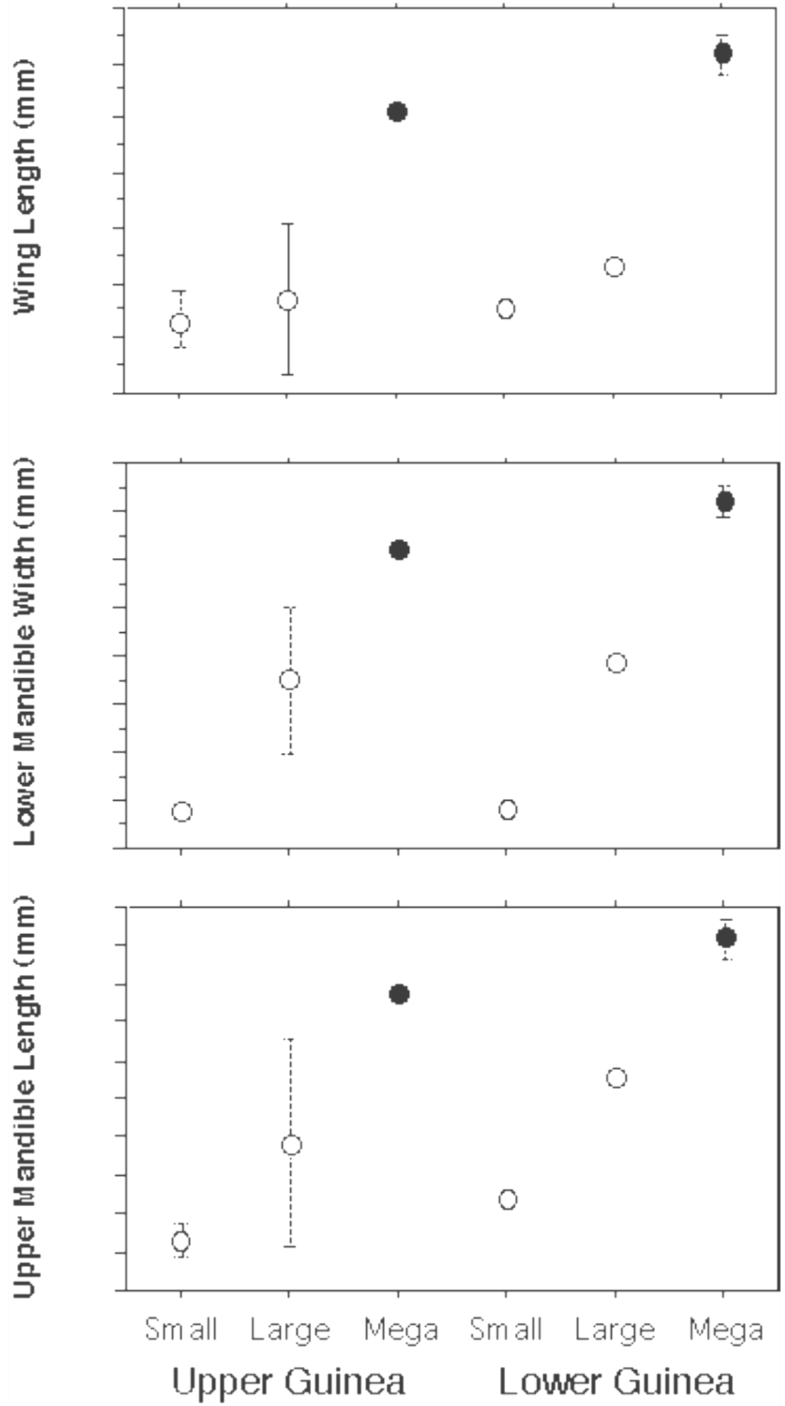
| large | Hard sedge (*S. verrucosa*) | 146.9 $\pm$ 2.0 | 3.26 $\pm$ 0.02 |
| mega | Ecotone Hard Sedge (*S. racemosa*) | 299.5$\pm$ 11.9 ECOTONE ONLY | 4.12$\pm$ 0.32 |

# Pattern of morphological variation between refugia is similar

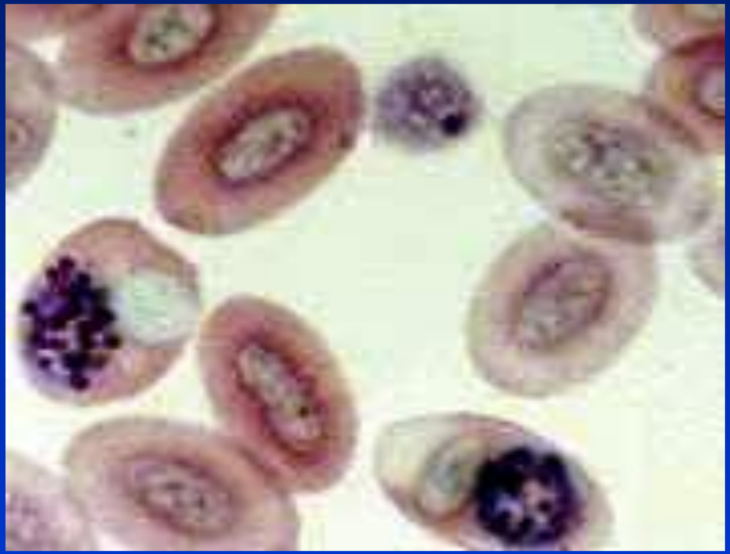



Smith et al. 2001 Genetica

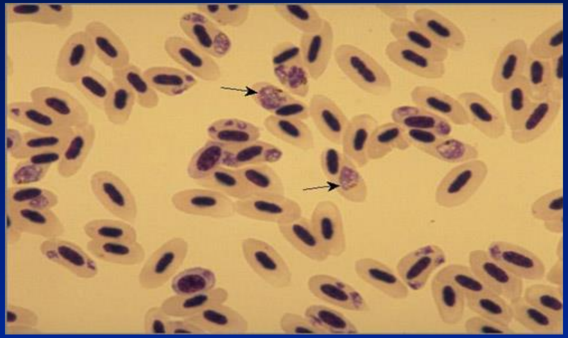
# Agents of Natural Selection?

- Food?
- Disease?



# Blood-borne parasites

Plasmodium relictum



Vectors

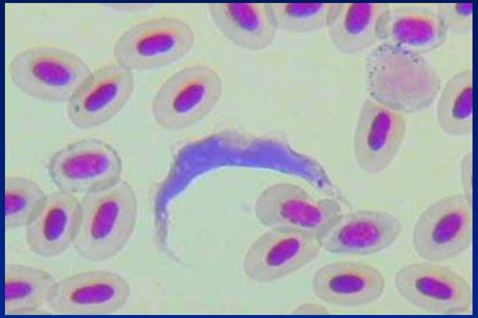
mosquito

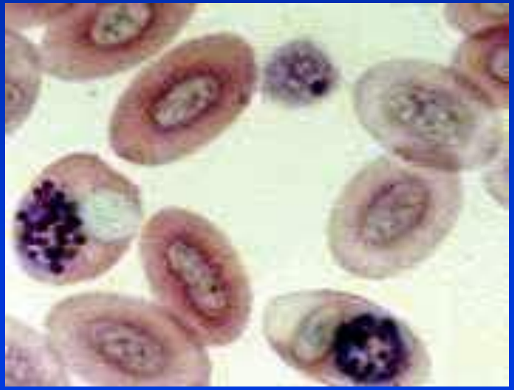
lousefly

midge

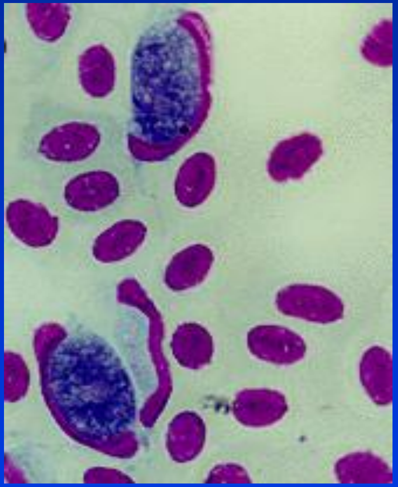
blackfly

Trypanosoma avium





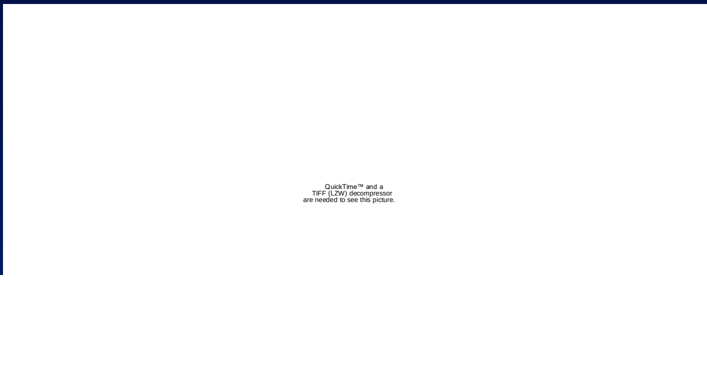
Haemoproteus columbae

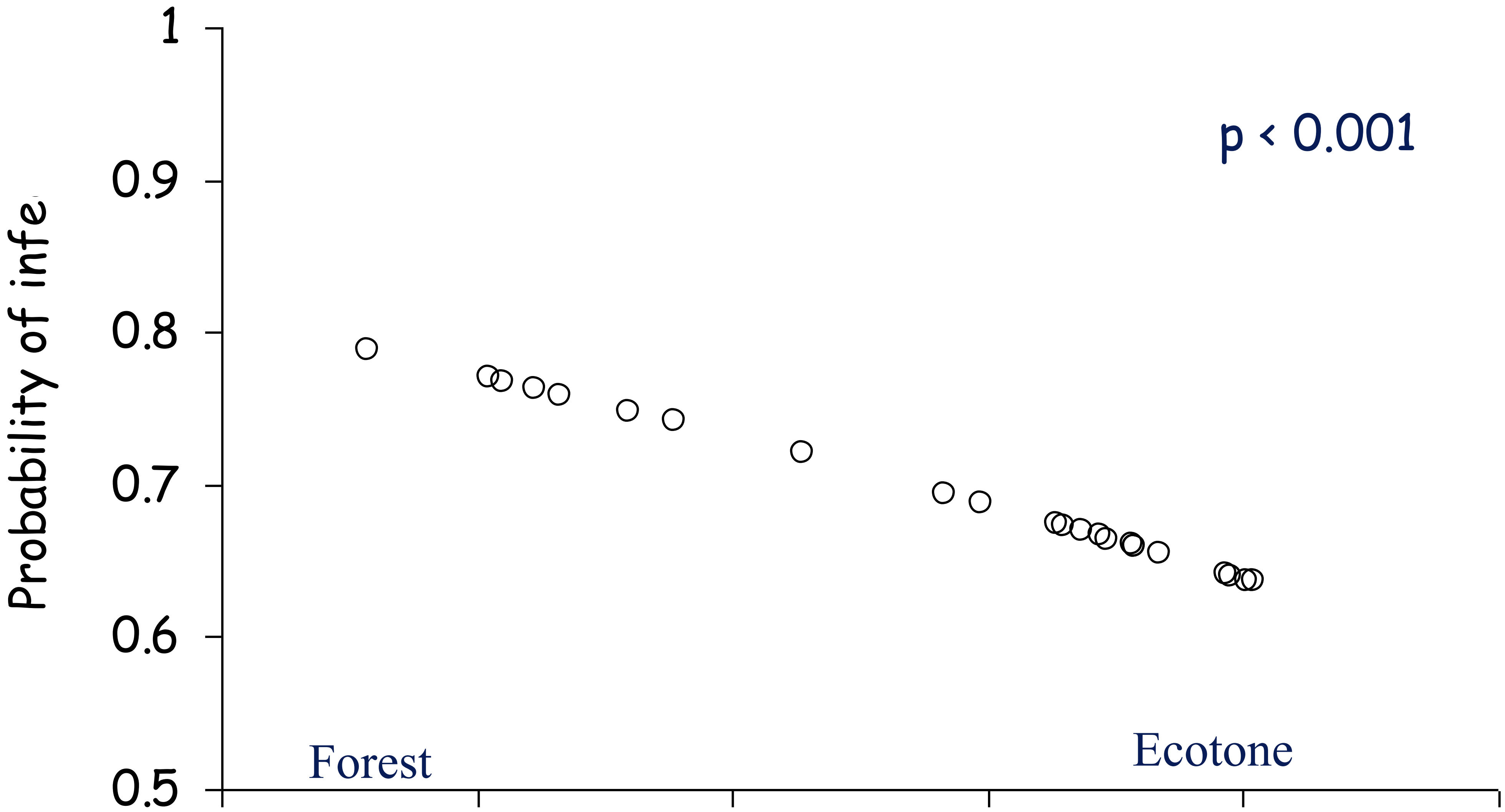


Leucocytozoon smithi

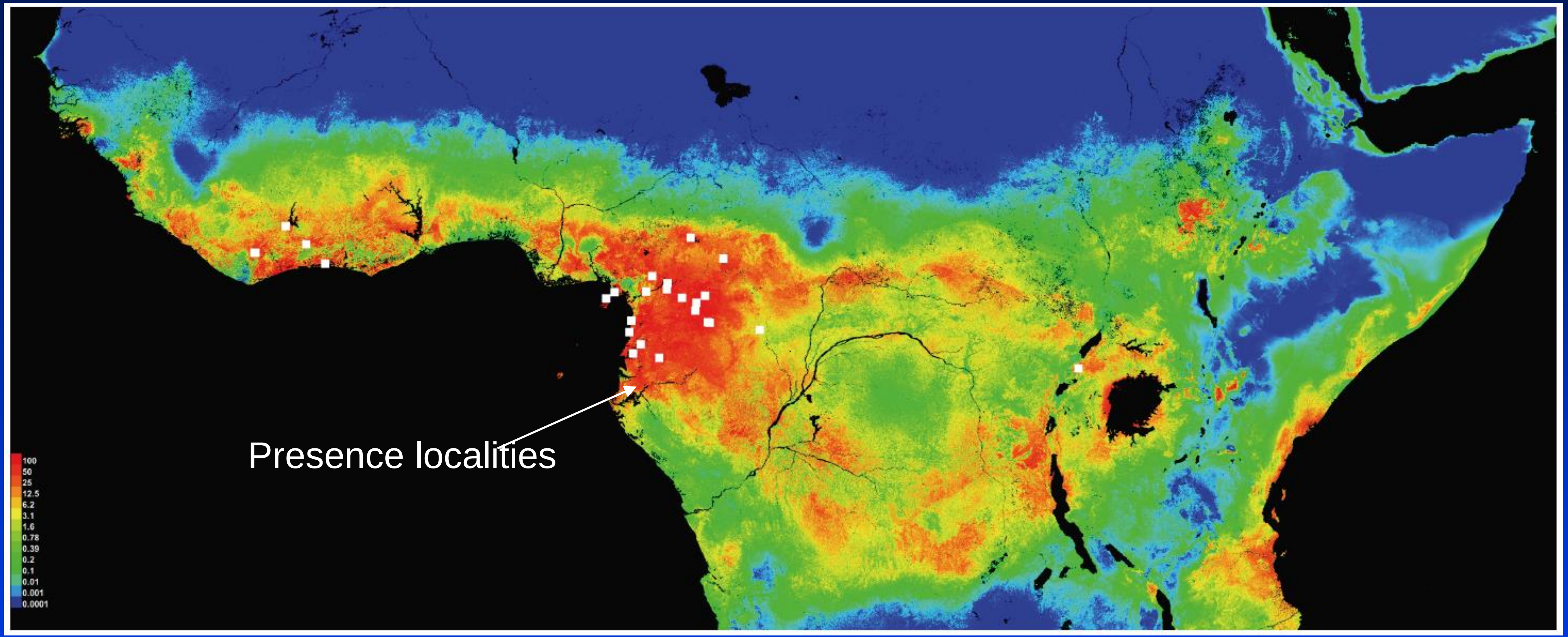
Host

# Infection with *Plasmodium &/or Haemoproteus*



# Africa - Maxent Predictions for Avian Malaria **with prevalence***





Least suitable conditions Most suitable conditions

* Presence localities weighted by relative prevalence

# Moving beyond simple surrogates of biodiversity…

# Putting Process on the Map

The steps:

1) Assess biodiversity pattern
2) Assess biodiversity process
3) Predict the influence of climate change
4) Combine 1-3 and levels of threat to identify critically important regions

# Ecuador

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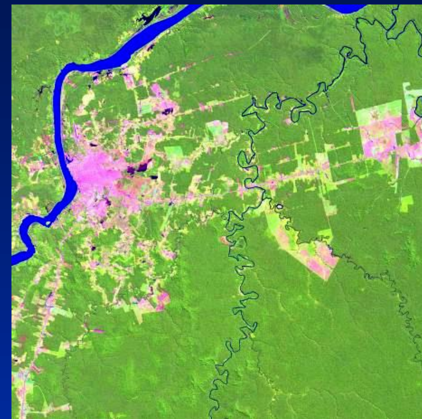
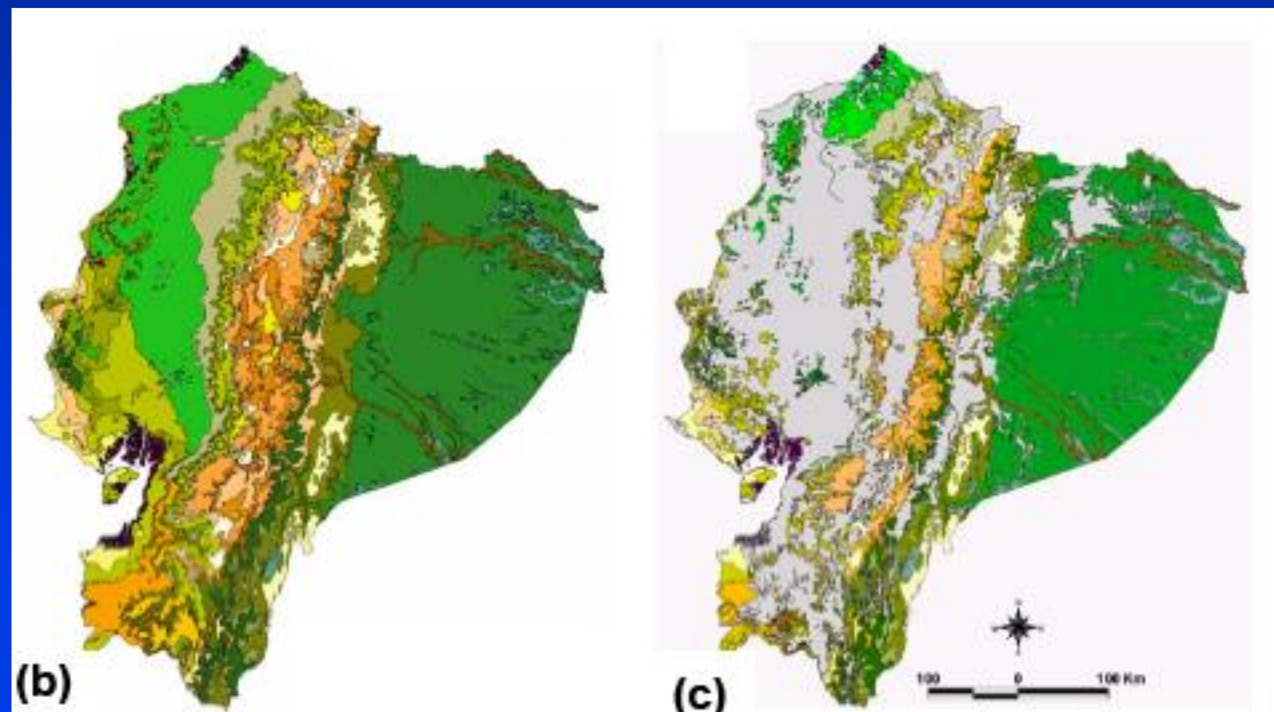


1984

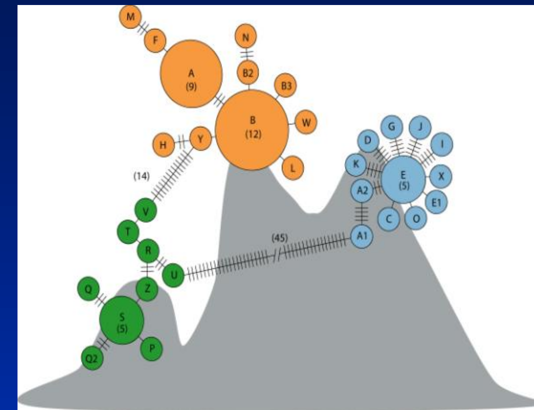
1997



# Point locality, genetic and phynotypic data

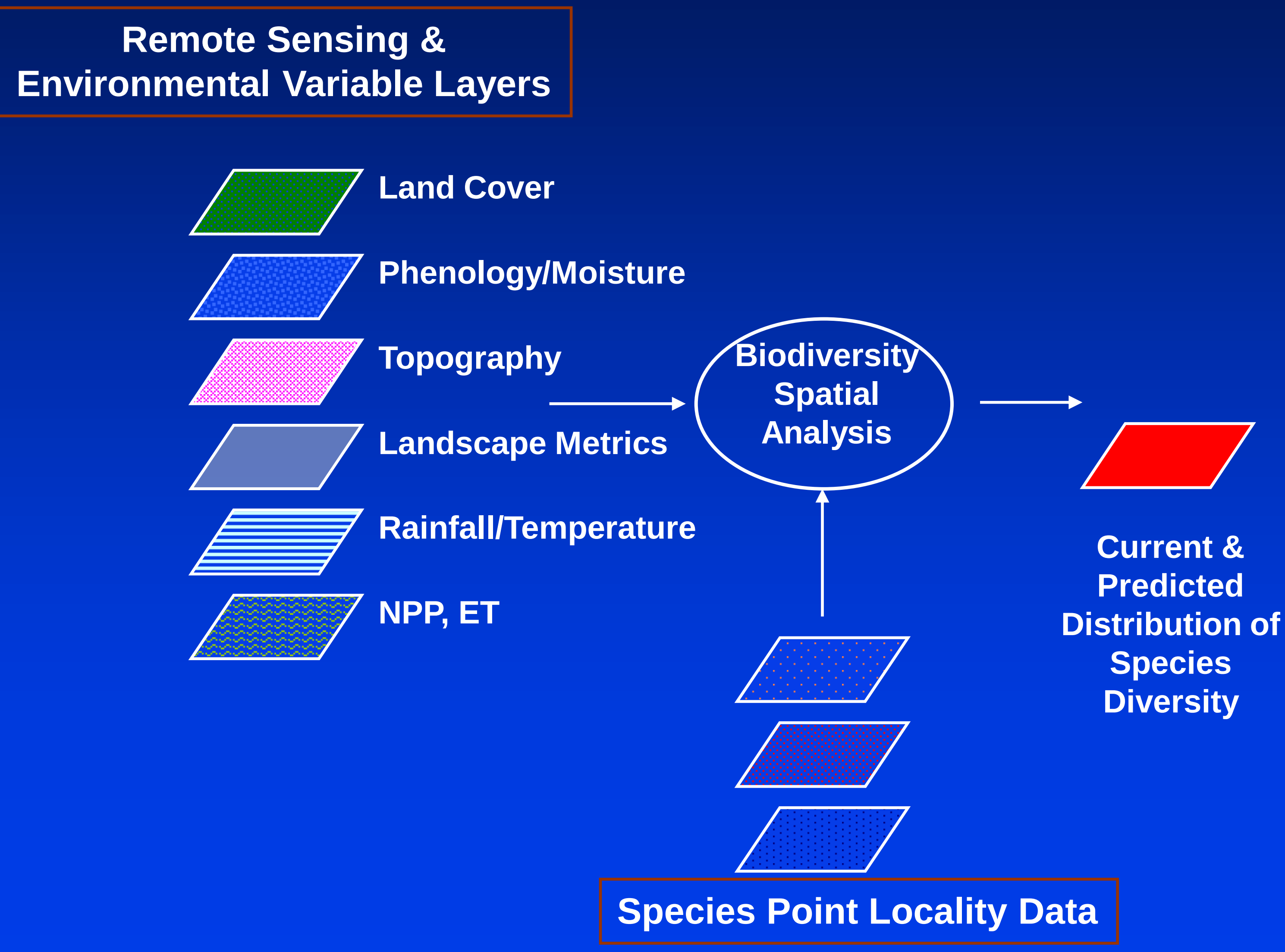
- **Birds**
- **Bats**
- **Frogs**
- **Small mammals**
- **Primates***
- **Trees***

***distribution data only**



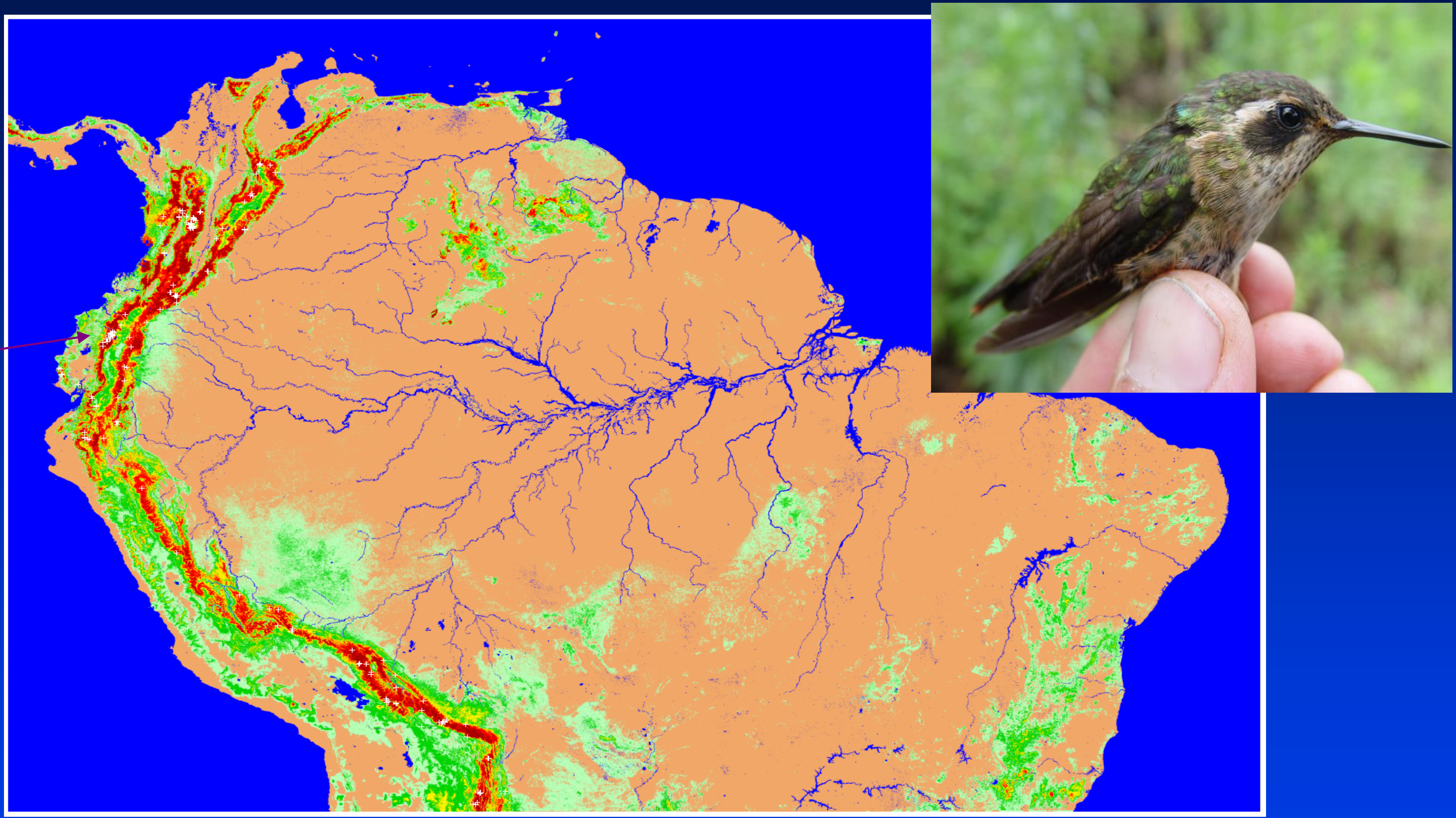
*White-plumed antbird*
*(Pithys albifrons)*

# Spatial Analysis Model



# Predicted Range of the Speckled Hummingbird

Point Locations



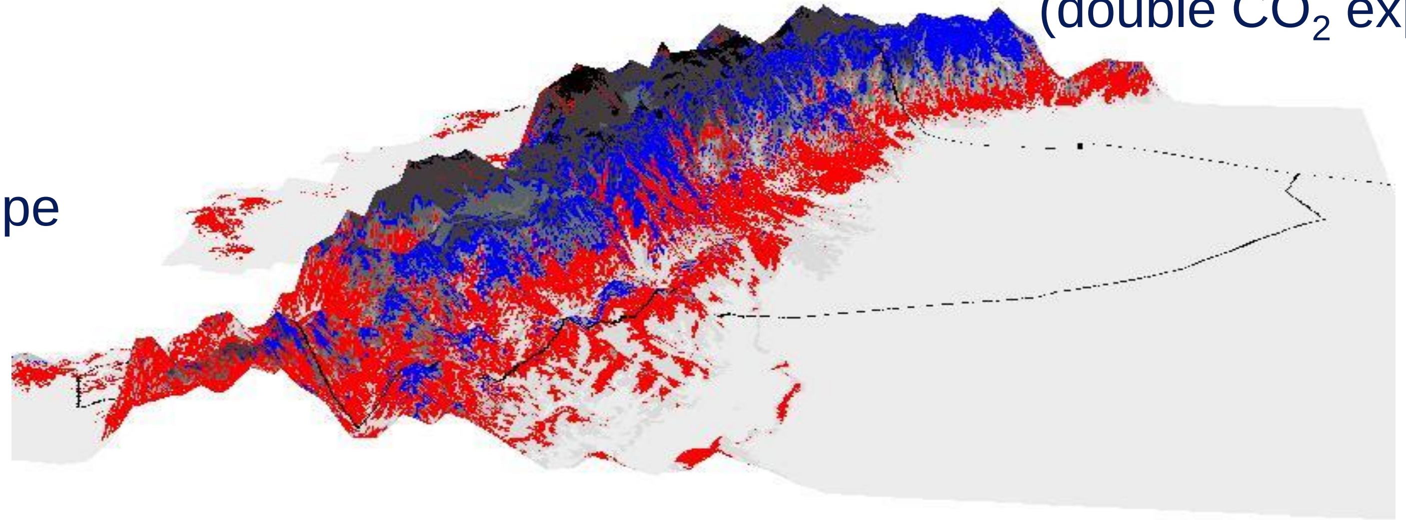
0 2 5 10 20 >50%

*Worst conditions* *Optimal conditions*

# Net loss of speckled hummingbird habitat with climate warming

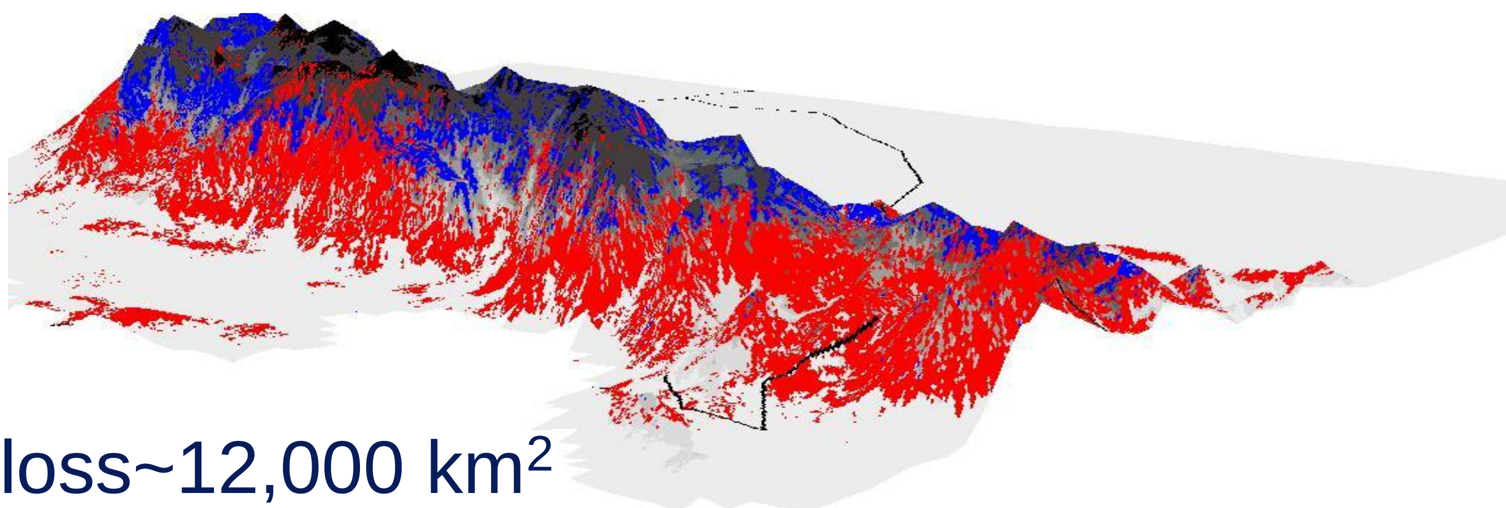
(double $CO_2$ experiment)

East Slope Andes



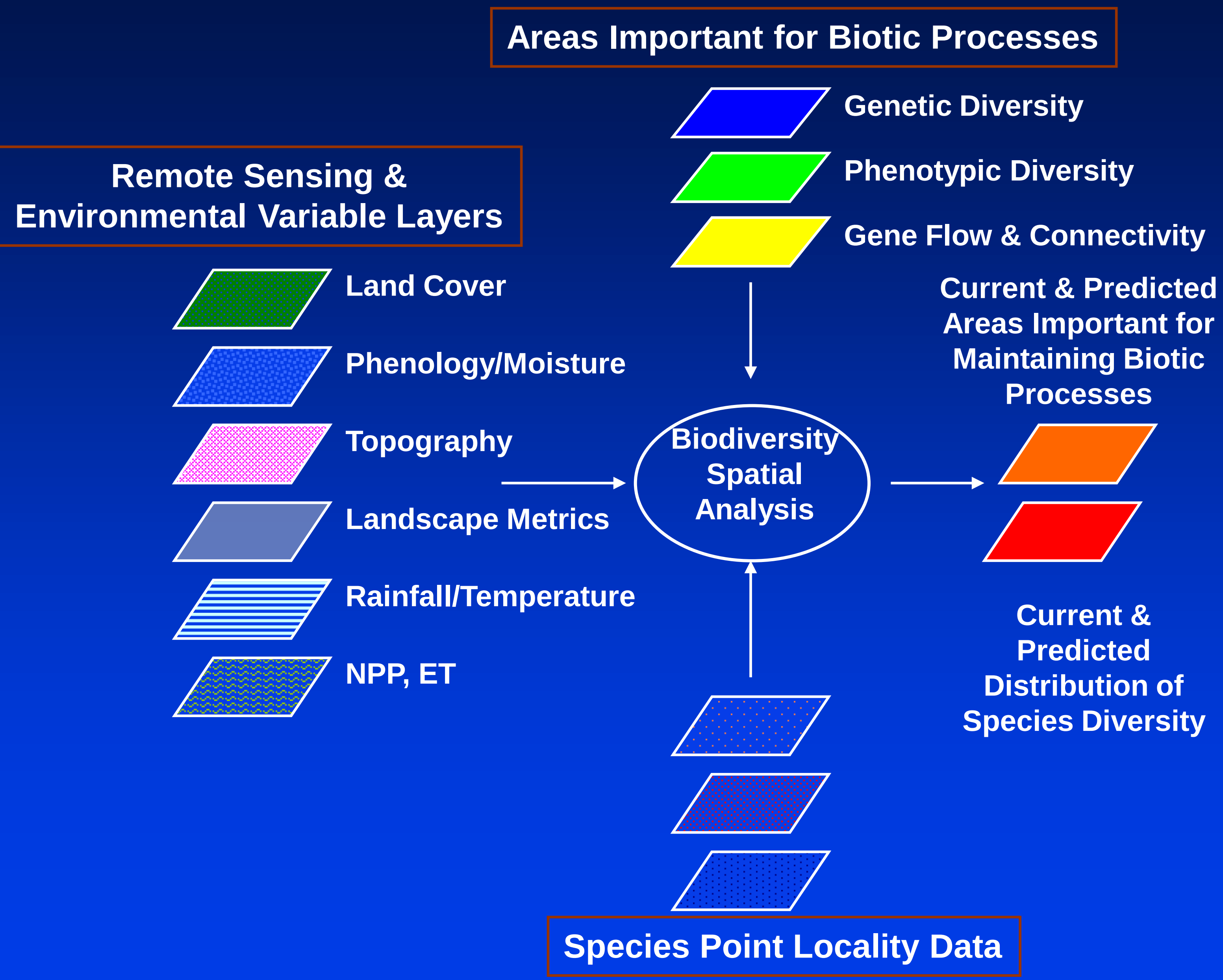
Areas becoming less suitable   Areas becoming more suitable

West Slope Andes



Habitat loss~12,000 $km^2$

# Spatial Analysis Model



# Evidence for differentiation along ecological gradients in the Andes

Wedge-billed woodcreeper
(*Glyphorynchus spirurus*)

N=196
29 sites

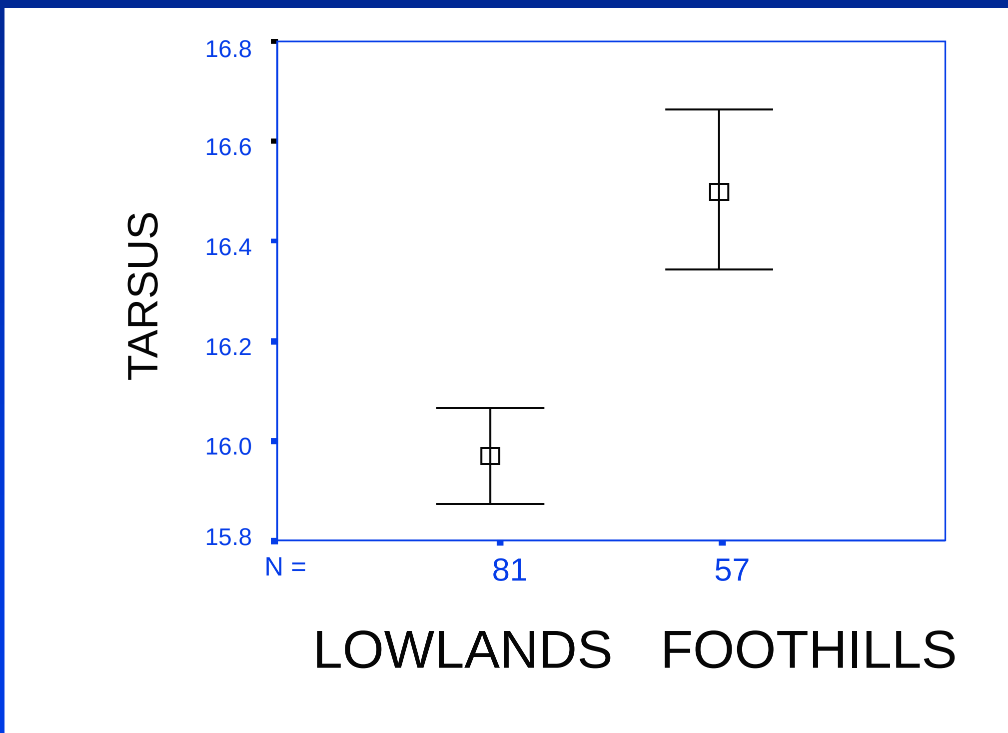


Lowlands
0-500m

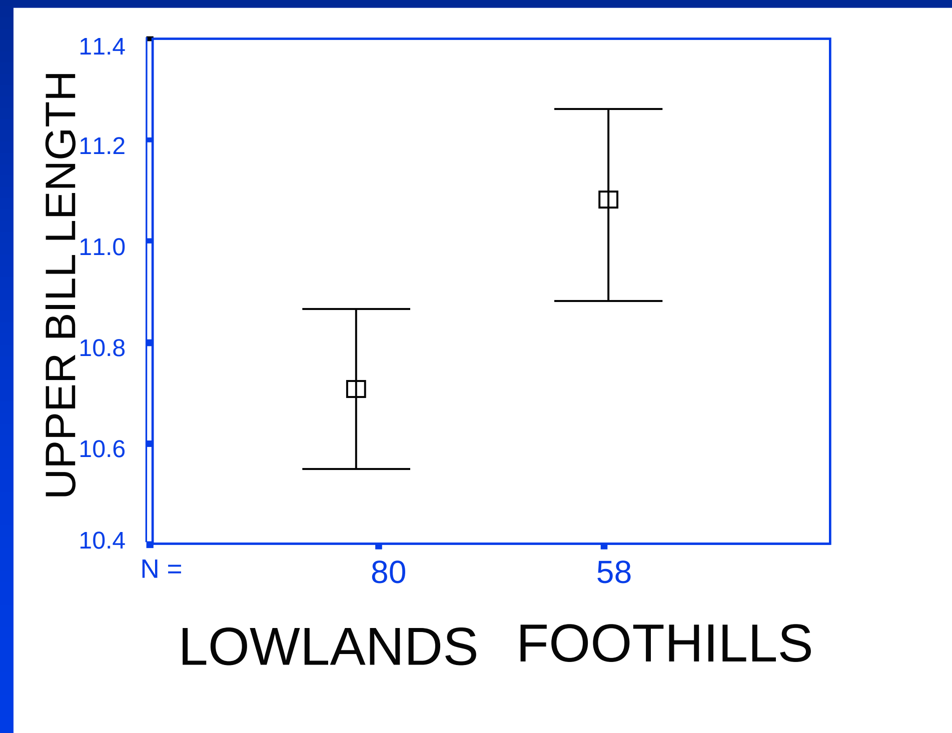

Foothills
800-1500m

# Morphological analysis

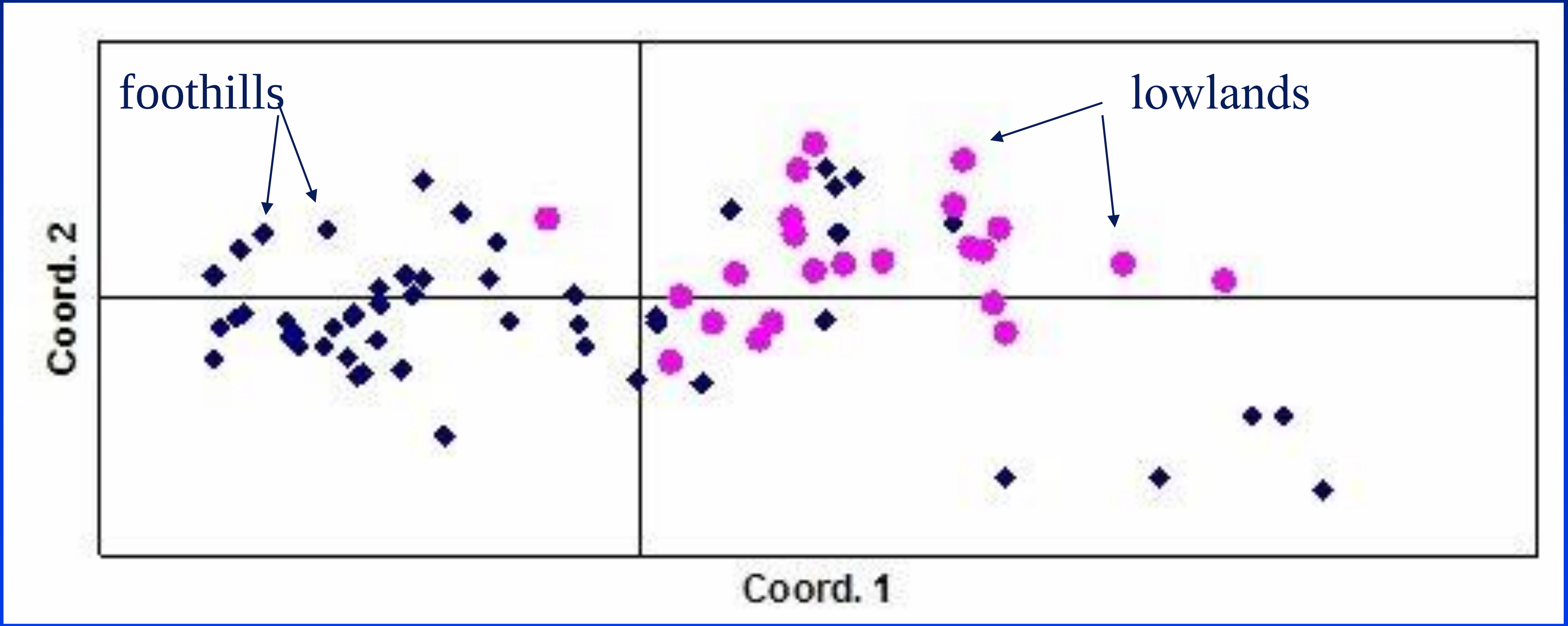
Tarsus length




Bill length



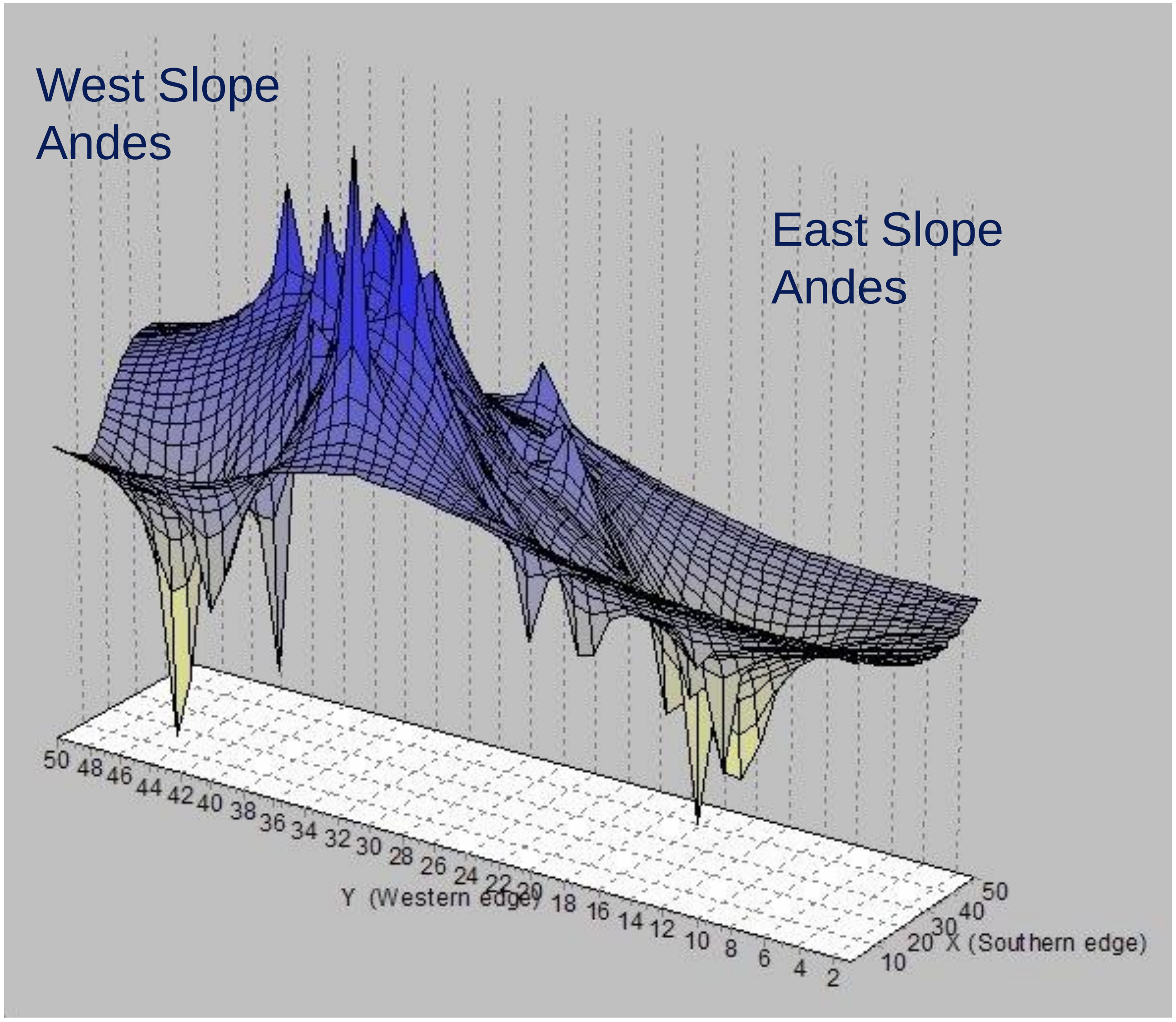
# Principal coordinates analysis of 74 individuals from the eastern slope of the Andes using 126 AFLP markers



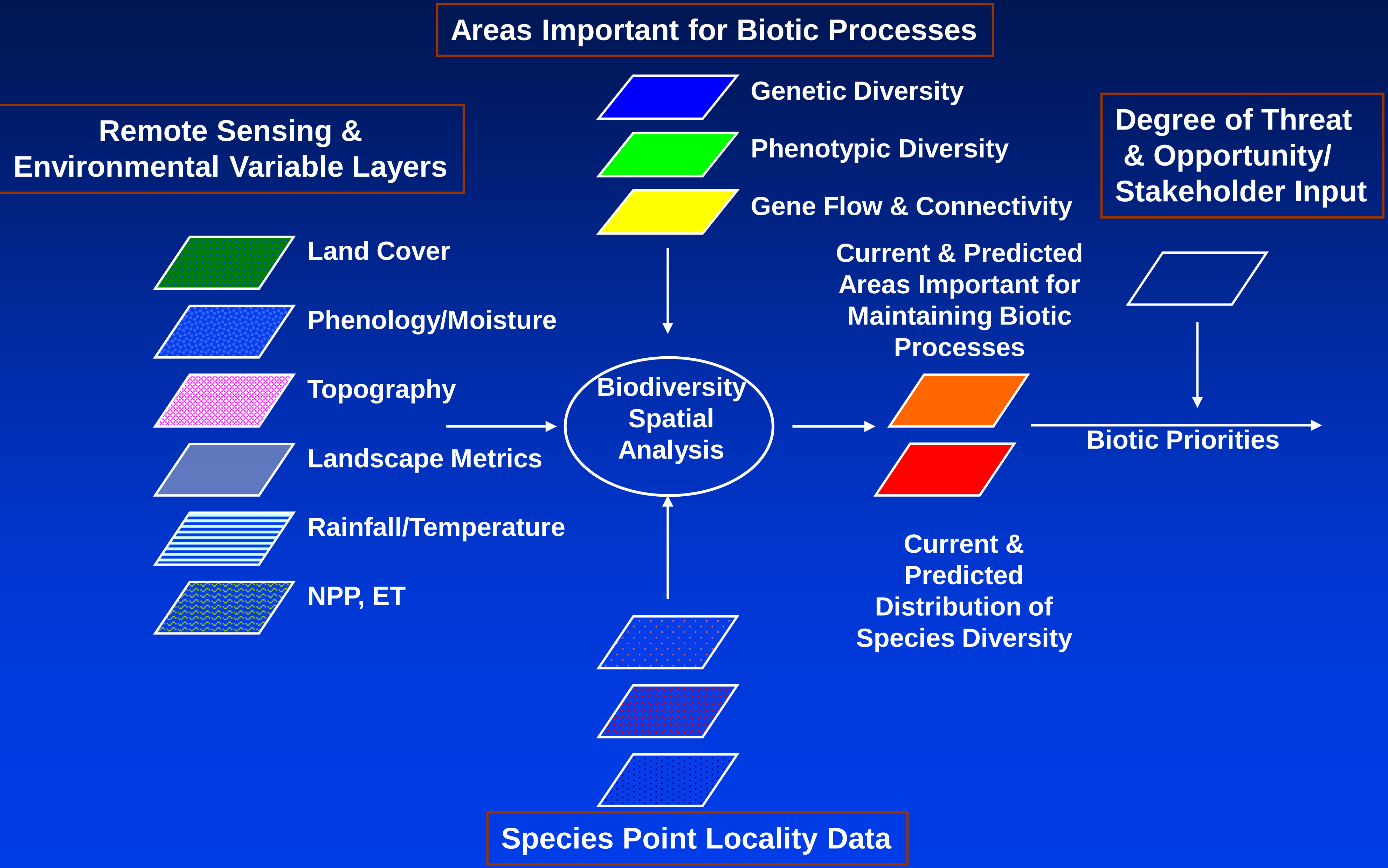
Lowlands

Foothills

# Genetic landscape for wedge-billed woodcreeper populations in the Andes of Ecuador

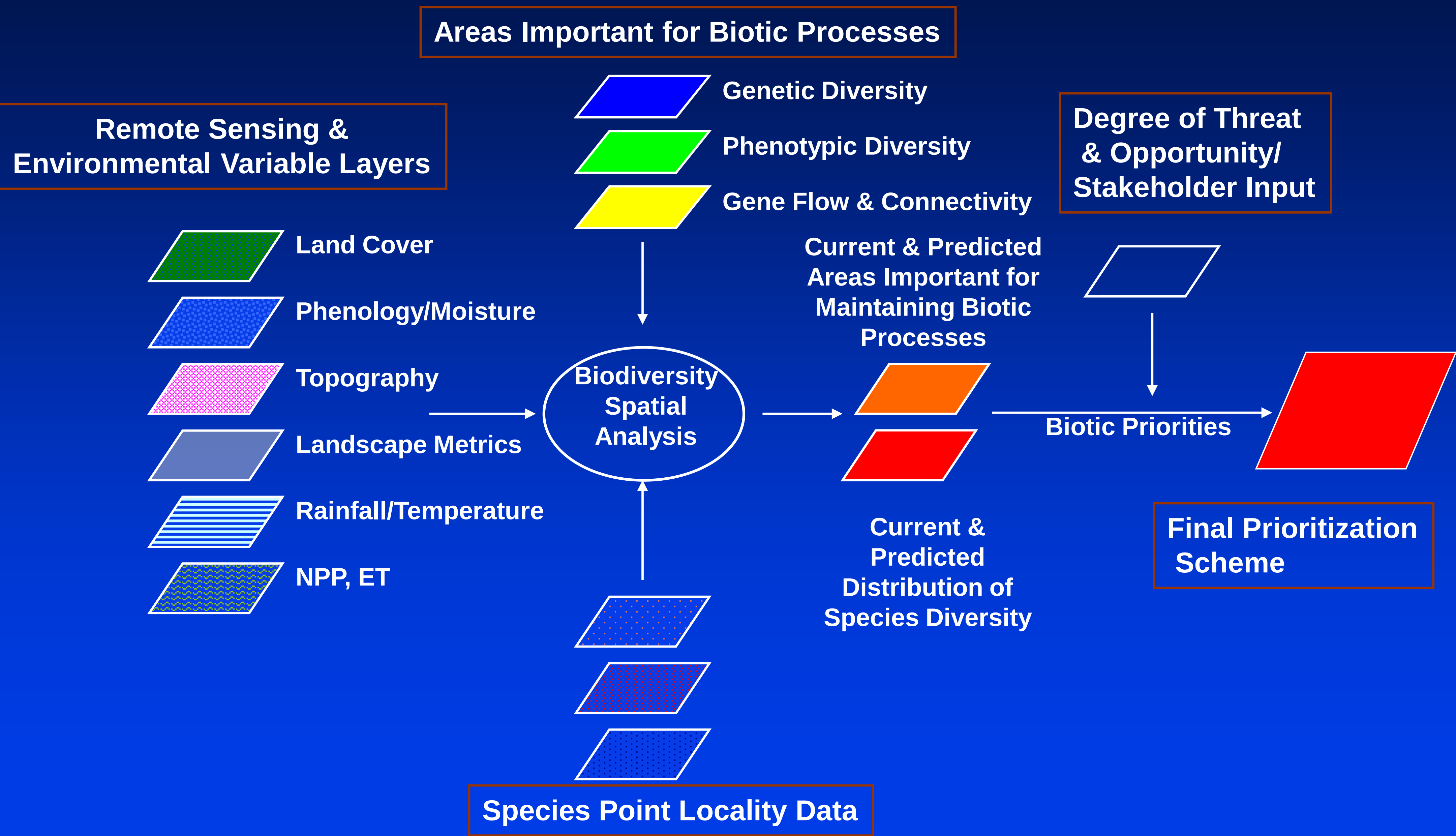



# Spatial Analysis Model



# Threats and opportunities and stakeholder input

# Spatial Analysis Model



# SUMMARY

1) Gradients can be important drivers of adaptive genetic variation

2) Conserving gradients may offer a bet hedging approach for conserving adaptive variation in the face of climate change

3) Integrating biodiversity pattern, process and degree of threat may offer a valuable approach for prioritizing regions for conservation

# Collaborators

Camille Bonneaud
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Sassan Saatchi
Chris Schneider
Ravinder Sehgal
Hans Slabbekoorn
Bob Wayne

# Support

NASA
NSF
National Geographic Society

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are needed to see this picture.

UCLA

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BOSTON UNIVERSITY