Spatial Explicit Occupancy Modeling of Mammal Community Using Markov Random Field with Imperfect Observations

MS Entrance of
Yunyi SHEN

UW Madison
Department of Forest and Wildlife Ecology

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1. Introduction
   - Island System
   - Markov Random Field
2. Methods
   - MRF of Apostle Islands
   - Formalization
   - Imperfect Observations
3. Primary Results
   - Fitting a APIS MRF of 2 Simulated Species
   - Fisher and Marten System
   - Coyote Fox Bobcat System
   - TJH: Land Systems with Elevation Gradient
4. Initial Discussion
5. Next Steps & Questions

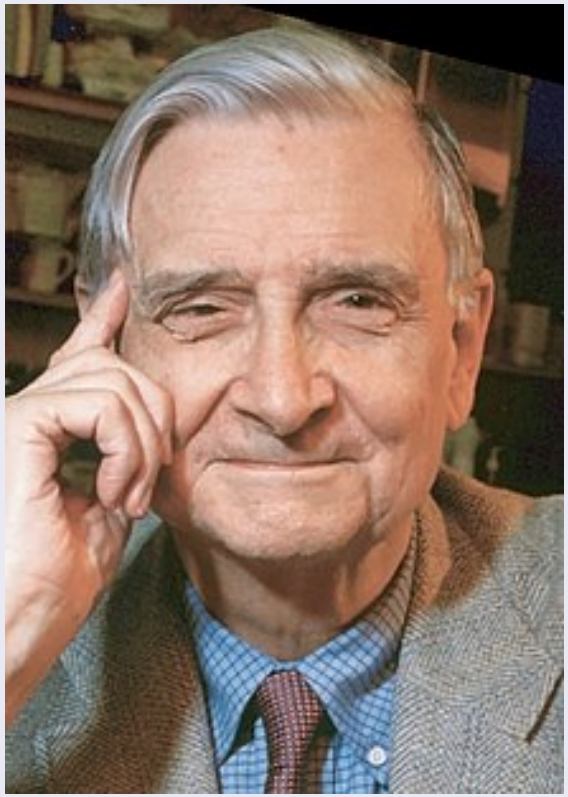
Introduction

- Island System
- Markov Random Field

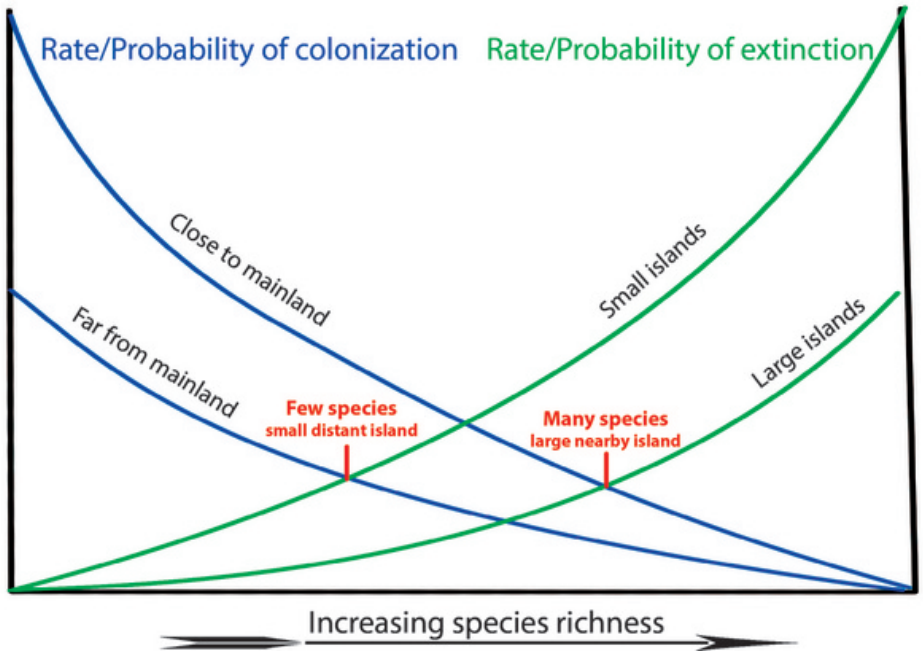
Island Biogeography

R.H. McArthur

E.O. Wilson



Equilibrium Theory of Island Biogeography



- Richness of Island is Equilibrium between:
  - **Dispersion**
  - **Extinction**
- Island as single individual
- Inter-island relationships

Mean Field Approximation of Islands

- Ignore shape of island
- Ignore dispersion limit on island

Mean Field Approximation of Islands

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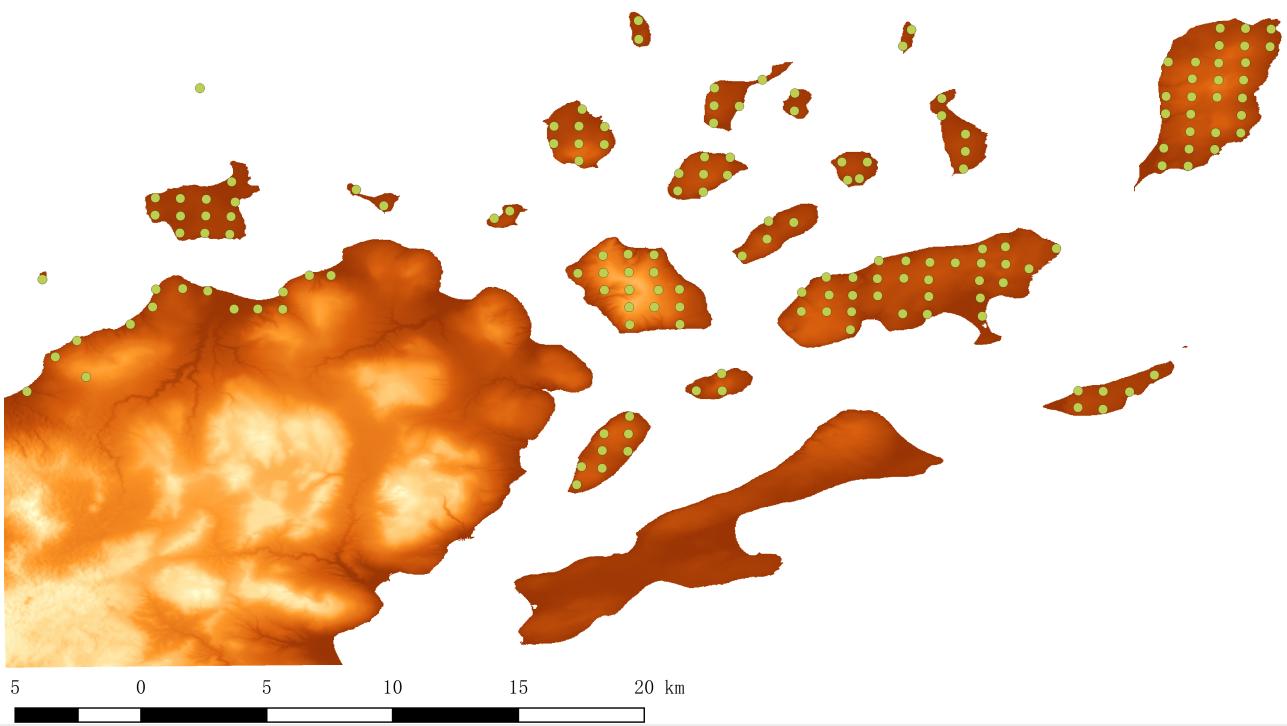
- Is it appropriate?
  Context dependent!

Three Interesting Spatial Scales

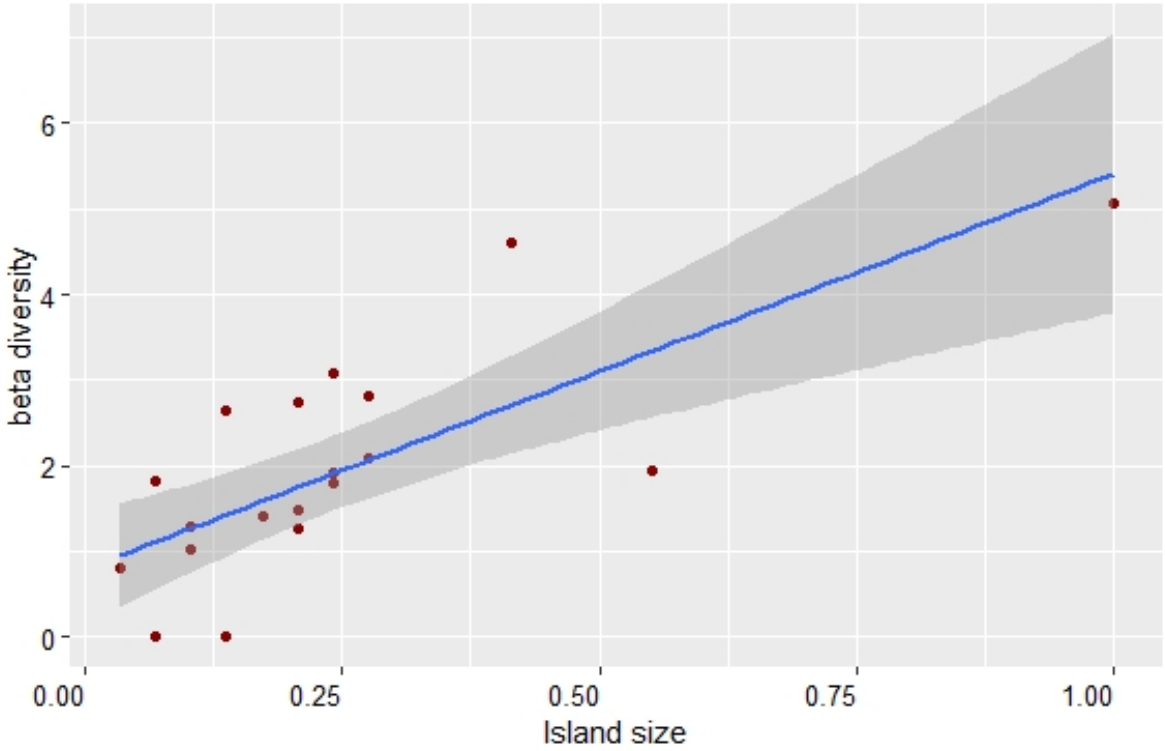
1. Inter island distance
2. Island length
3. Dispersion/homerange

- $1 \simeq 2$: Shape effect
- $2 \simeq 3$: Intra island structure

Apostle Islands



Simple Test on β-diversity



- β-diversity roughly tells us the spatial structure of diversity
- Larger island has richer spatial structure (p=1.71e-4, adj-R^2=0.53)

Exchangable Approximation of Species

- Species are similar

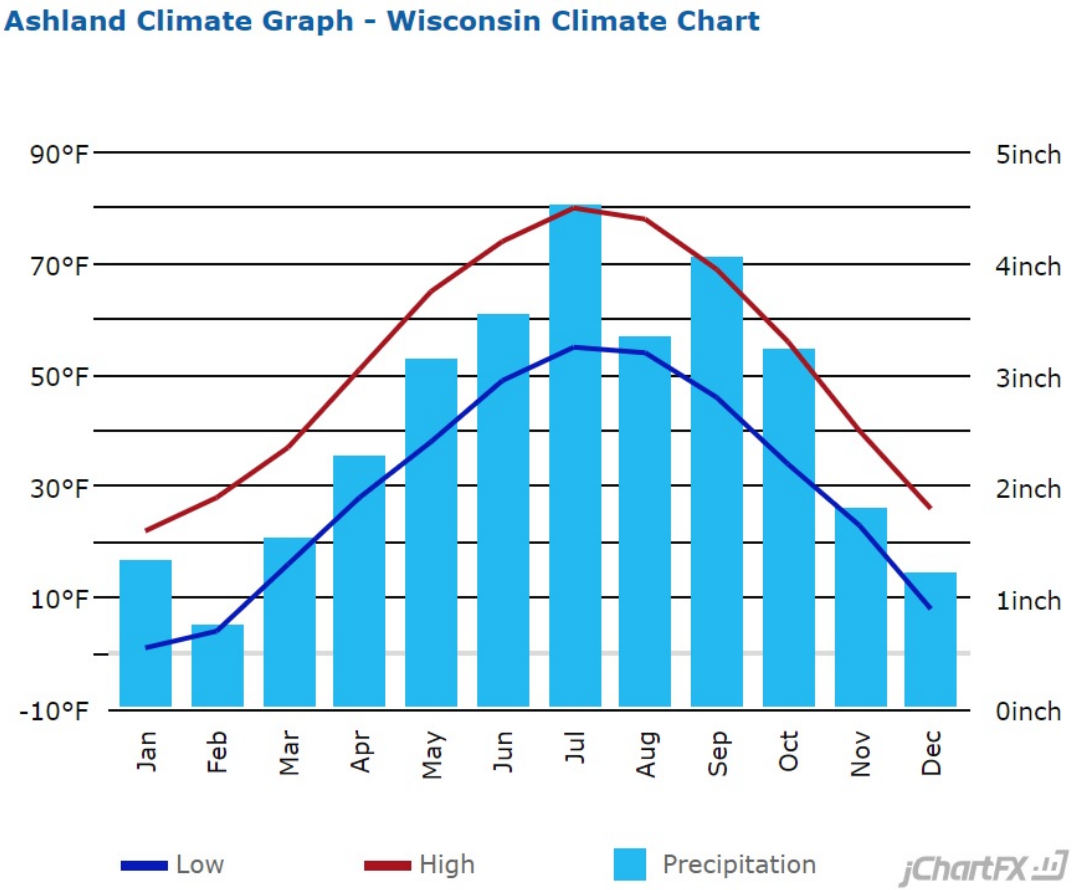
Exchangable Approximation of Species

- Species are similar
- Is it appropriate?
  Context dependent!

Resources and Species Similarity

- Lots of island research are in tropical area with rich resources
- What about Apostles?

Apostle Islands Climate



Resources and Species Similarity

- Lots of island research are in tropical area with rich resources
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Resources and Species Similarity

- Lots of island research are in tropical area with rich resources
- What about Apostles?
  - Temperate area, less resources
  - Harsh winter

Big Questions

How do we distinguish different signals from distribution and evaluate the contribution between:

- Environmental sorting
- Direct Interactions (e.g. exclusion)
- Spatial Auto-correlation

Explicit Modeling Needed

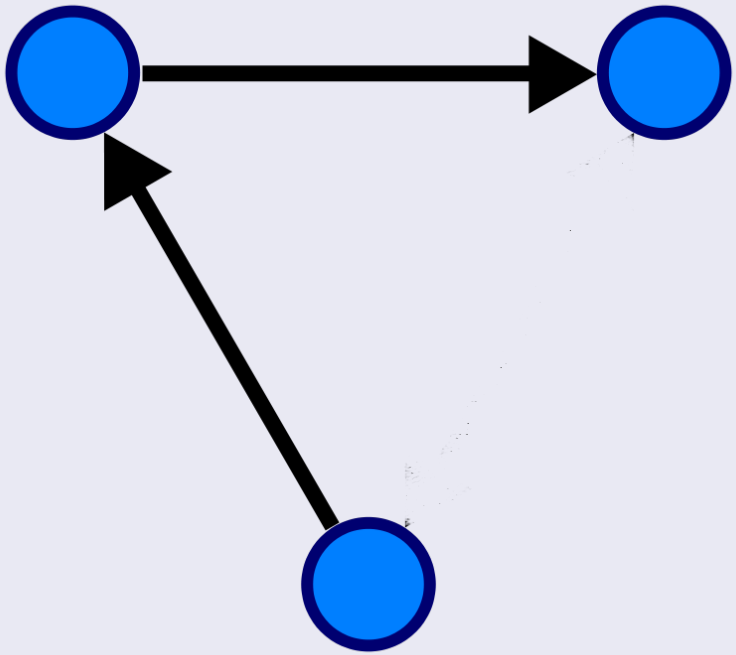
- Both inter and intra island spatial relationships
- Interspecific relationships
- So that we can compare different processes' contribution!

More Specific Question

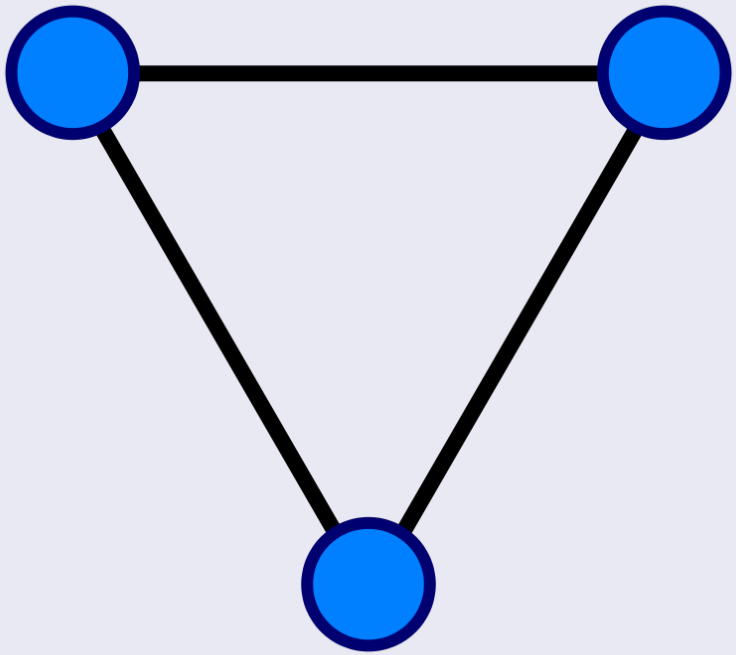
Spatial and competition, which has the strongest influence on canid's distribution on APIS?

Representing Relationships, Graph

Directed Graph



Undirected Graph



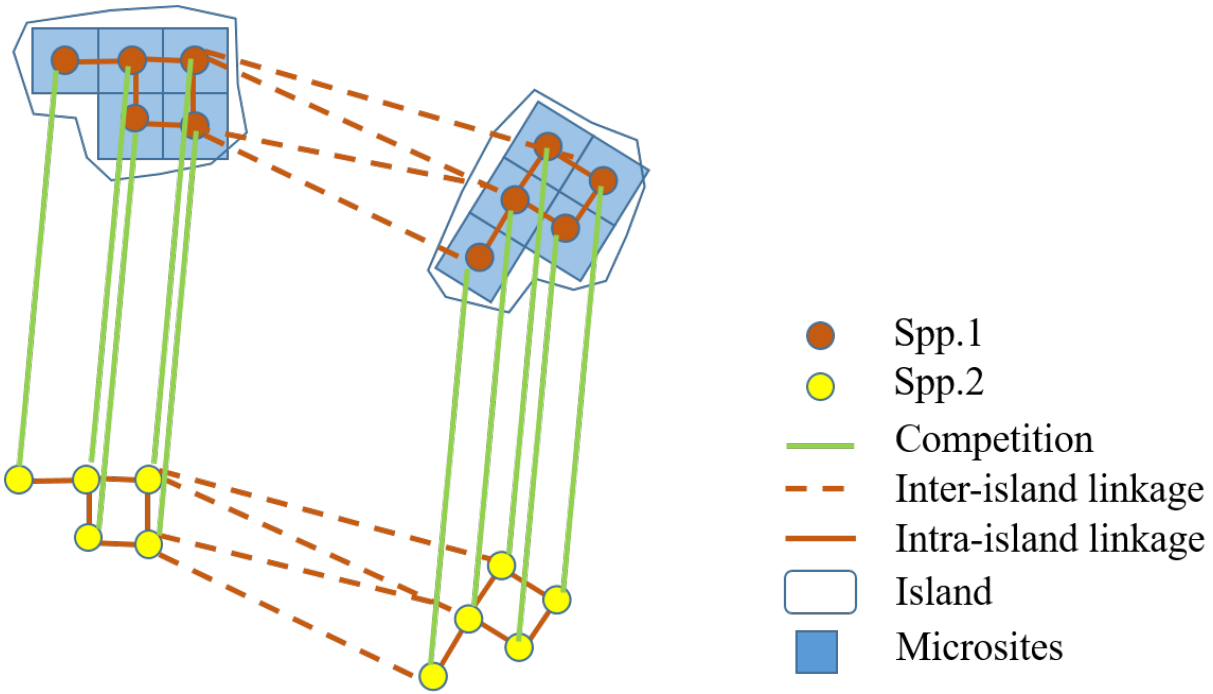
Probabilistic Graph Model

- Vertices are random variables (in our case, presence/absence of a certain species at certain microsite)
- Edges are correlations or conditional
- PGM for different graph:
  - Bayesian Network: Directed (Acyclic)
  - **Markov Random Field**: Undirected

Why MRF

- Allow *cycles*: e.g. a-b-c-a was allowed in MRF but not BN
- Undirected nature of spatial autocorrelation and niche overlap
- Defines an Energy

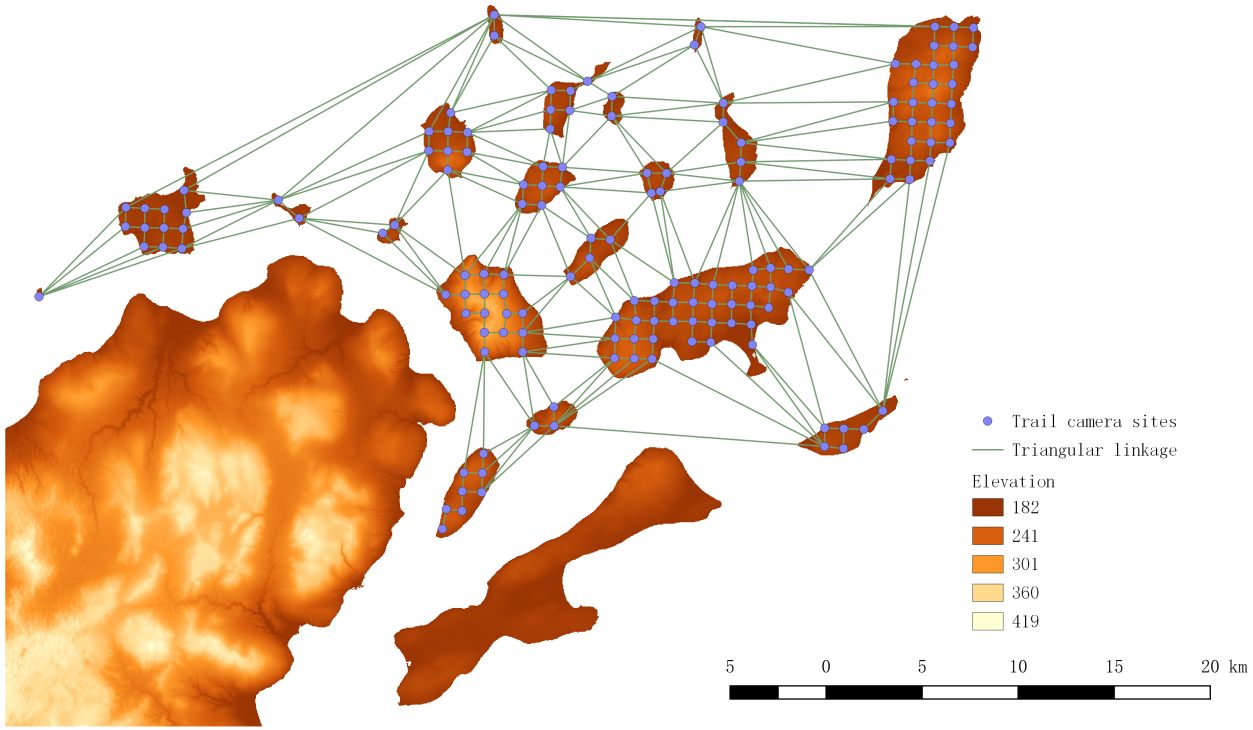
A Conceptual Example: 2 Islands and 2 Species



Method

- MRF of Apostle Island

Microsite Linkage: Delaunay Triangle



Mainland Linkage

- If a site has mainland as its nearest interisland linkage, it is linked to mainland.

Modeling Pattern as Pattern

- Distribution pattern should be view as a random vector, for S sites and w species, it is $S \times w$ dimensional vector

$$\mathbf{Z} = (Z_1^1, Z_1^2 \ldots Z_2^1, Z_2^2, \ldots Z_i^l \ldots Z_S^w)^T \in \{-1, +1\}^{Sw}$$

- An example for 2 species and 2 sites:

$$\mathbf{Z} = (+1, -1, -1, +1)^T$$

Spp1 occurs on site 1 but not 2, spp2 occurs on site 2 but not 1

Markov Random Field: Probability of a Certain Distribution Pattern

- Probability of pattern $\mathbf{Z}$ is given by

$$
\begin{aligned}
P(\mathbf{Z}|\theta) \propto exp[\sum_{k=1}^{w}(\mathbf{X}\beta_k\mathbf{Z}_k \\
+ \frac{1}{2}\mathbf{Z}_k^T\mathbf{D}_k^{in}\mathbf{Z}_k \\
+ \frac{1}{2}\mathbf{Z}_k^T\mathbf{D}_k^{ex}\mathbf{Z}_k \\
+ \sum_{l>k}\eta_{lk}\mathbf{Z}_k^T\mathbf{Z}_l)]
\end{aligned}
\tag{1}
$$

- $C(\theta)$ is called *partition function* and is usually intractable

MRF is an Energy Based Model

- MRF defined an potential energy function (a.k.a. Hamiltonian in physics)
- Can be used to evaluate contribution of different terms

Imperfect Observations

- Infer detection probability from the detection history assuming occupancy won't change.
- Also contains inter-specific interaction but assumed to be local:

$$P(y_{1ij}, y_{2ij}, ...|Z_{1i}, Z_{2i}, ...) \propto exp(\sum_{k=1}^{w}[\beta_k^{det} X_{ij}^{det} y_{kij} I_{Z_{ki}=1} + \sum_{l>k} \delta_{kl} y_{kij} y_{lij} I_{Z_{ki}=1} I_{Z_{li}=1}]) \quad (2)$$

Bayesian Framework: Sampling from Posterior

- This task is generally hard because of the *partition function* (one cannot evaluate the likelihood!)
- I will use Murray 2014's parameter exchanging method to deal with this problem

Evaluating Different Interactions

- Habitat Selection Matrix:
  - Evaluate the **landscape scale niche partitioning** of species
  - I used covariance of linear predictors (a.k.a. external field)
  - Positive means spp1 and spp2 has similar habitat selection in landscape scale

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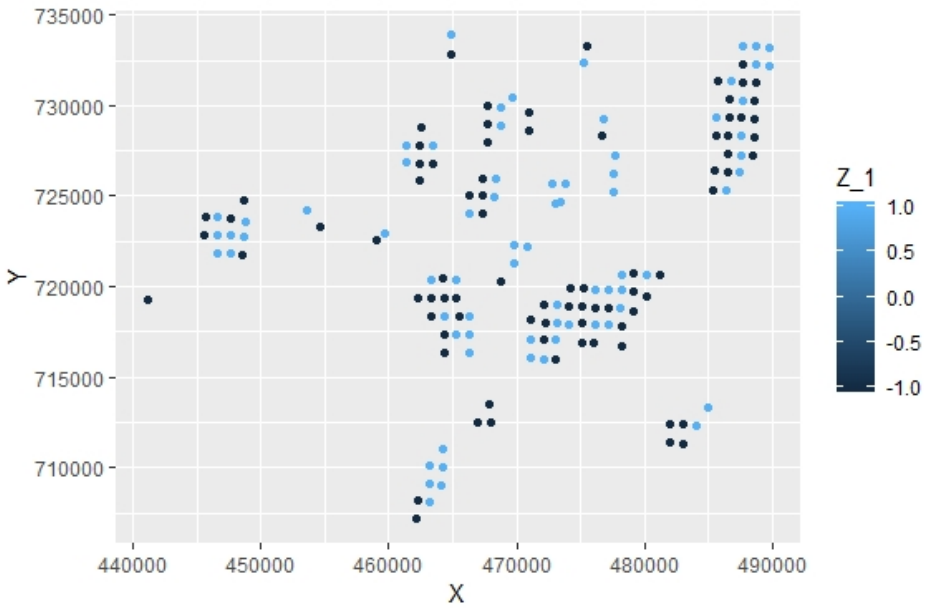
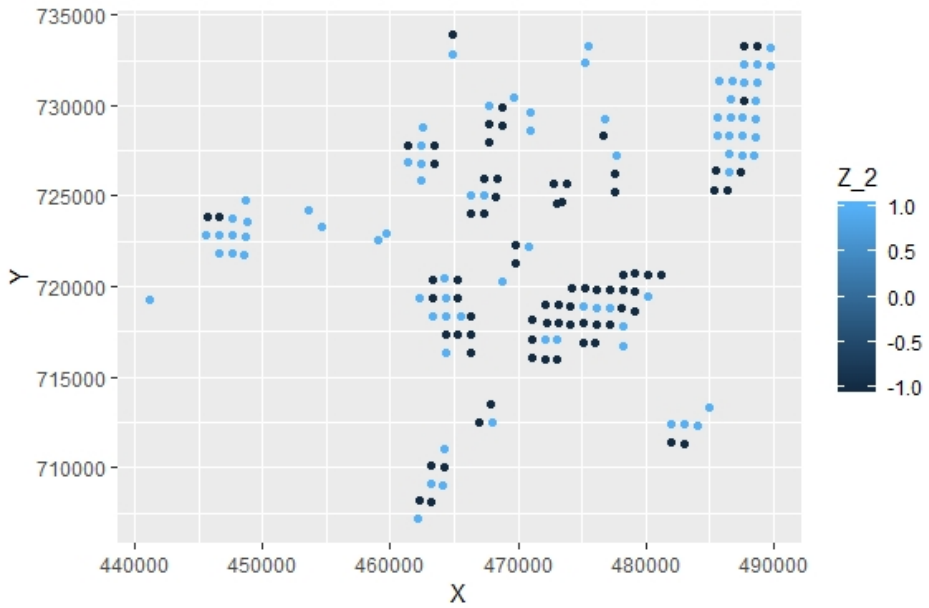
- Direct Association
  - Evaluate **local direct association** between species that cannot be explained by environmental sorting
  - Use the coupling matrix in MRF model
- Detection as measure of behavior
  - Evaluate local direct association between **detection** that cannot be explained by environment
  - Coupling matrix in detection MRF model

Primary Results

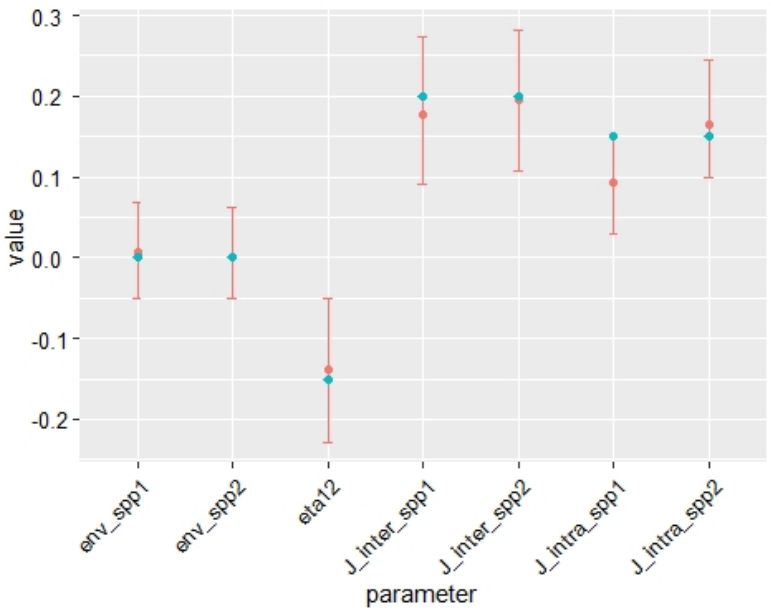
- Fitting MRF of 2 simulated species
  - 4 repeats
  - False-negative
- Real Case Studies
  - Island System
    - Fisher-Marten
    - Coyote-Fox-Bobcat
  - Mountain System
    - Leopardcat-Civet-Marten
    - Muskdeer-Tuftsdeer-Muntjac

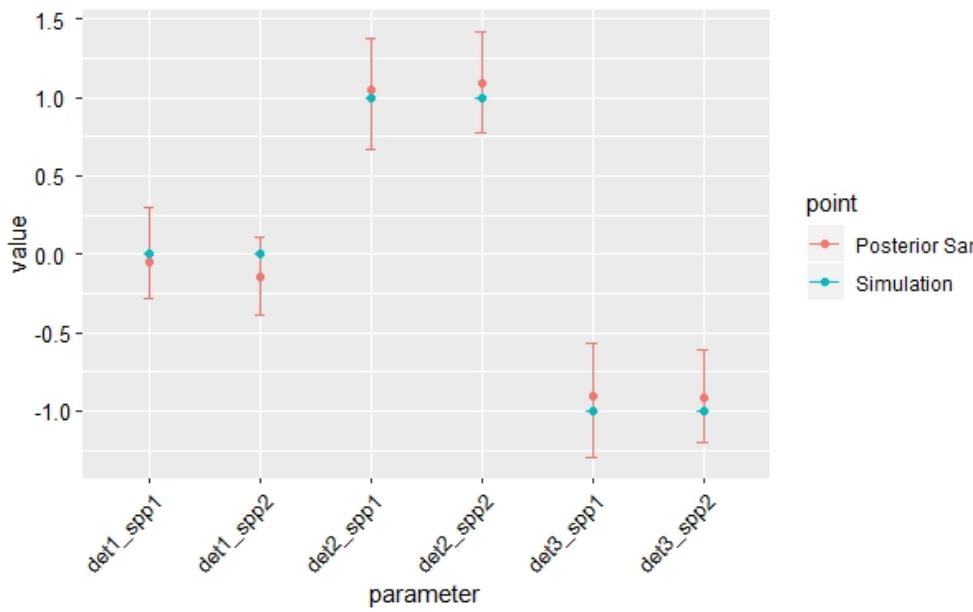
Simulated Distribution Pattern





Fitting Parameters

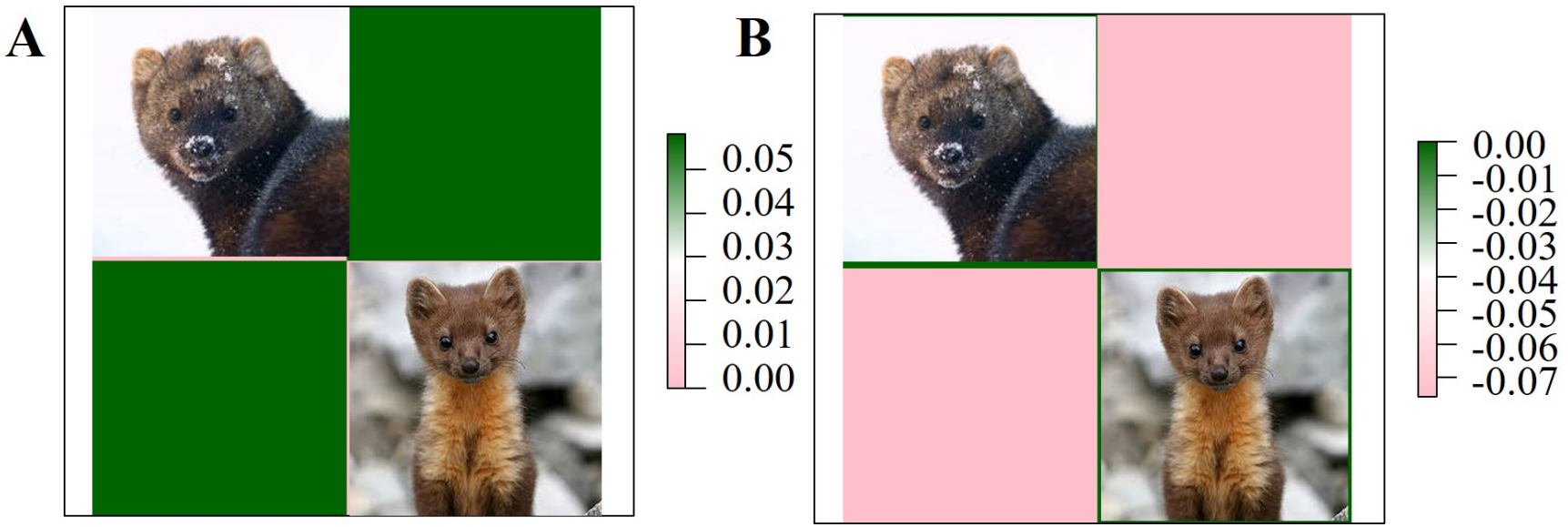




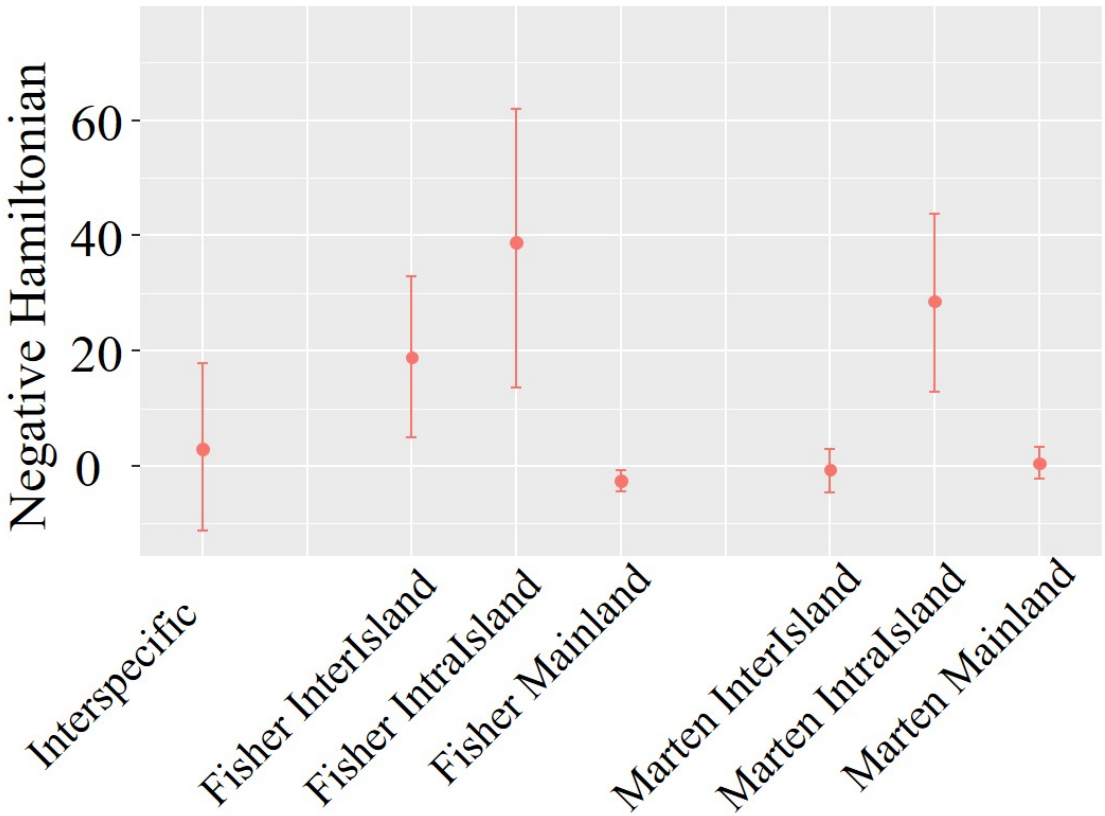
APIS, Two Systems Tested

- Fisher-Marten
- Coyote-Fox-Bobcat

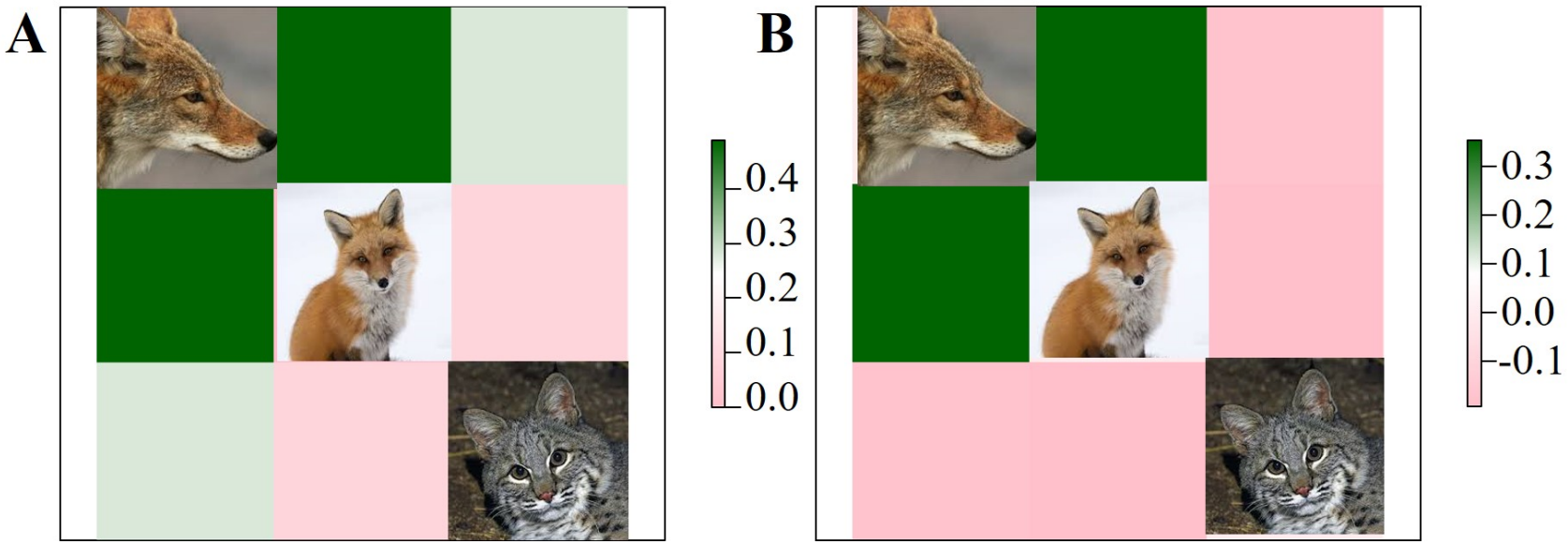
Fisher-Marten: Direct Association



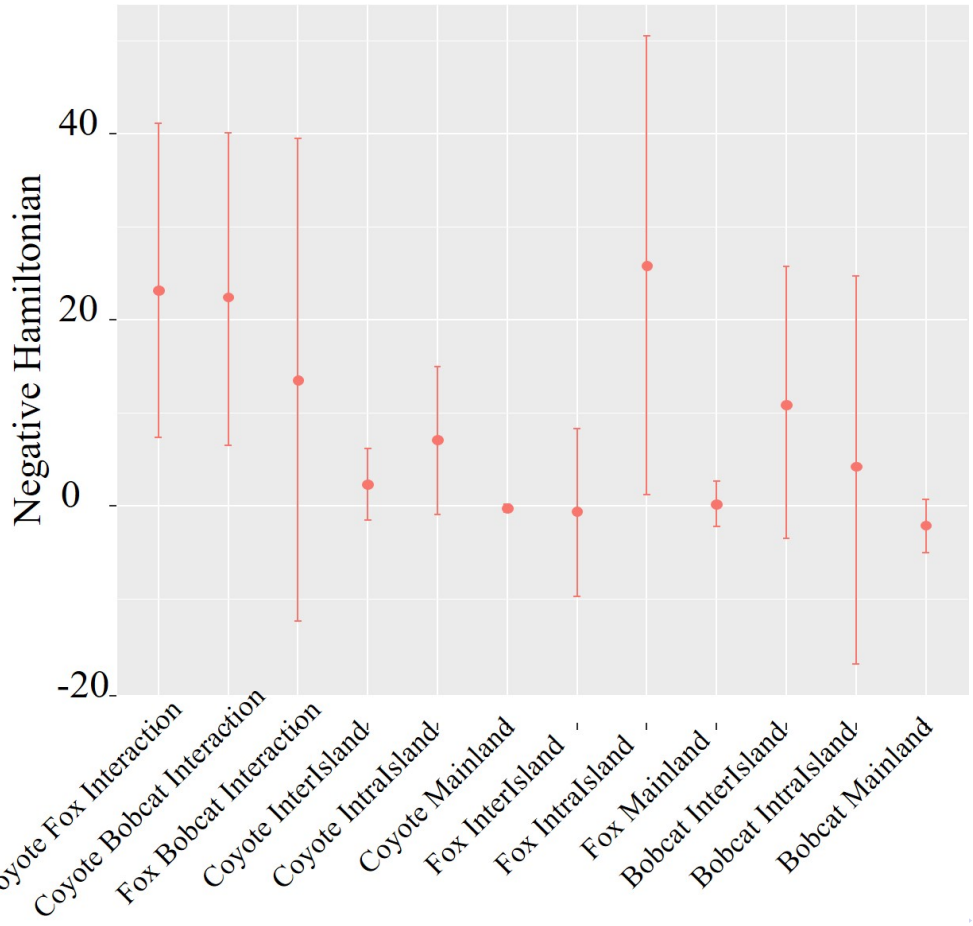
Fisher-Marten: Evaluate Contribution



Coyote Fox Bobcat: Direct Association



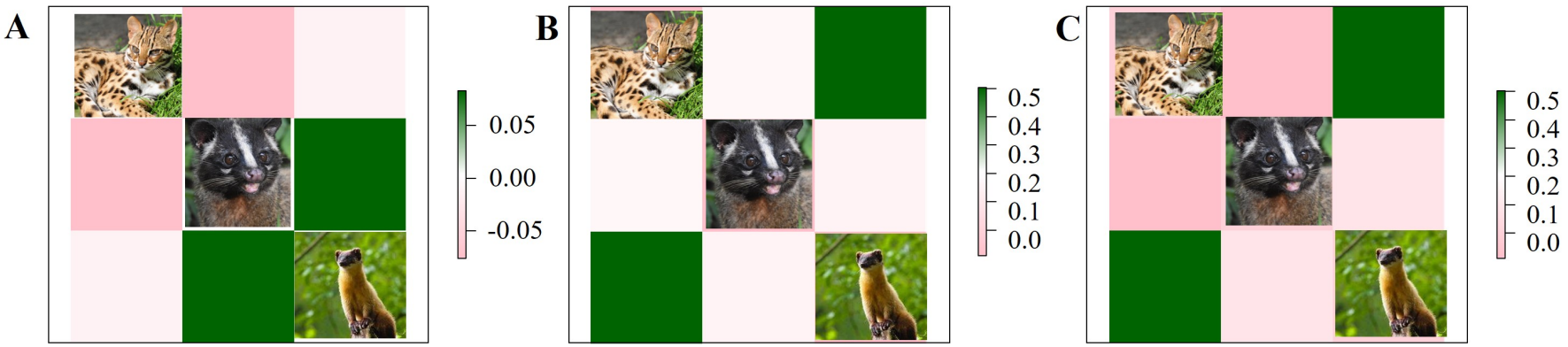
Coyote Fox Bobcat: Evaluate Contribution



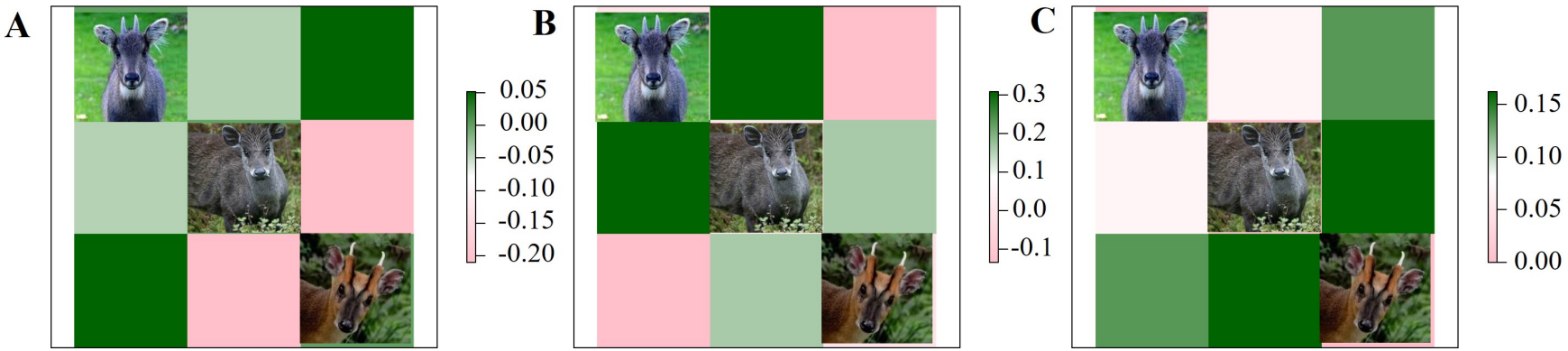
Two Distinct System

- Carnivore: Leopardcat-Civet-Marten
- Herbivore: Muskdeer-Tuftsdeer-Muntjac

Carnivore: Interaction Matrices



Herbivore: Interaction Matrices



Next Step

- Model selection based on DIC
- Model evaluation
- Snapshot WI data

Questions and Comments are Welcomed!

Thank you