UQÀM UQAR

UNIVERSITÉ DE MONTPELLIER

IMPACT OF BIOTIC INTERACTIONS ON THE GEOGRAPHICAL REPARTITION OF SPECIES

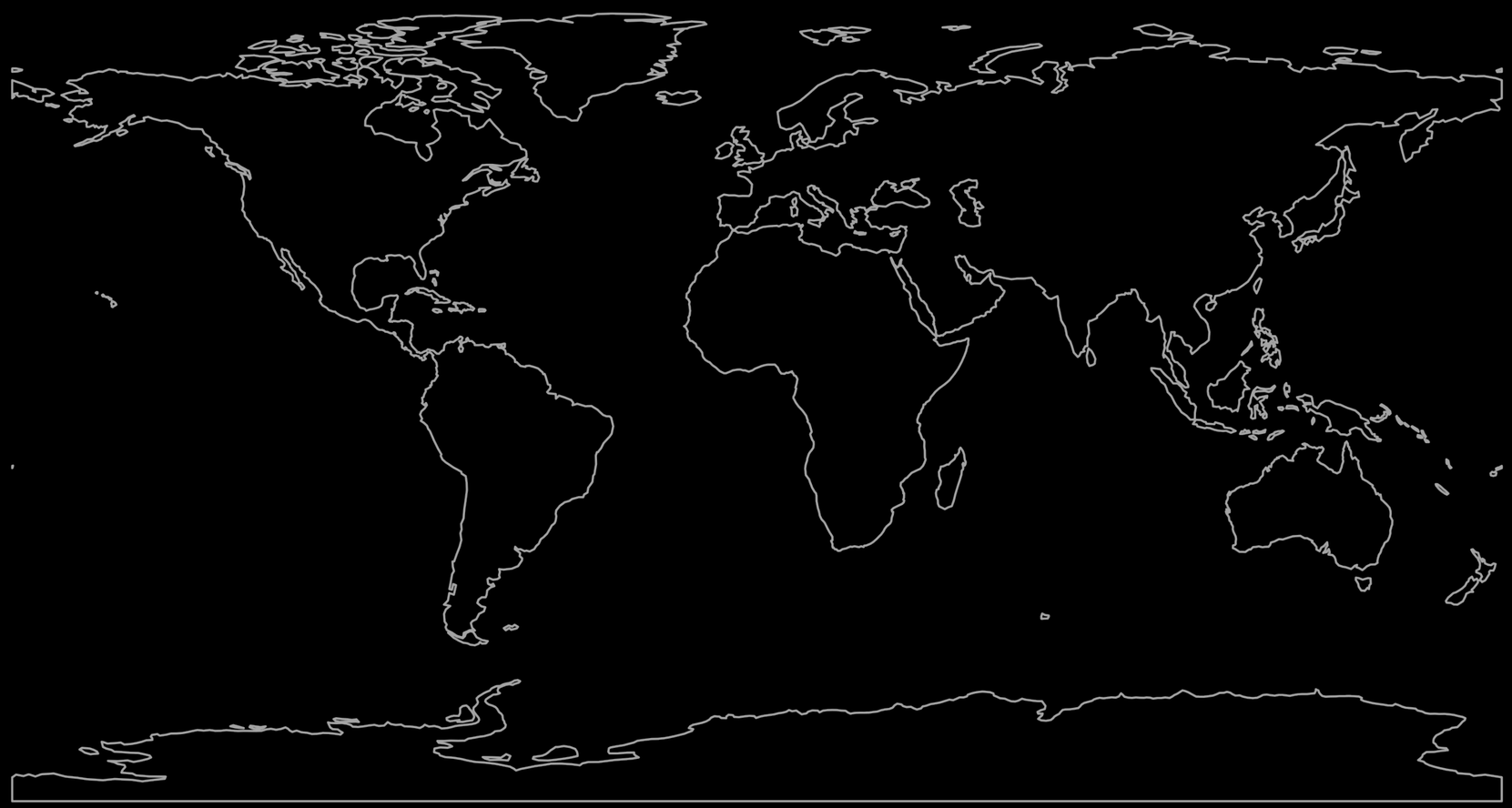
Genoble, February 9th

Kévin Cazelles

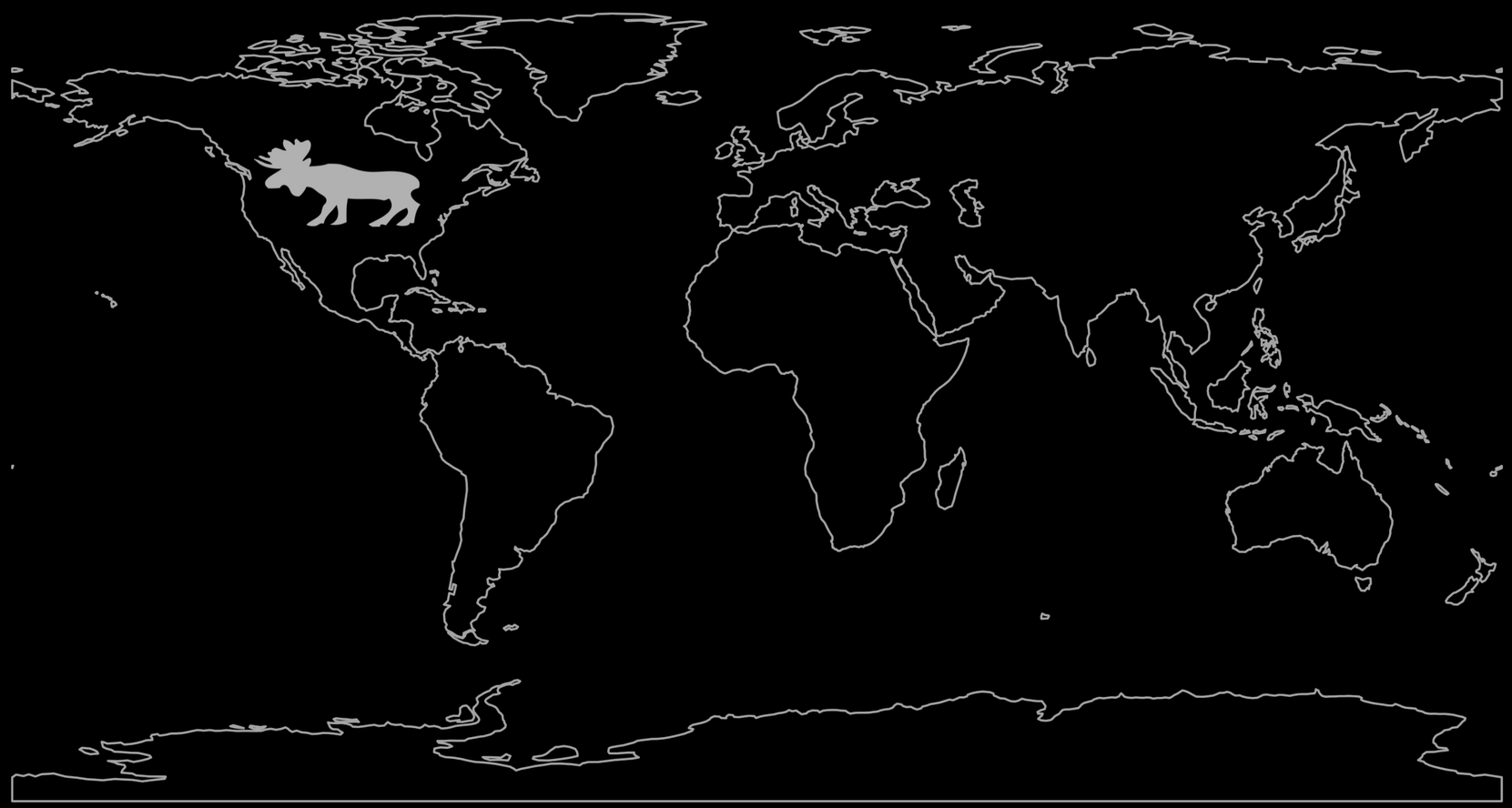
INTRODUCTION

Biogeography and biotic interactions

Biogeography?



Biogeography



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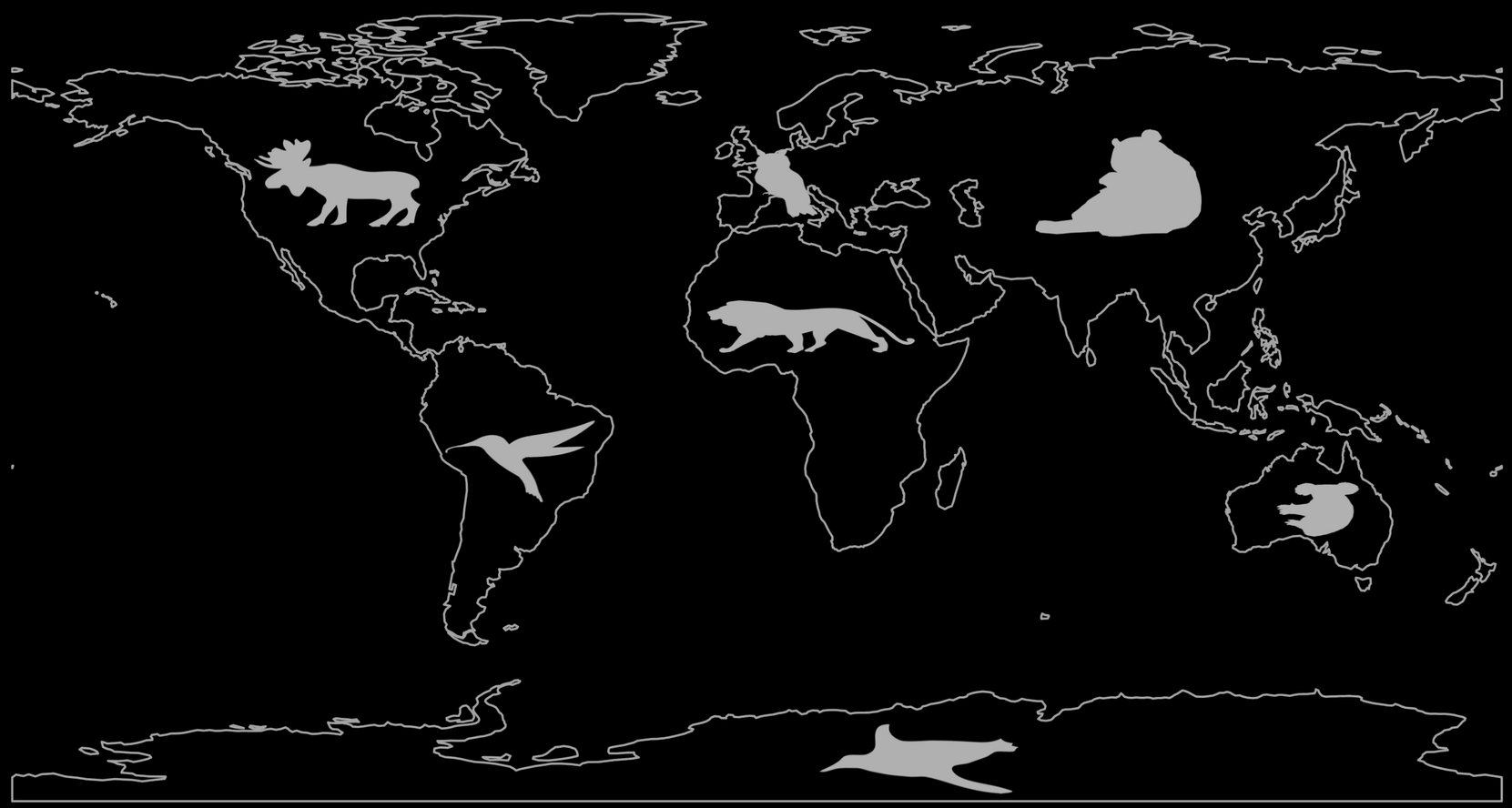
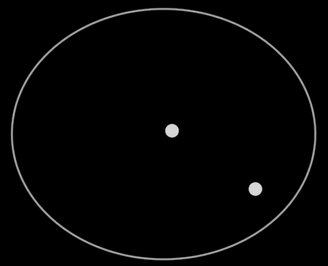


Individuals to population

e.g. temperature



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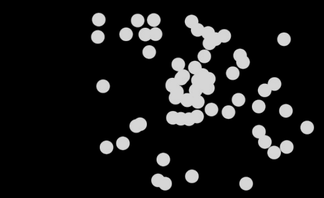
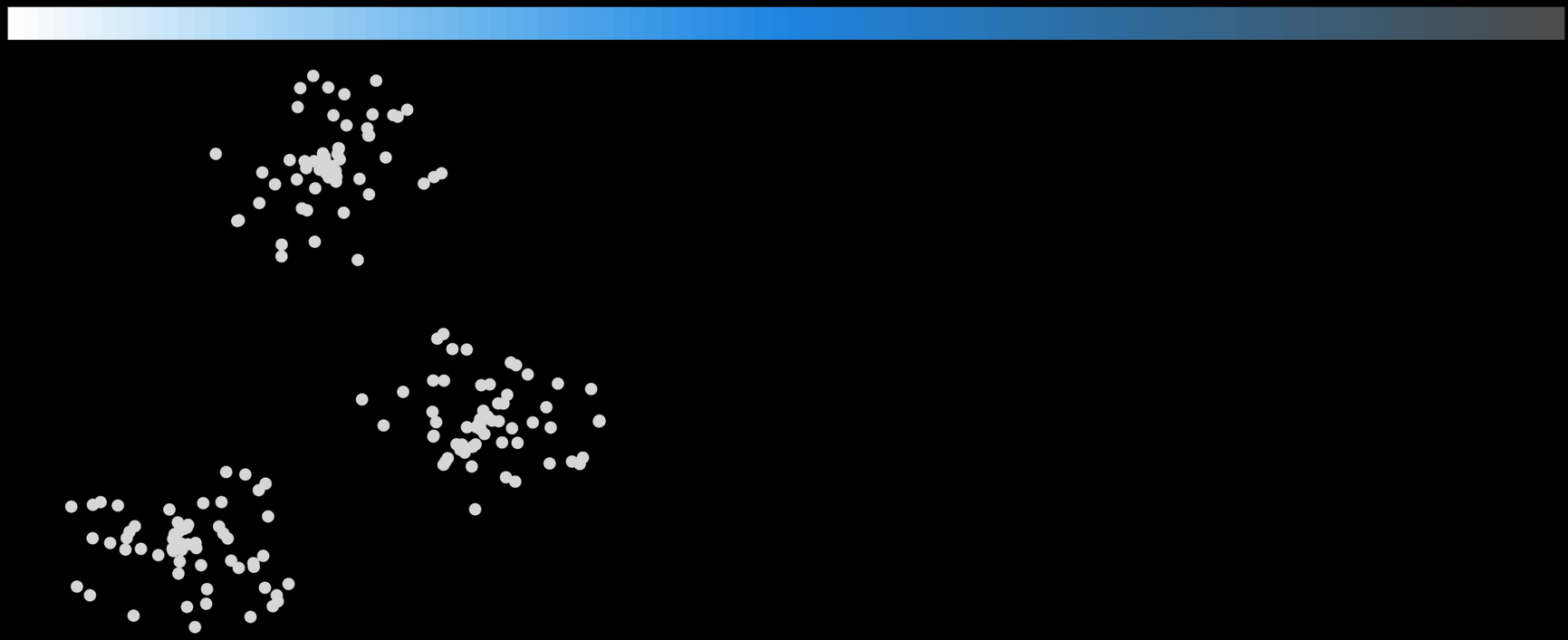


Population to metapopulations



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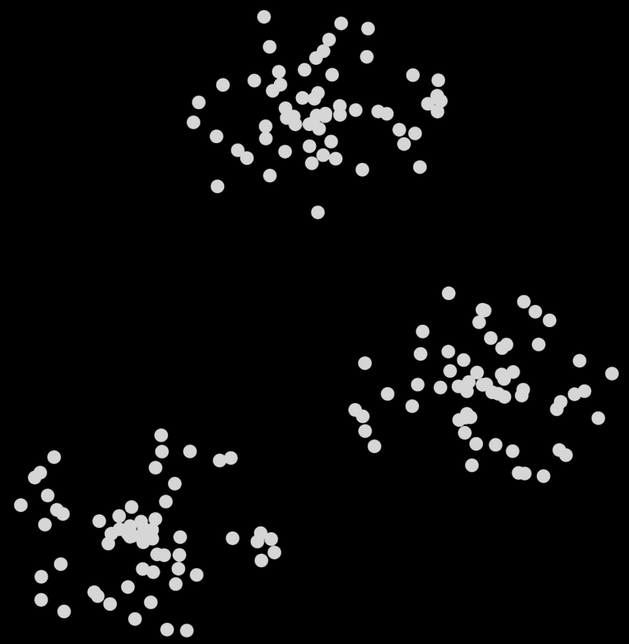

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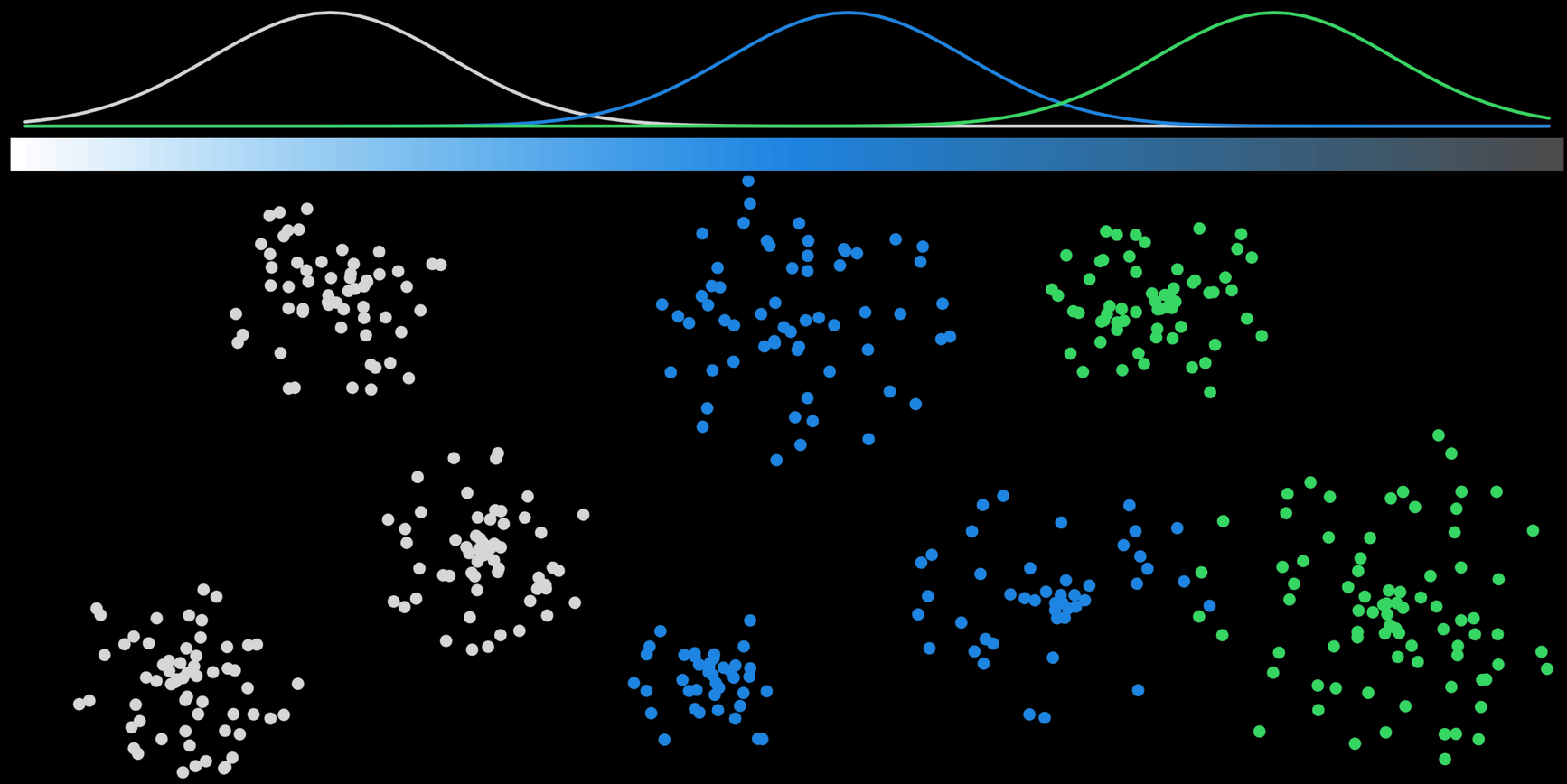
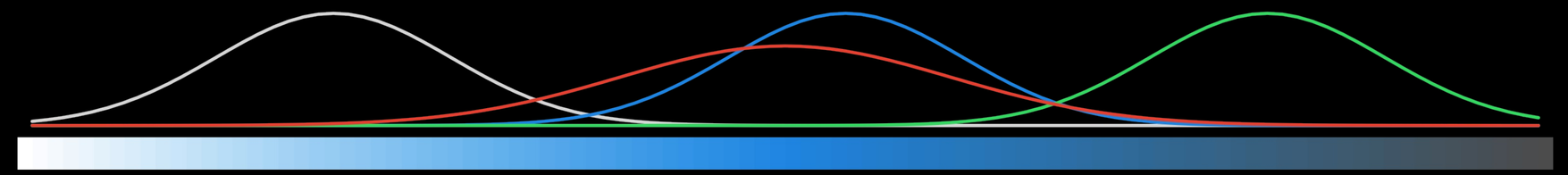
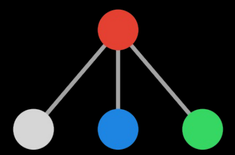
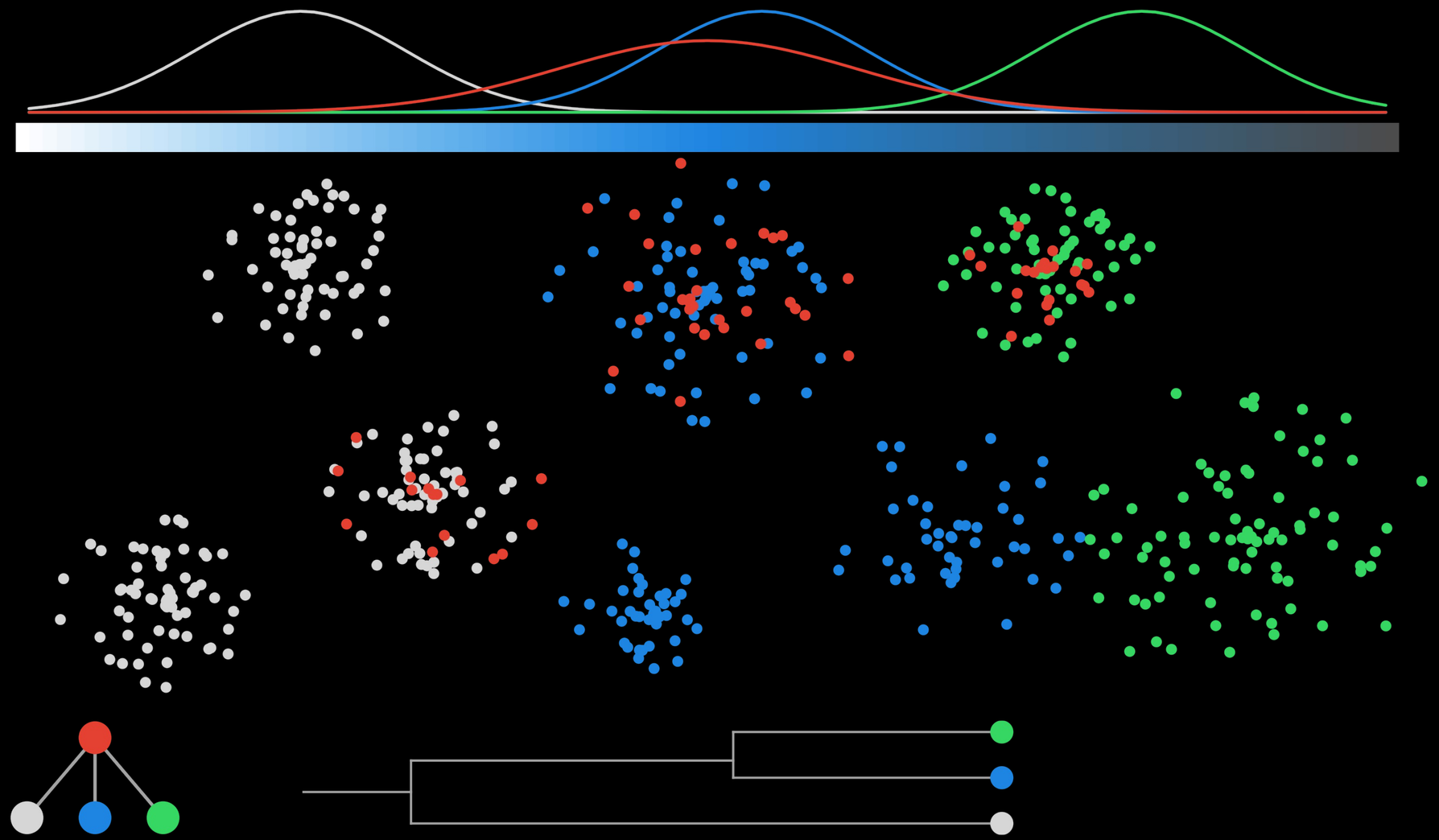


Metapopulations to metacommunities





Metacommunities through time



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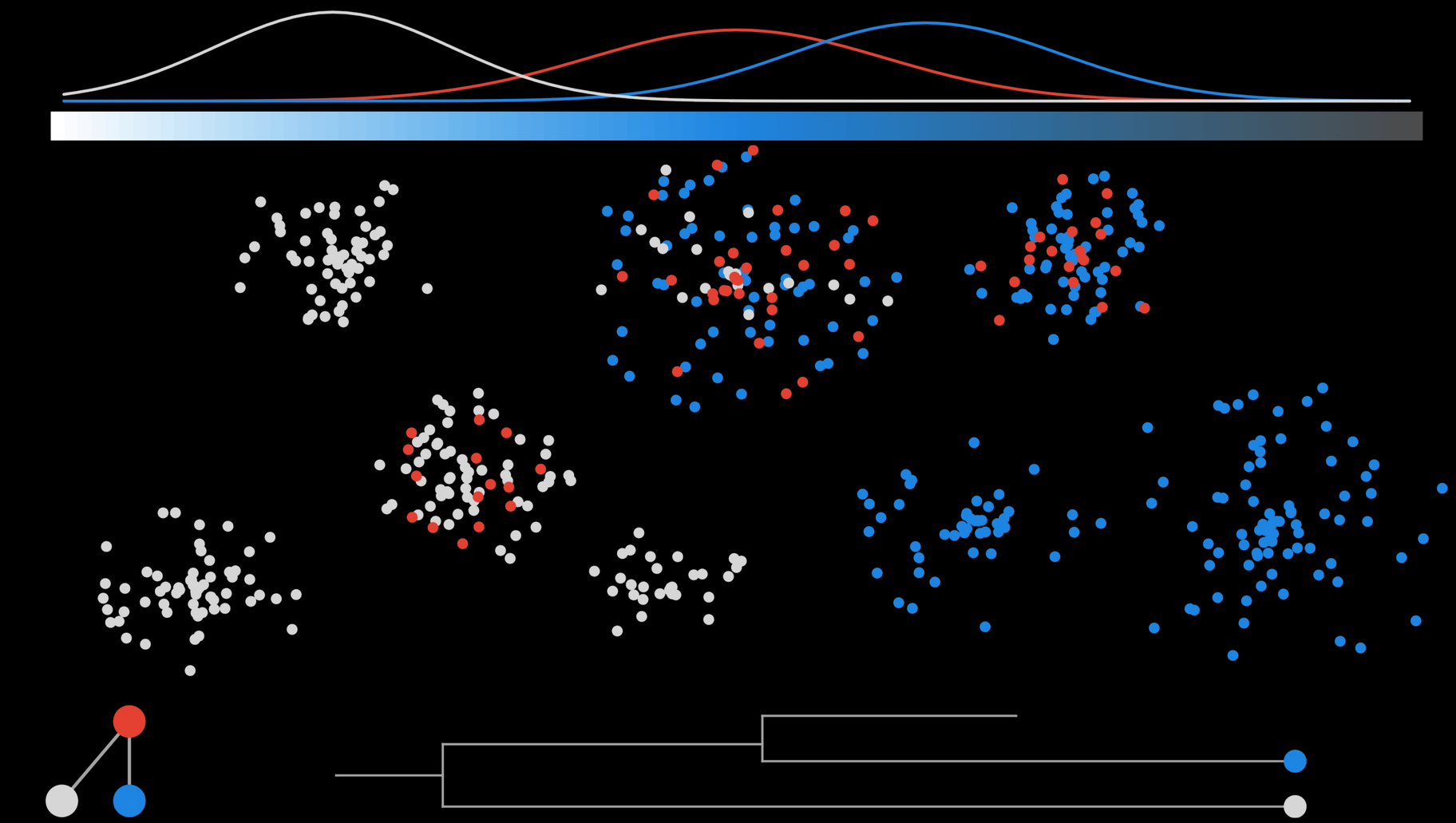

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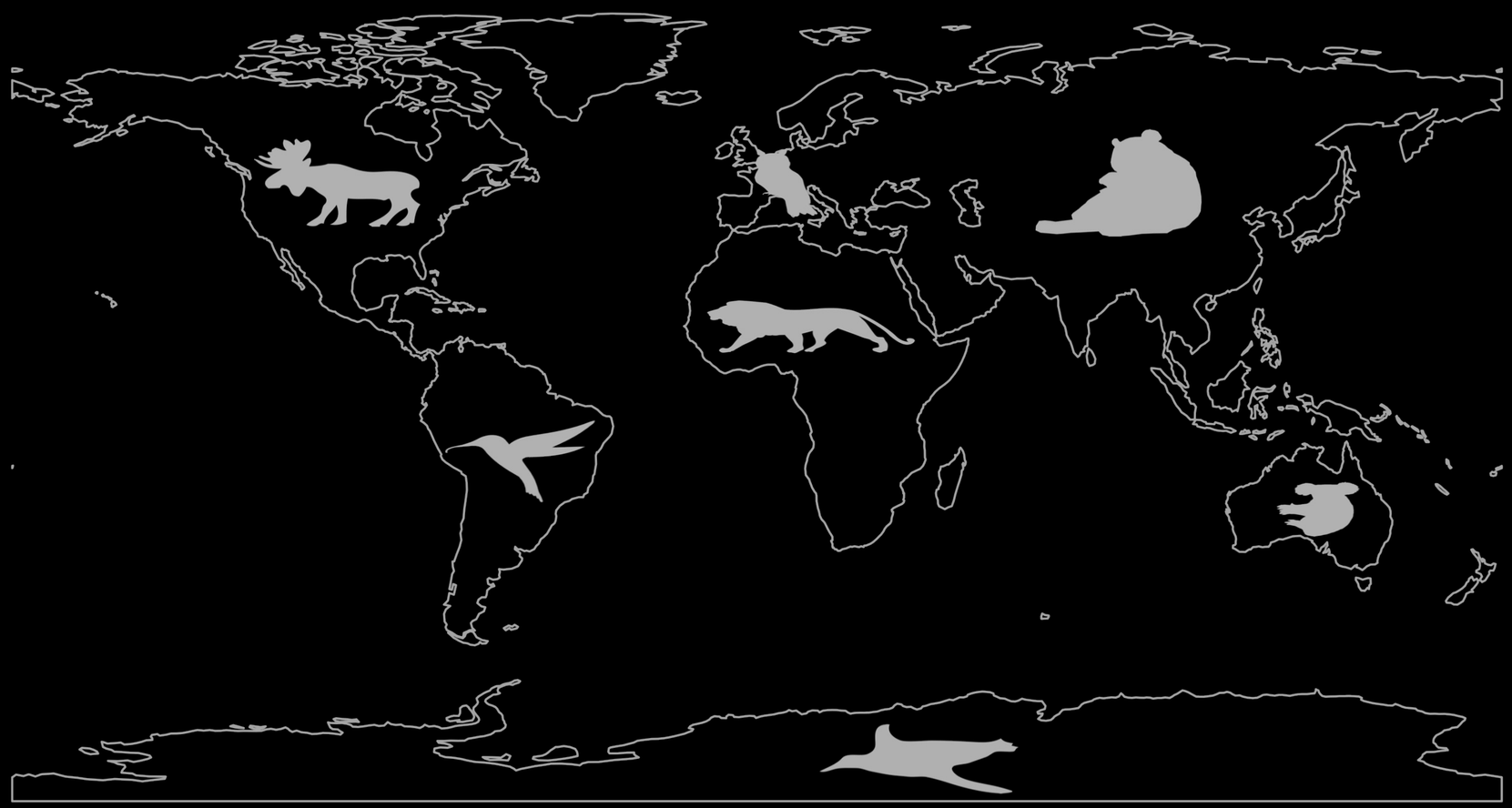

Factors shaping species distributions

1. Abiotic variables

Factors shaping species distributions

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2. Dispersion

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3. Ecological interactions

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INTERDEPENDENT

Predicting species distributions

Today

Predicting species distributions

Today

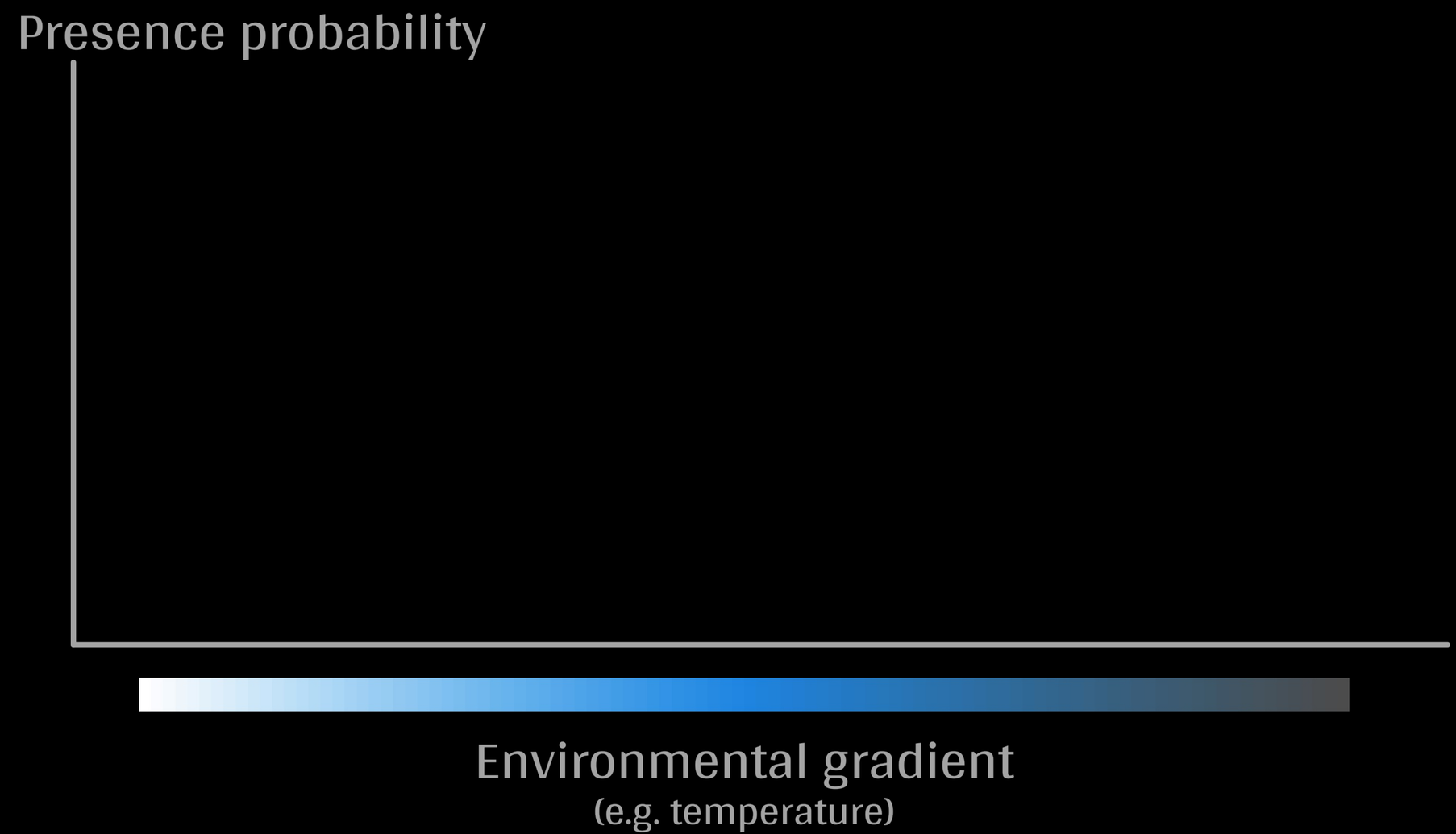
Tomorrow

Predicting species distributions

Today

Tomorrow

Species Distribution Models (SDMs)



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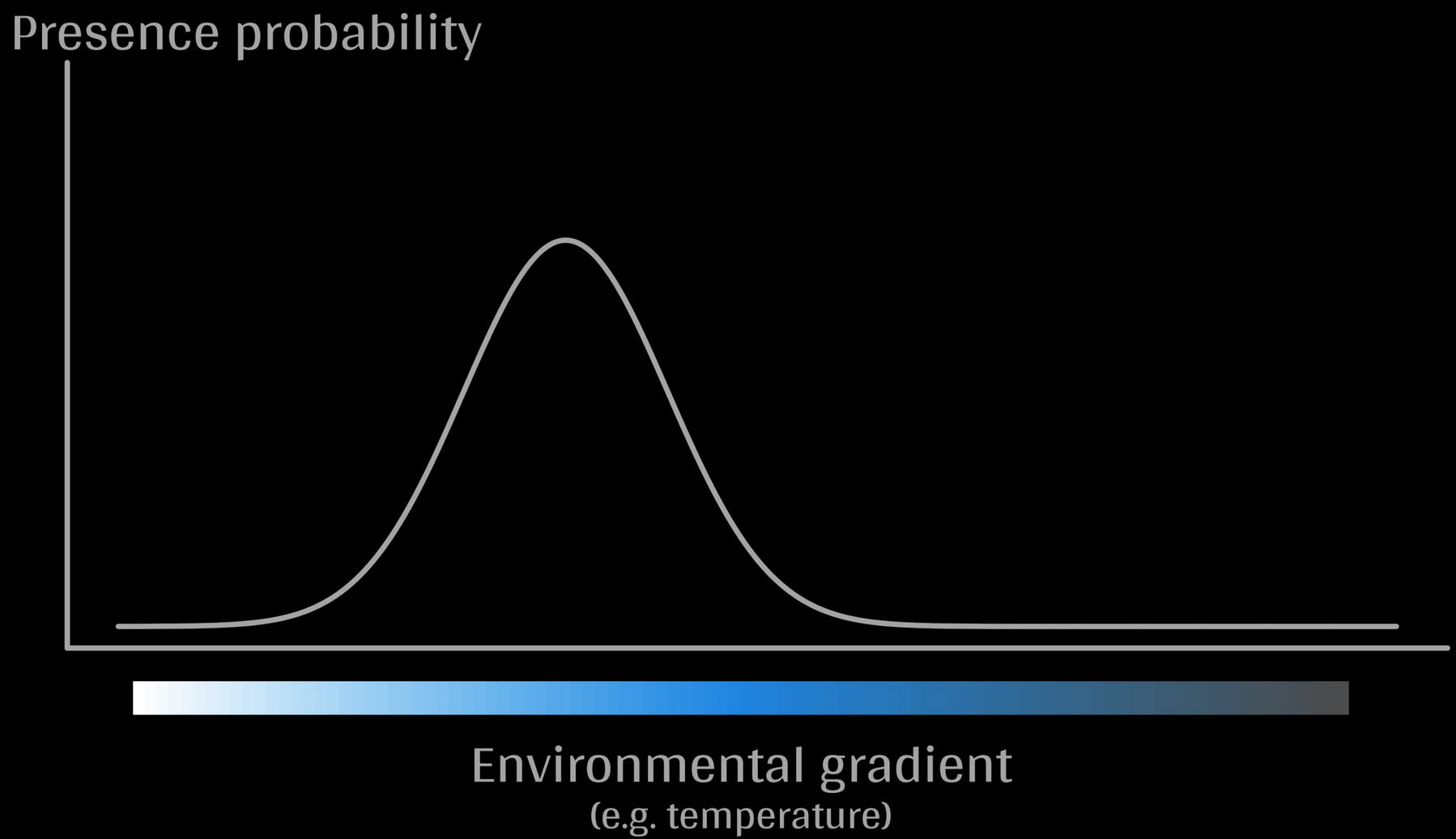

Predicting species distributions

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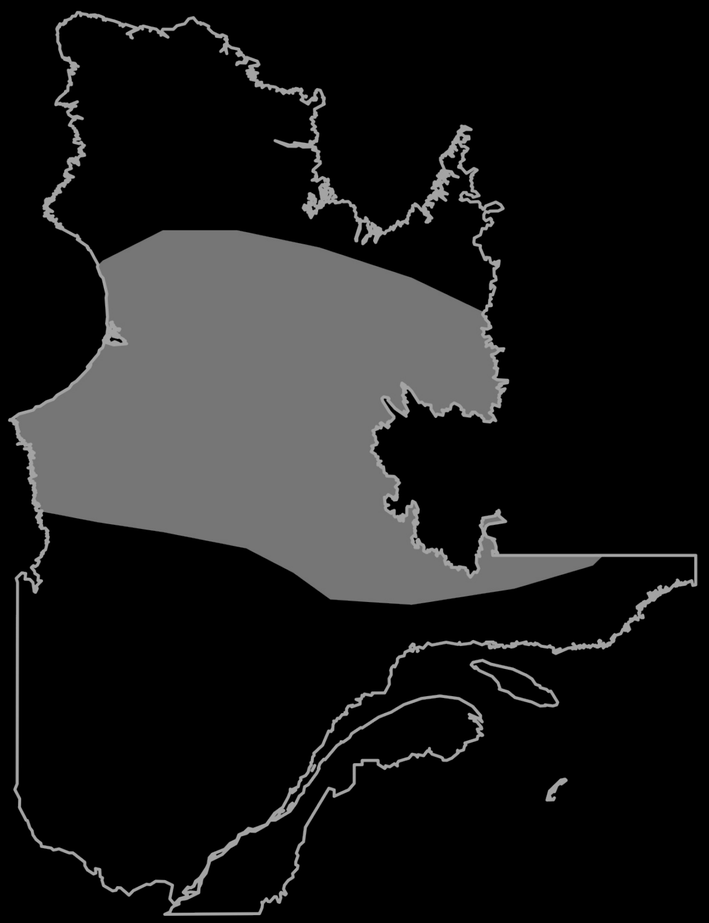
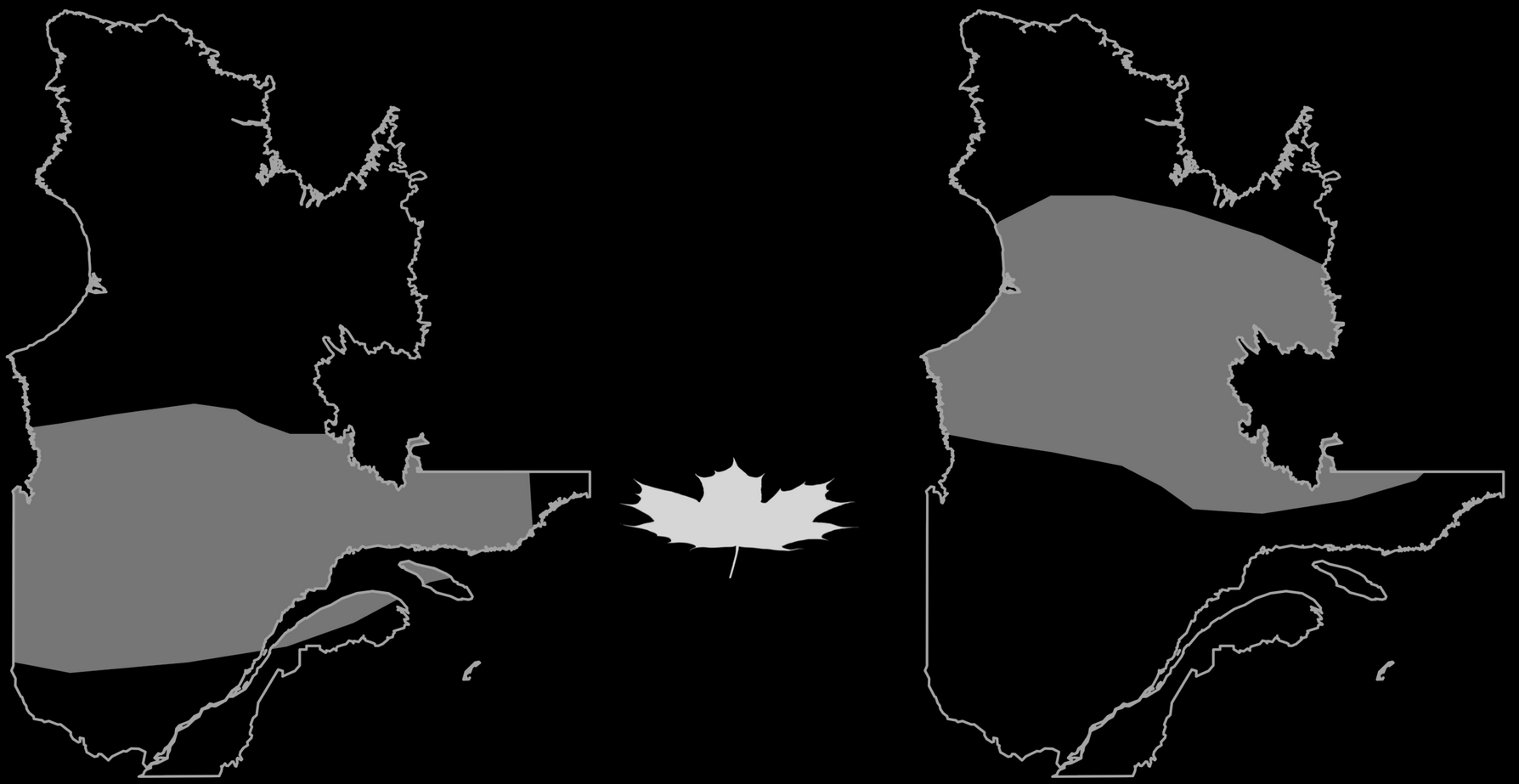


Tomorrow

Predicting species distributions



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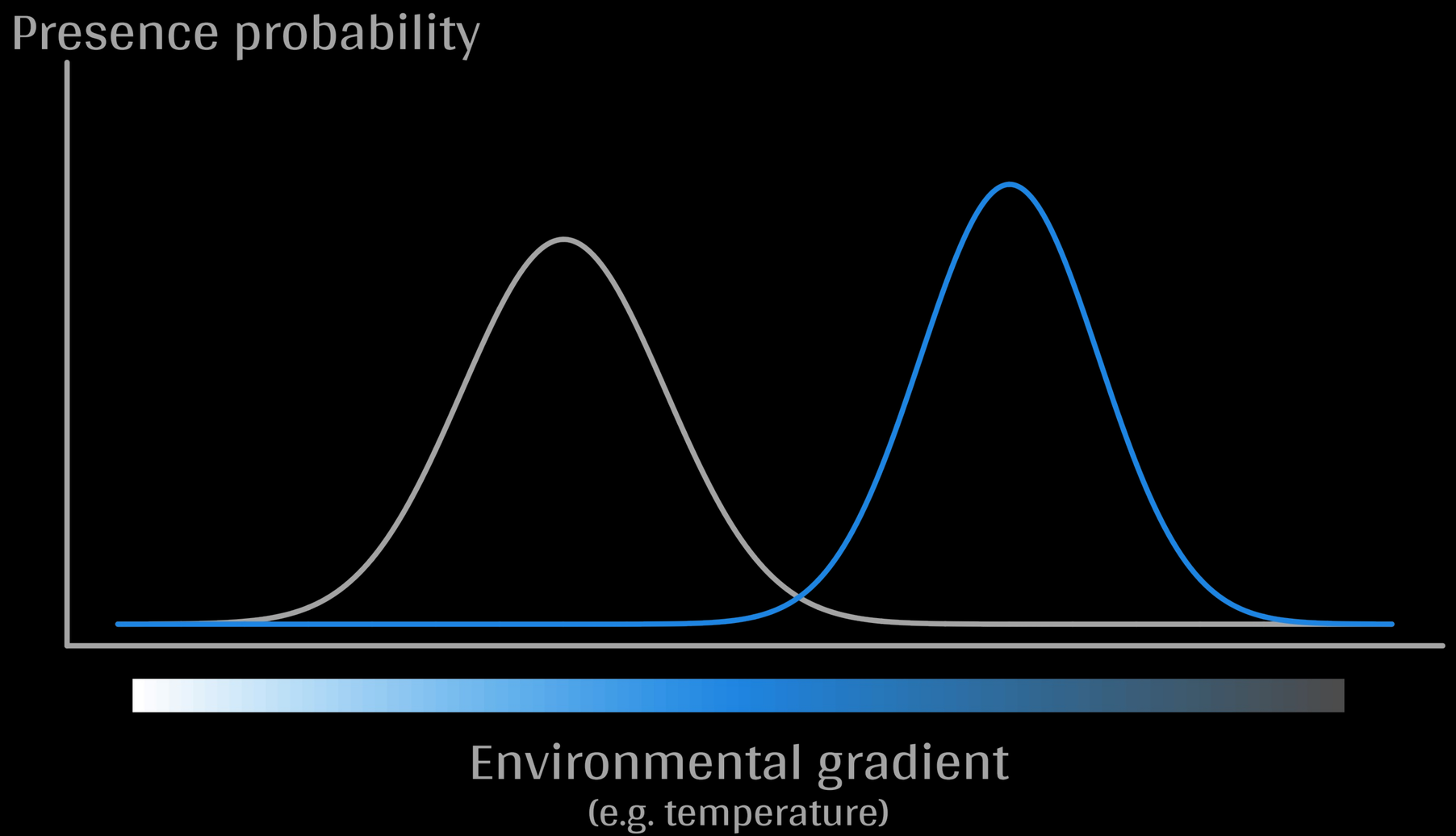

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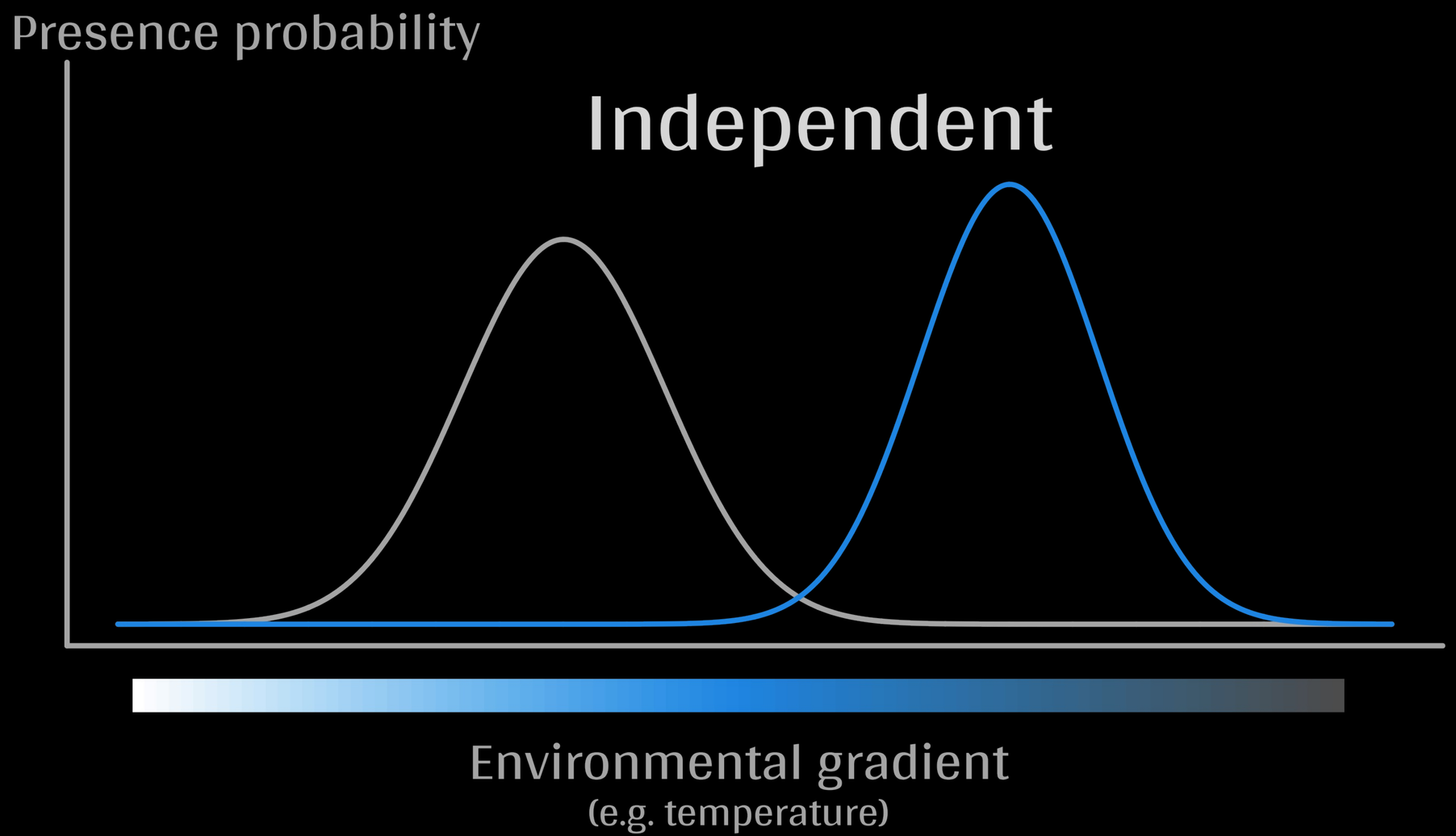
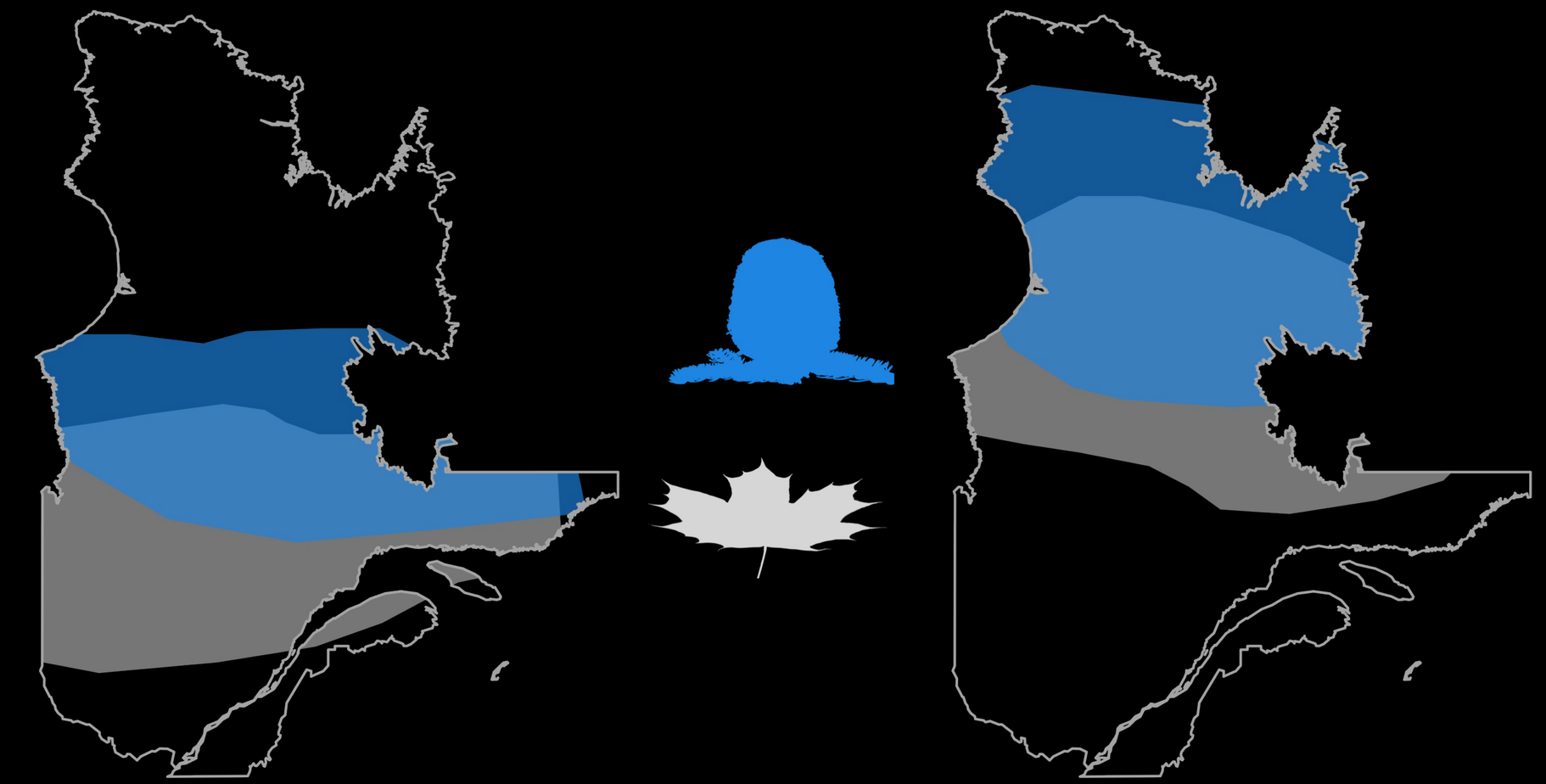


Predicting species distributions



Predicting species distributions

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Joint Species Distribution Models (JSDMs)

- Clark et al, 2014, Ecological Applications
- Pollock et al, 2014, Methods in Ecology and Evolution

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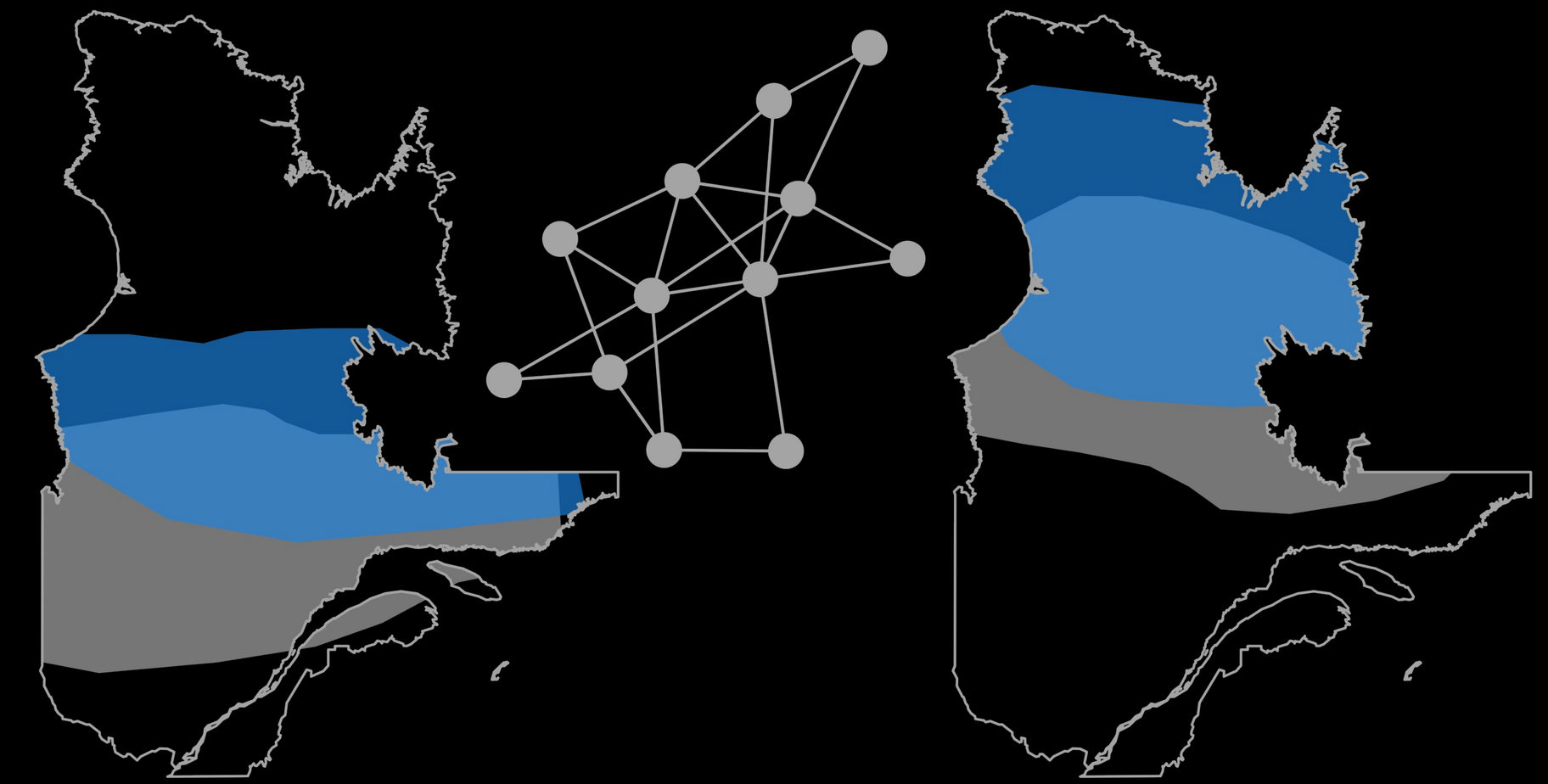
Theory

- Gravel et al, 2011, Ecology Letters

Predicting species distributions



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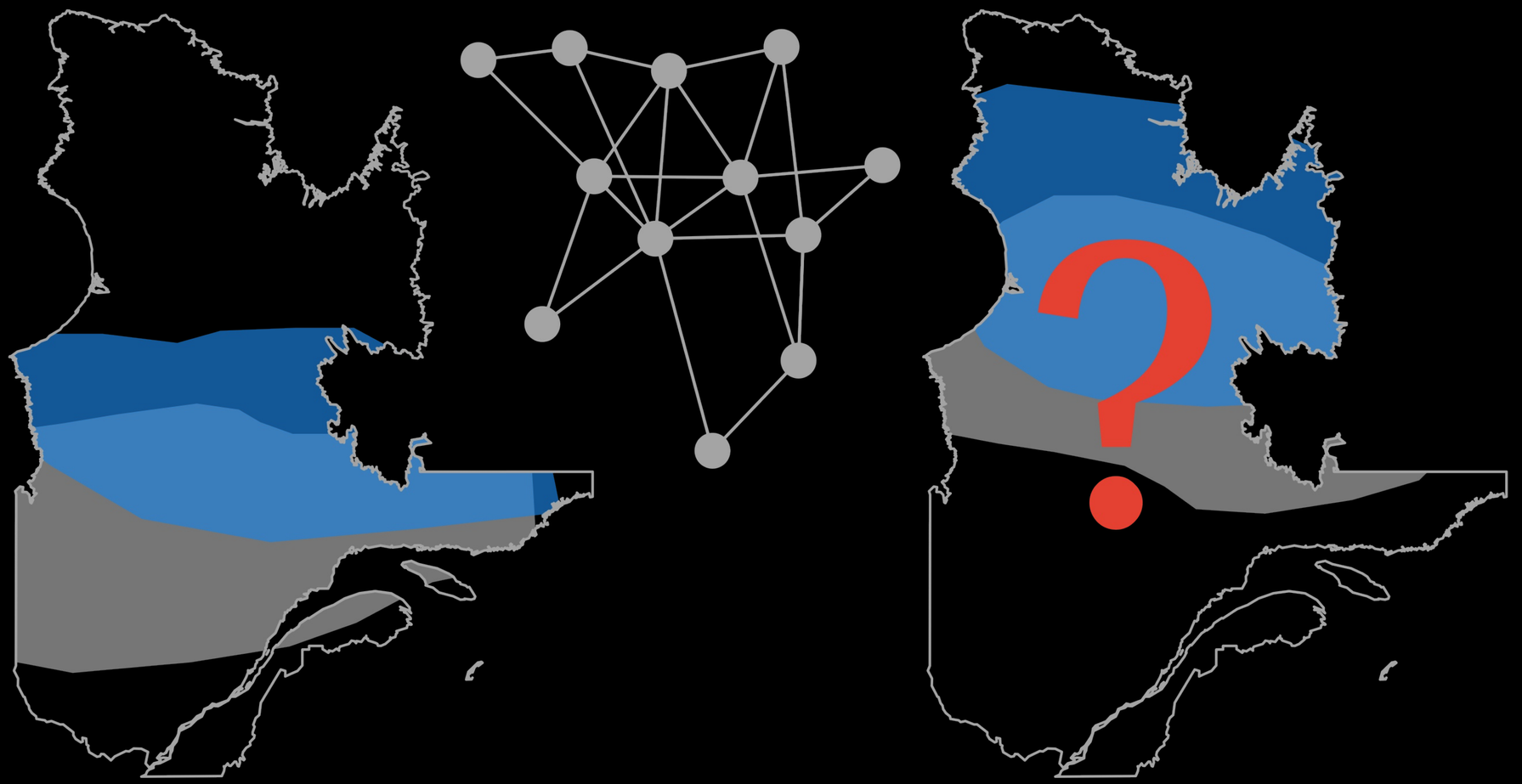

Questions

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2. How the properties of ecological networks influence co-occurrence?

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2. How the properties of ecological networks influence co-occurrence?

3. Can we infer interactions from co-occurrence?

THEORY OF ISLAND BIOGEOGRAPHY AND BIOTIC INTERACTIONS

How to integrate biotic interactions into distribution models?

MacArthur et Wilson (1963, 1967)

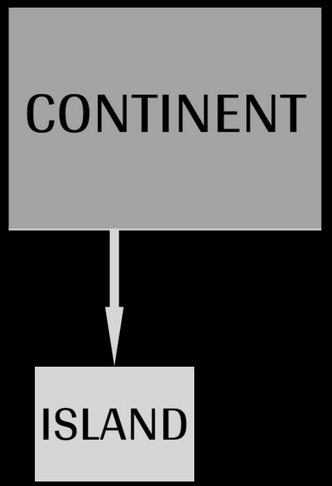
CONTINENT

MacArthur et Wilson (1963, 1967)

CONTINENT

ISLAND

MacArthur et Wilson (1963, 1967)



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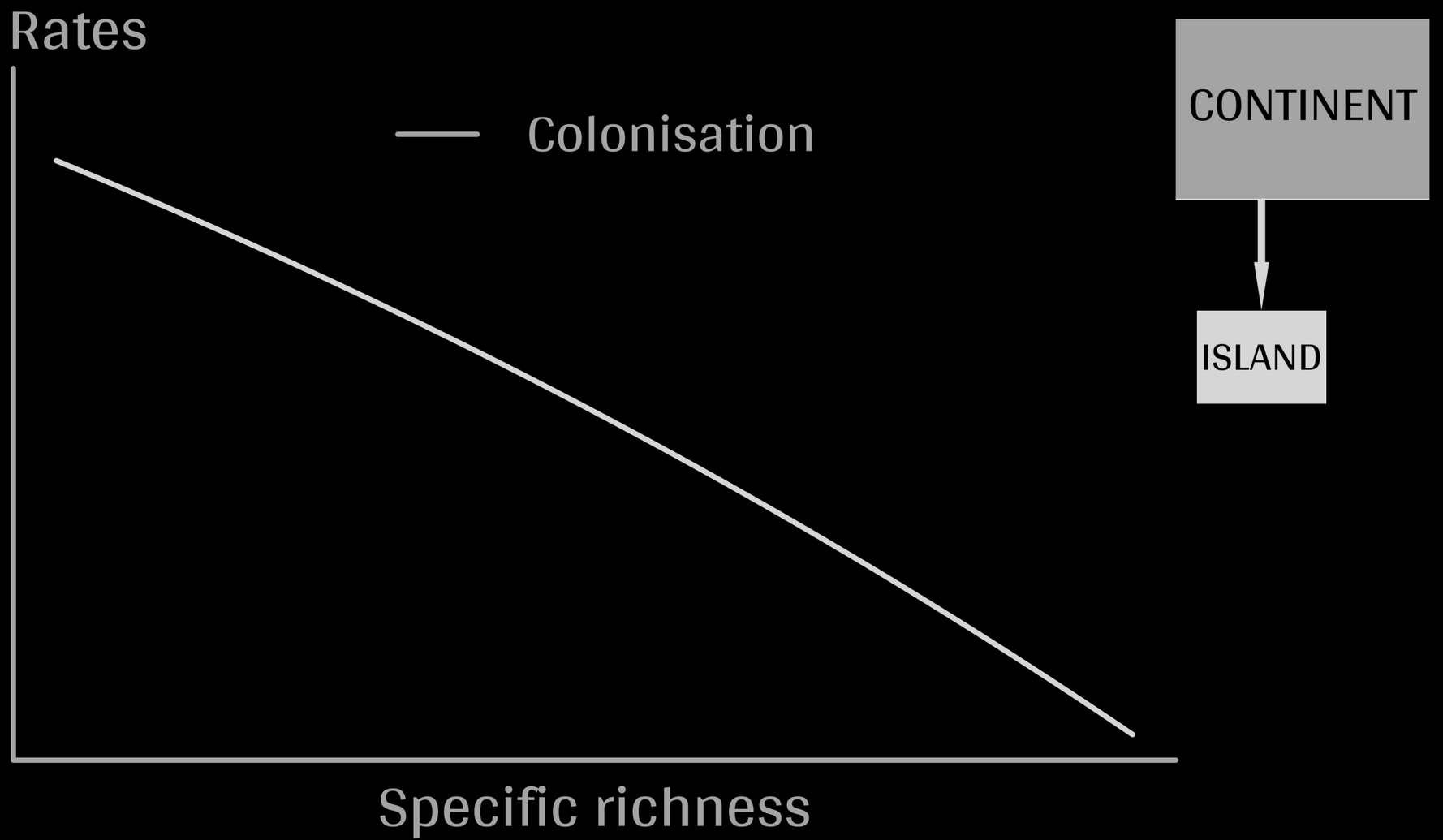

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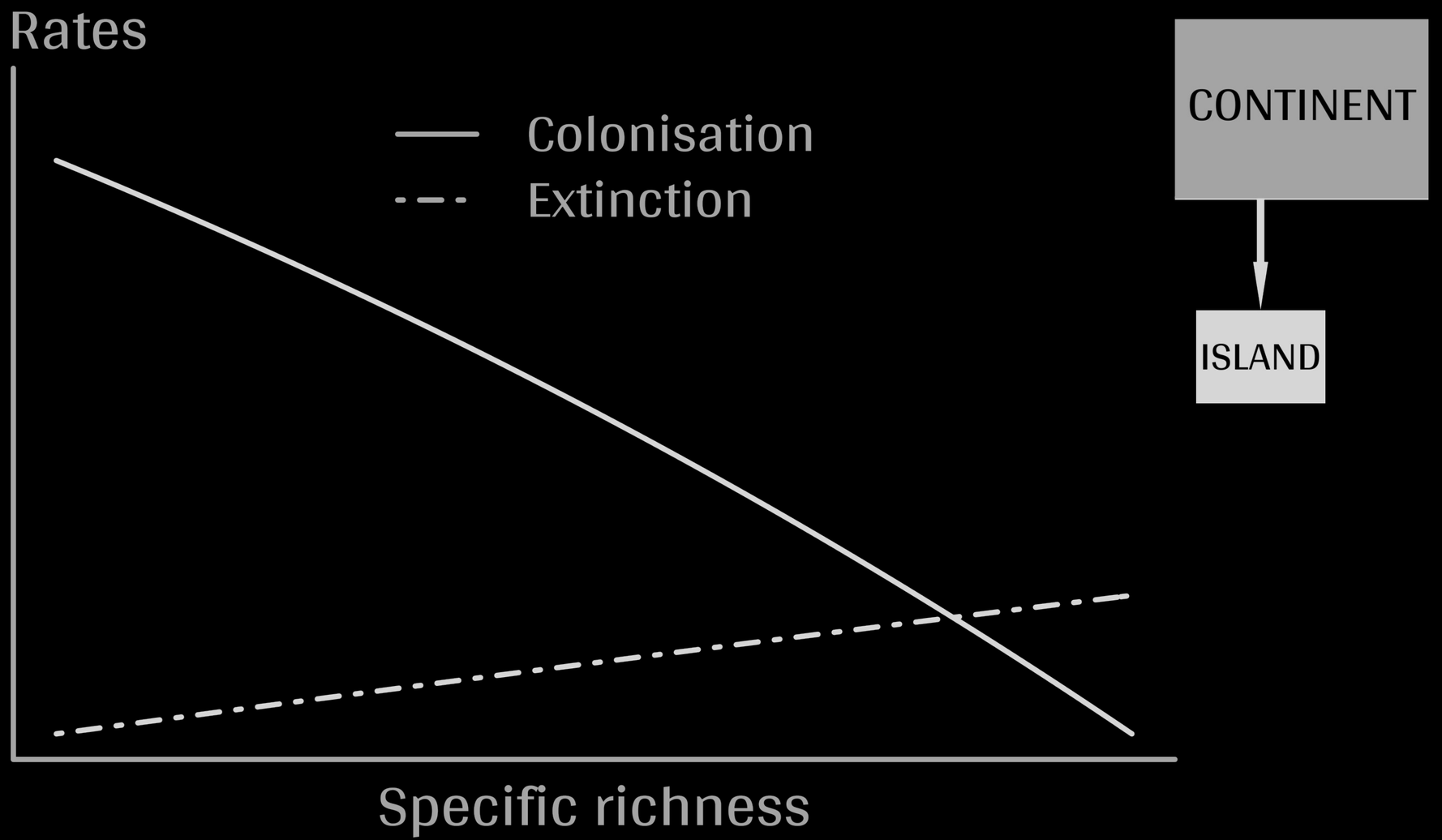

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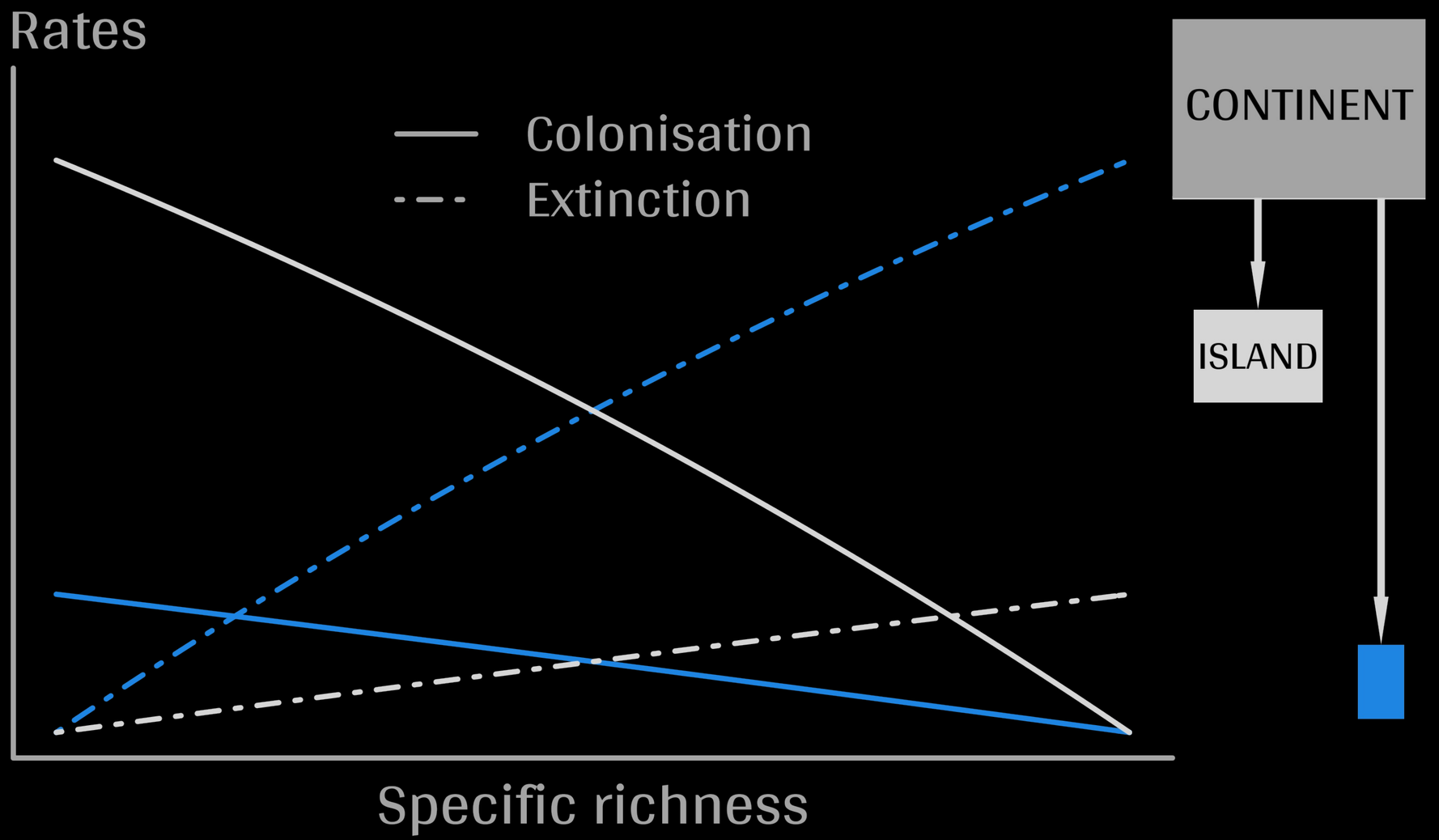

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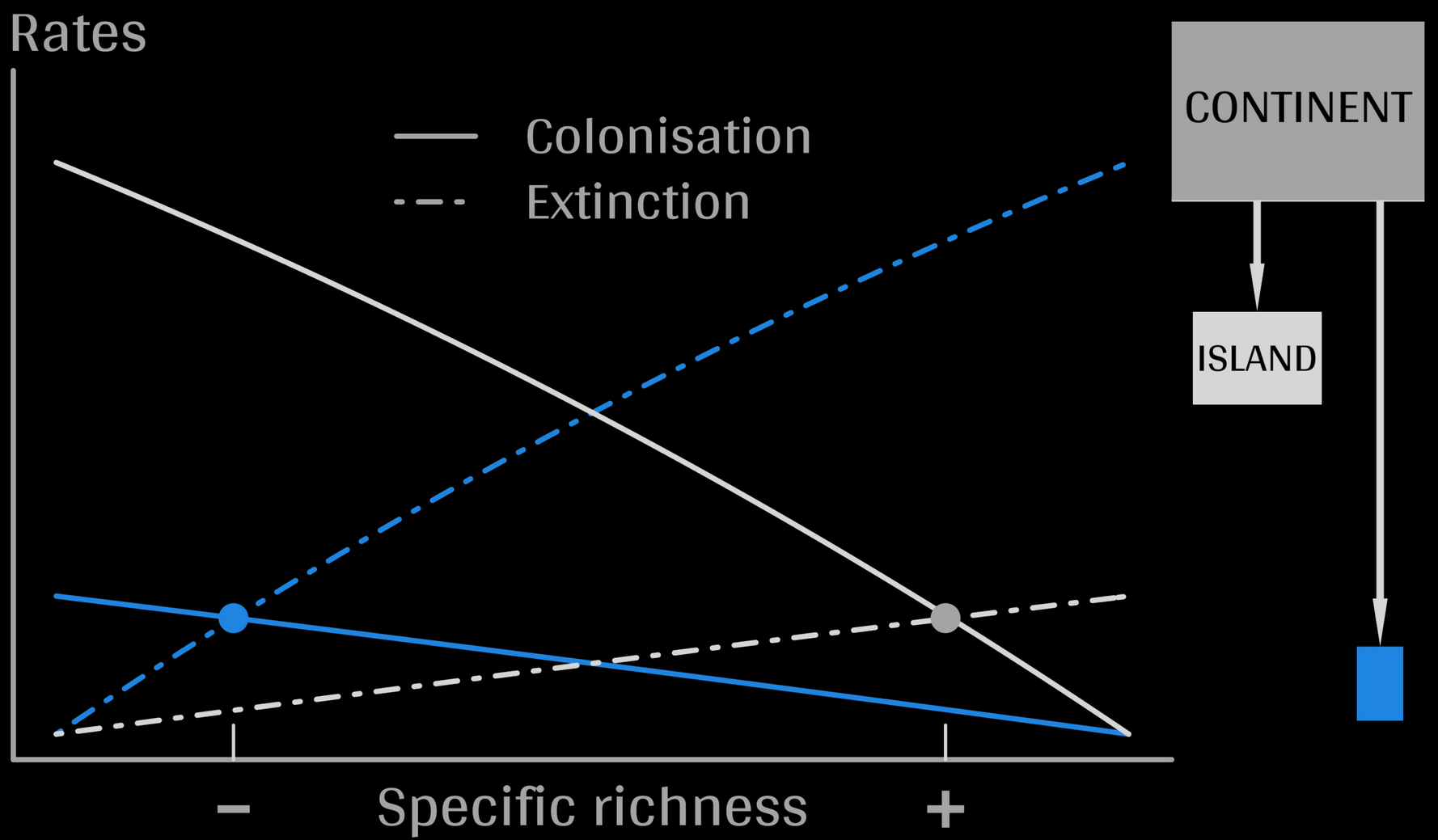

Model properties

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3. Elegant, easy to expand

Model properties

1. Colonisation/extinction dynamics

2. Equilibrium

3. Elegant, easy to expand

4. Biotic and abiotic constraints are missing

Assumption of independence released

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1. Island without prey = no predator colonisation
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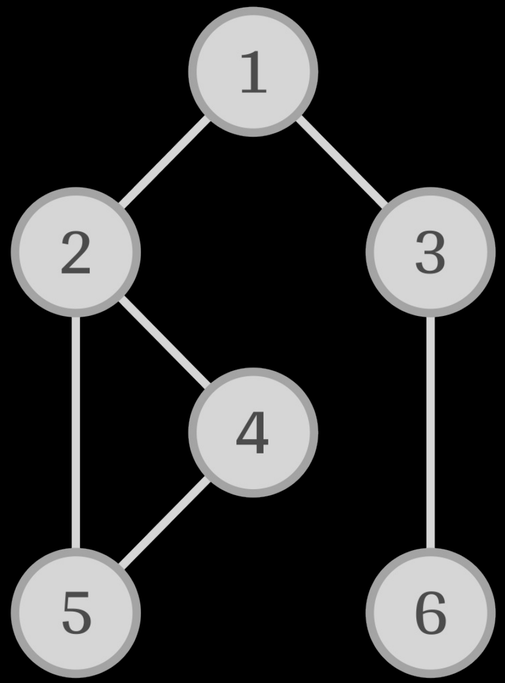
Colonisation and extinction depend on the local community

What did I do?

Regional pool



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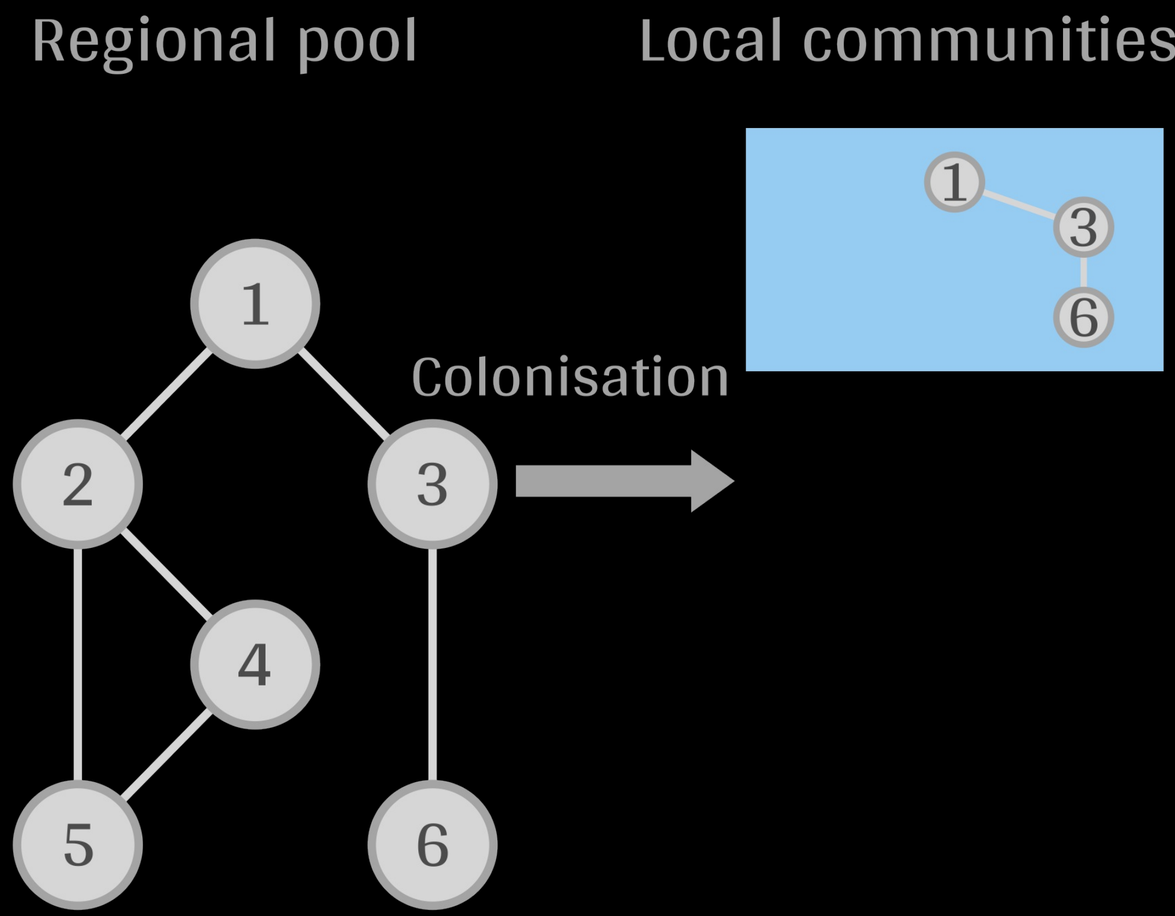

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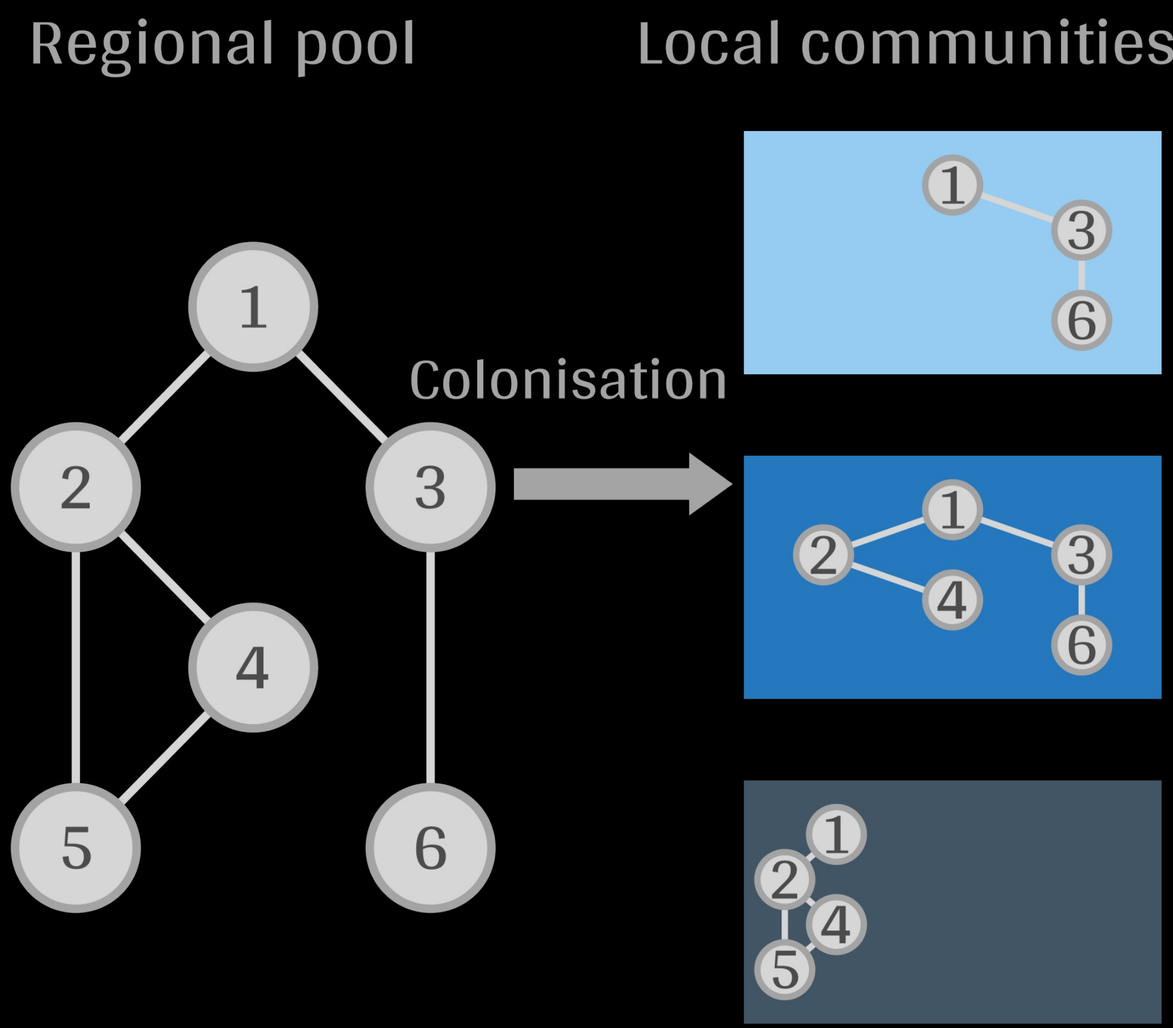
Regional pool
Local communities
1
2
3
4
5
6
Colonisation
1
3
6
1
2
3
4
6
1
2
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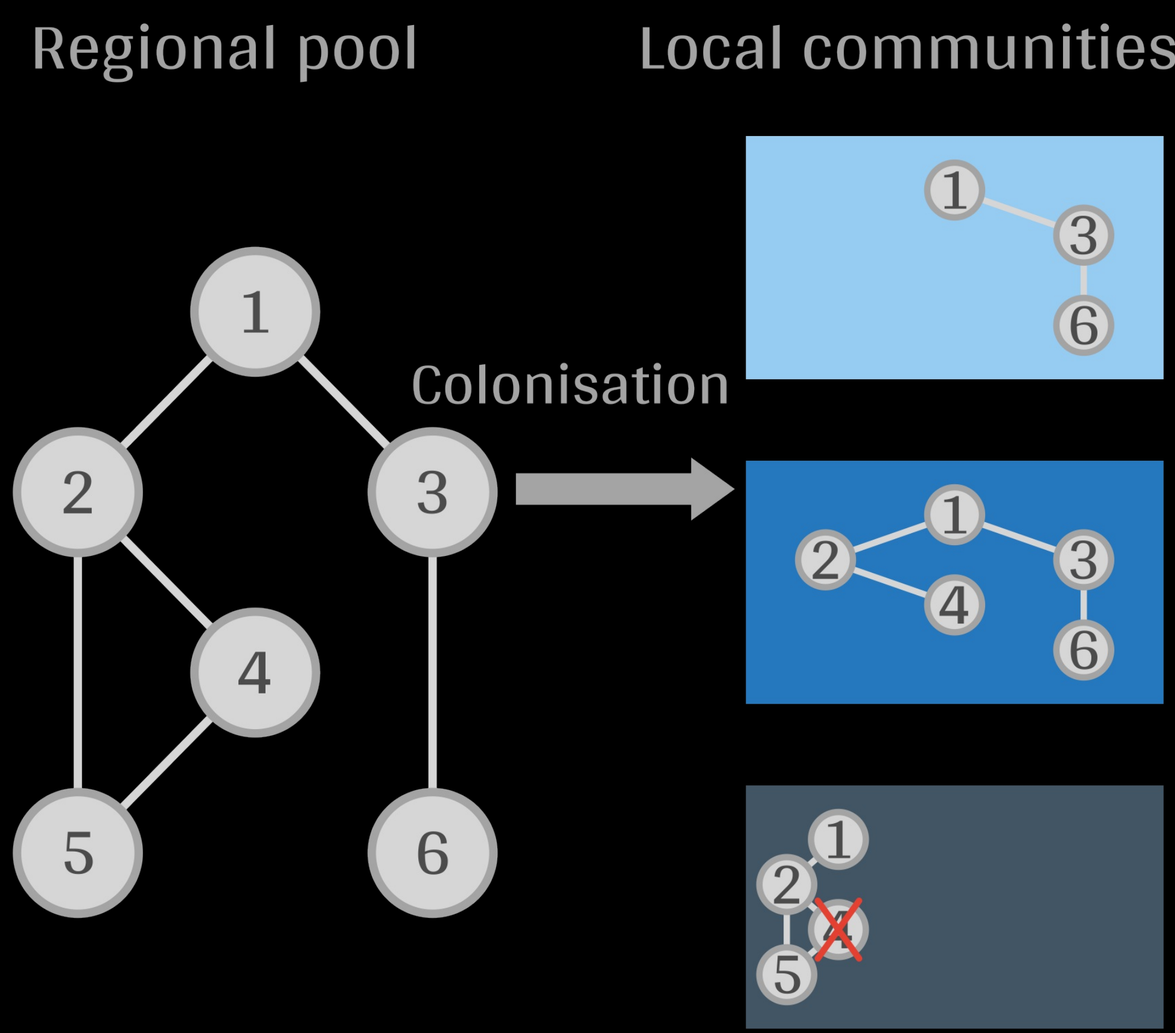
5

What did I do?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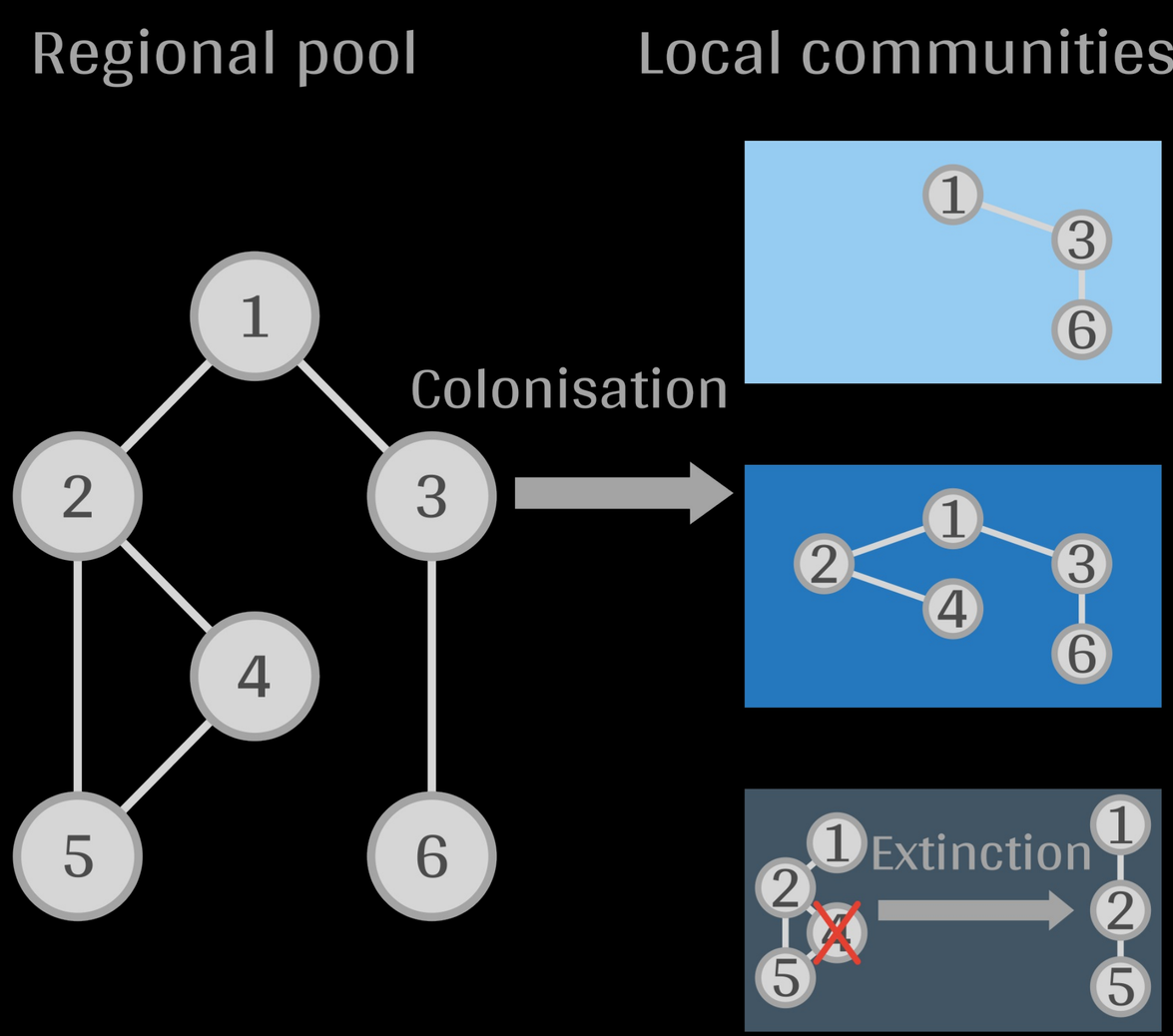
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Extinction
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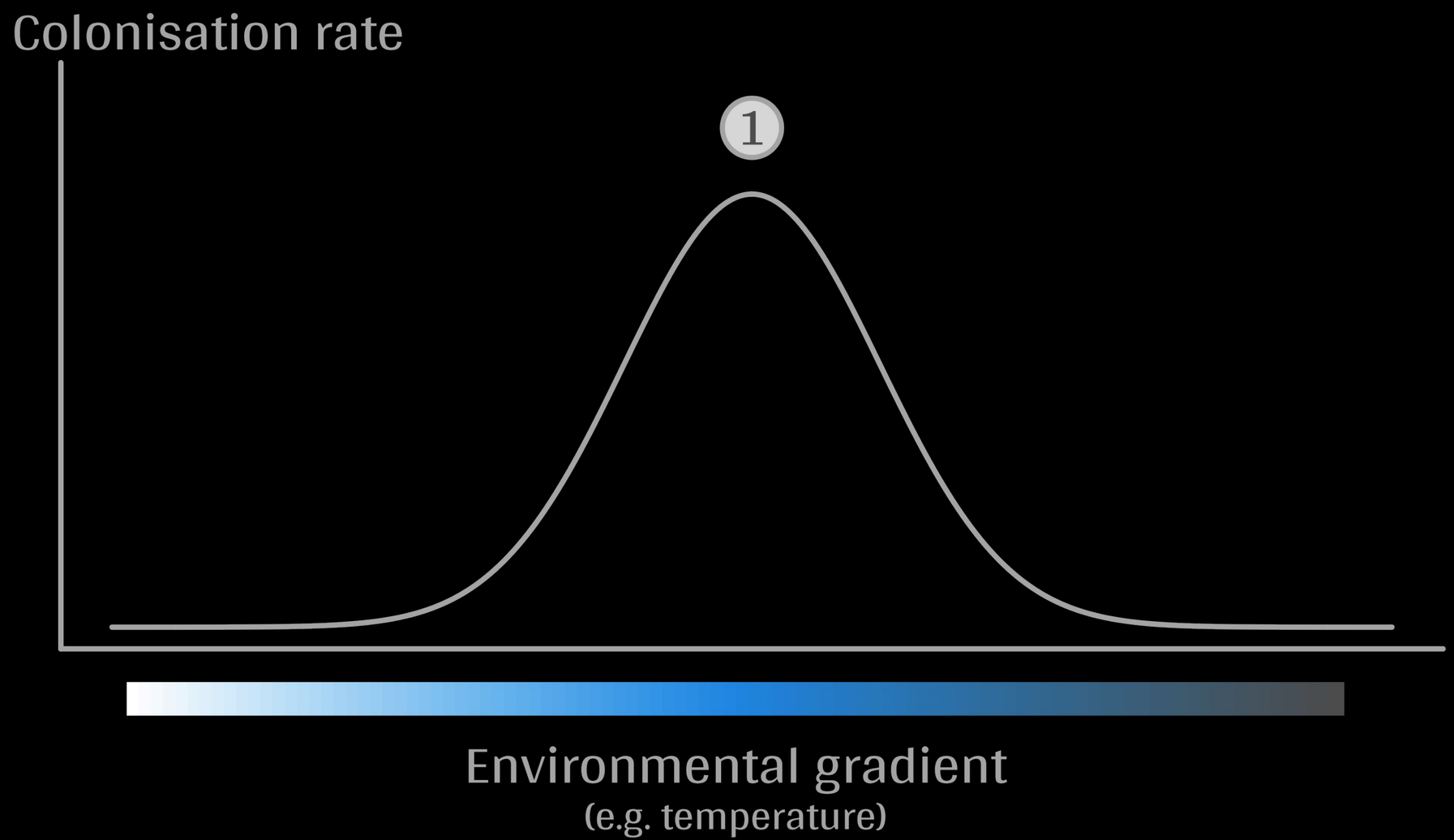
Abiotic variables vary



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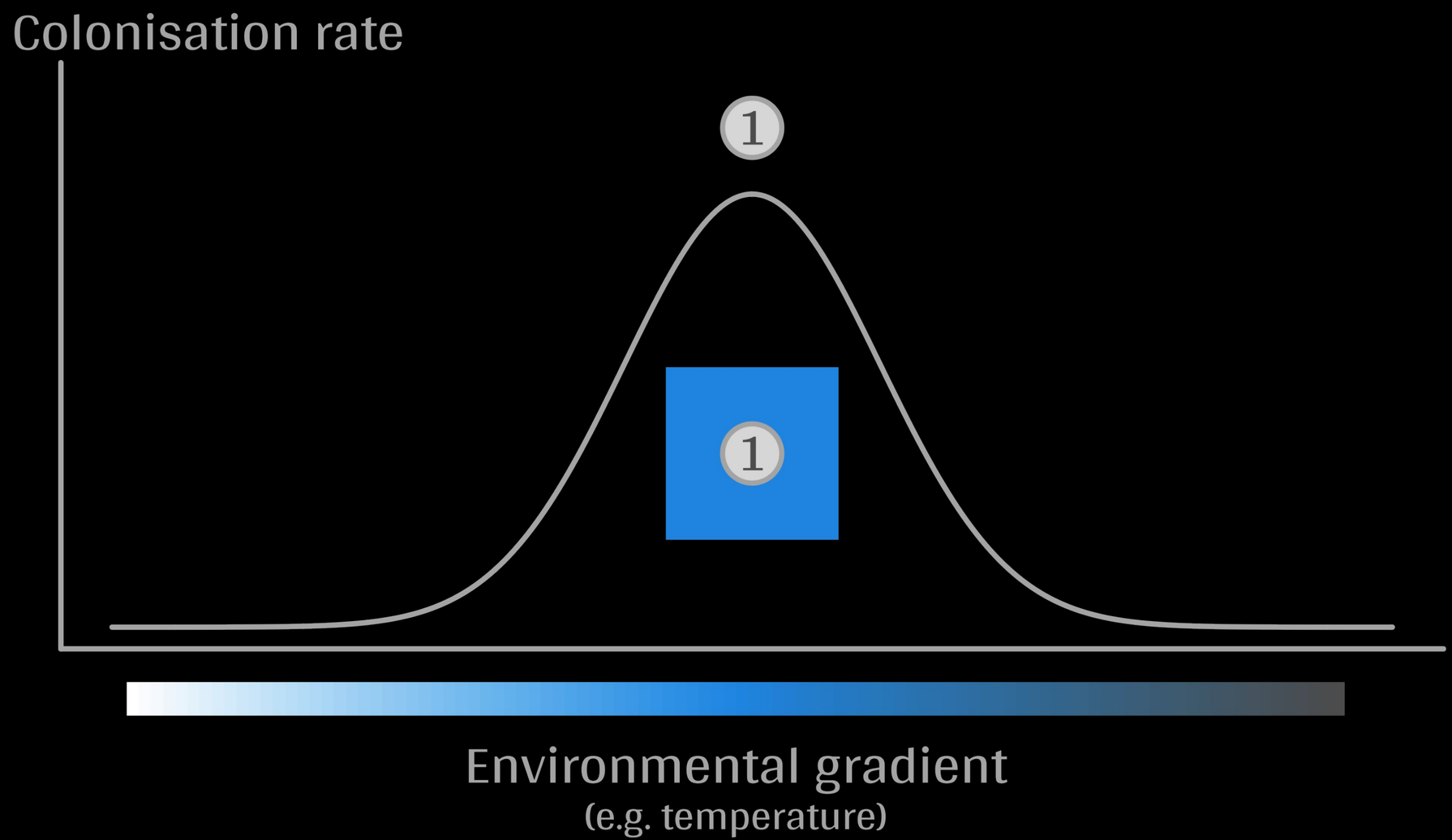

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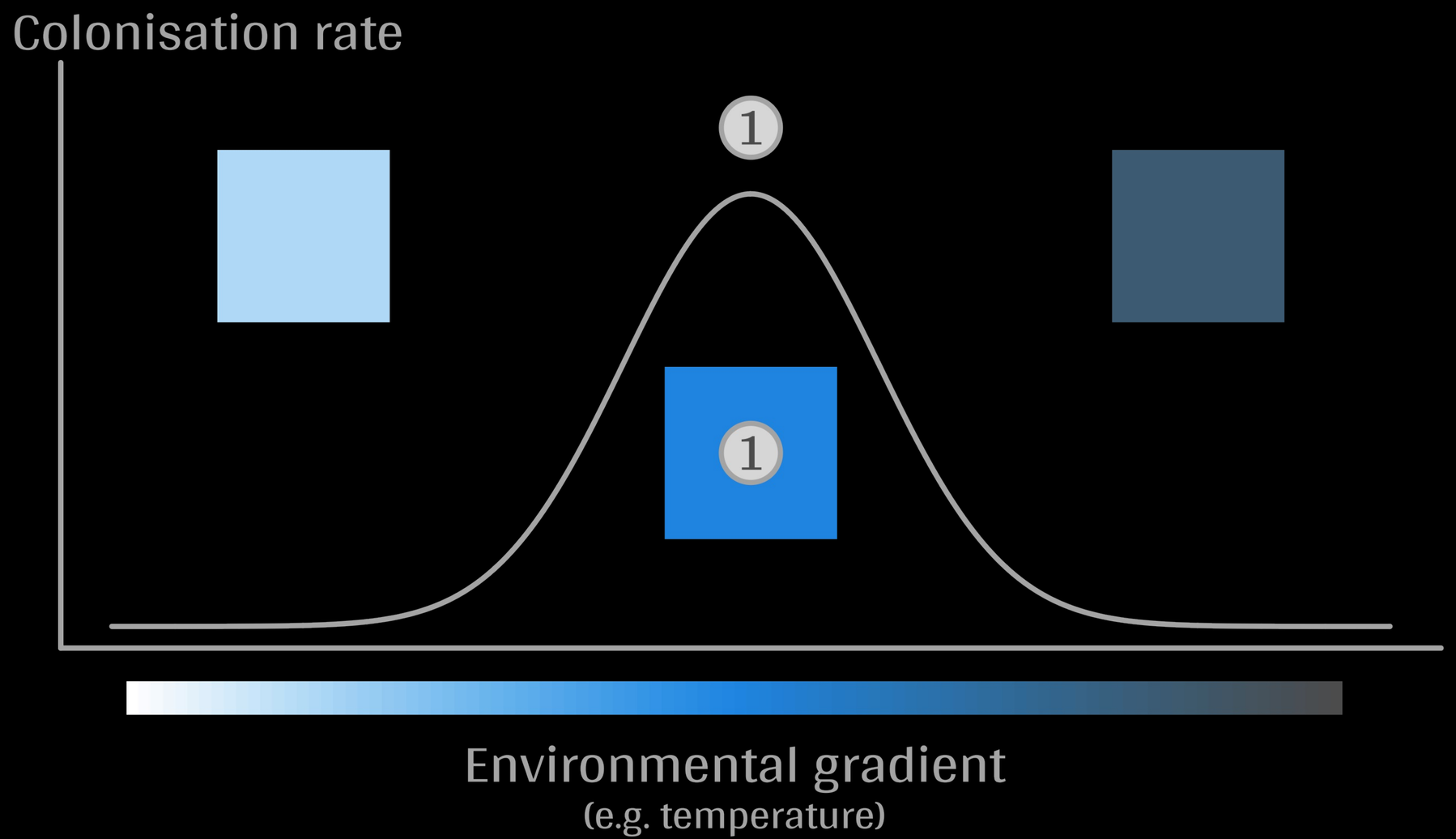

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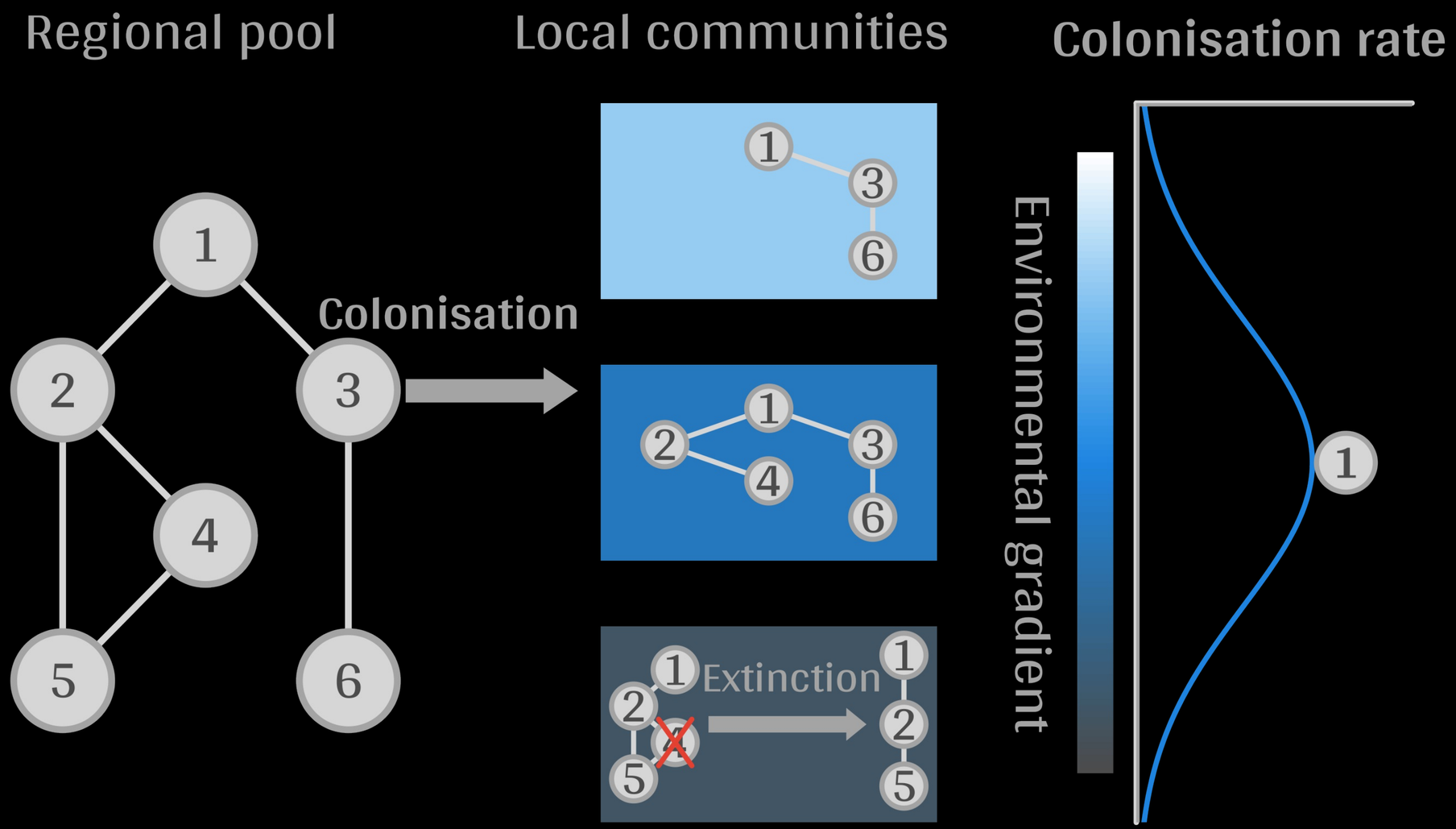
Regional pool
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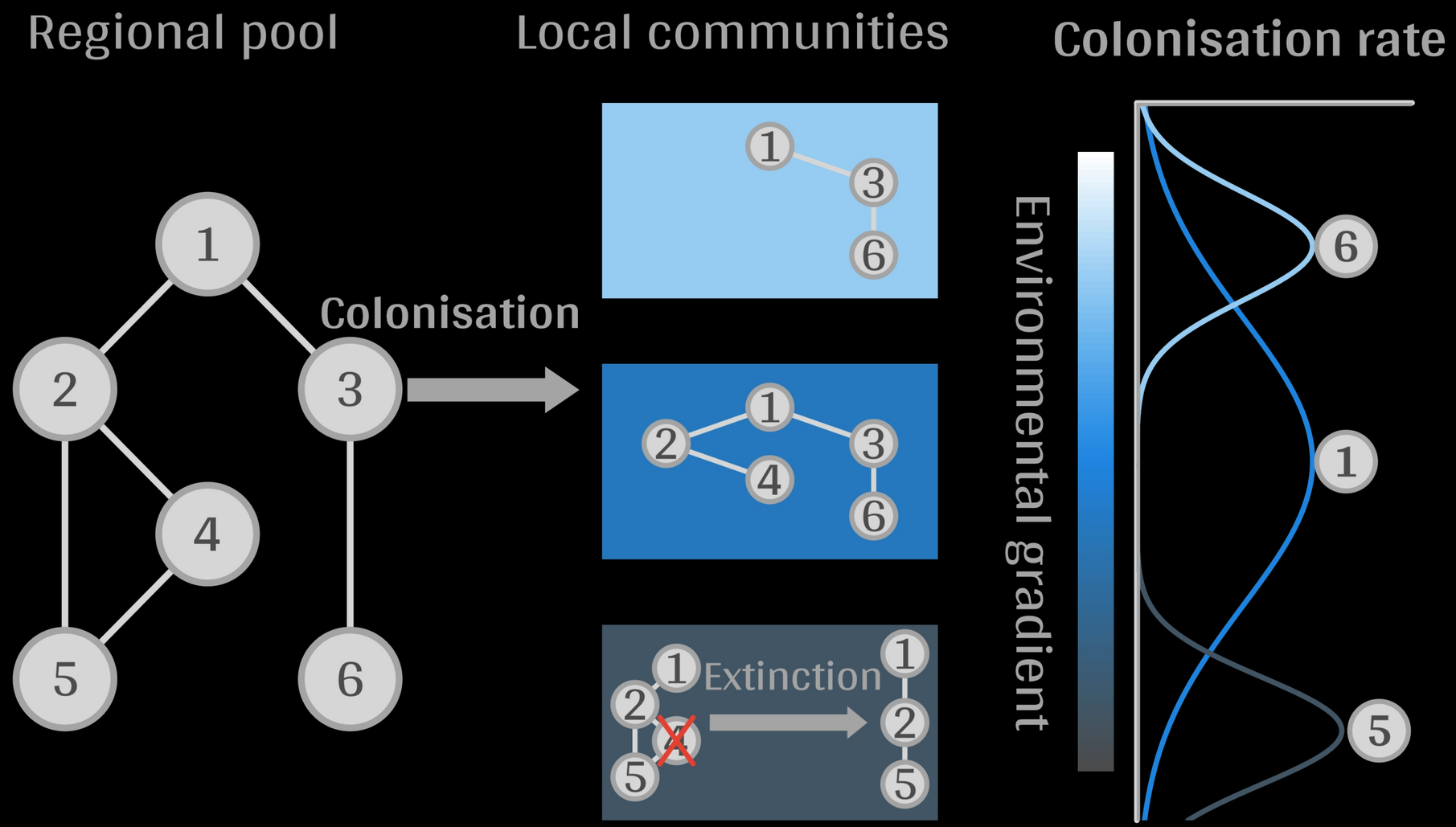
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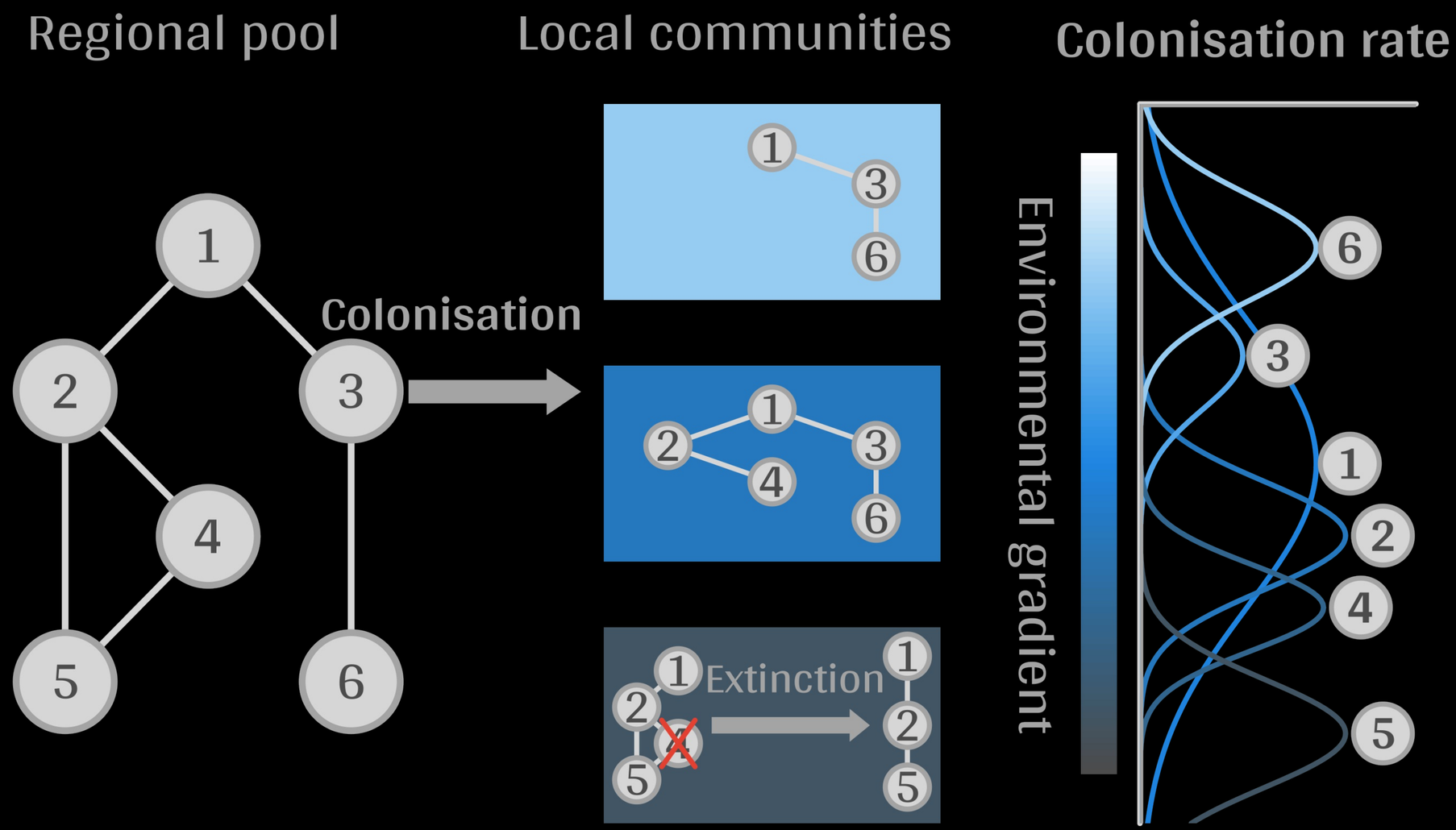
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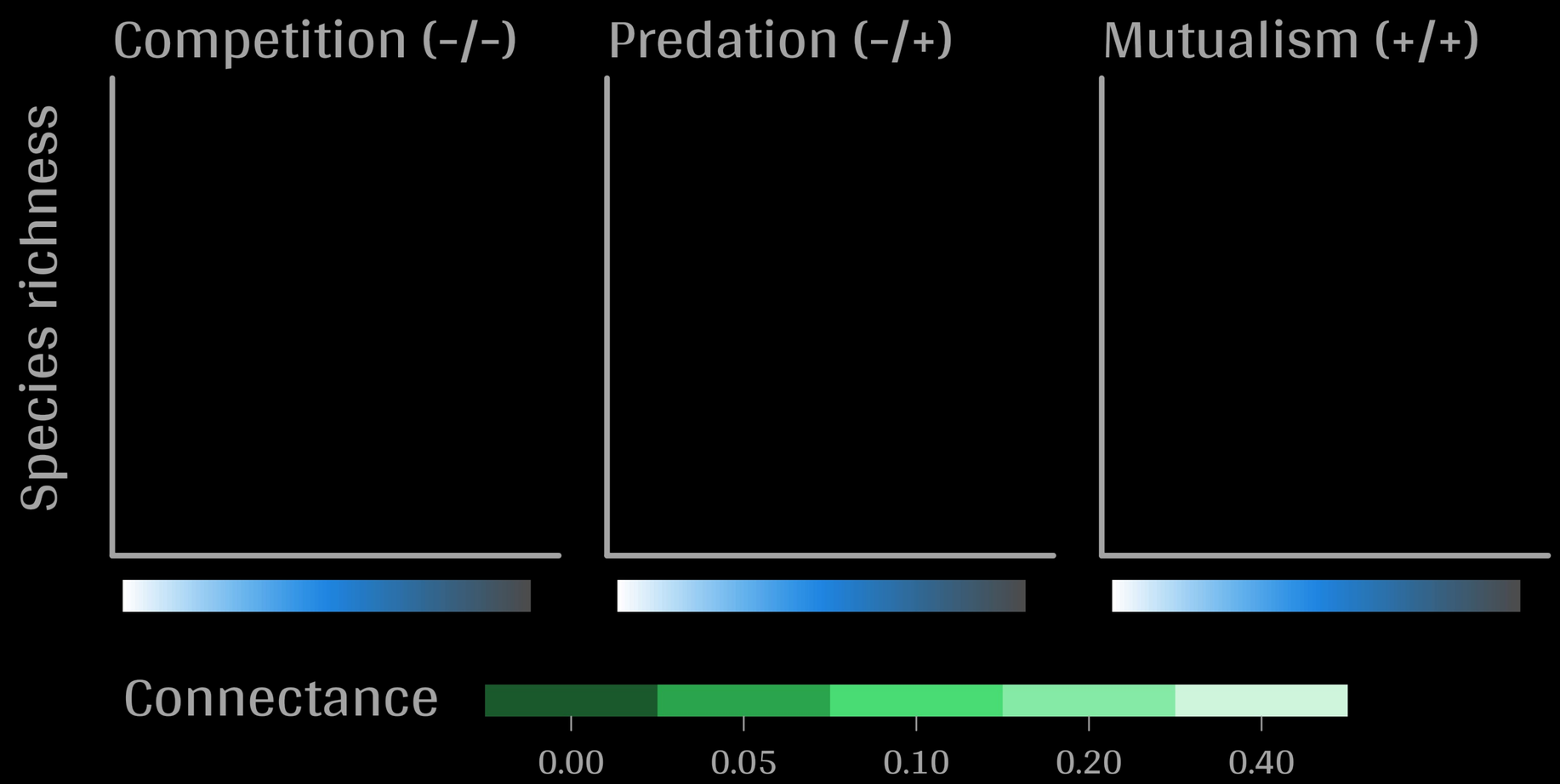
Results: the classical theory revisited



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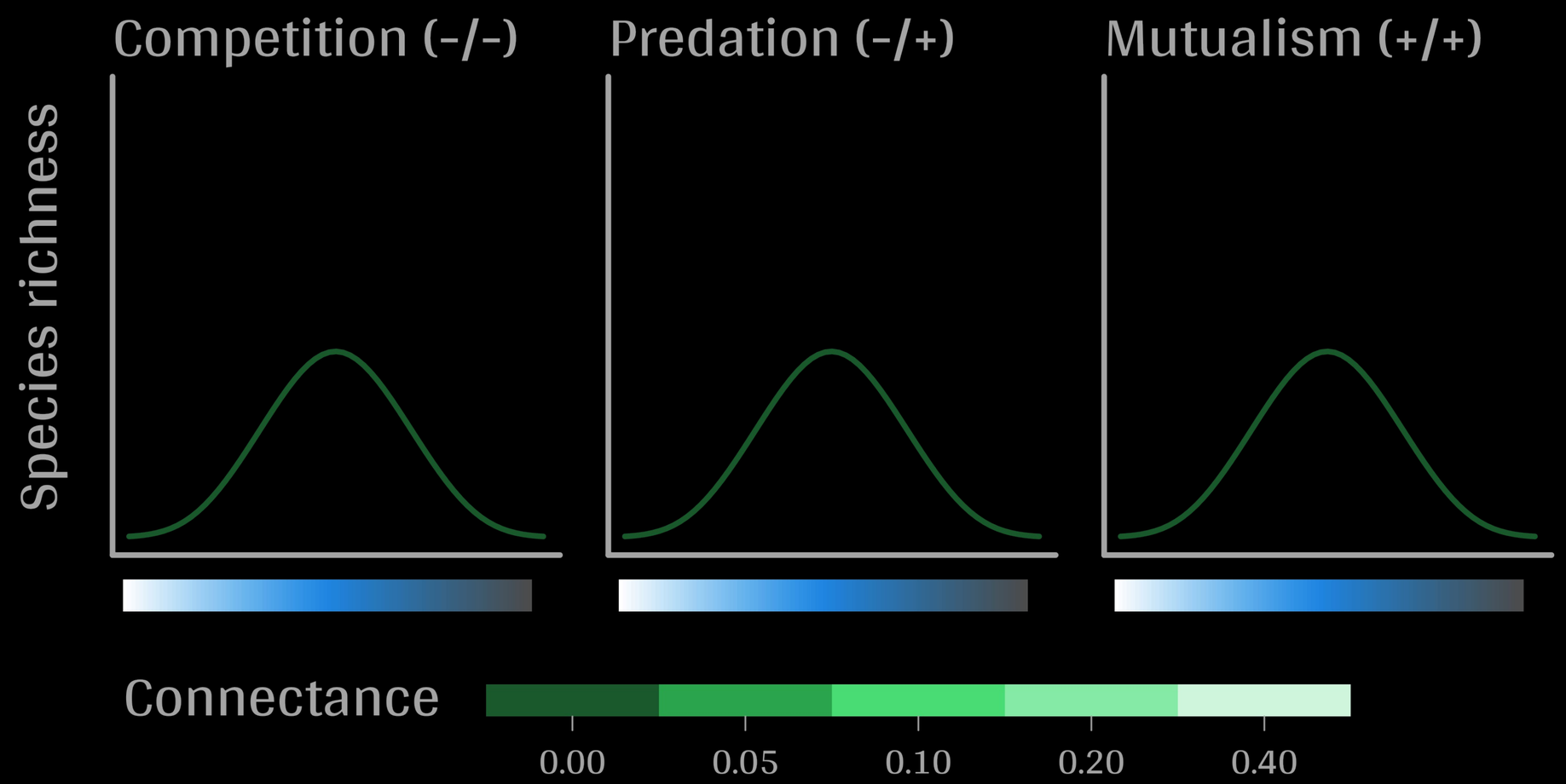

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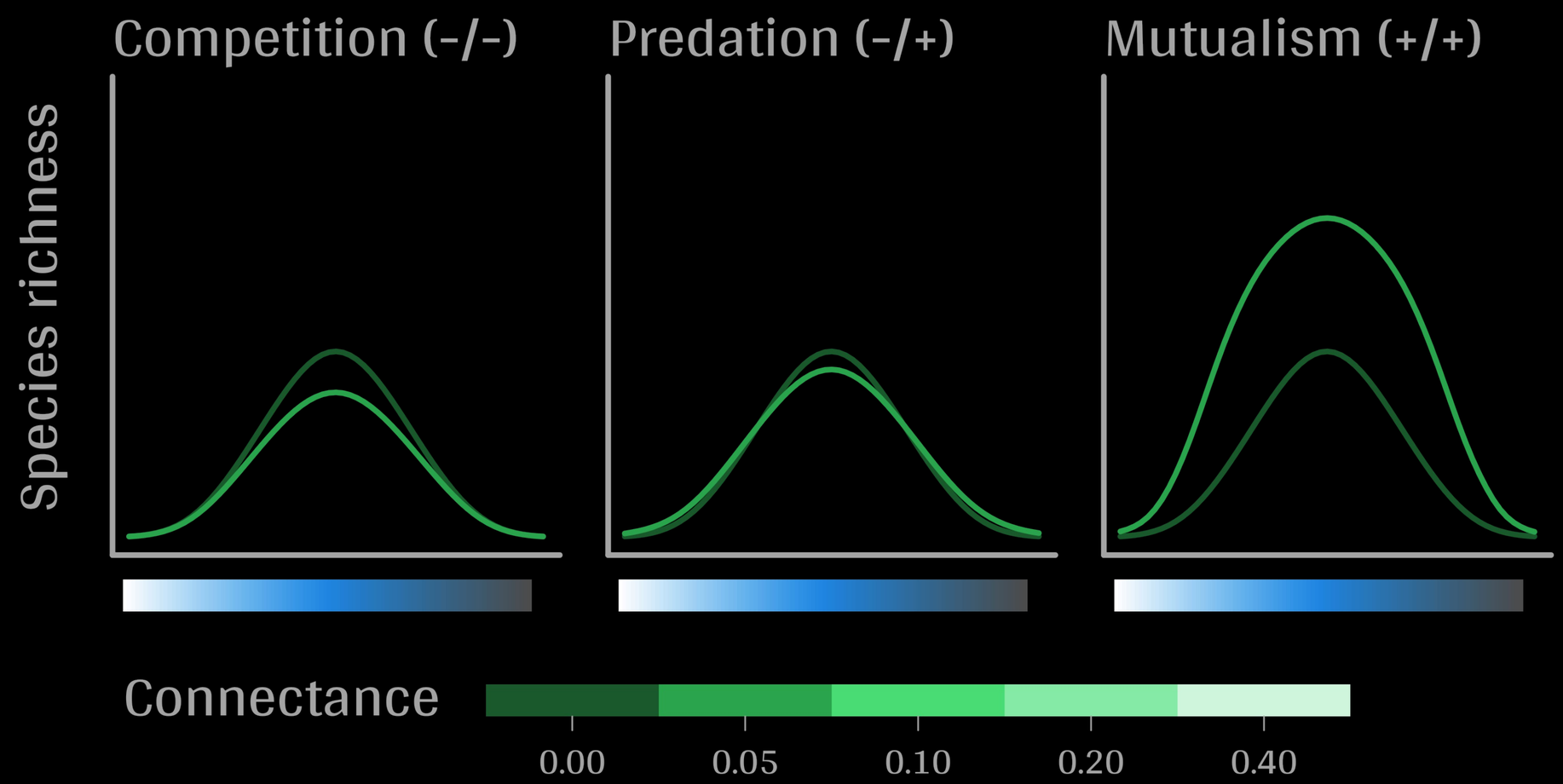

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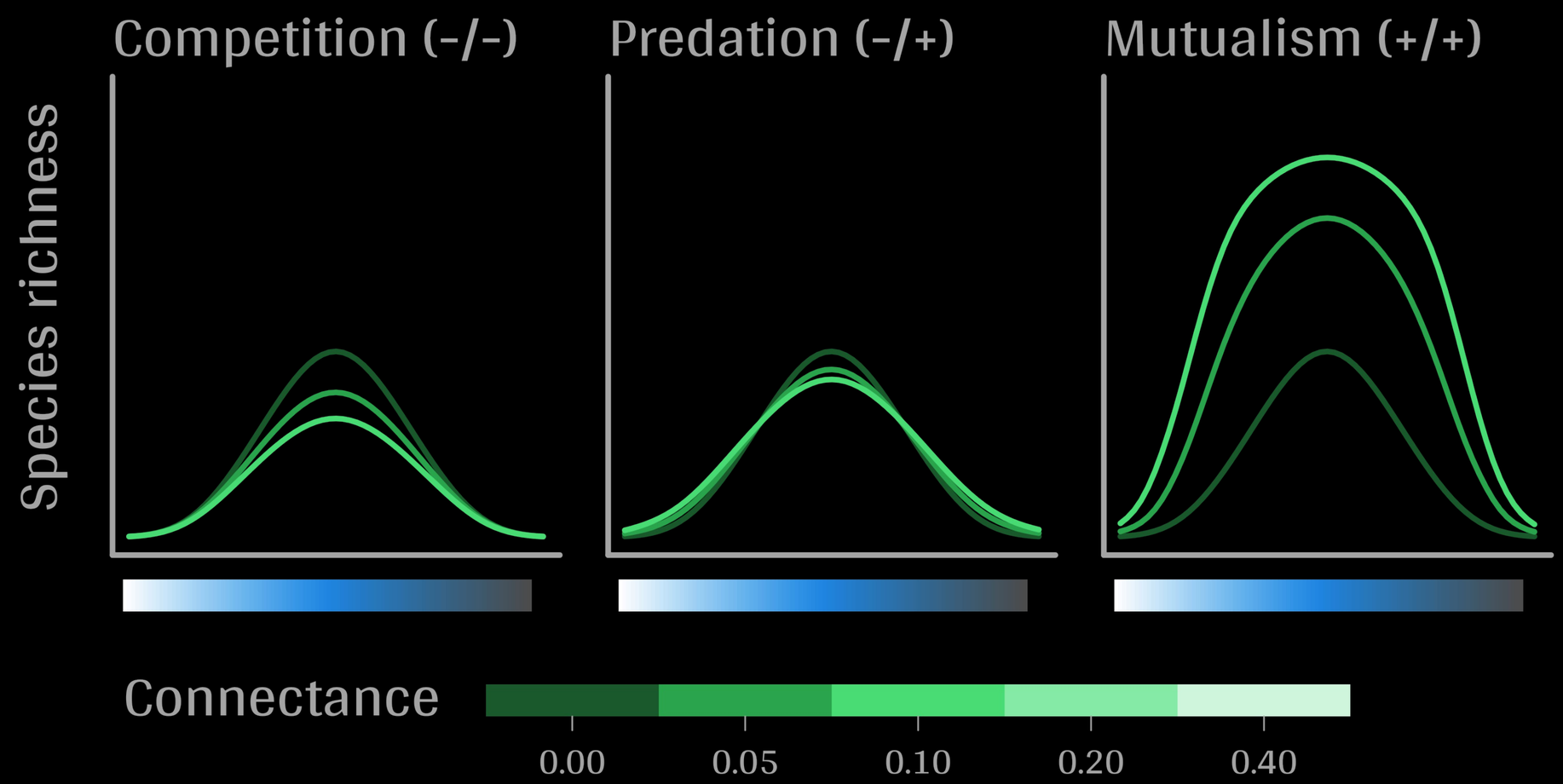

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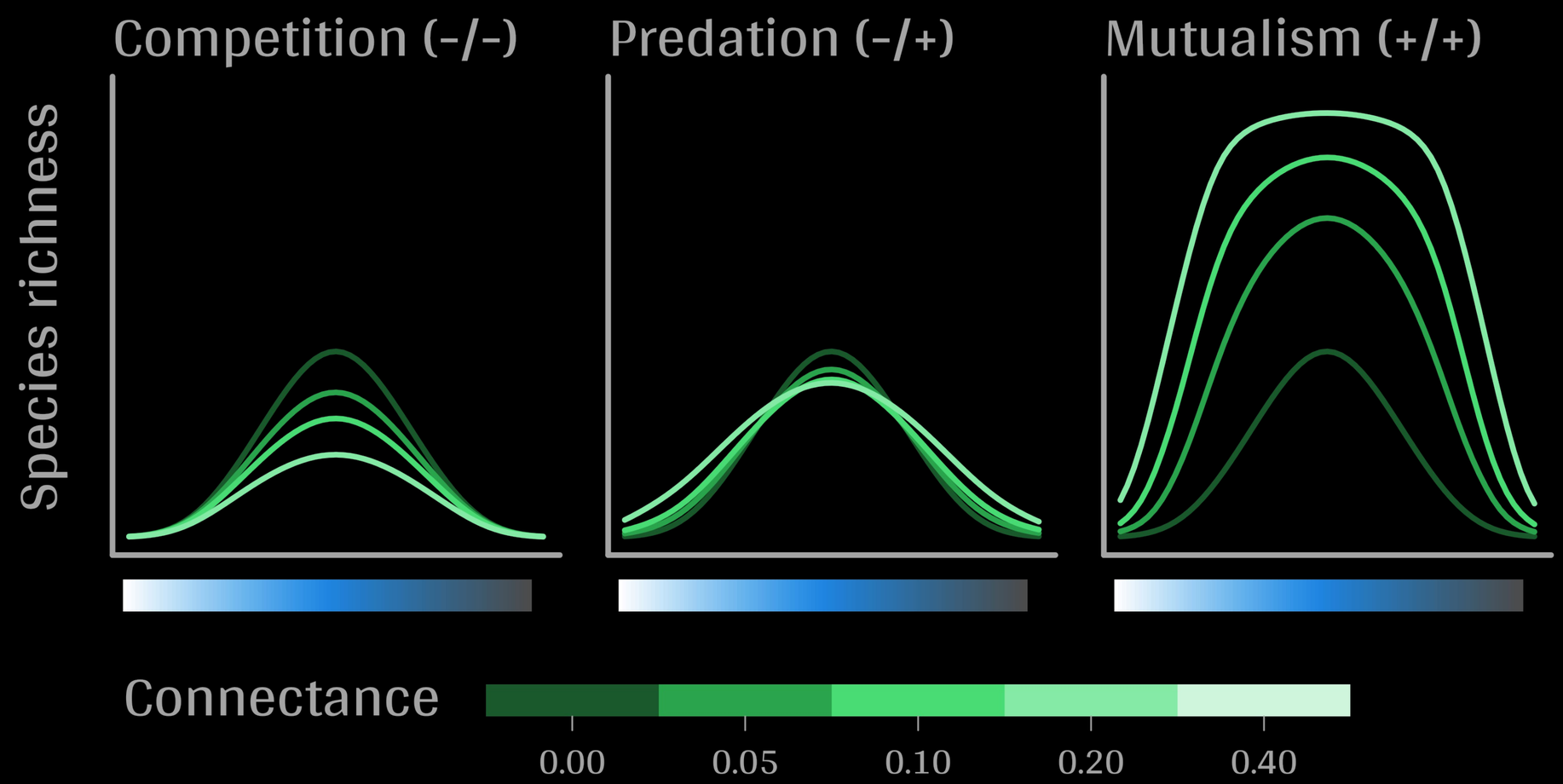

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Community $C_k = \{0, 1, 0, 0, \ldots, 1, 0\}$

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Cazelles et al, 2016, Ecography.

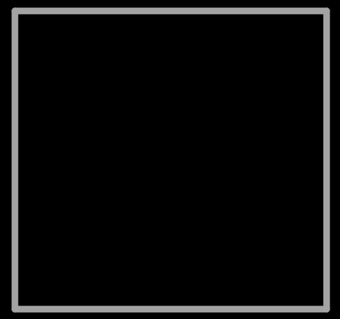
CO-OCCURRENCE AND ECOLOGICAL NETWORK

How the properties of ecological networks influence co-occurrence?

Co-occurrence and biotic interactions

1 2

Co-occurrence and biotic interactions



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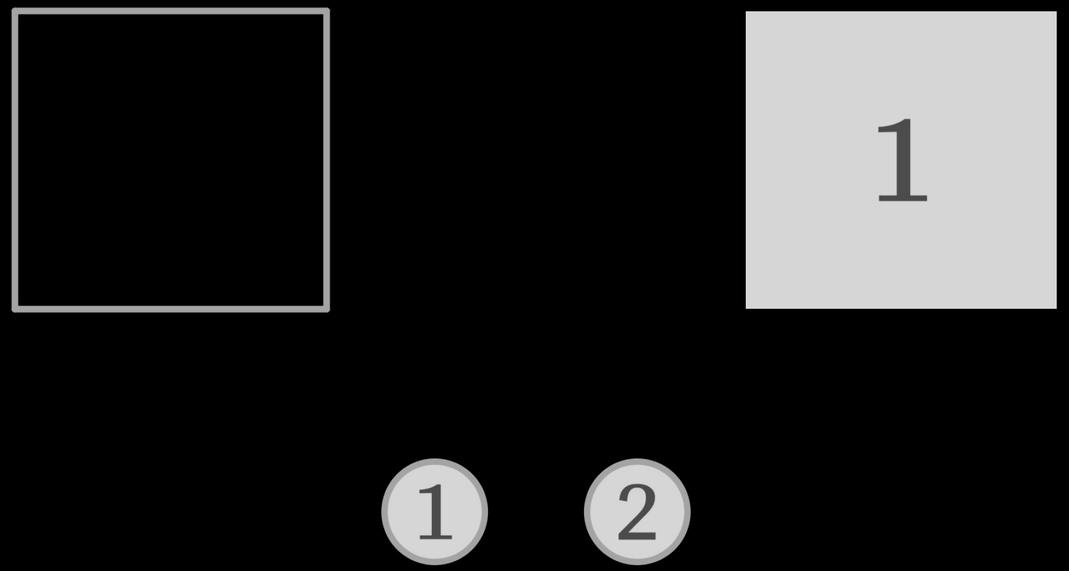

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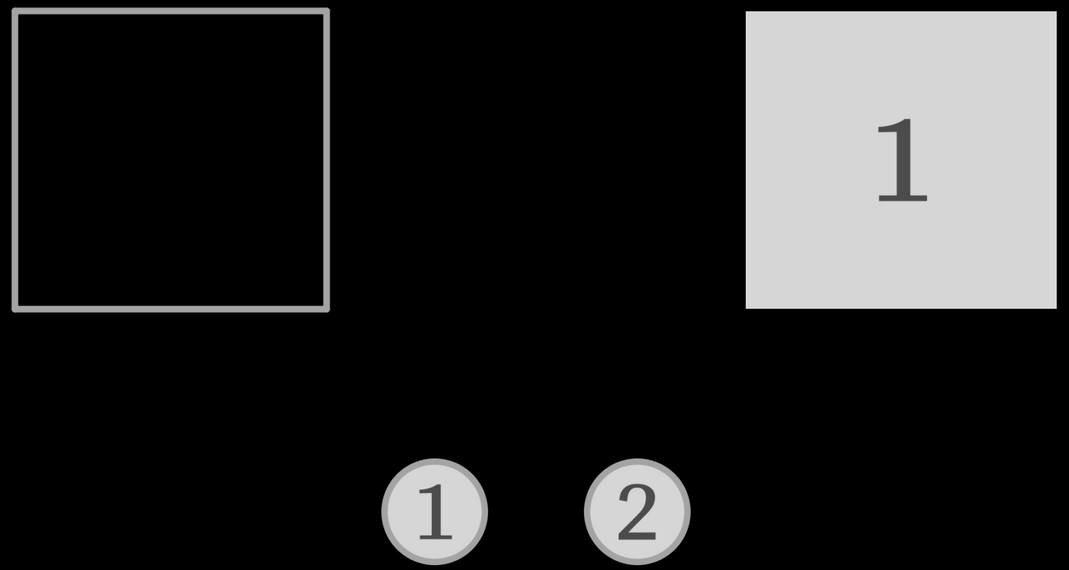

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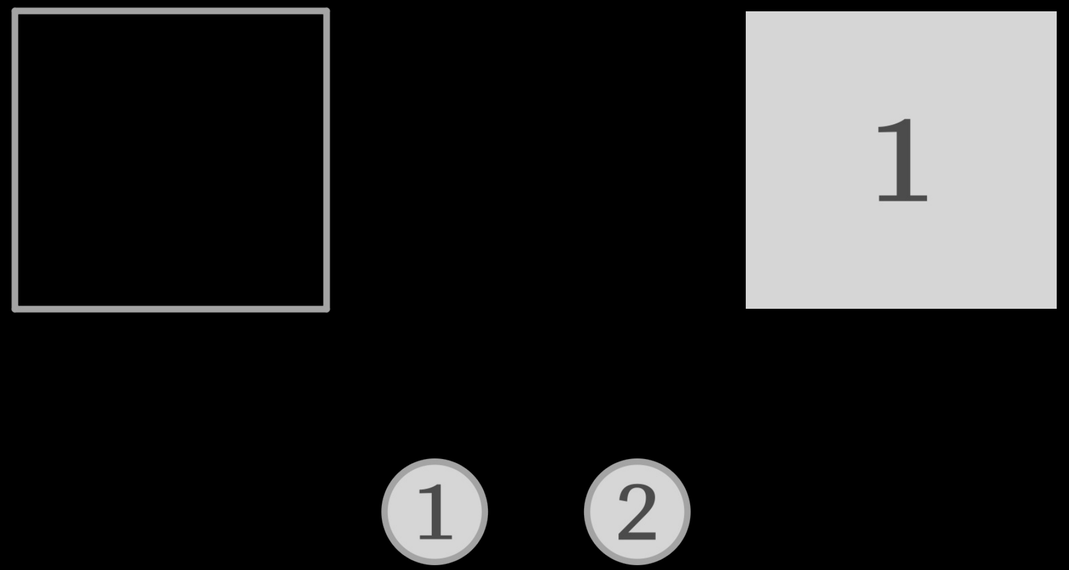
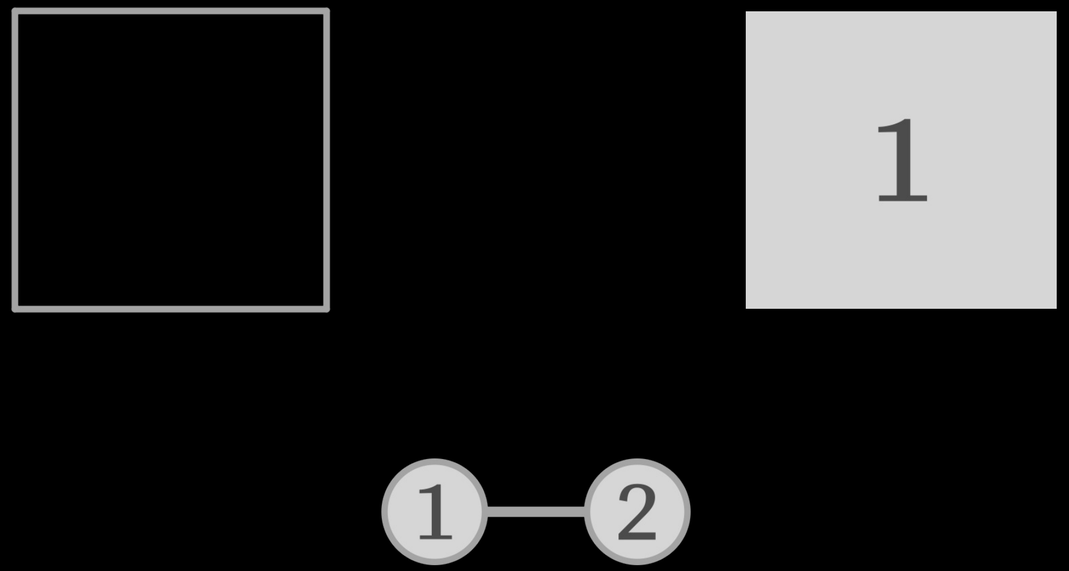
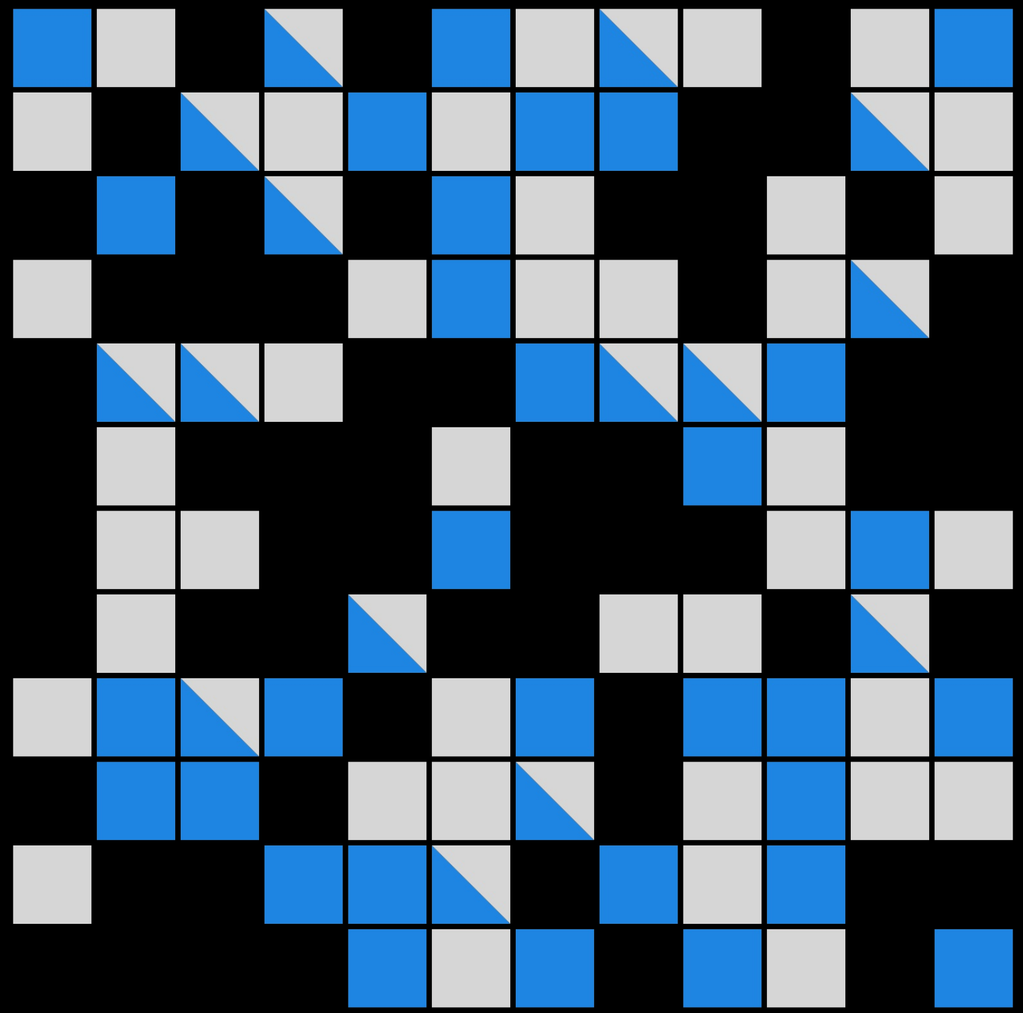


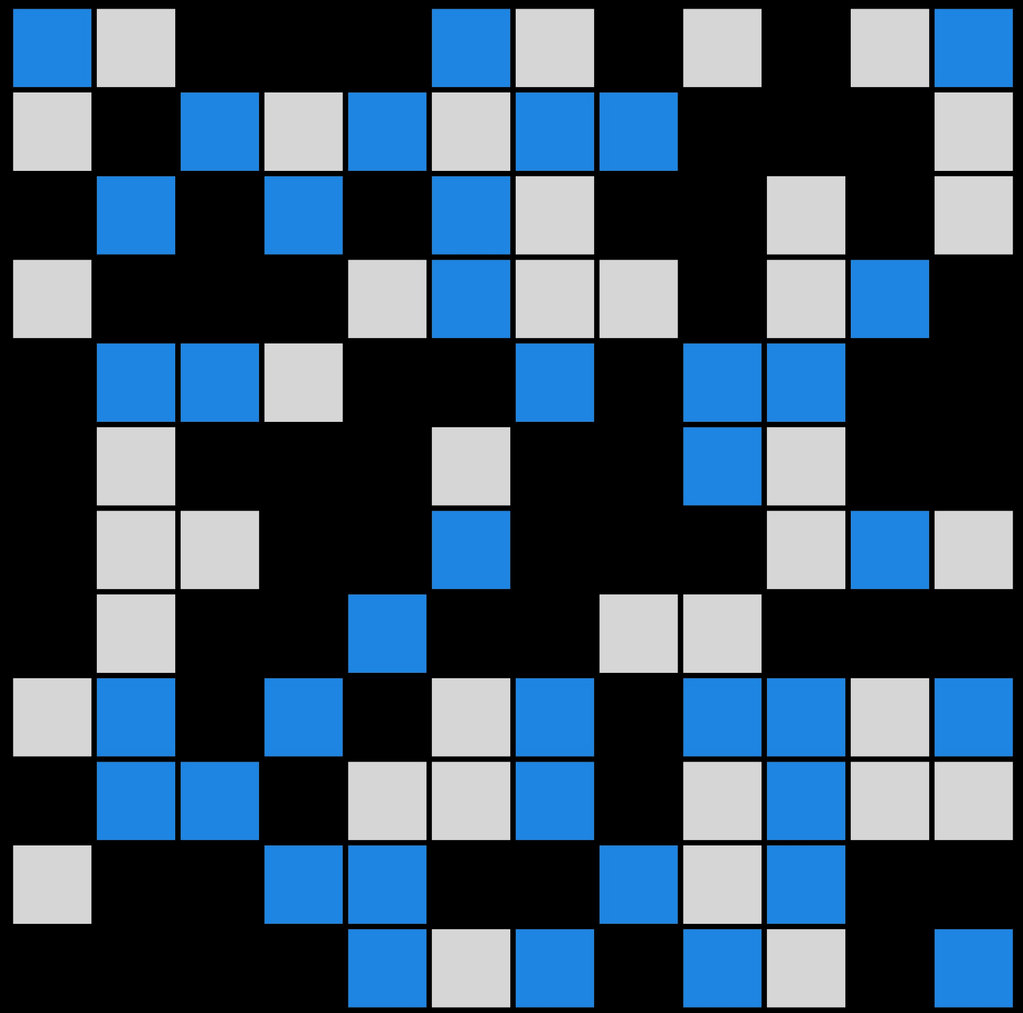
Co-occurrence and biotic interactions



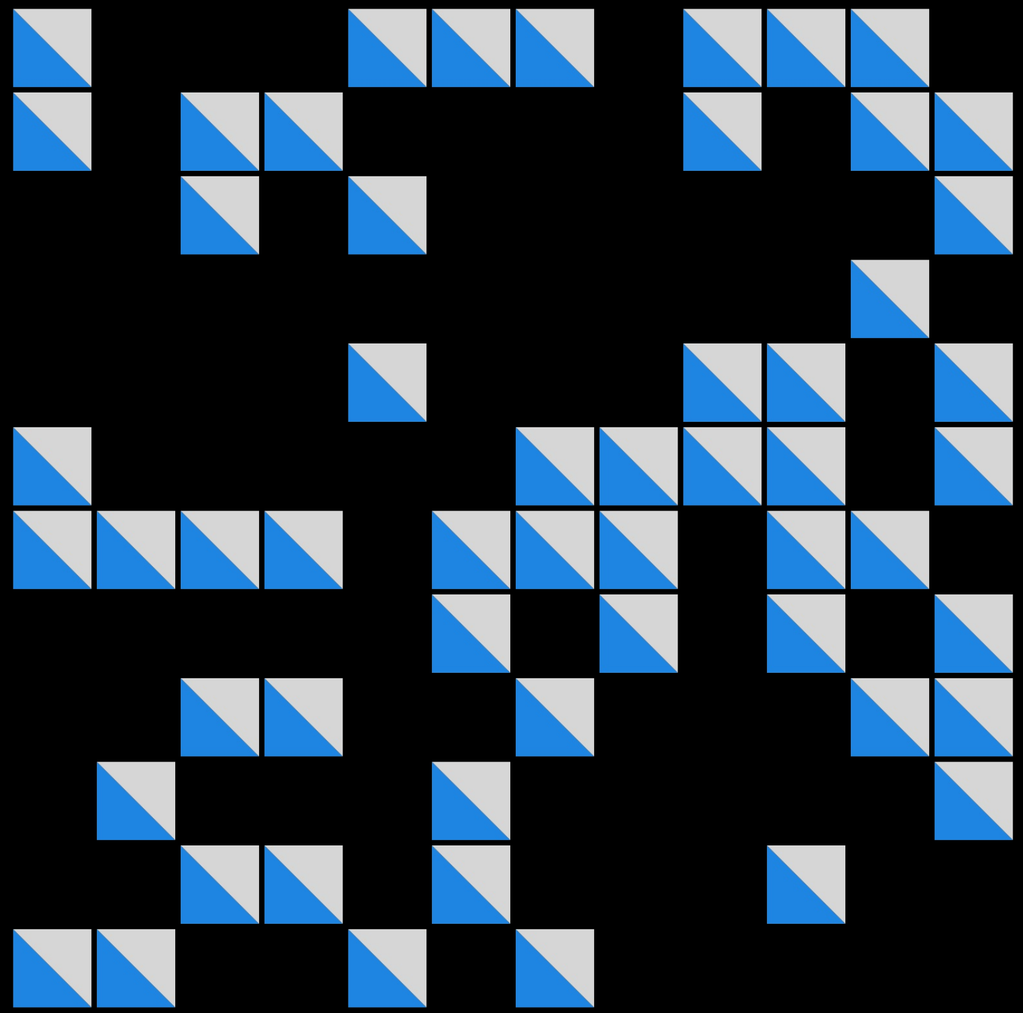
Checkerboard distribution (Diamond 1975)



Checkerboard distribution (Diamond 1975)



Checkerboard distribution (Diamond 1975)



What did I do?

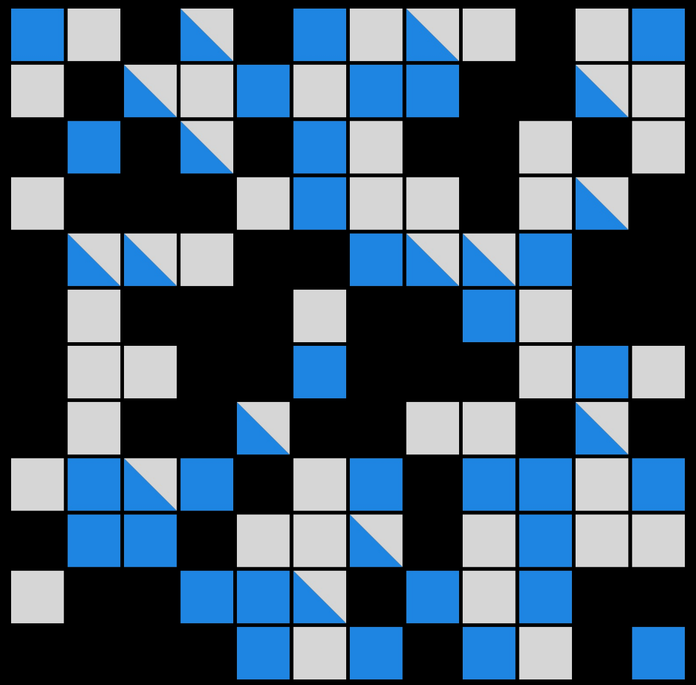
Observed vs Expected $P(X_i, X_j) - P(X_i)P(X_j)$

What did I do?

Observed vs Expected

$$P(X_i, X_j) - P(X_i)P(X_j)$$

$$P(X_i, X_j) - P(X_i)P(X_j) = 0$$

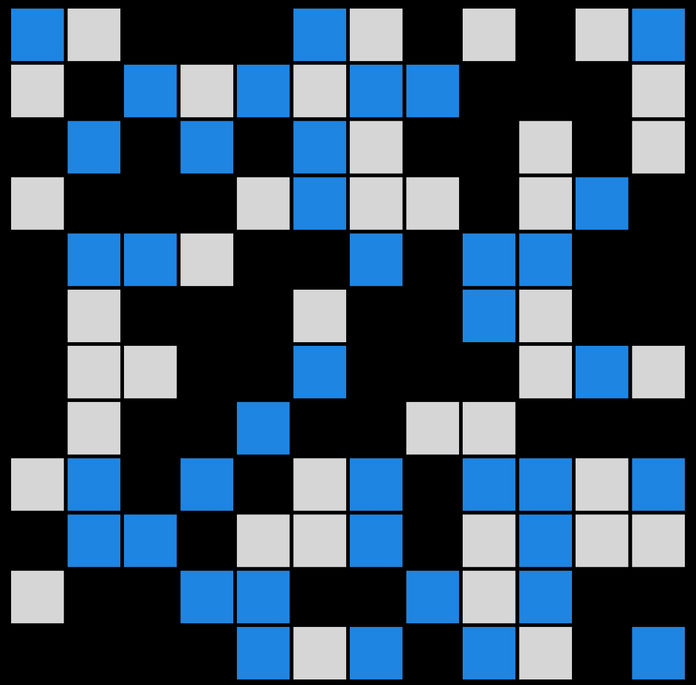


What did I do?

Observed vs Expected

$$P(X_i, X_j) - P(X_i)P(X_j)$$

$$P(X_i, X_j) - P(X_i)P(X_j) < 0$$

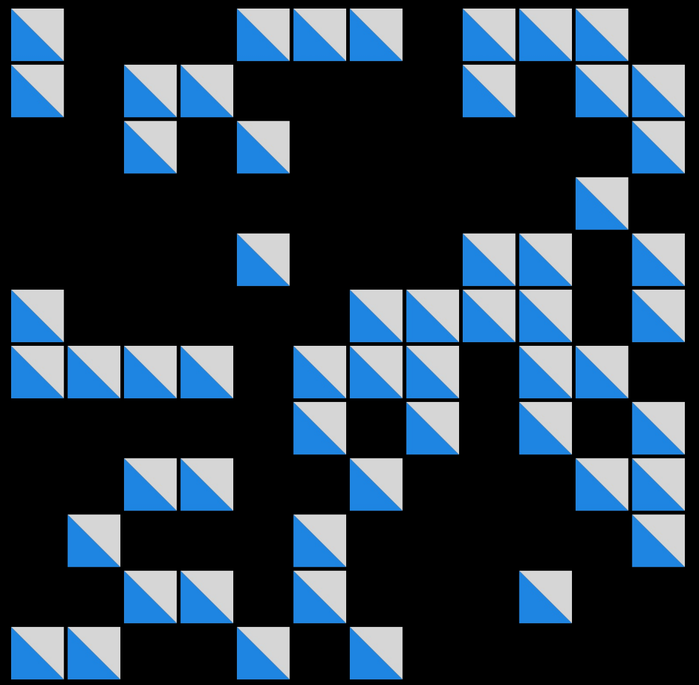


What did I do?

Observed vs Expected

$$P(X_i, X_j) - P(X_i)P(X_j)$$

$$P(X_i, X_j) - P(X_i)P(X_j) > 0$$

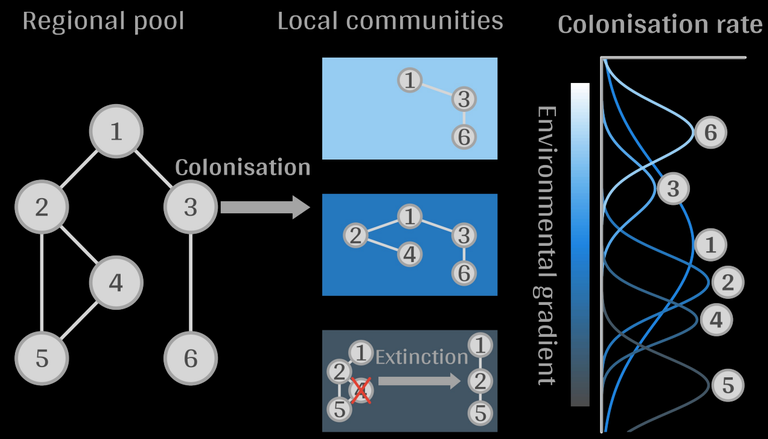


What did I do?

Observed vs Expected

$$P(X_i, X_j) - P(X_i)P(X_j)$$

Simulated co-occurrence (trophic interactions)



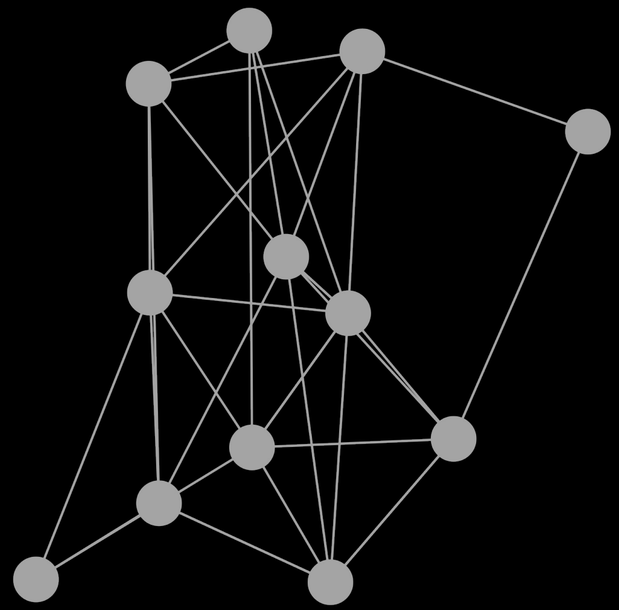
What did I do?

Observed vs Expected

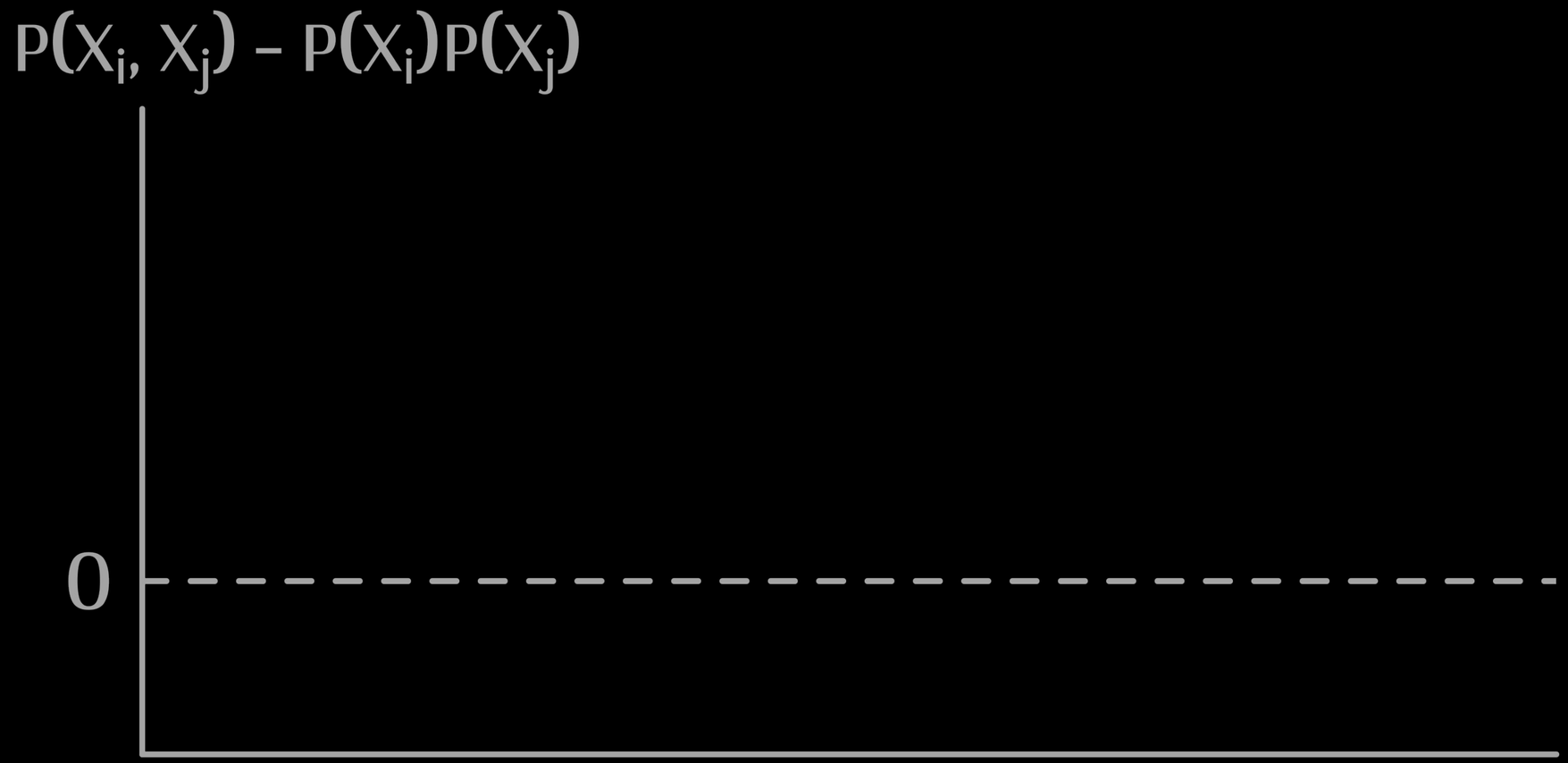
$$P(X_i, X_j) - P(X_i)P(X_j)$$

Simulated co-occurrence (trophic interactions)

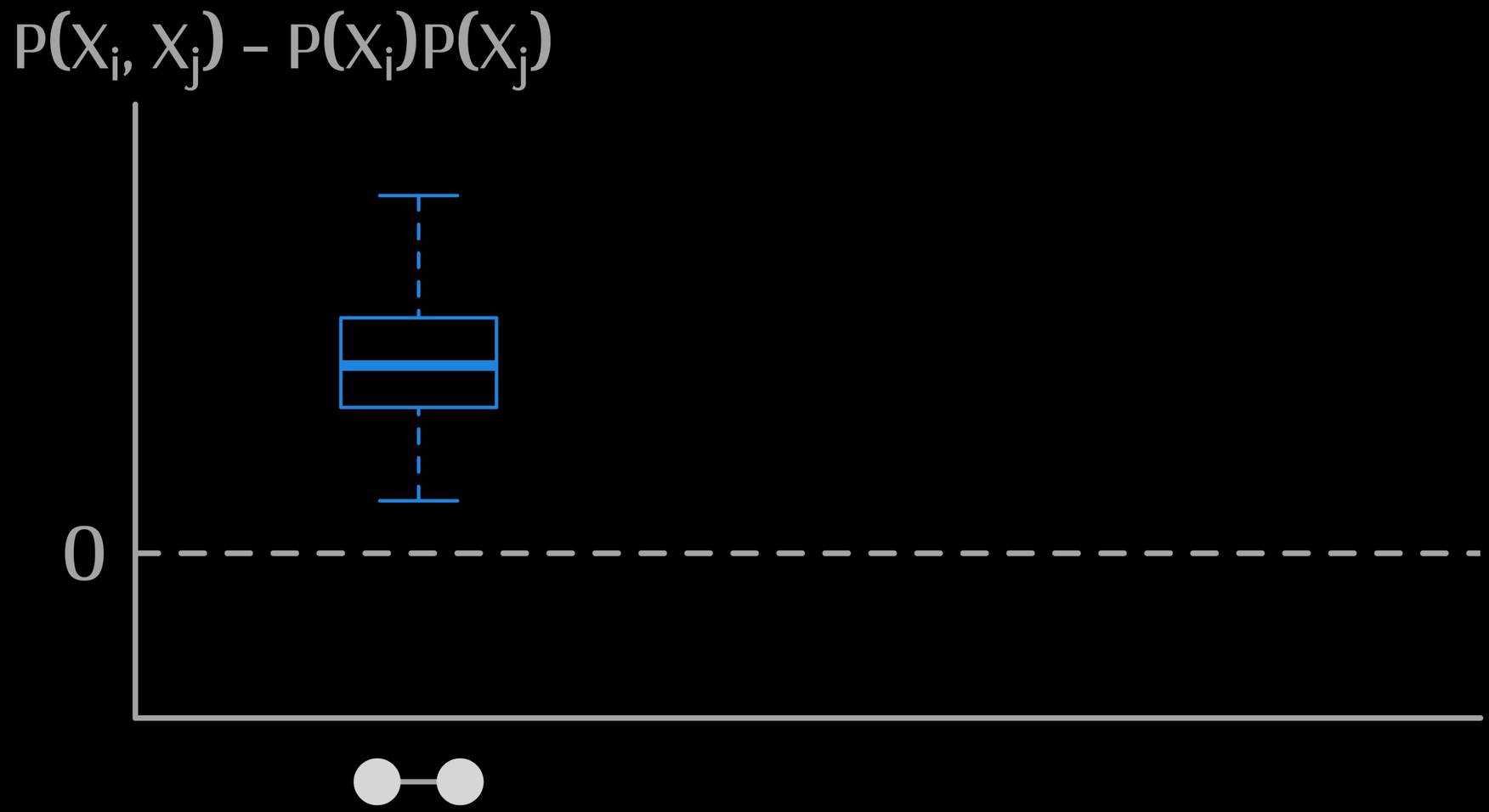
Simulated networks



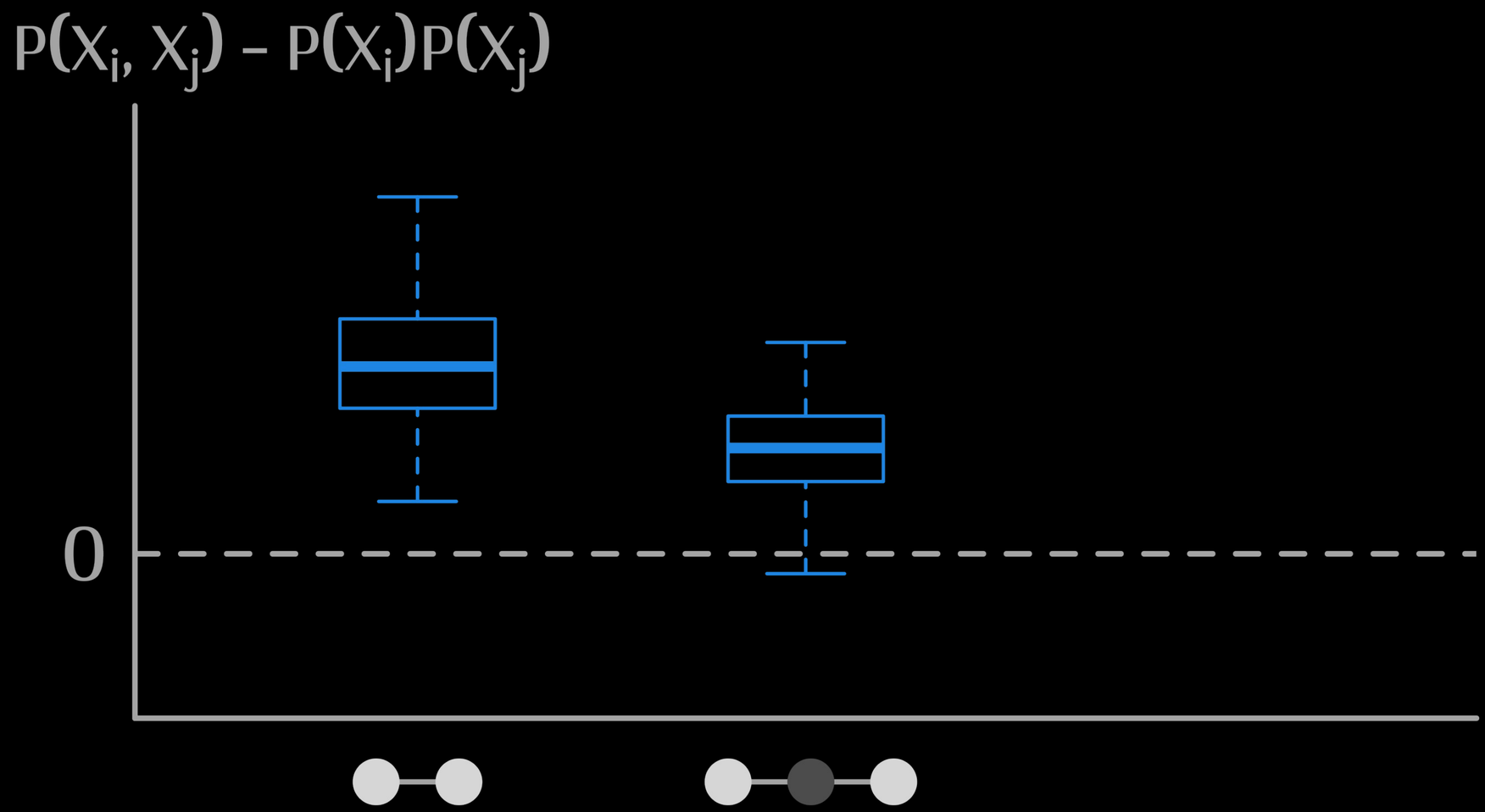
Co-occurrence and shortest path



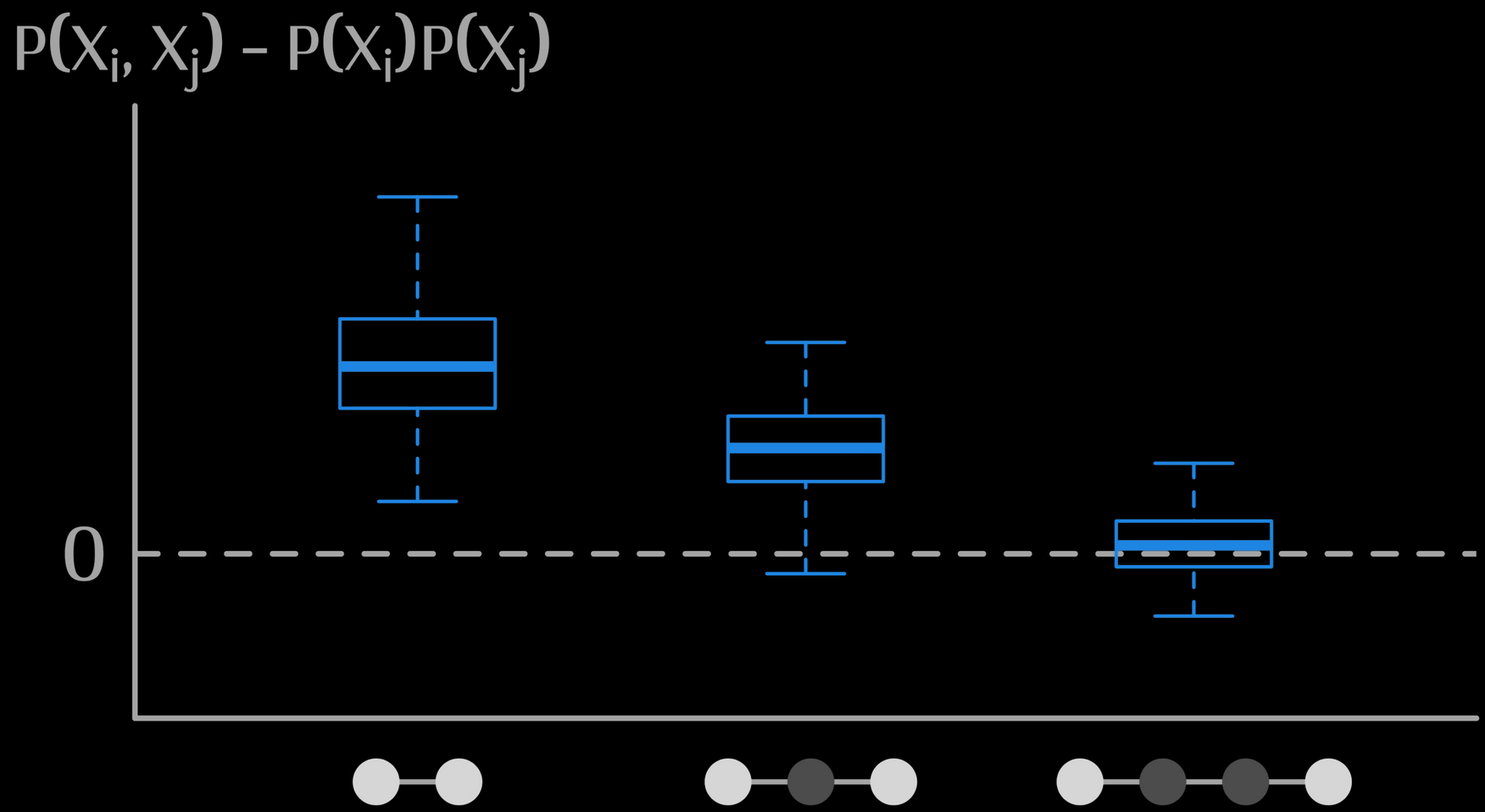
Co-occurrence and shortest path



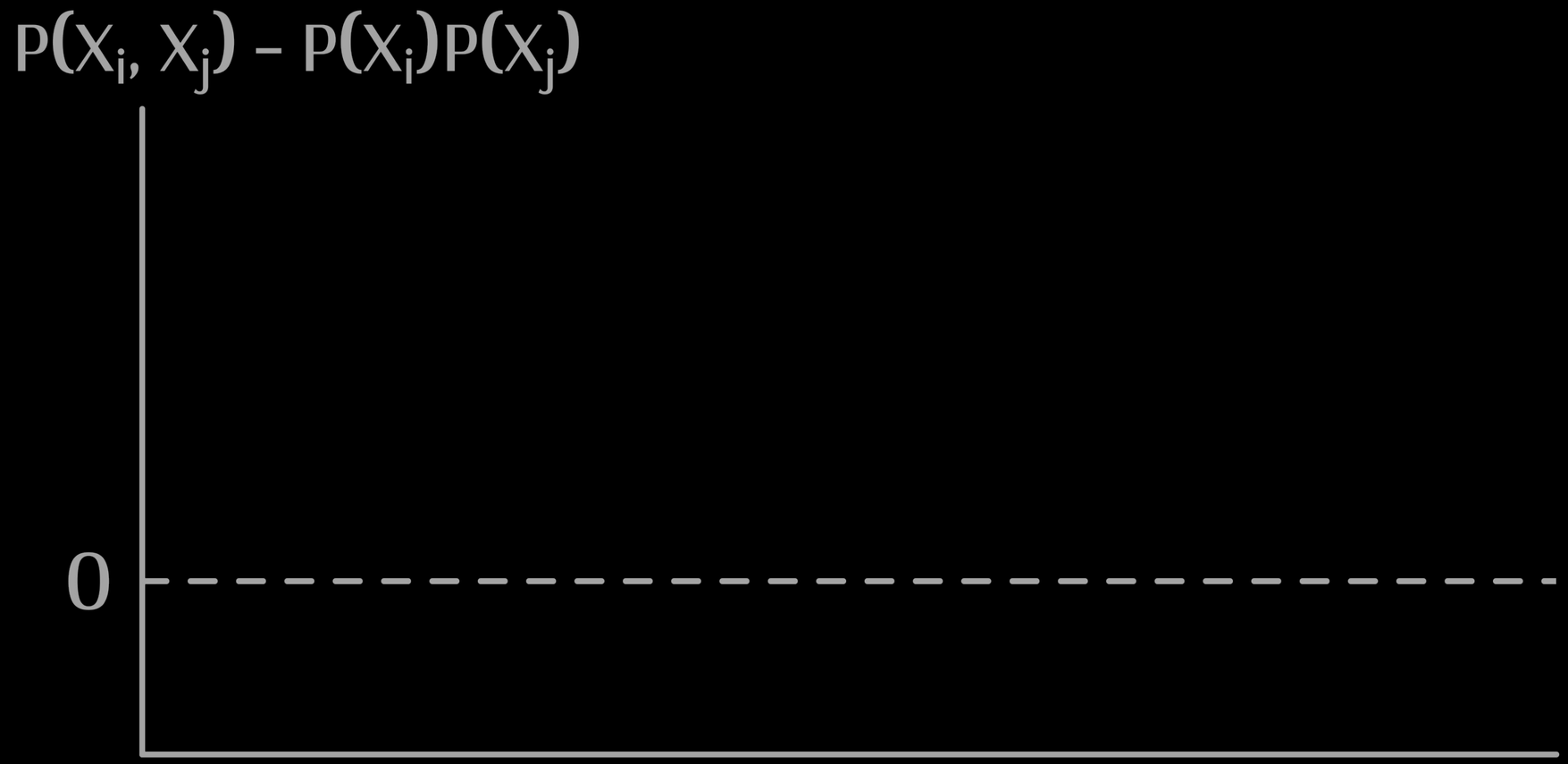
Co-occurrence and shortest path



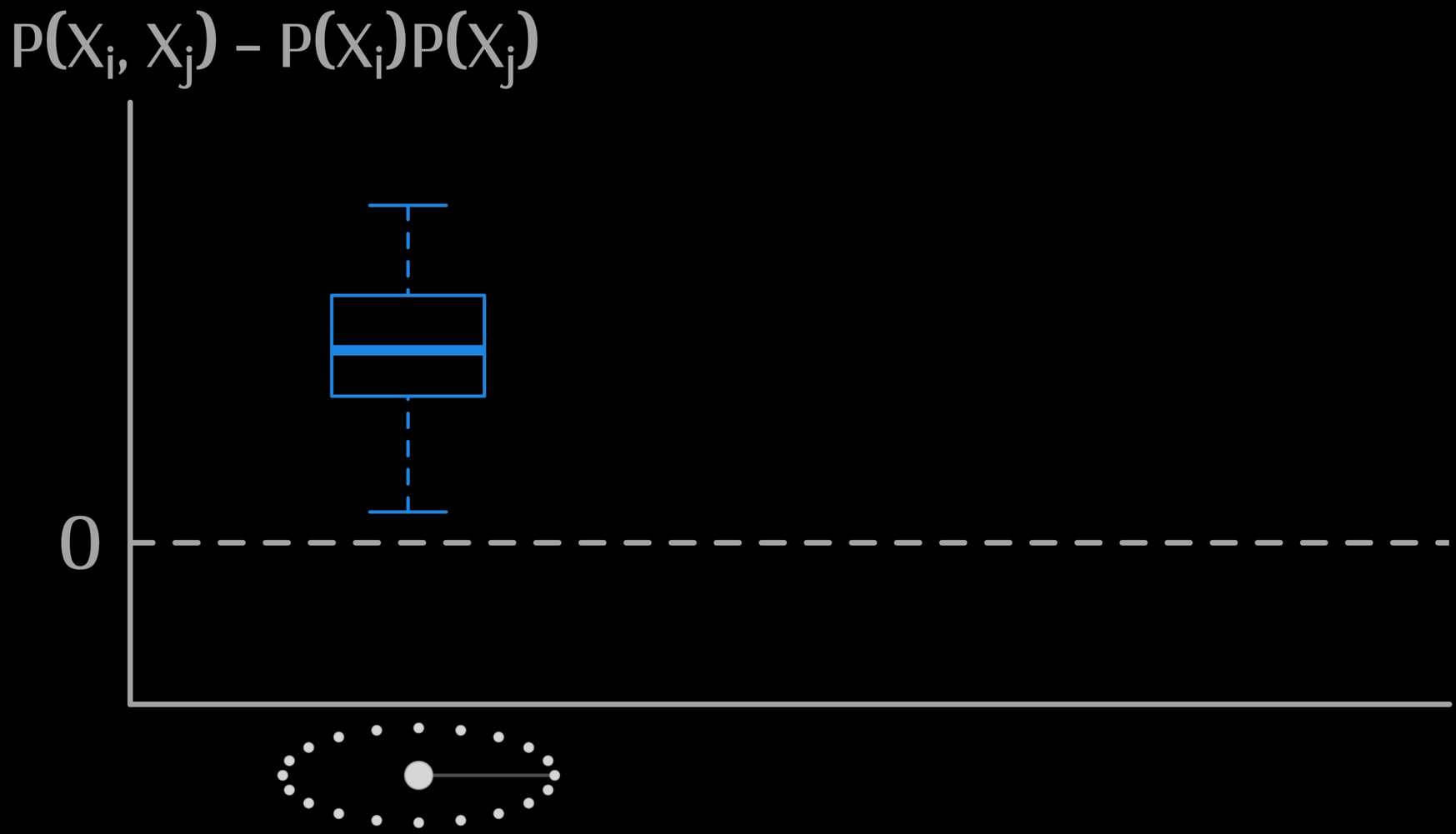
Co-occurrence and shortest path



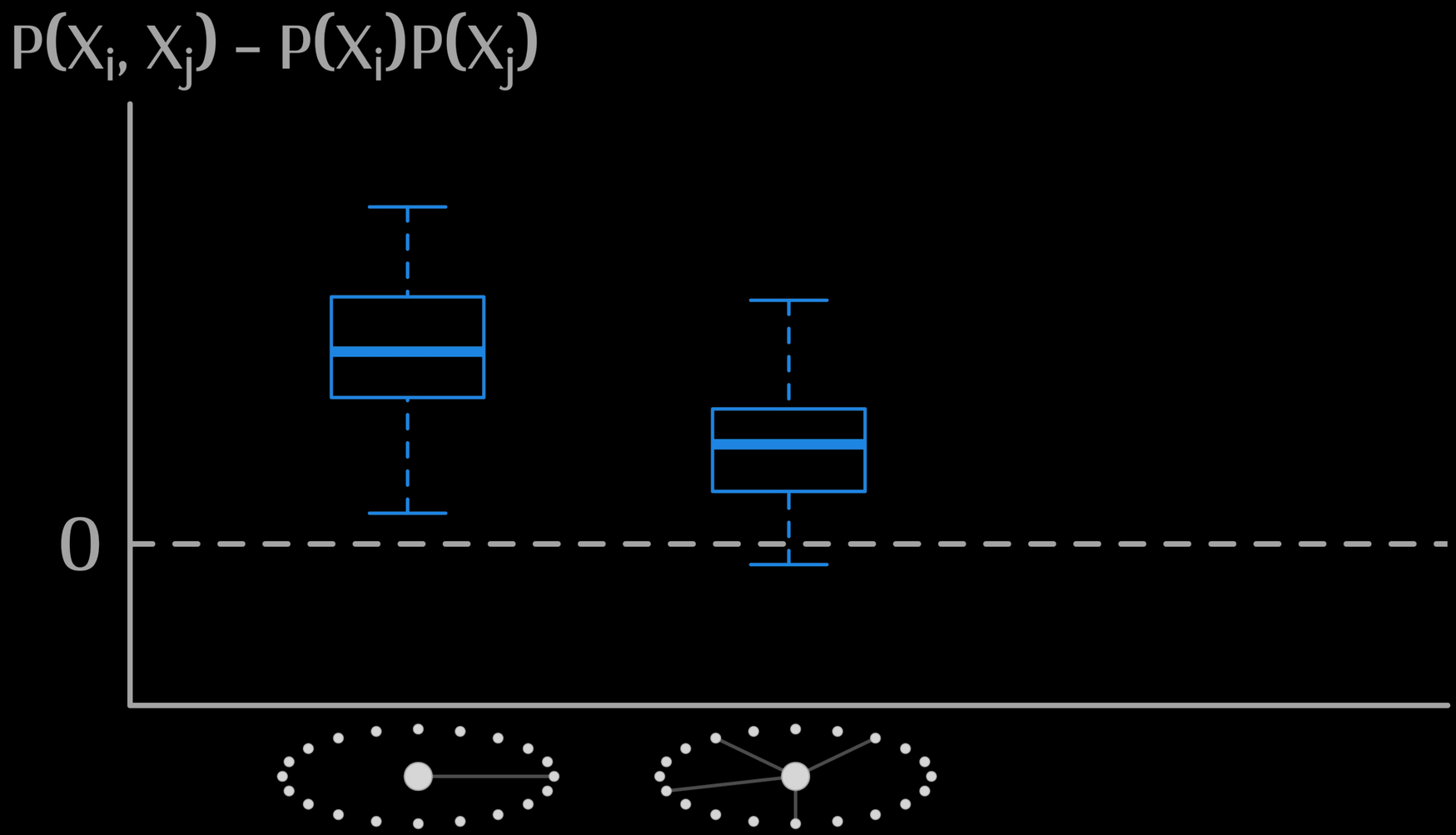
Co-occurrence and degree



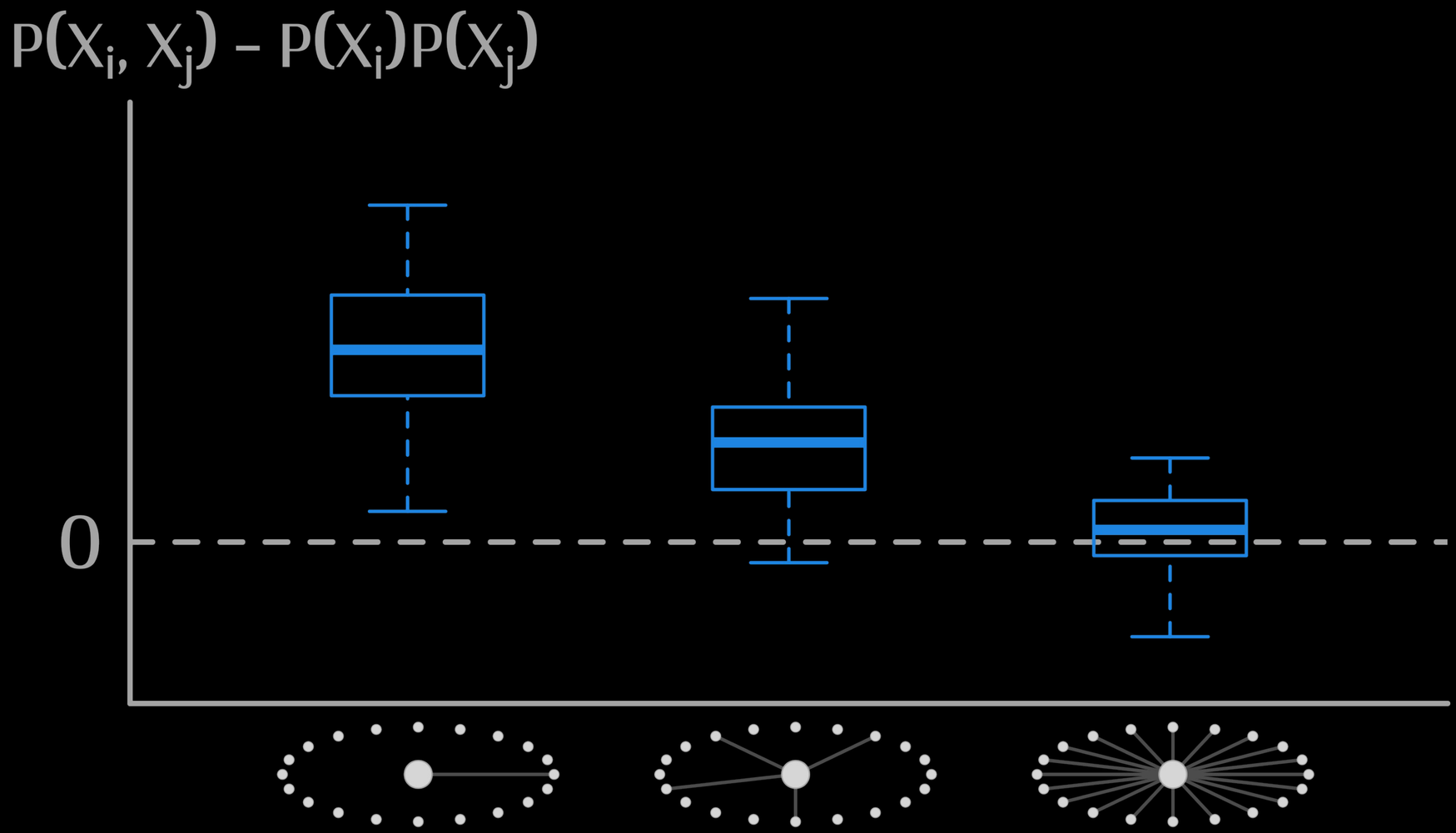
Co-occurrence and degree



Co-occurrence and degree



Co-occurrence and degree



Conclusion and limits

Shortest path ↑ detection ↓

Conclusion and limits

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Conclusion and limits

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Abiotic variables?

Conclusion and limits

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Abiotic variables?

Empirical data?

Conclusion and limits

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Abiotic variables?

Empirical data?

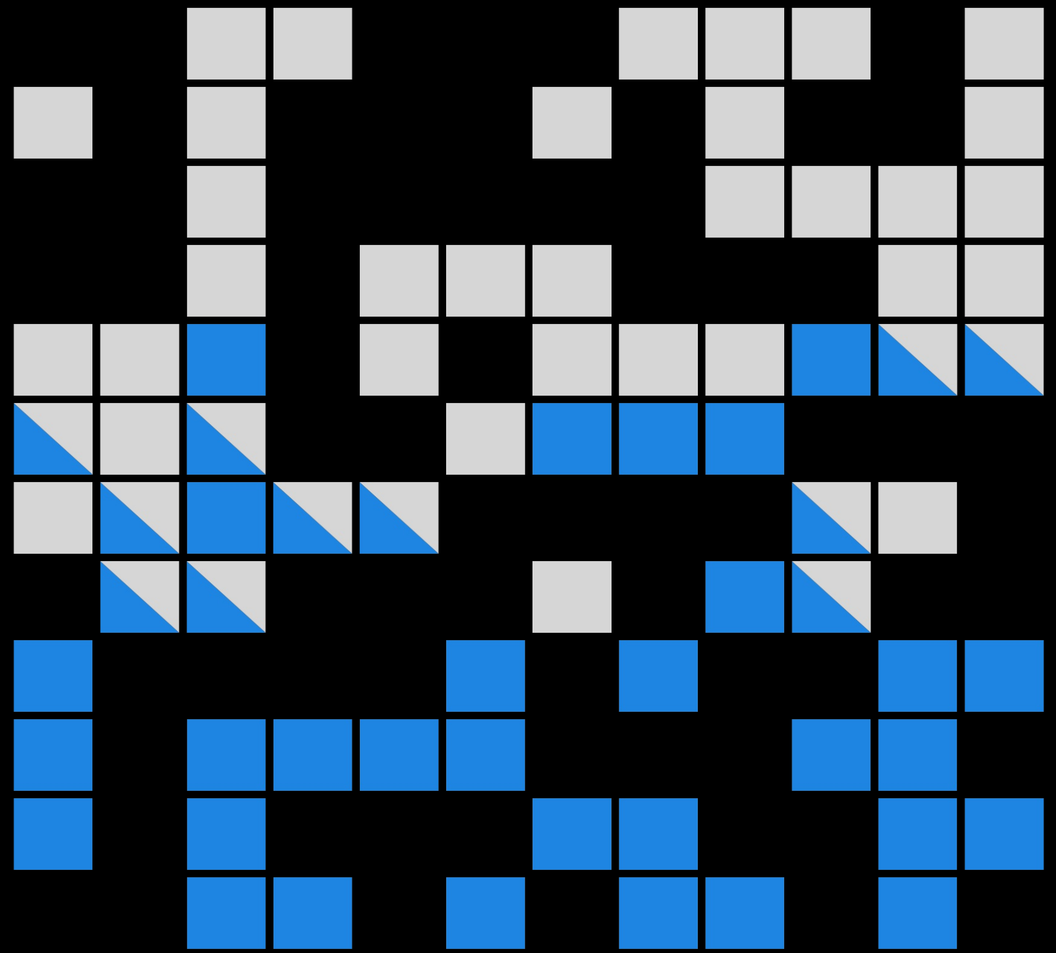
Cazelles et al, 2016, Theoretical Ecology.

DEALING WITH REAL DATA SETS

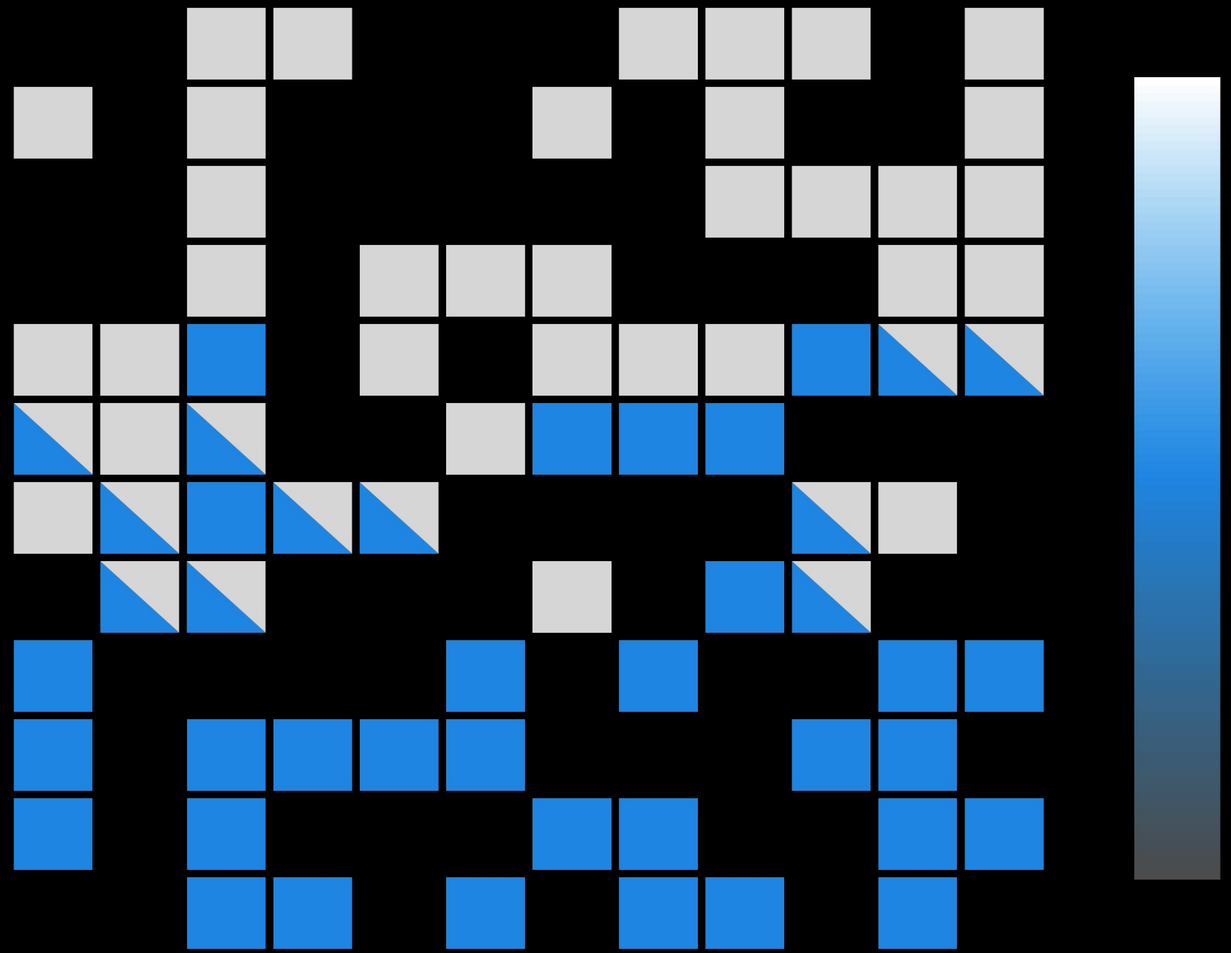
Co-occurrence and empirical networks

Cazelles et al, 2017, in prep

Abiotic variables



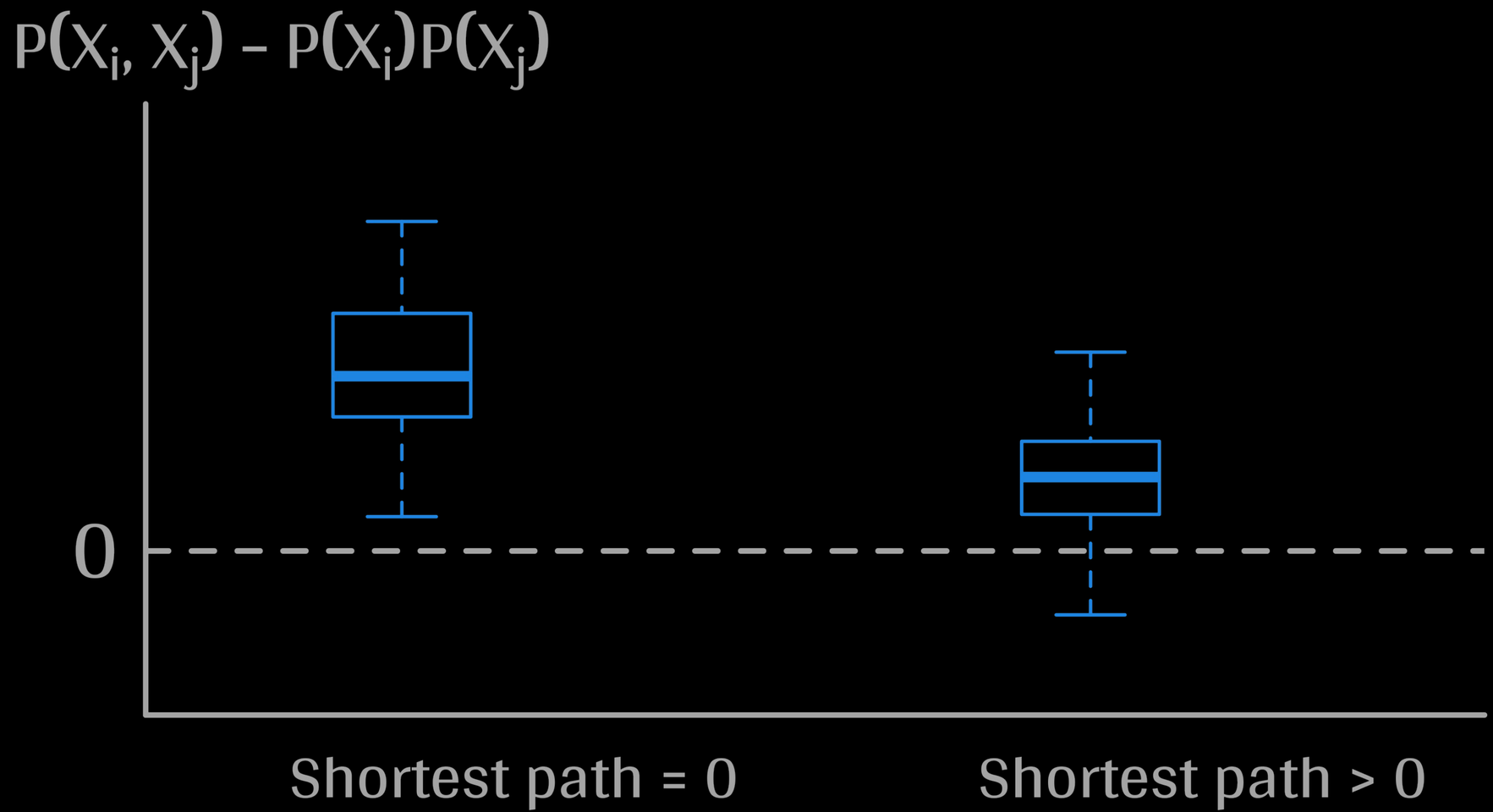
Abiotic variables



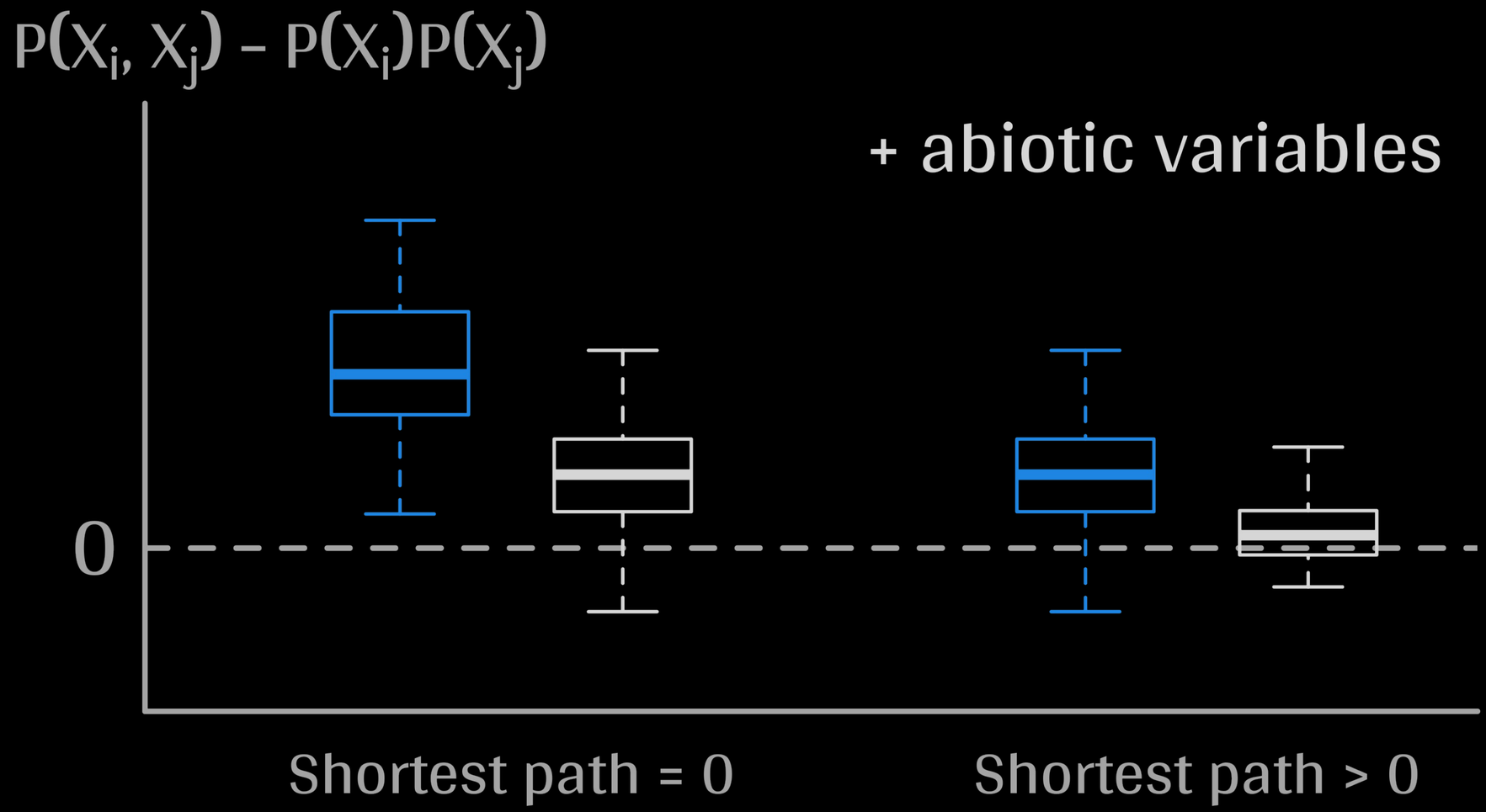
Integrating abiotic variables (G)

$P(X_{i,G}, X_{j,G})$ **vs** $P(X_{i,G})P(X_{j,G})$

Integrating abiotic variables (G)



Integrating abiotic variables (G)



What did I do?

Five data sets

What did I do?

Five data sets

$P(X_{i,G}, X_{j,G})$ vs $P(X_{i,G})P(X_{j,G})$

What did I do?

Five data sets

$P(X_{i,G}, X_{j,G})$ vs $P(X_{i,G})P(X_{j,G})$

SDMs to assign presence probabilities given abiotic context

What did I do?

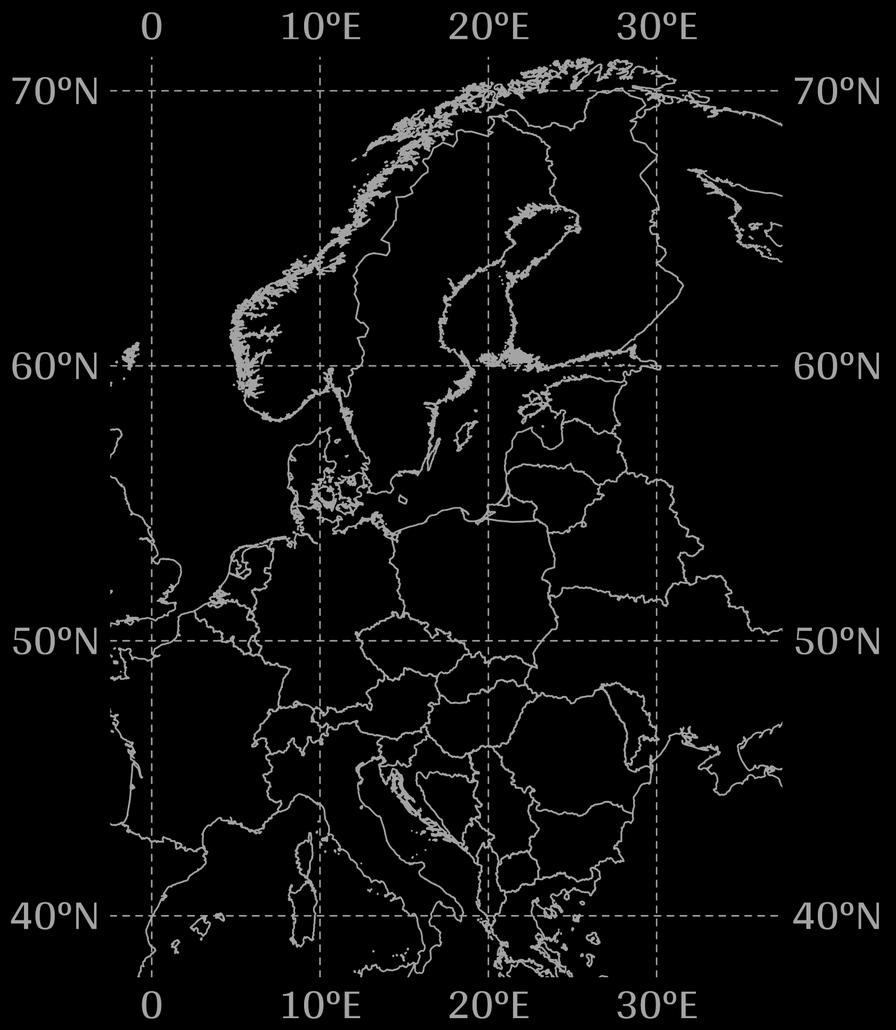
Five data sets

$P(X_{i,G}, X_{j,G})$ vs $P(X_{i,G})P(X_{j,G})$

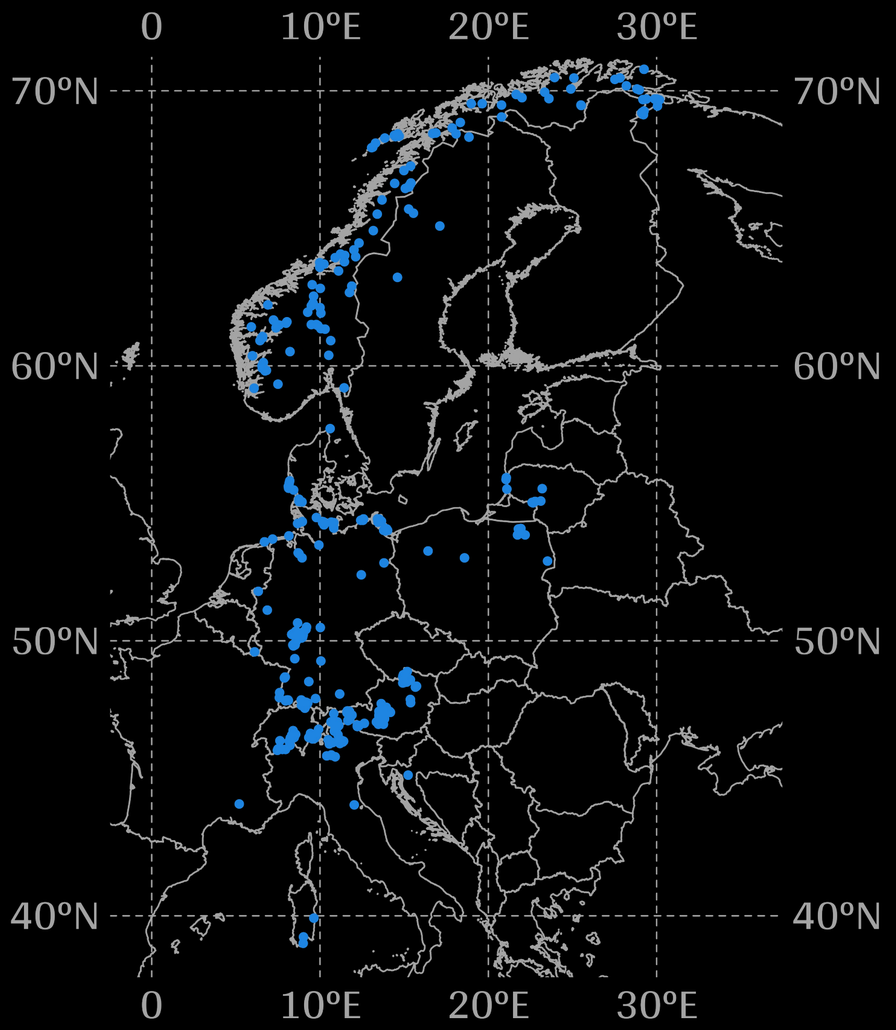
SDMs to assign presence probabilities given abiotic context

Detection ↓ once abiotic variables integrated

Kopelke et al, submitted, Ecology



Kopelke et al, submitted, Ecology



Three levels networks

Willow → Galler → Parasitoids

52 → 96 → 126 species

Three levels networks

Willow → Galler → Parasitoids

52 → 96 → 126 species

Willow → Galler

Three levels networks

Willow → Galler → Parasitoids

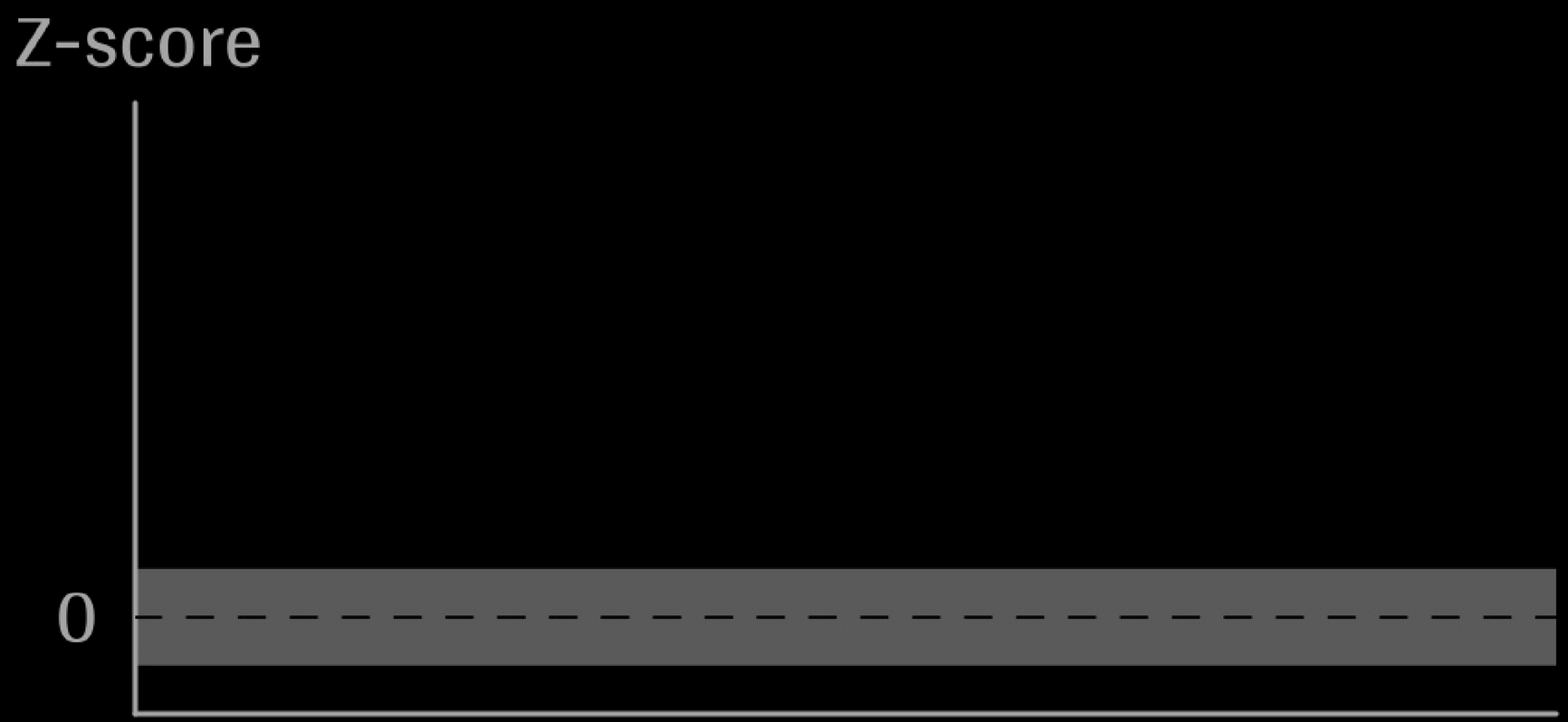
52 → 96 → 126 species

Willow → Galler

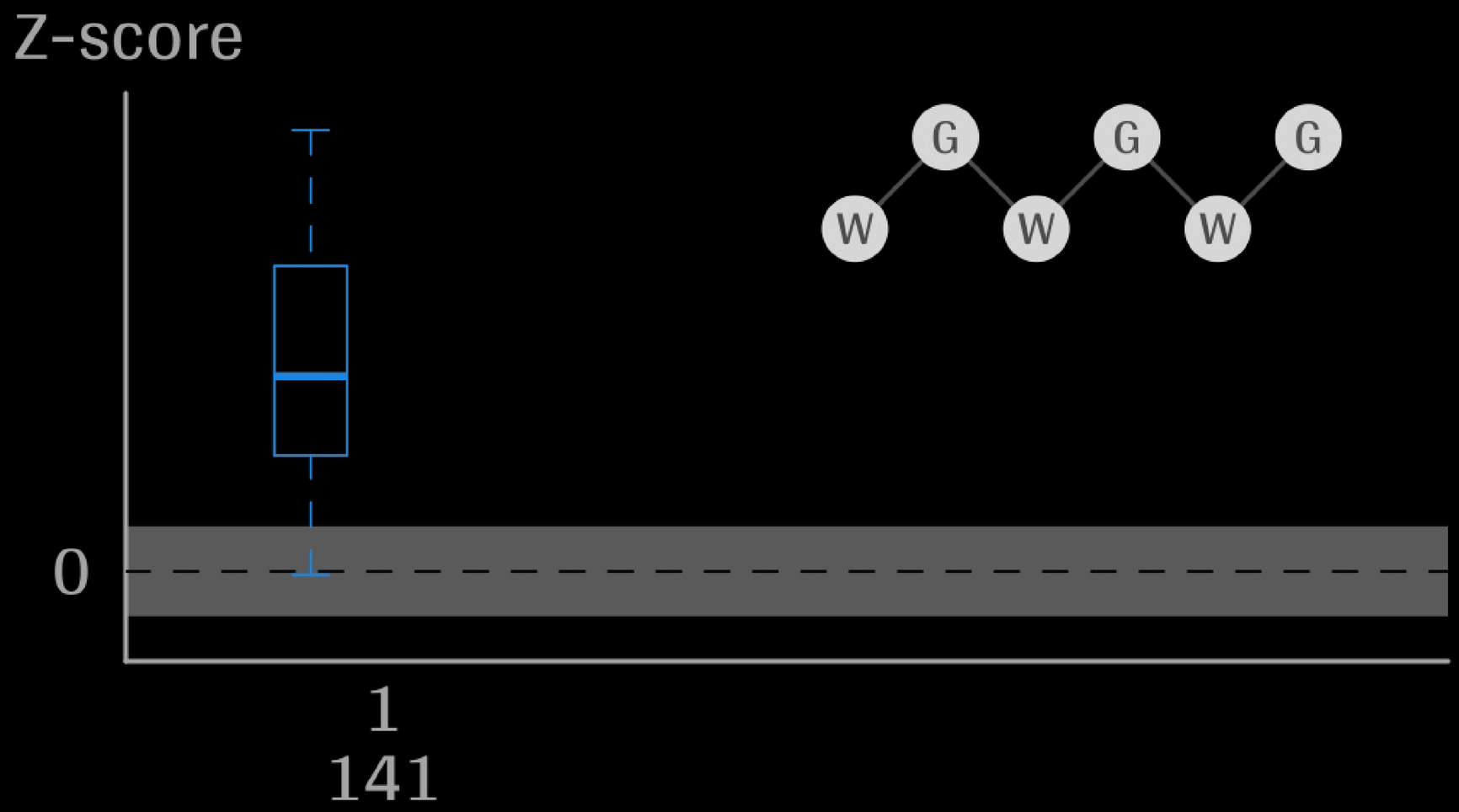
Galler → Parasitoids

Willow → Galler

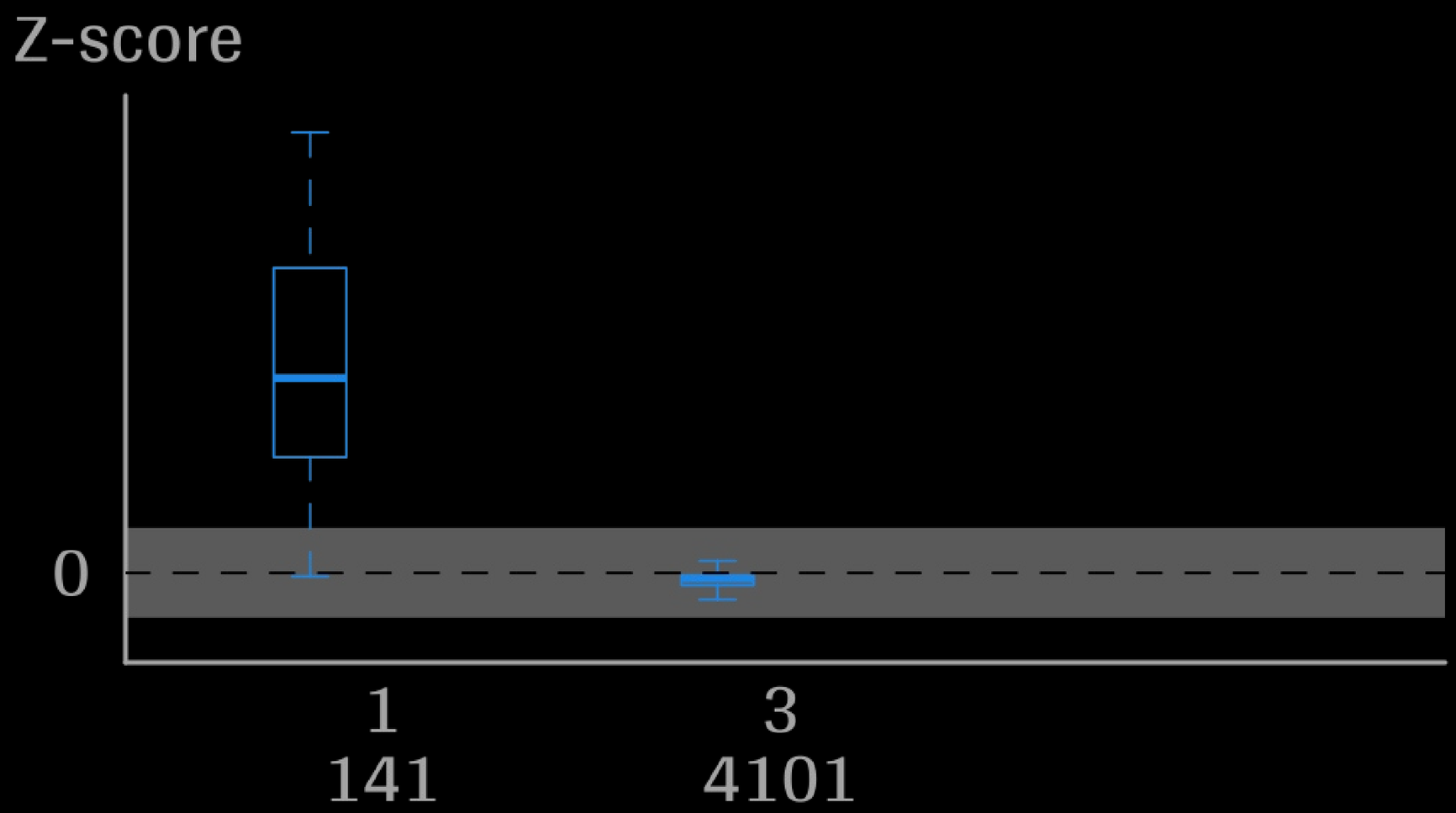
Willow → Galler



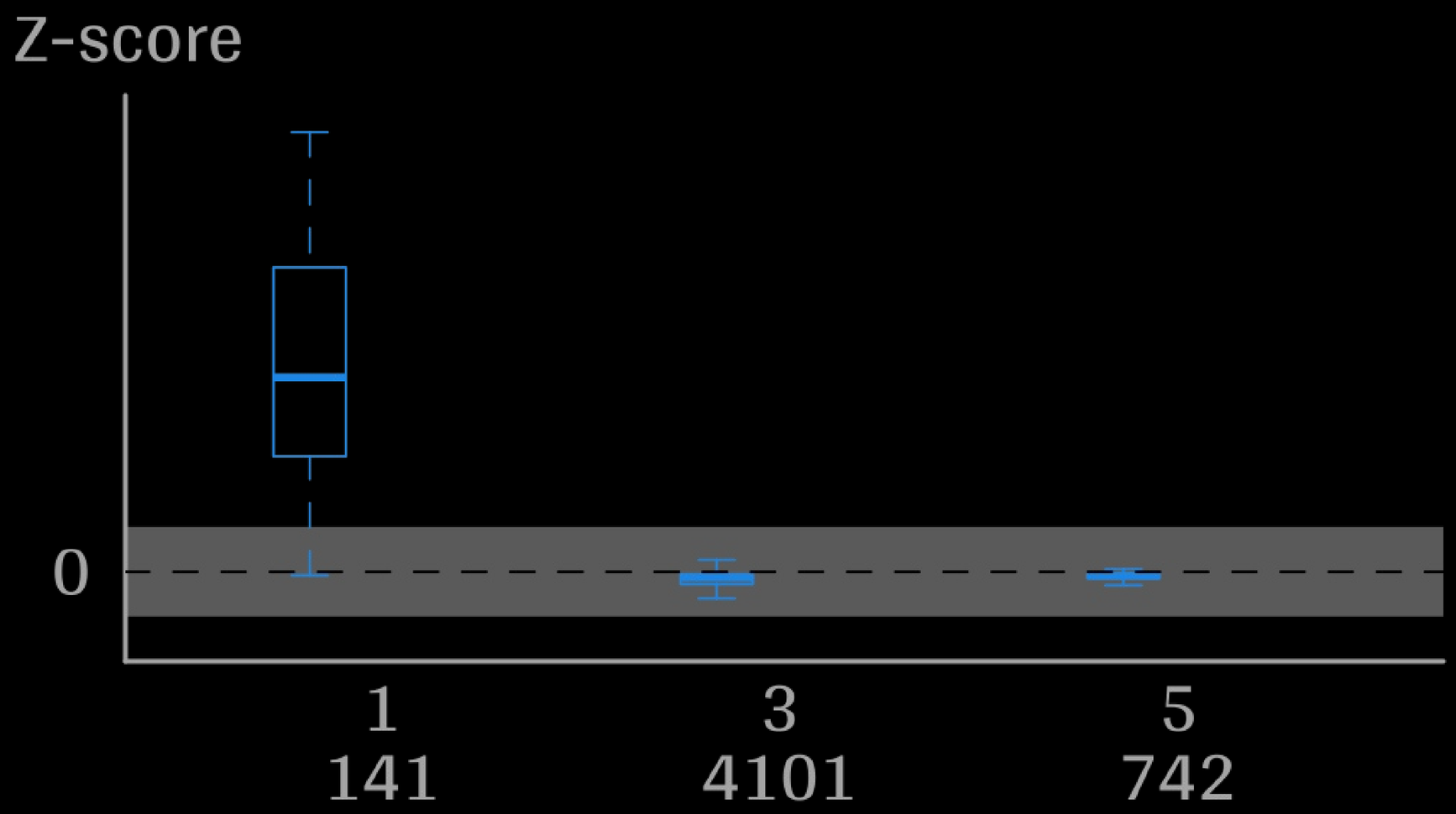
Willow → Galler



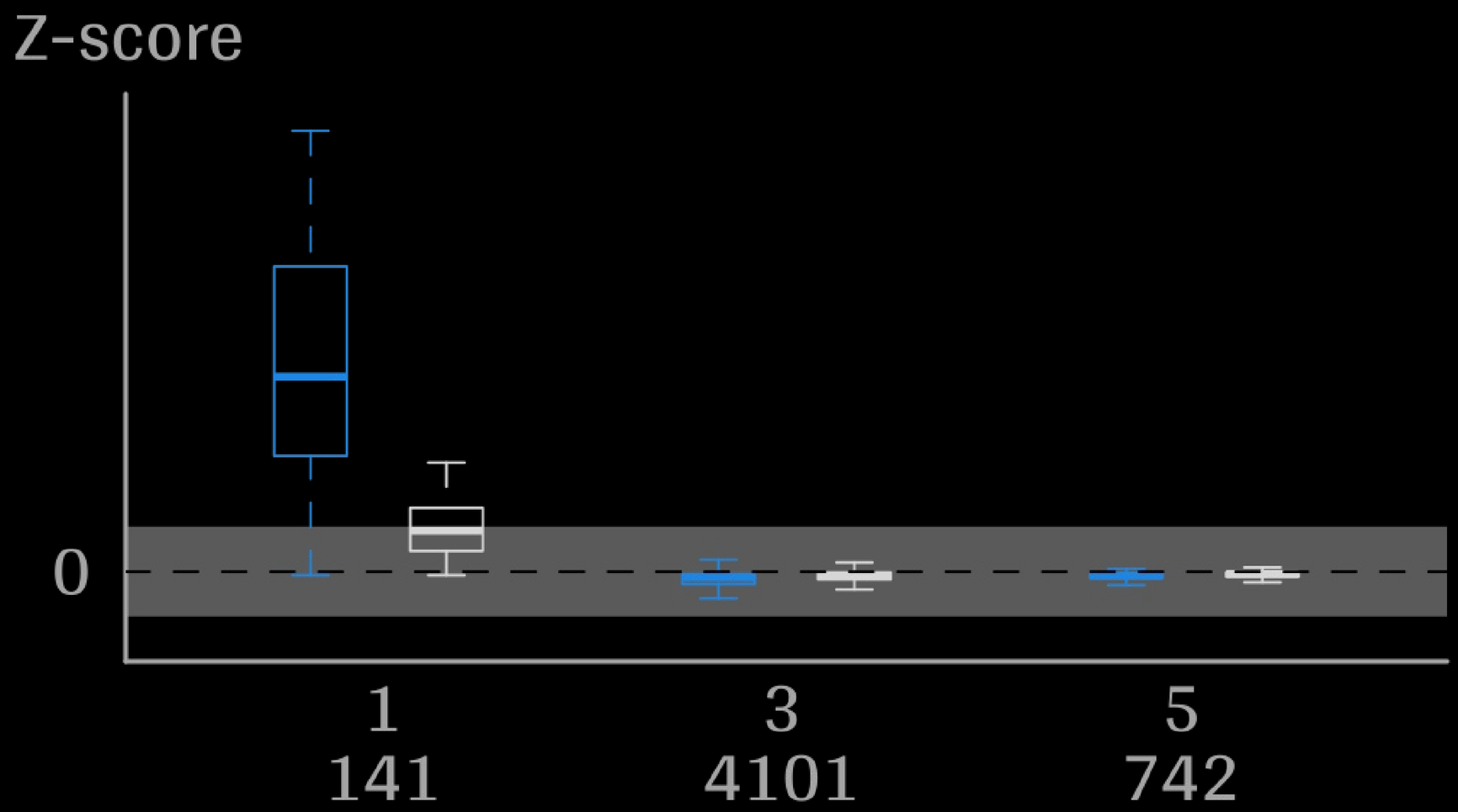
Willow → Galler



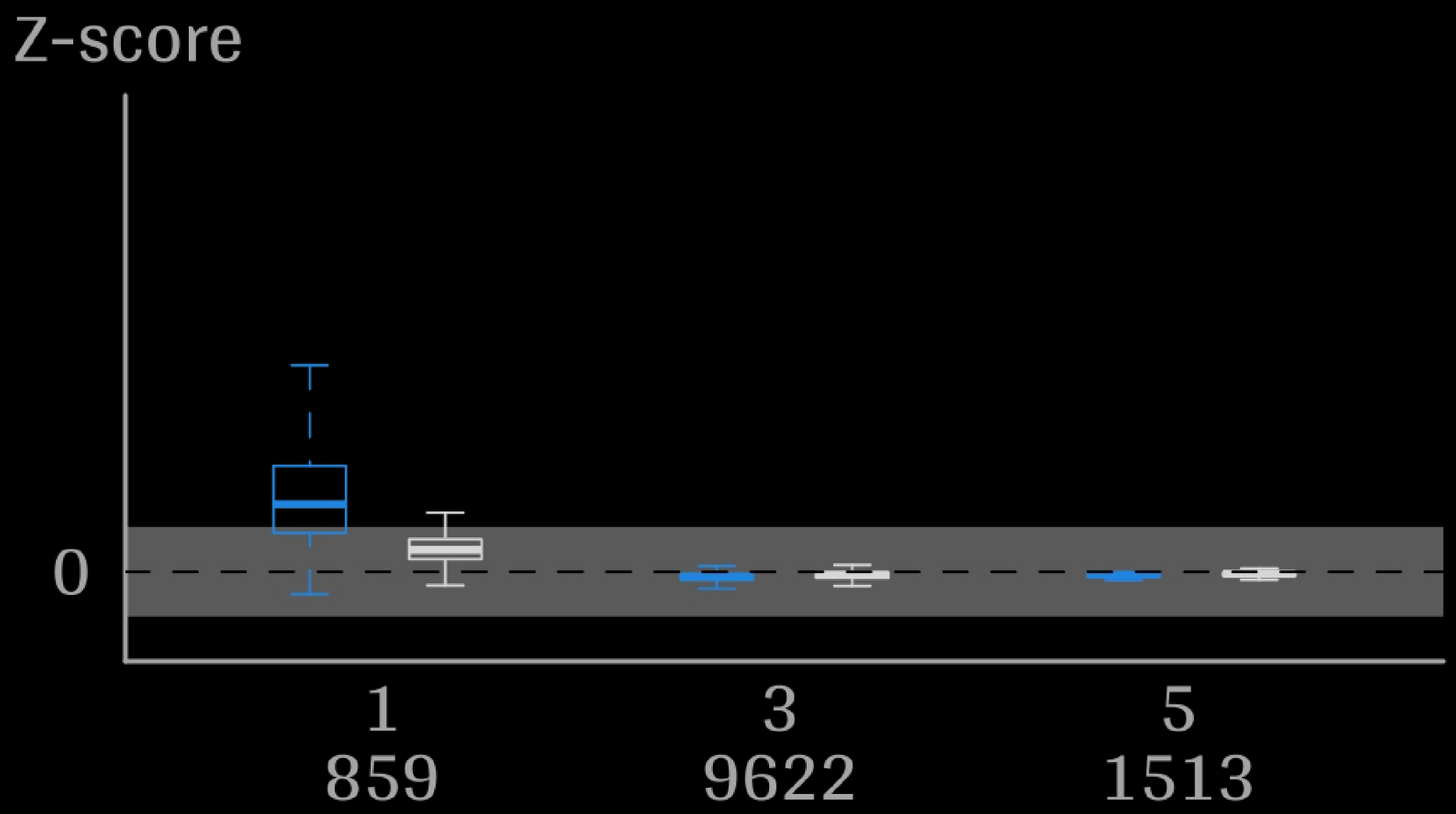
Willow → Galler



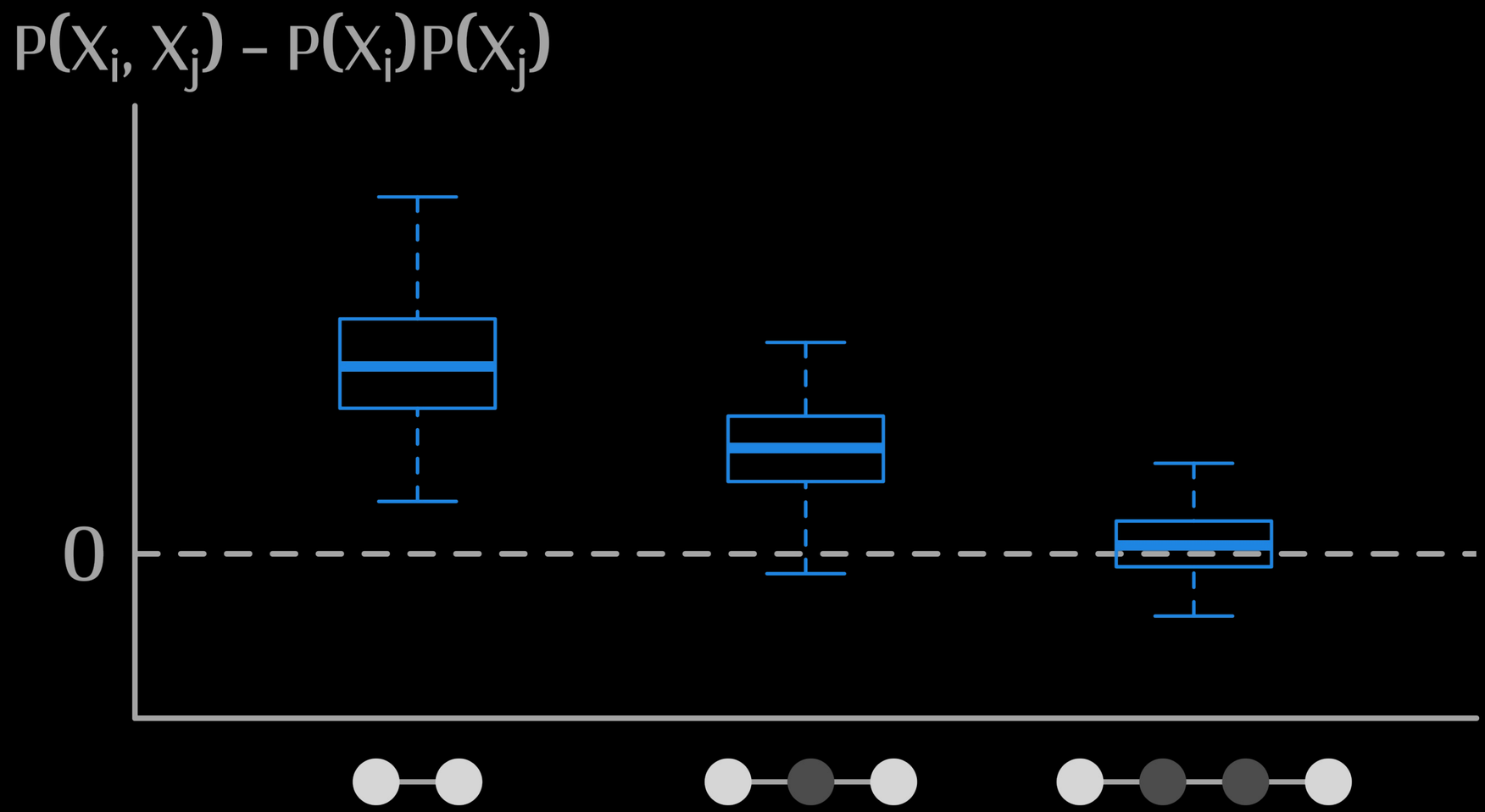
Willow → Galler



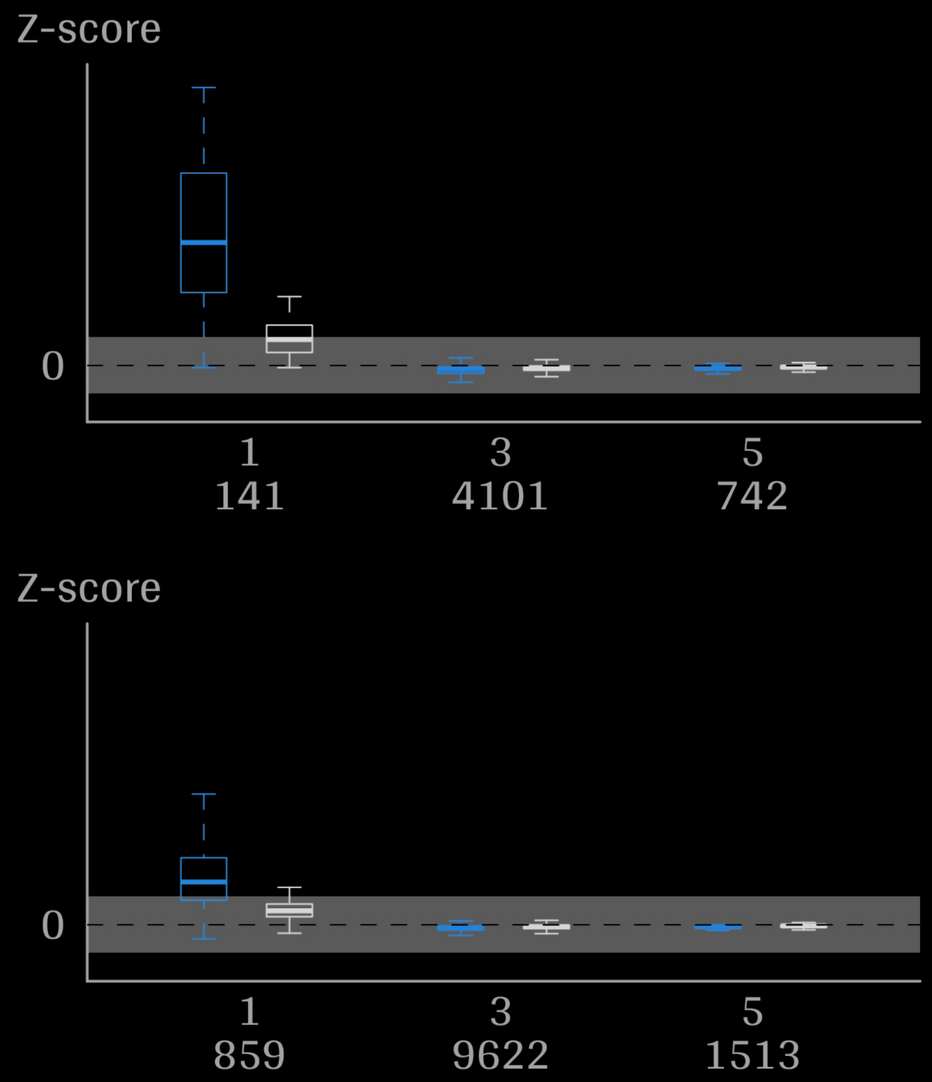
Galler → Parasitoids



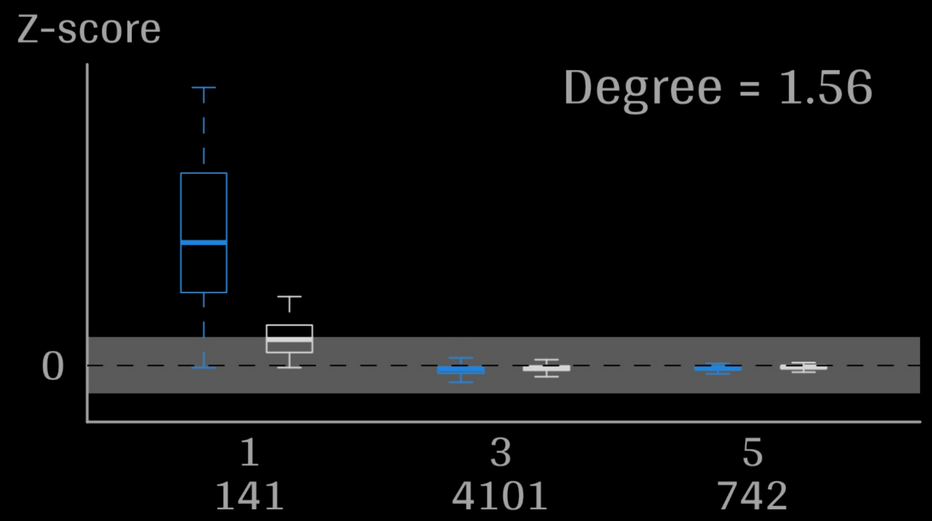
Co-occurrence and shortest path

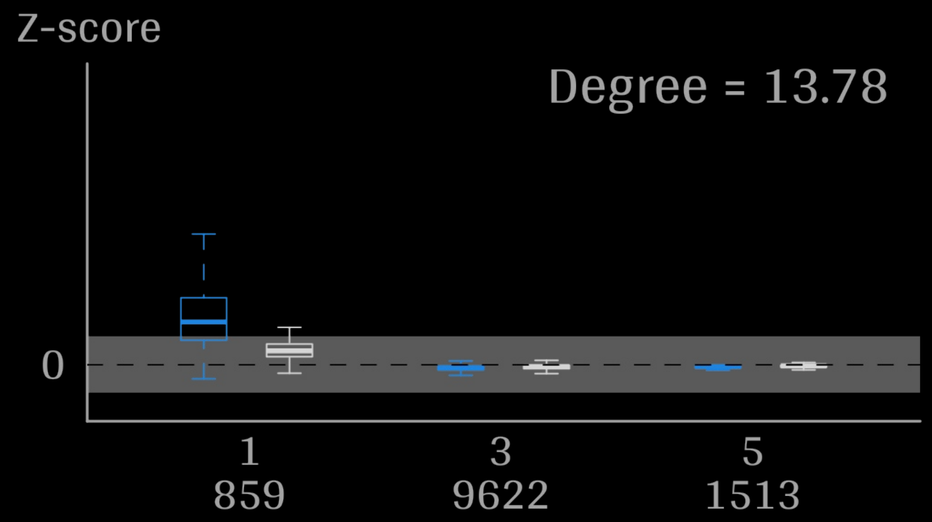


Willow → Galler vs Galler → Parasitoids

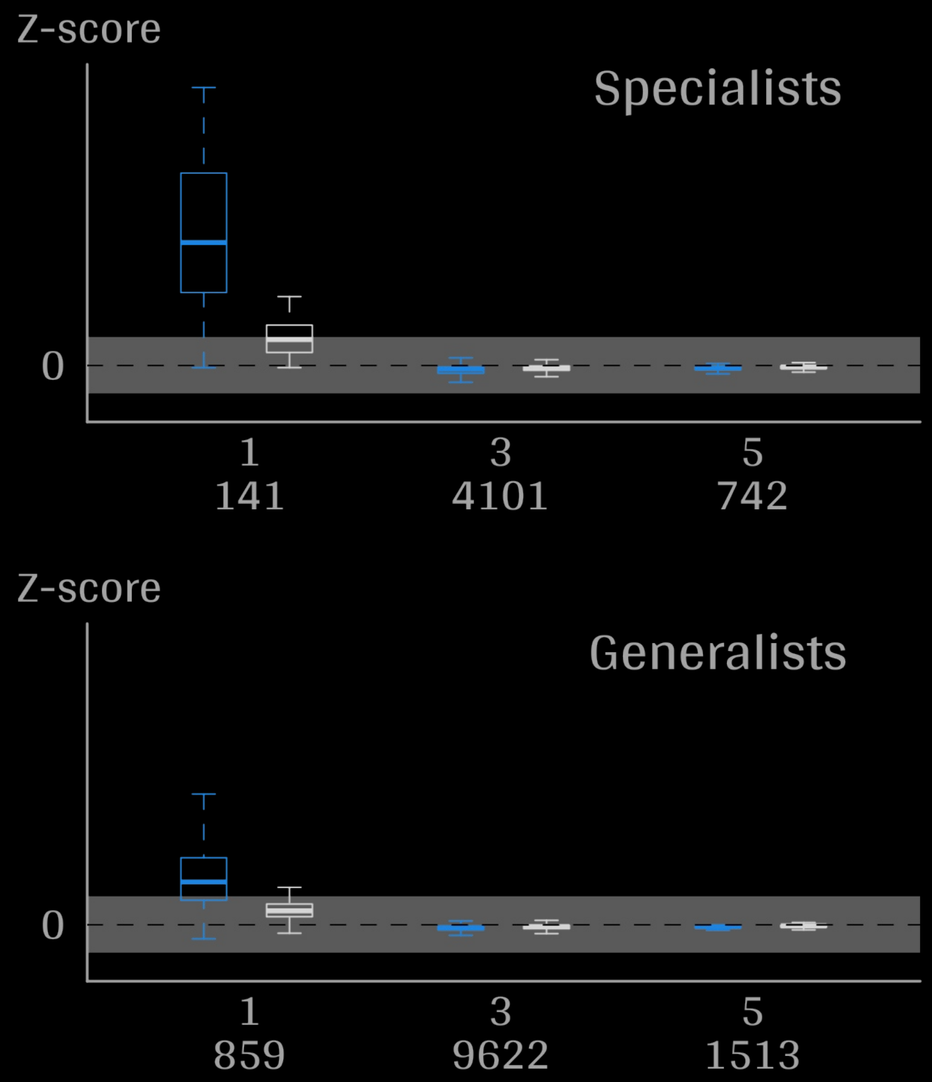


Willow → Galler vs Galler → Parasitoids

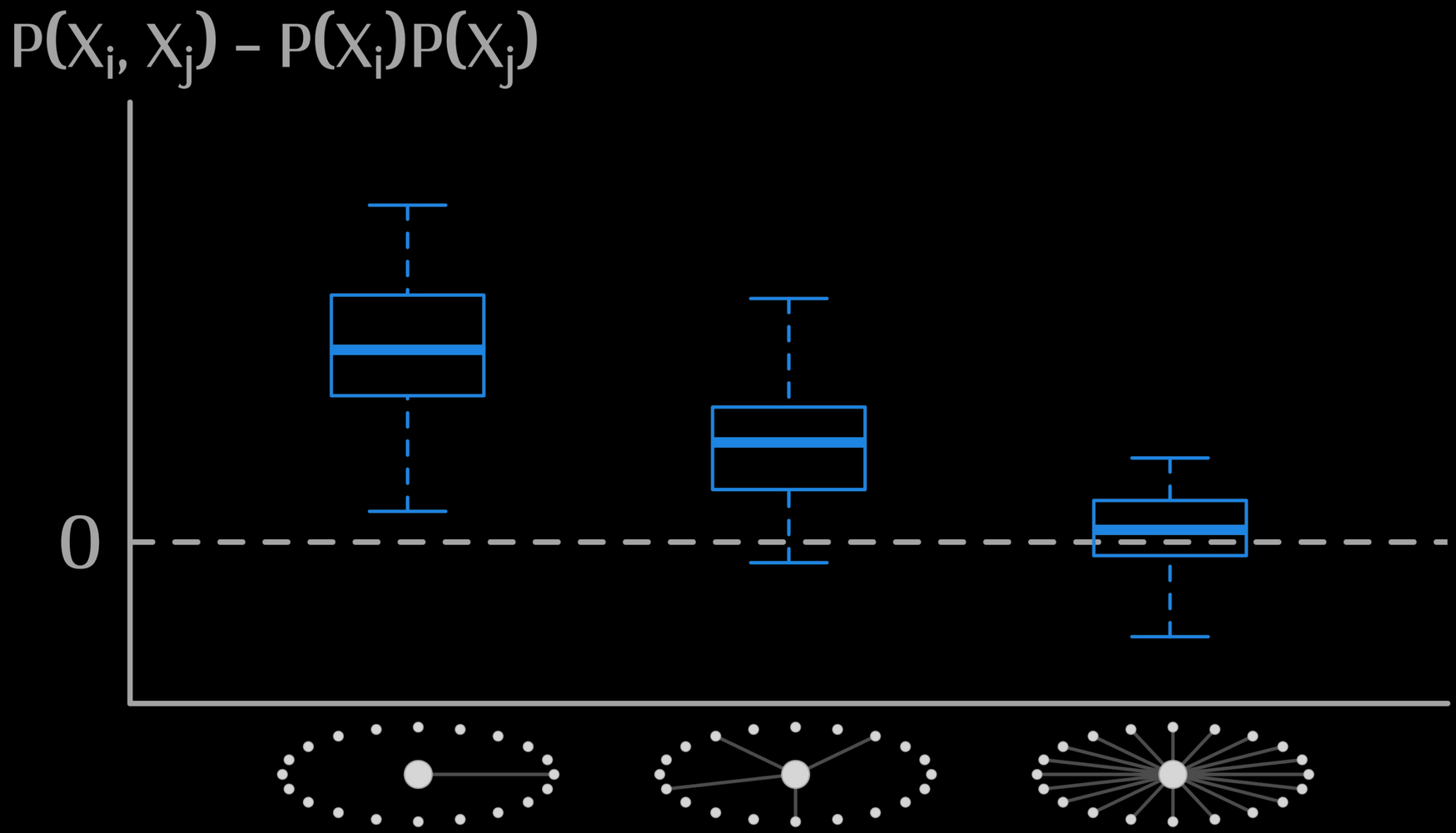




Willow → Galler vs Galler → Parasitoids



Co-occurrence and degree



Conclusion

Shortest path ↑ detection ↓

Conclusion

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Conclusion

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Using empirical data sets.

Conclusion

Shortest path ↑ detection ↓

Degree ↑ detection ↓

Using empirical data sets.

Cazelles et al, 2017, in prep

Concluding remarks and perspectives

Towards better predictions?

Answers

1. How to integrate biotic interactions into distribution models?

Answers

1. How to integrate biotic interactions into distribution models?

    Network distribution models (NDMs)

Answers

2. How the properties of ecological networks influence co-occurrence?

Answers

2. How the properties of ecological networks influence co-occurrence?

shortest path ↑ detection ↓

degree ↑ detection ↓

Answers

3. Can we infer interactions from co-occurrence?

Answers

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   depends on the network properties

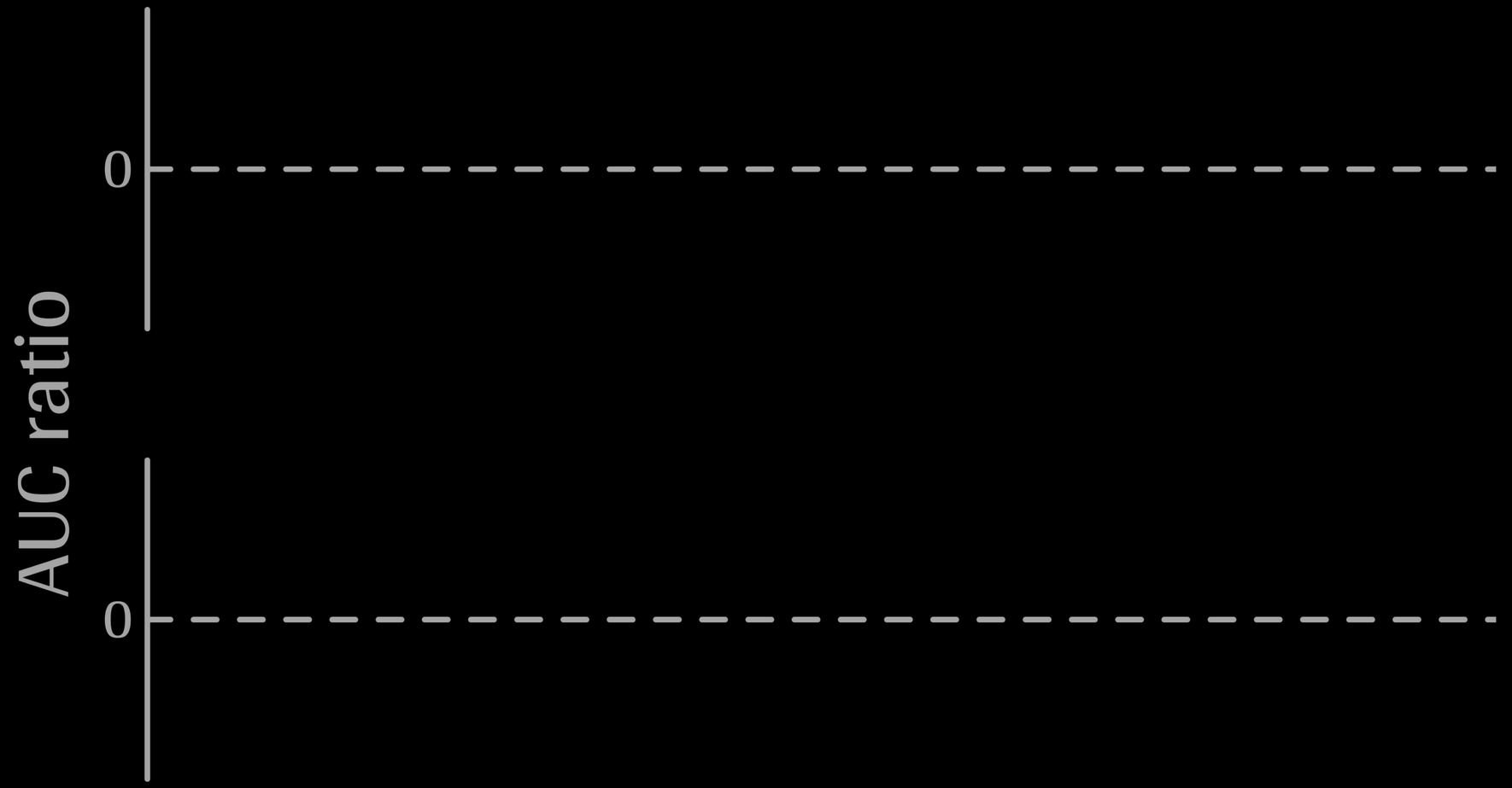
Answers

3. Can we infer interactions from co-occurrence?

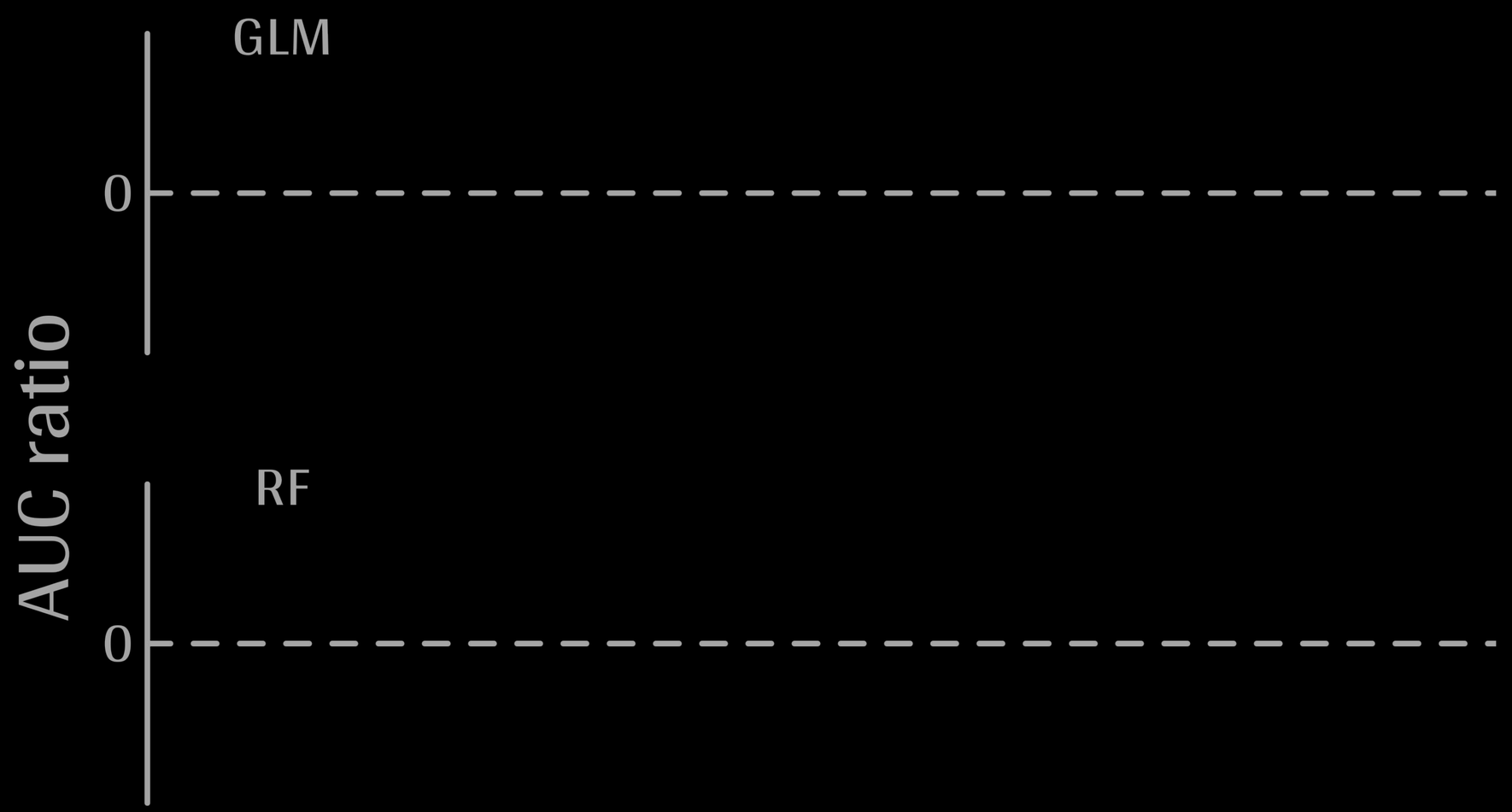
   depends on the network properties

   depends on the spatial scale (literature)

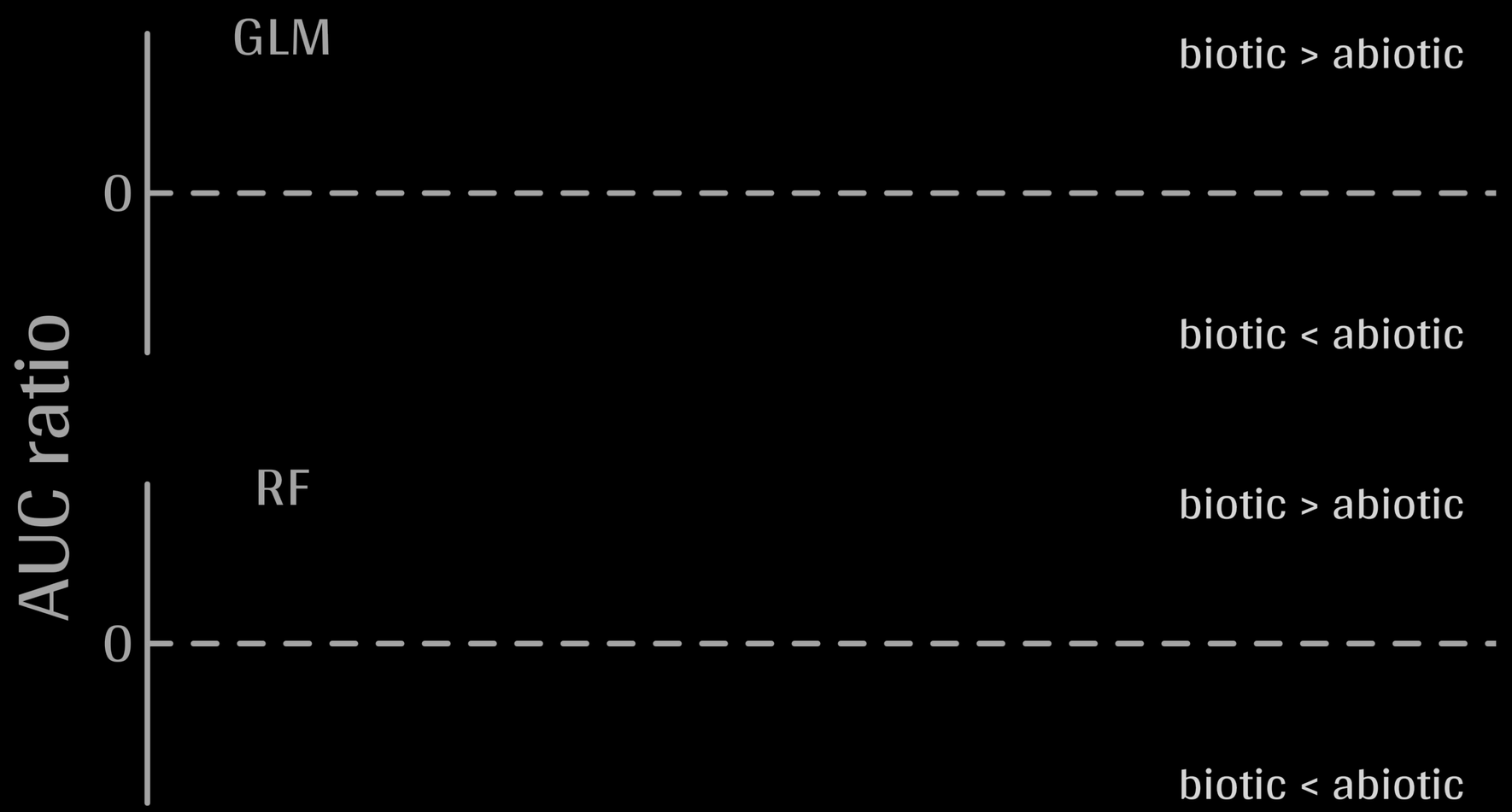
Using species as predictors?



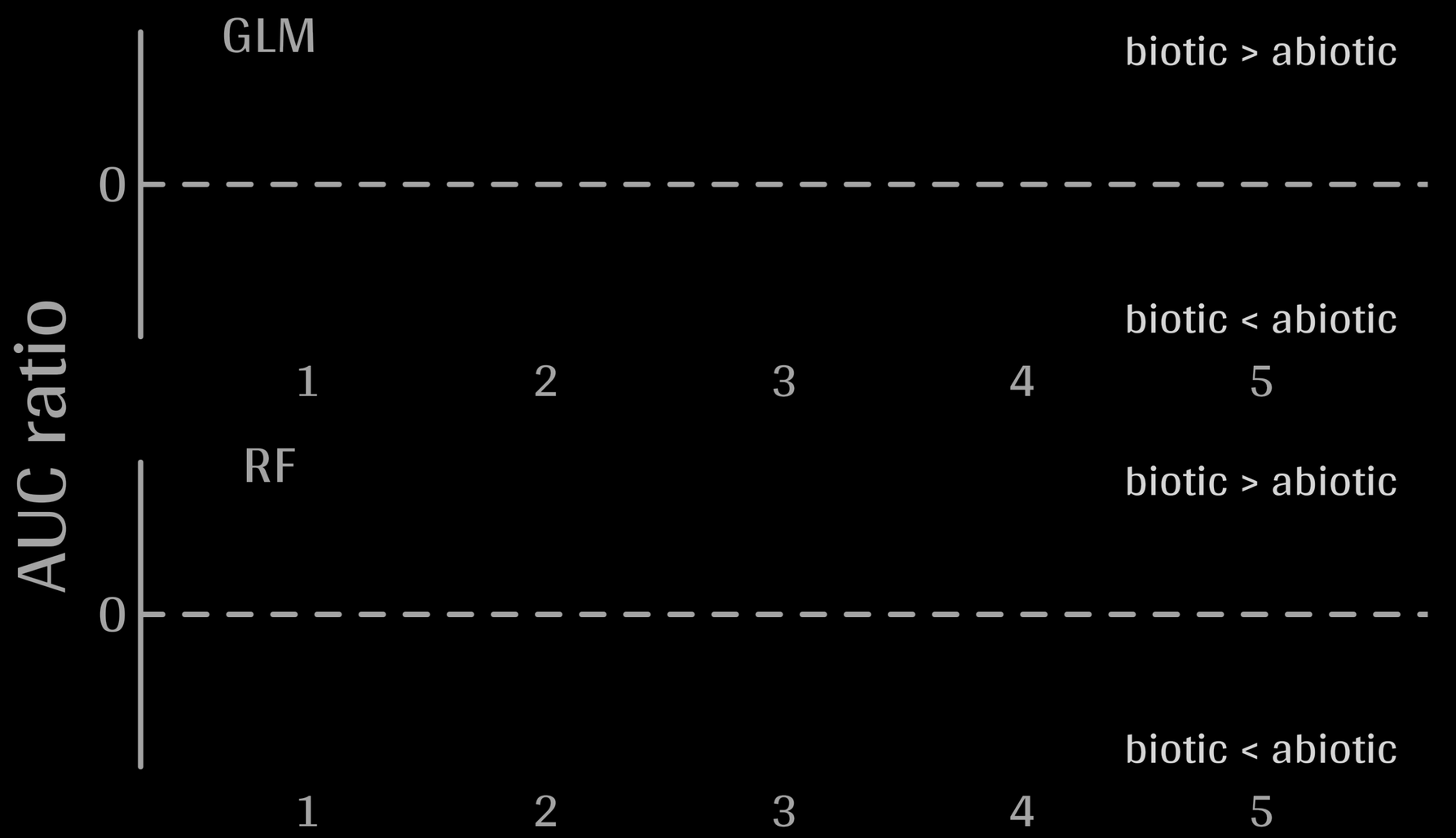
Using species as predictors?



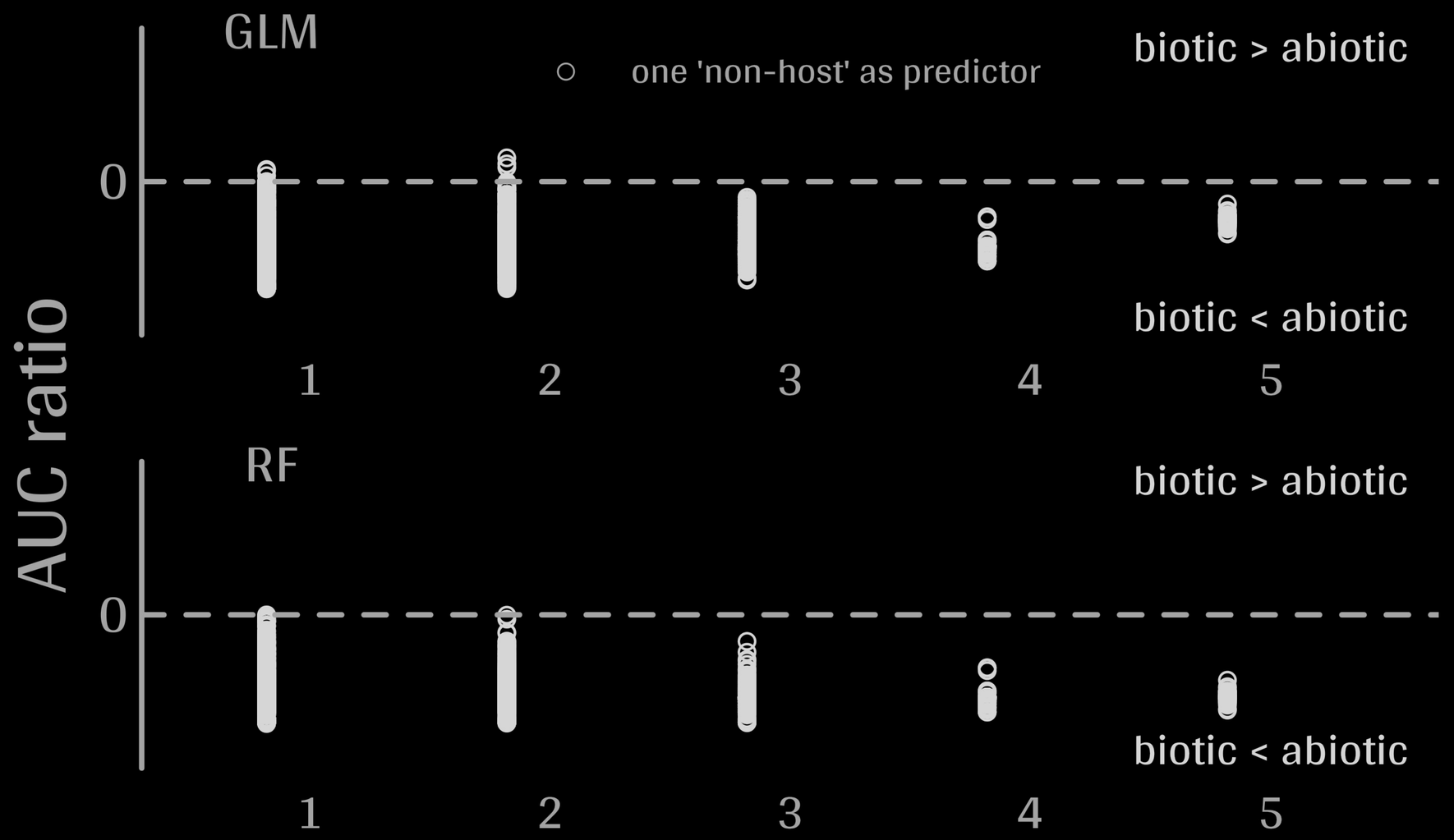
Using species as predictors?



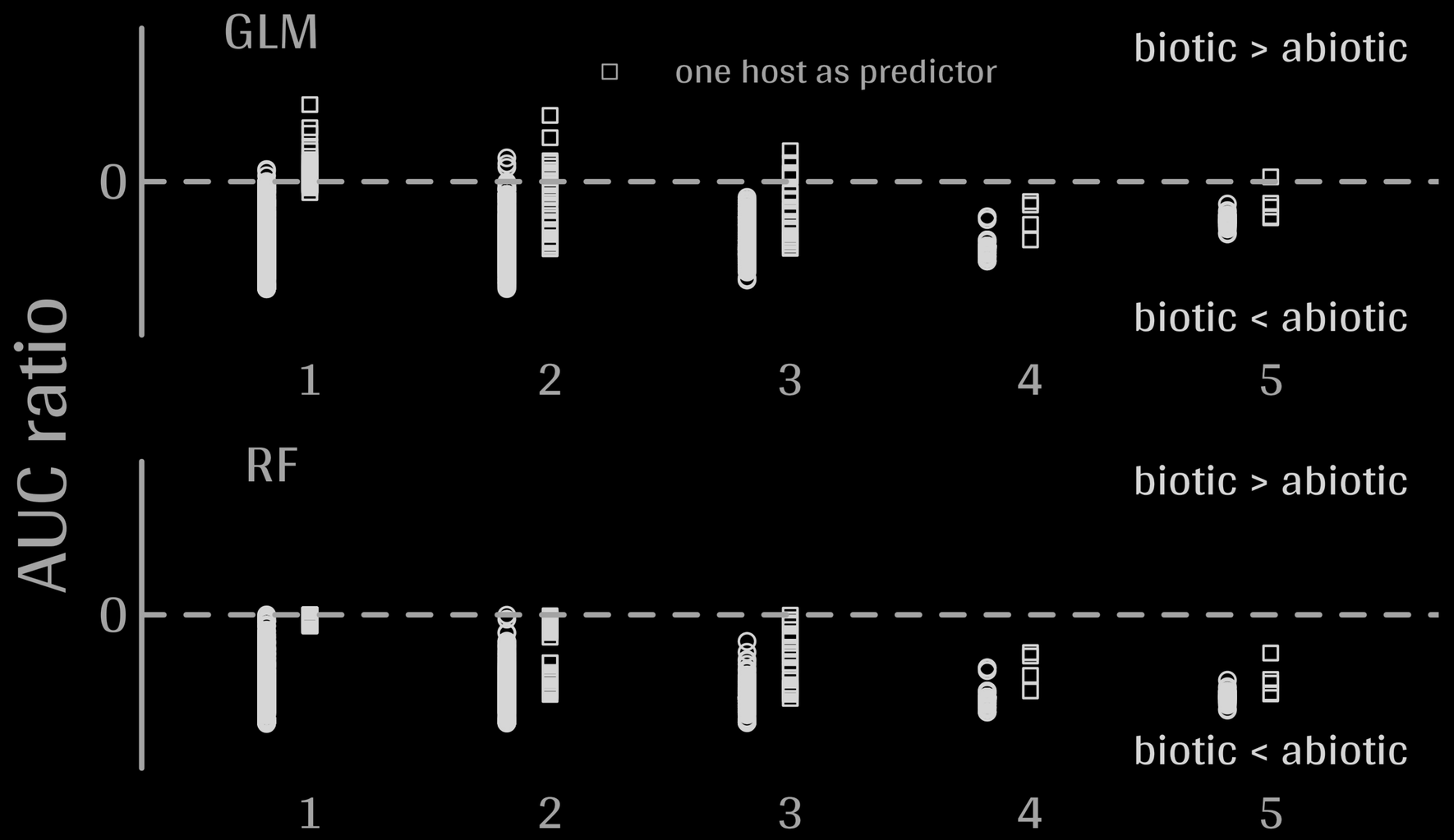
Using species as predictors?



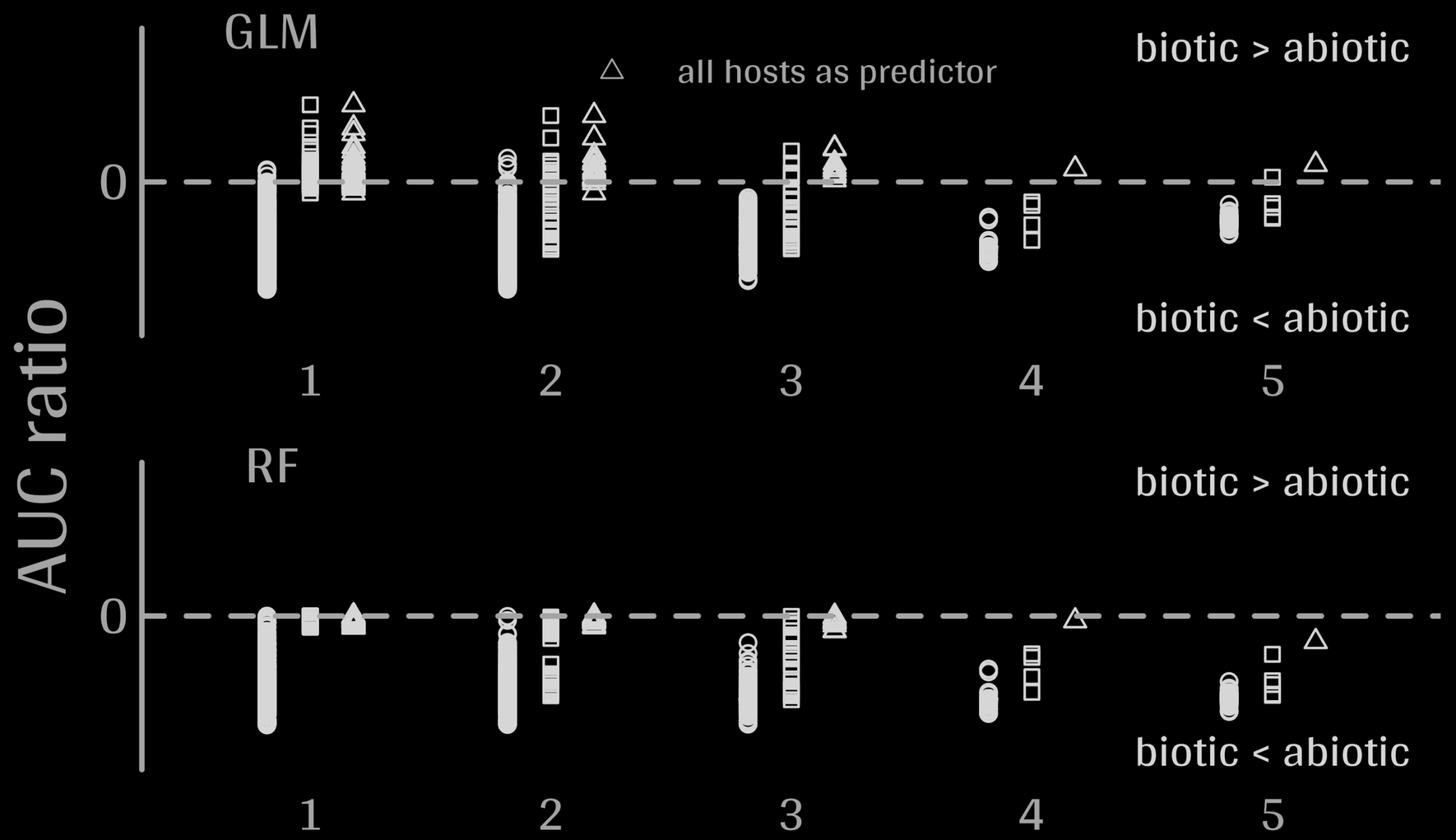
Using species as predictors?



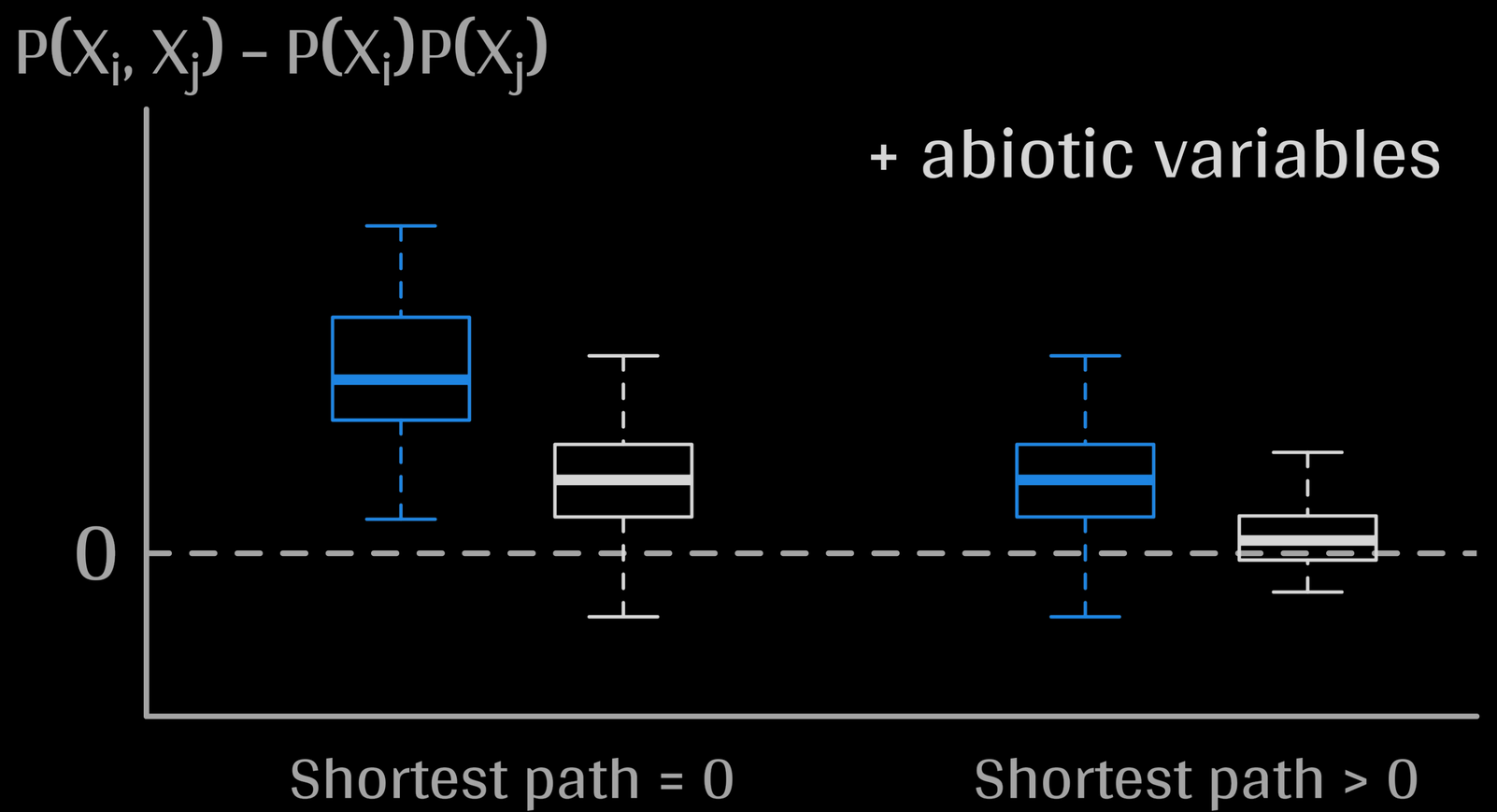
Using species as predictors?



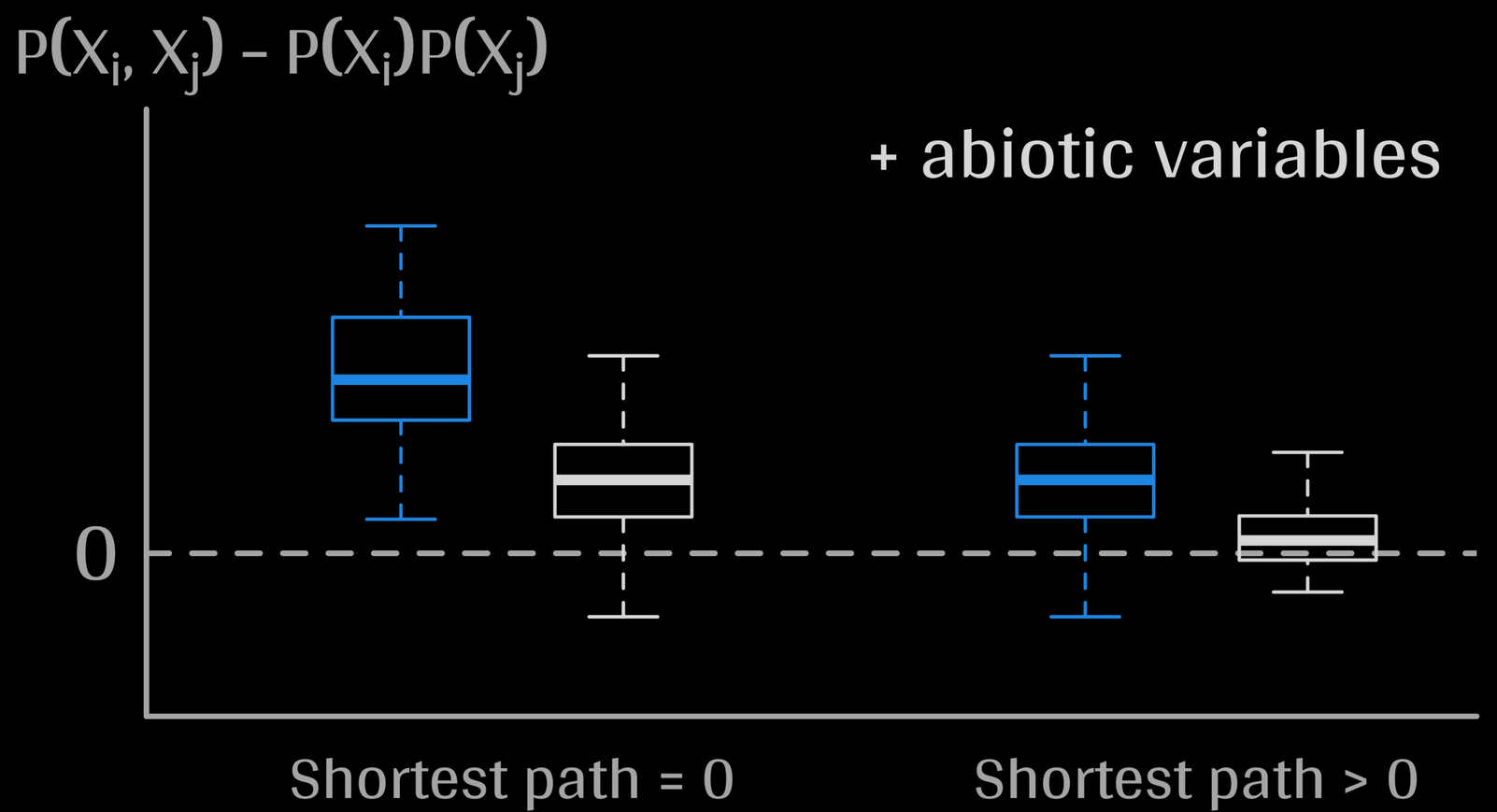
Using species as predictors?



What do we really integrate?



What do we really integrate?



INTERDEPENDENCY

Towards mechanistic NDMs?

Better than JSDMs? (more information)

Towards mechanistic NDMs?

Better than JSDMs? (more information)

Network Distribution Models (NDMs)

Towards mechanistic NDMs?

Better than JSDMs? (more information)

Network Distribution Models (NDMs)

Network W , abiotic variable(s) E

Towards mechanistic NDMs?

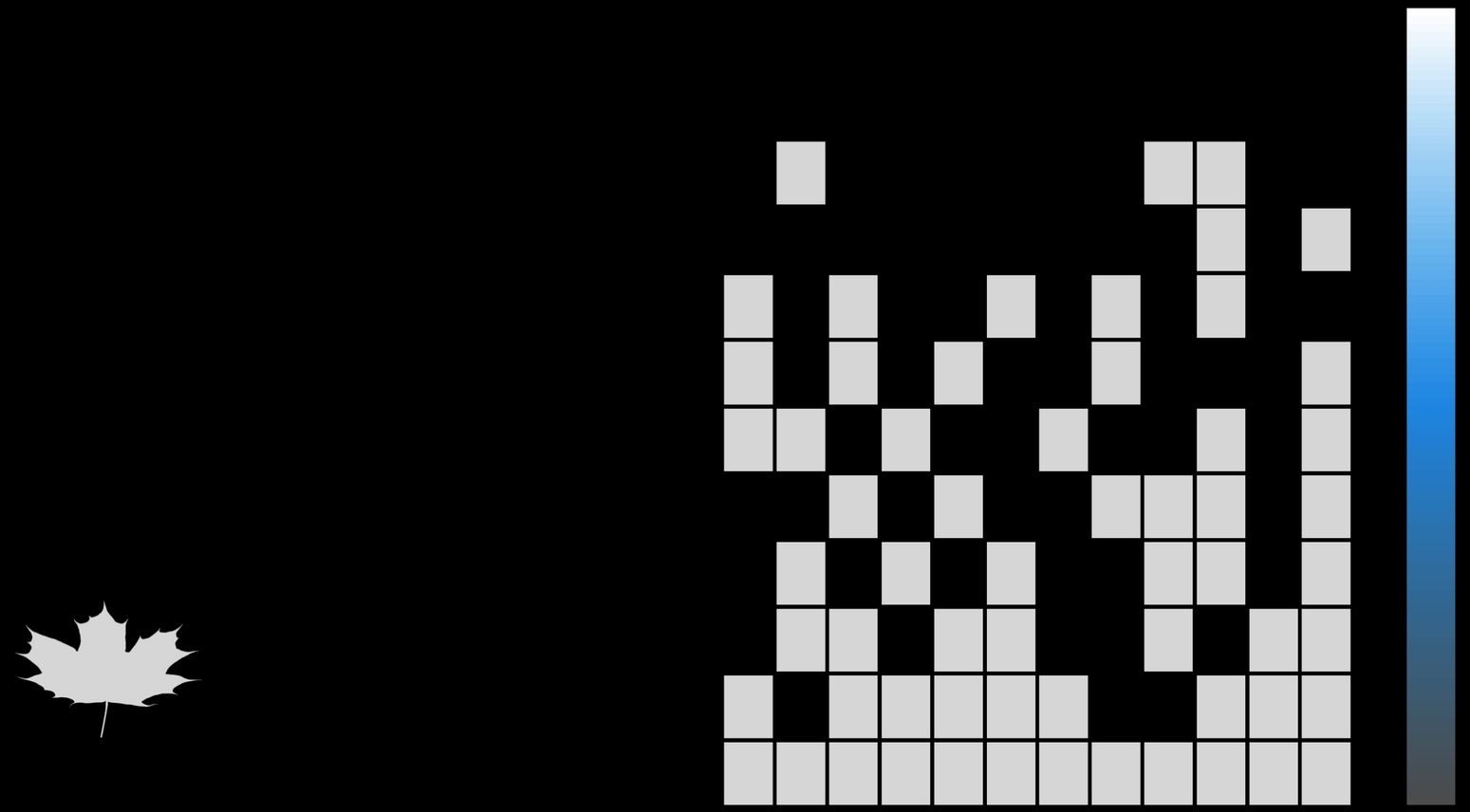
Better than JSDMs? (more information)

Network Distribution Models (NDMs)

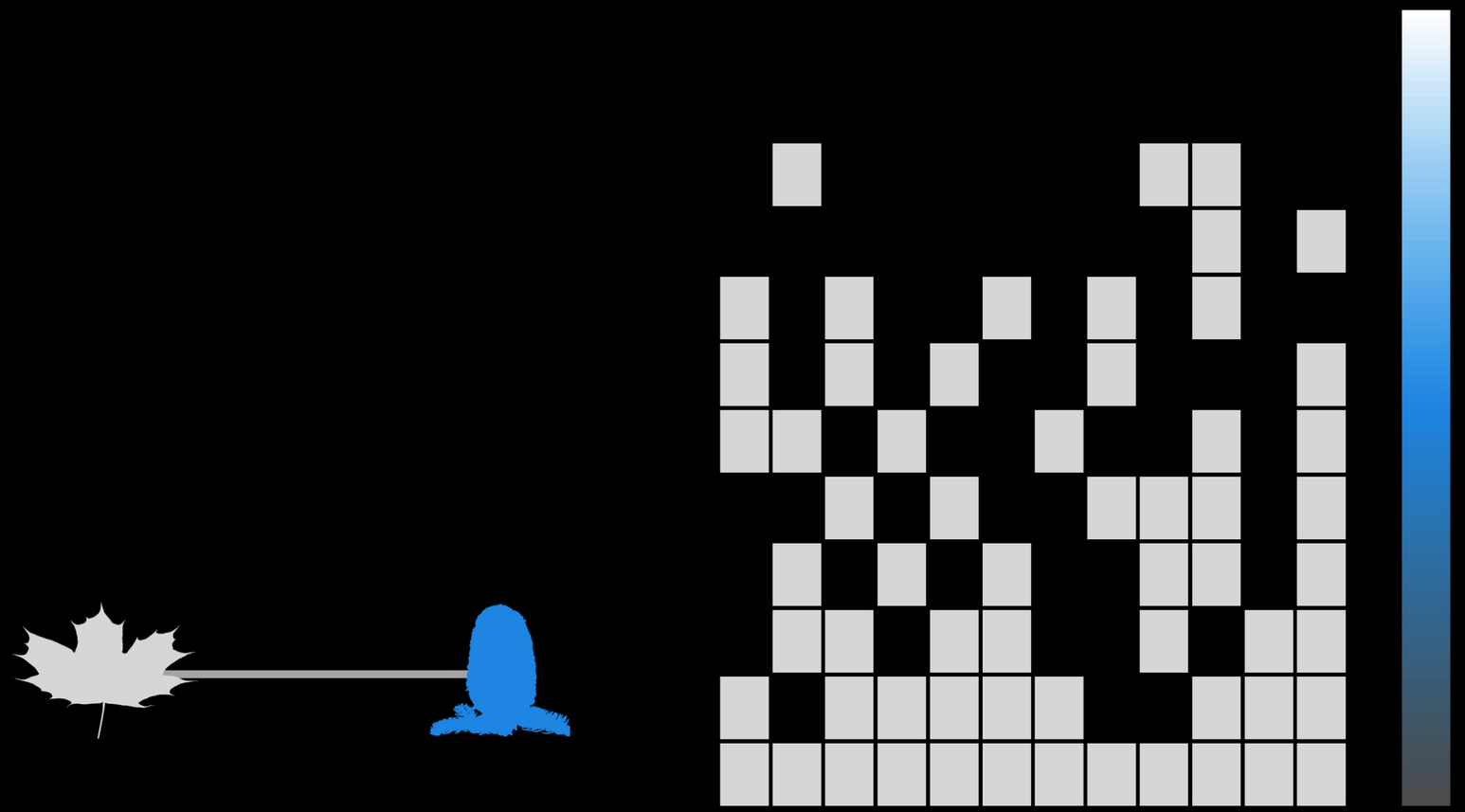
Network W , abiotic variable(s) E

How to predict interactions?

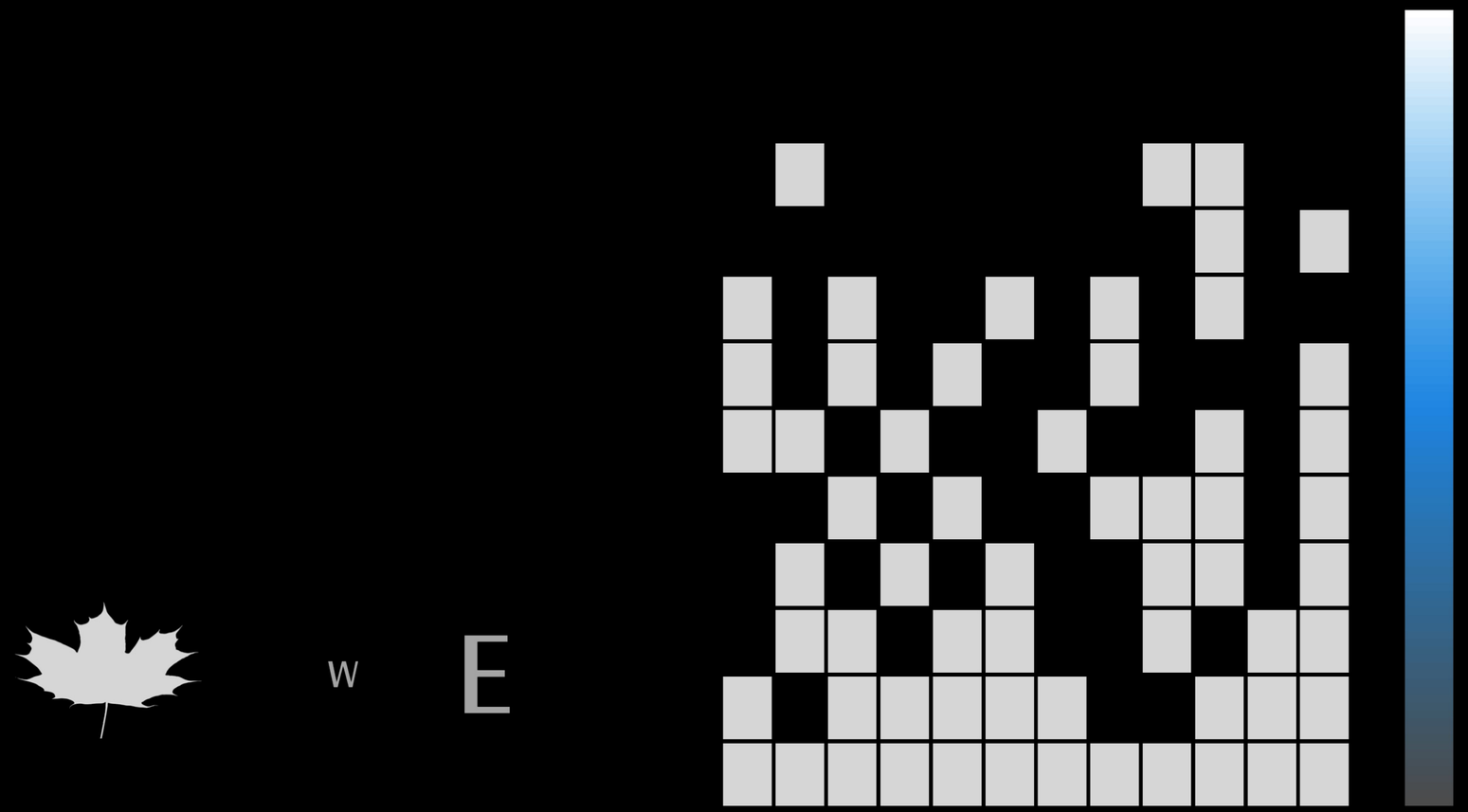
Towards mechanistic NDMs?



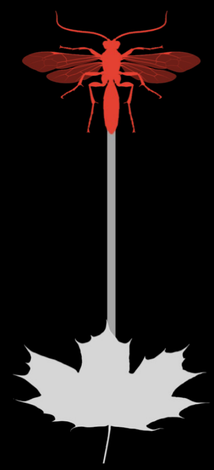
Towards mechanistic NDMs?



Towards mechanistic NDMs?

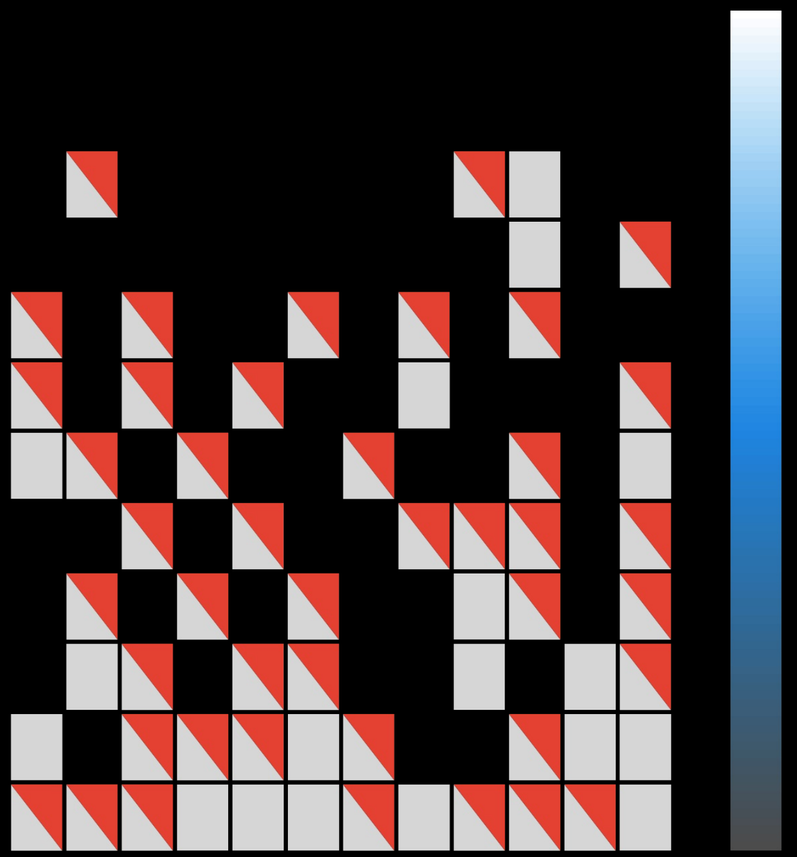


Towards mechanistic NDMs?

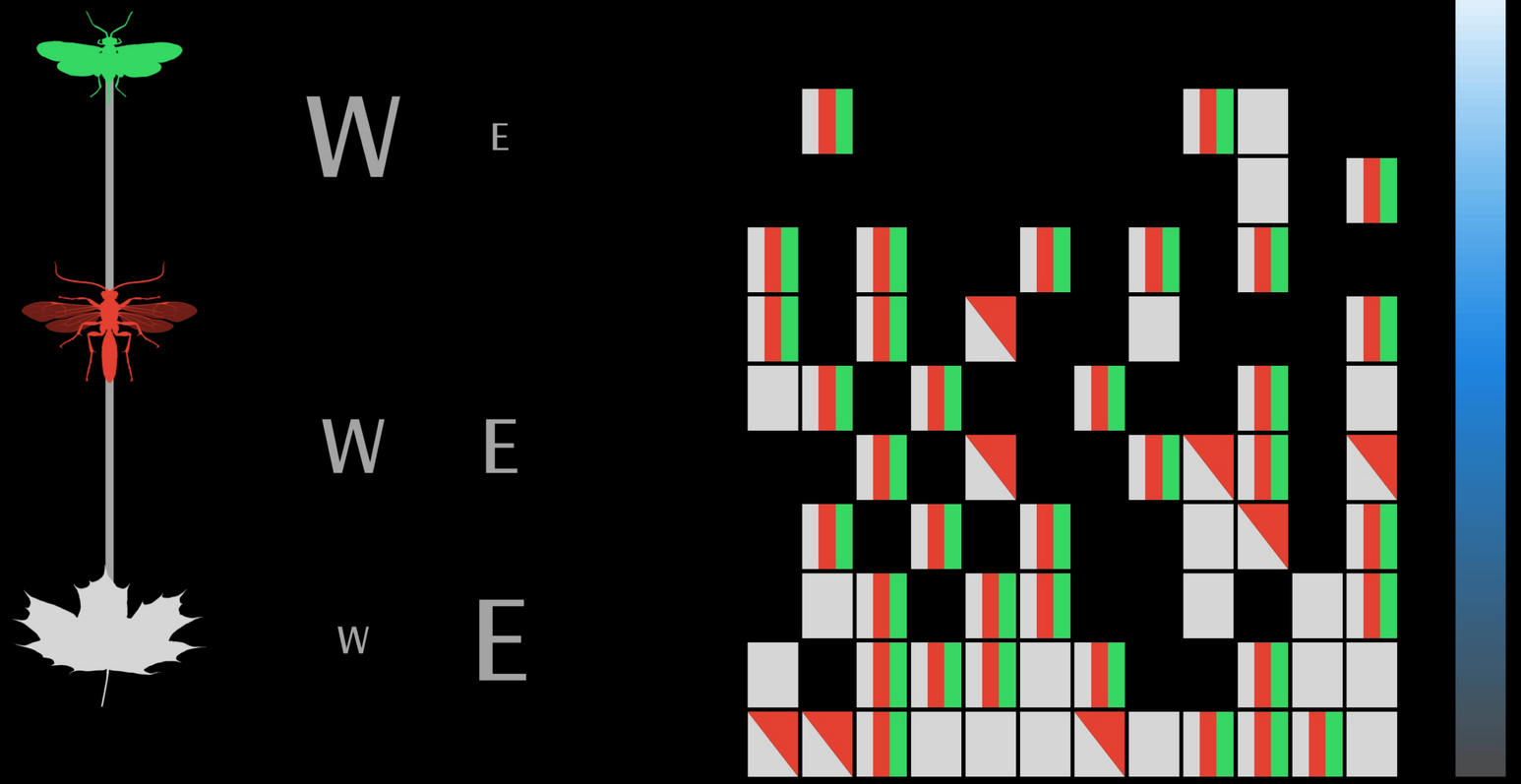


W E

w E



Towards mechanistic NDMs?



Urgently needed

Interactions ++ ⟶ predictions easier

Berlow et al, 2009, PNAS

Urgently needed

Interactions ++ ⟶ predictions easier

Berlow et al, 2009, PNAS

WWF, Living Planet Report 2016 

> If current trends continue to 2020 vertebrate populations may decline by an average of 67 per cent compared to 1970.

THANK YOU

Merci

Figure 1

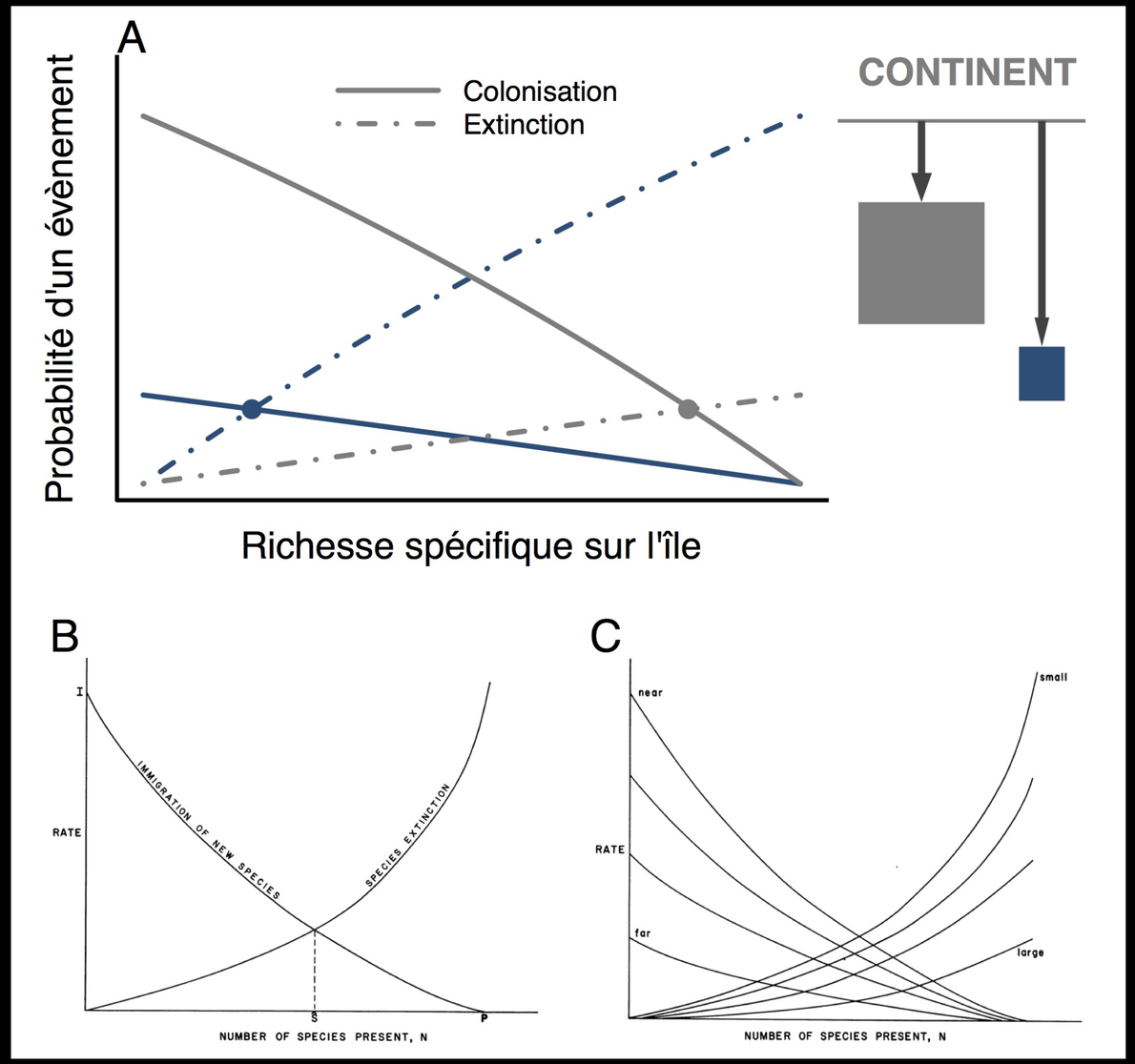

A
Probabilité d'un évènement
Colonisation
Extinction
CONTINENT
Richesse spécifique sur l'île
B
I
RATE
IMMIGRATION OF NEW SPECIES
SPECIES EXTINCTION
S
P
NUMBER OF SPECIES PRESENT, N
C
near
small
RATE
far
large
NUMBER OF SPECIES PRESENT, N

Figure 2

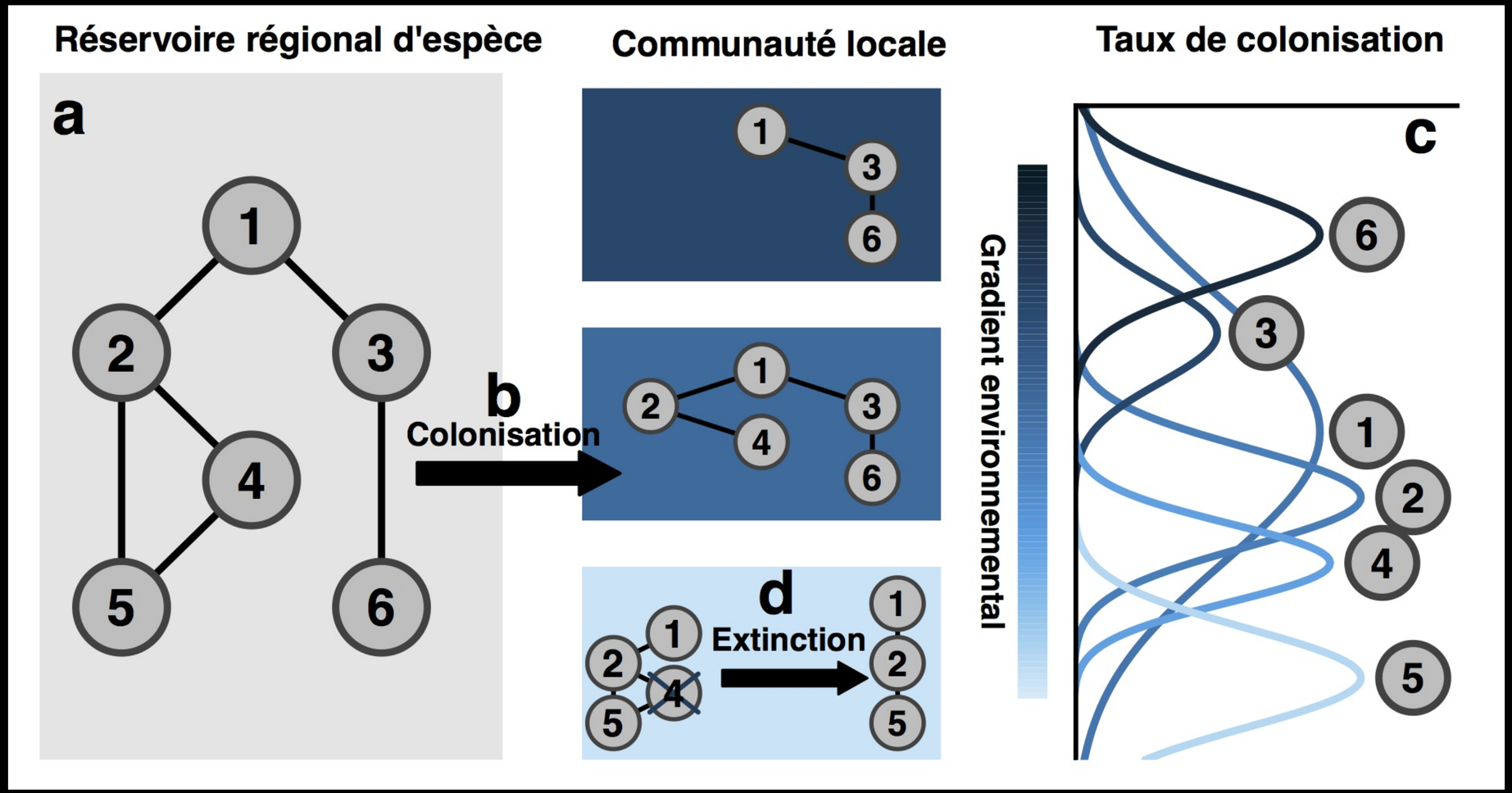

Réservoire régional d'espèce
Communauté locale
Taux de colonisation
a
b
Colonisation
c
d
Extinction
Gradient environnemental
1
2
3
4
5
6

Figure 3

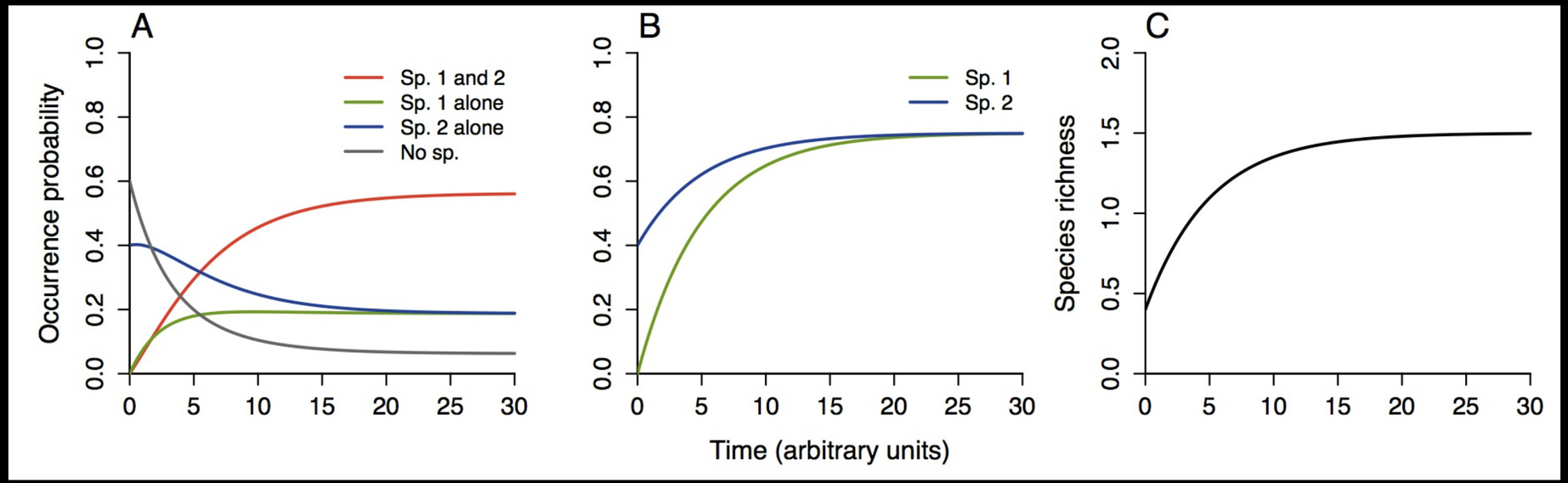

A
B
C
Occurrence probability
Species richness
Time (arbitrary units)
Sp. 1 and 2
Sp. 1 alone
Sp. 2 alone
No sp.
Sp. 1
Sp. 2
0.0
0.2
0.4
0.6
0.8
1.0
0.5
1.5
2.0
0
5
10
15
20
25
30

Figure 4

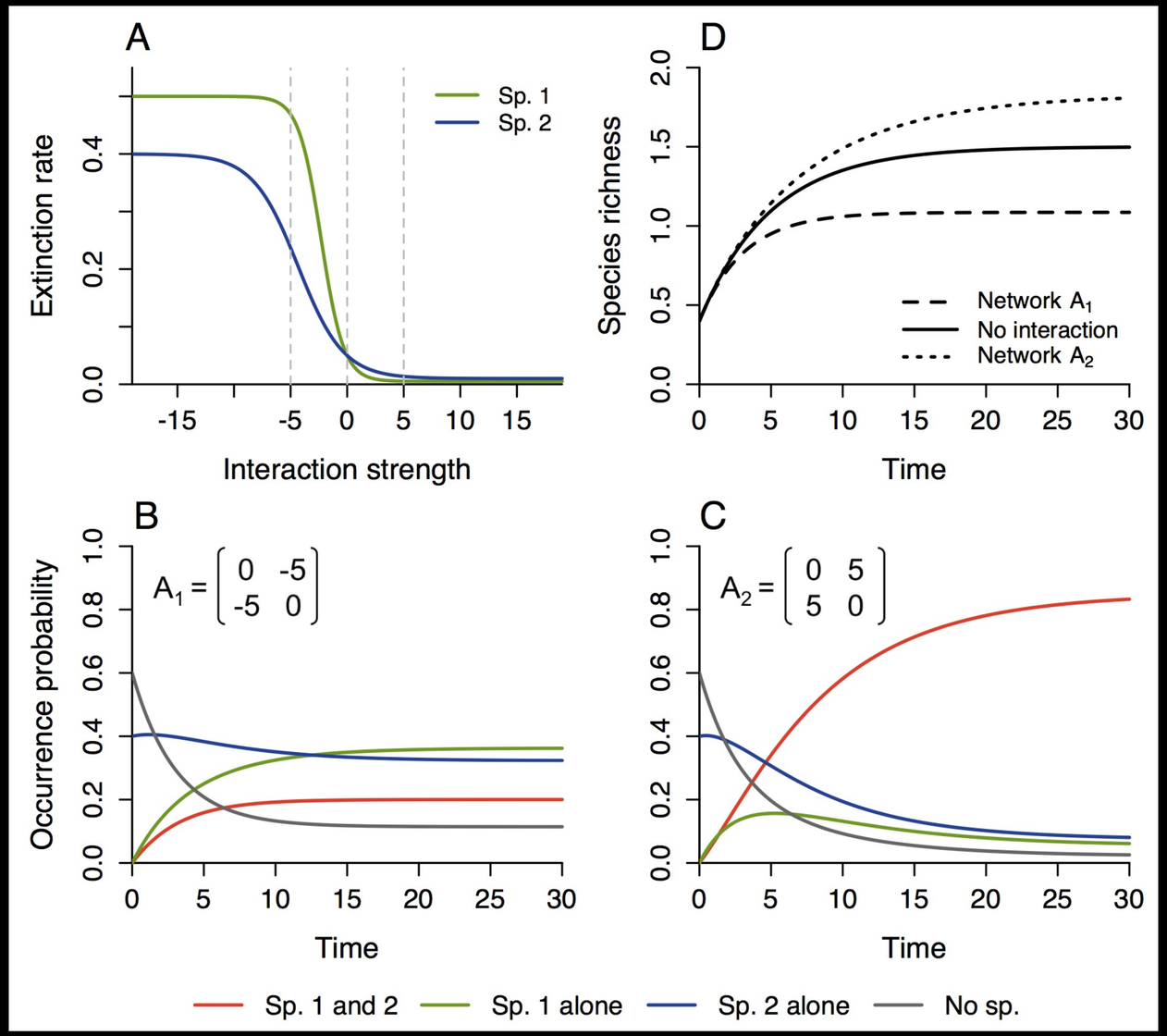

A
Extinction rate
0.0
0.2
0.4
-15
-5
0
5
10
15
Interaction strength
Sp. 1
Sp. 2
D
Species richness
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25
30
Time
Network A_1
No interaction
Network A_2
B
Occurrence probability
0.0
0.2
0.4
0.6
0.8
1.0
$A_1 = \begin{pmatrix} 0 & -5 \\ -5 & 0 \end{pmatrix}$
0
5
10
15
20
25
30
Time
C
$A_2 = \begin{pmatrix} 0 & 5 \\ 5 & 0 \end{pmatrix}$
Time
Sp. 1 and 2
Sp. 1 alone
Sp. 2 alone
No sp.

Figure 5

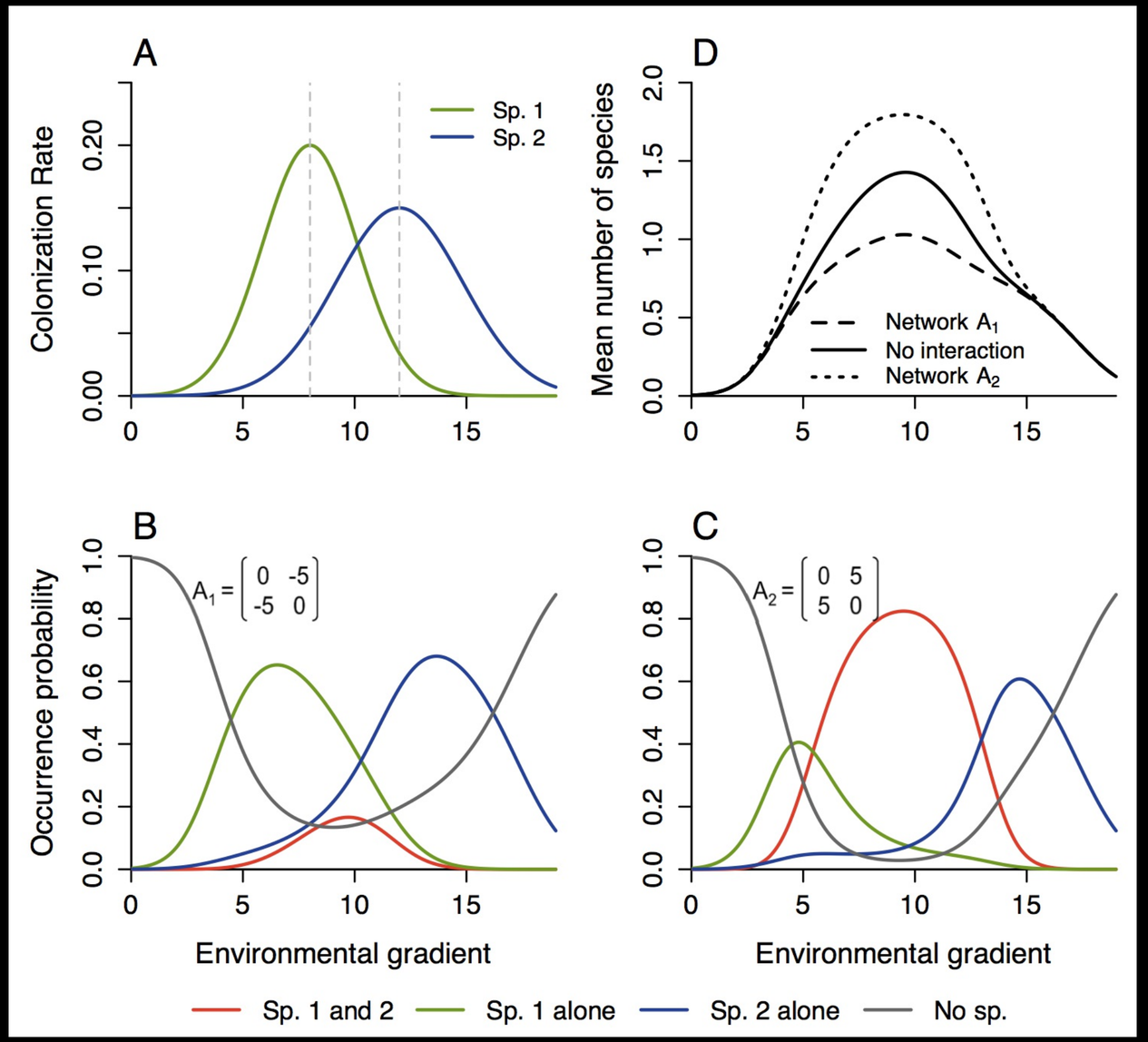

A
Colonization Rate
0.00
0.10
0.20
0
5
10
15
Sp. 1
Sp. 2
D
Mean number of species
0.0
0.5
1.0
1.5
2.0
Network A_1
No interaction
Network A_2
B
Occurrence probability
$A_1 = \begin{bmatrix} 0 & -5 \\ -5 & 0 \end{bmatrix}$
Environmental gradient
C
$A_2 = \begin{bmatrix} 0 & 5 \\ 5 & 0 \end{bmatrix}$
Environmental gradient
Sp. 1 and 2
Sp. 1 alone
Sp. 2 alone
No sp.

Figure 6

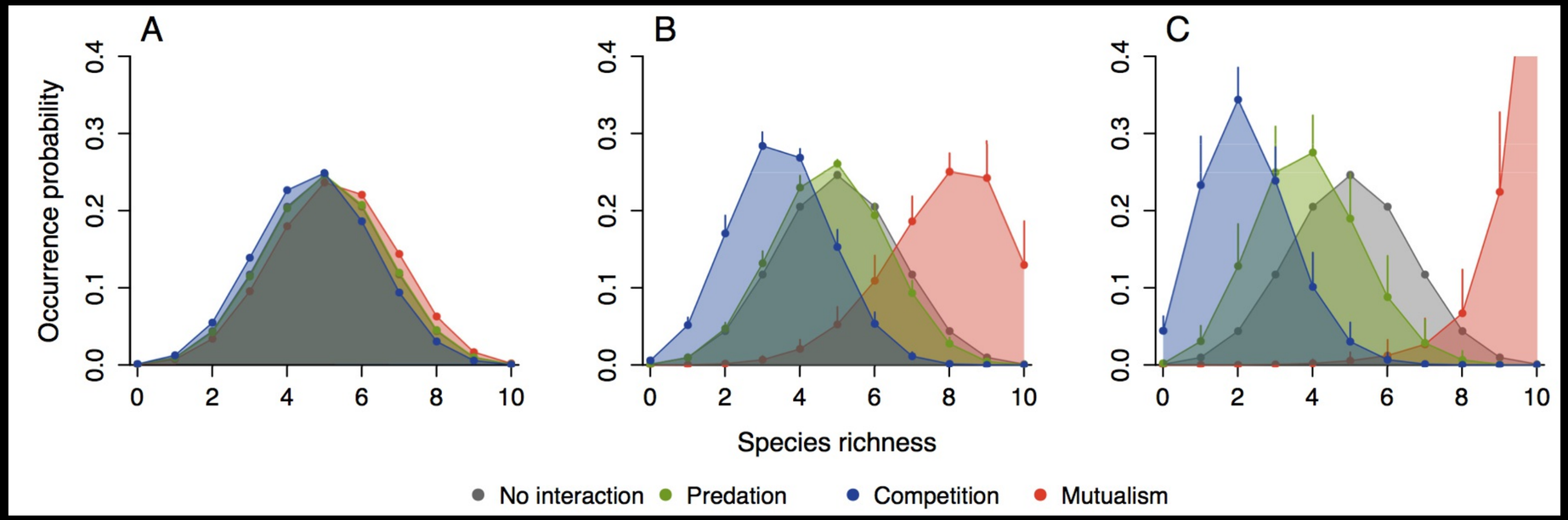

A
B
C
Occurrence probability
0.0
0.1
0.2
0.3
0.4
0
2
4
6
8
10
Species richness
No interaction
Predation
Competition
Mutualism

Figure 7

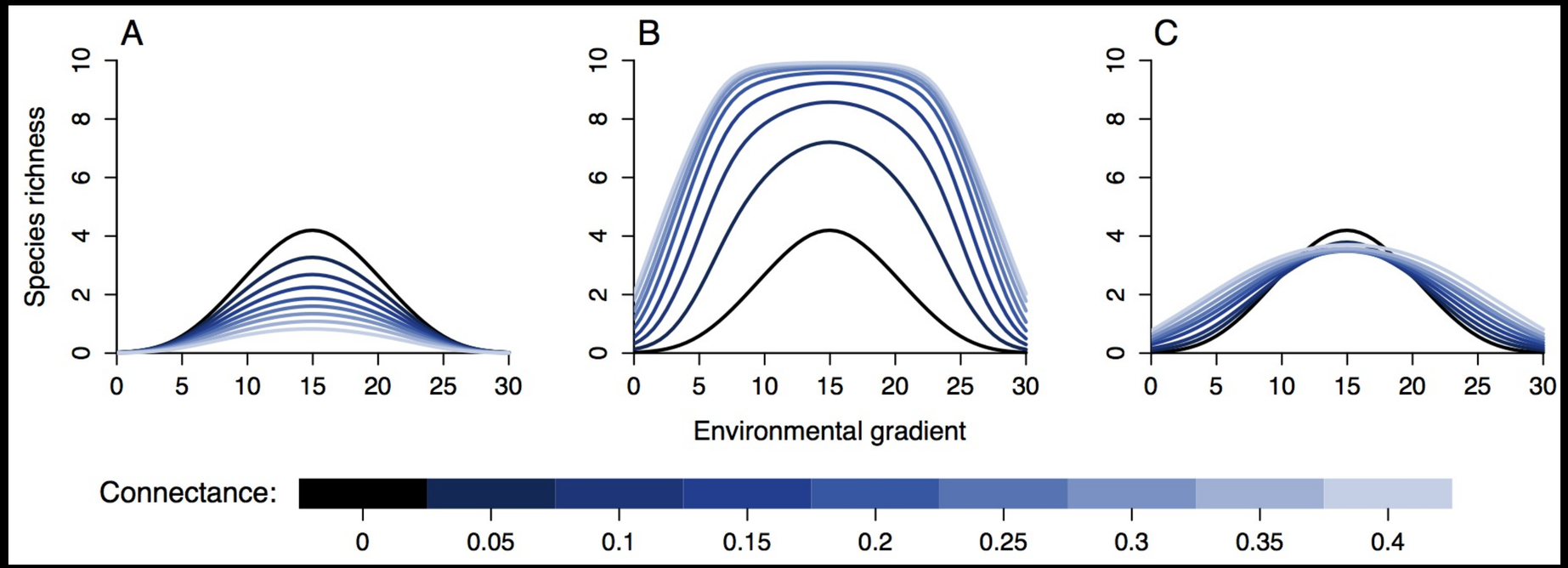

A
B
C
Species richness
0
2
4
6
8
10
0
5
10
15
20
25
30
Environmental gradient
Connectance:
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Figure 8

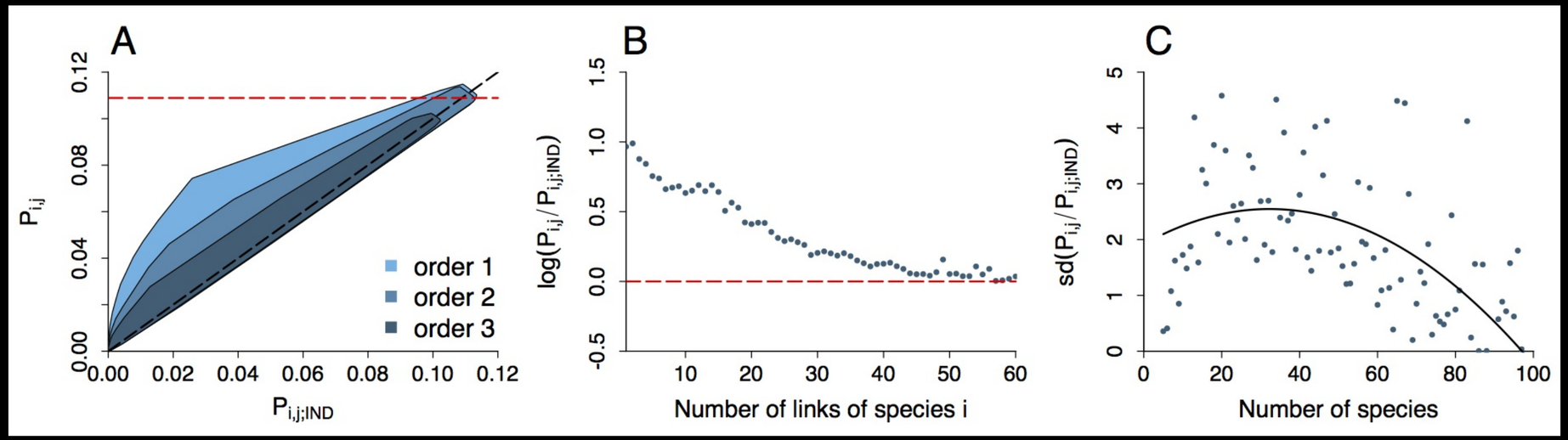

A
B
C
$P_{i,j}$
$P_{i,j;IND}$
0.00
0.04
0.08
0.12
0.00
0.02
0.04
0.06
0.08
0.10
0.12
order 1
order 2
order 3
$\log(P_{i,j}/P_{i,j;IND})$
-0.5
0.0
0.5
1.0
1.5
10
20
30
40
50
60
Number of links of species i
$sd(P_{i,j}/P_{i,j;IND})$
0
1
2
3
4
5
0
20
40
60
80
100
Number of species

Figure 9

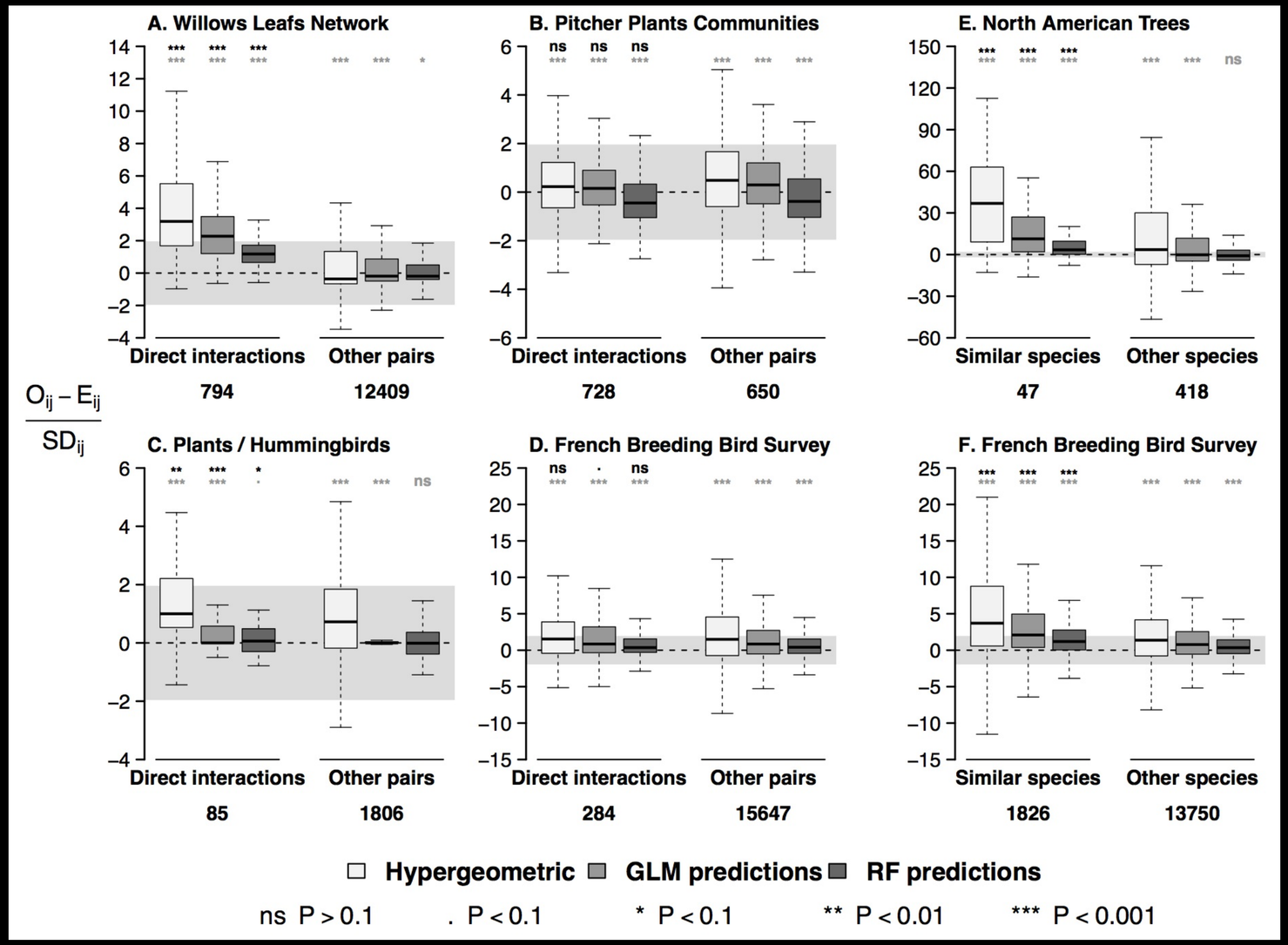

A. Willows Leafs Network
B. Pitcher Plants Communities
E. North American Trees
C. Plants / Hummingbirds
D. French Breeding Bird Survey
F. French Breeding Bird Survey
$\frac{O_{ij} - E_{ij}}{SD_{ij}}$
Direct interactions
Other pairs
Similar species
Other species
794
12409
728
650
47
418
85
1806
284
15647
1826
13750
Hypergeometric
GLM predictions
RF predictions
ns P > 0.1
. P < 0.1
* P < 0.1
** P < 0.01
*** P < 0.001

Figure 10

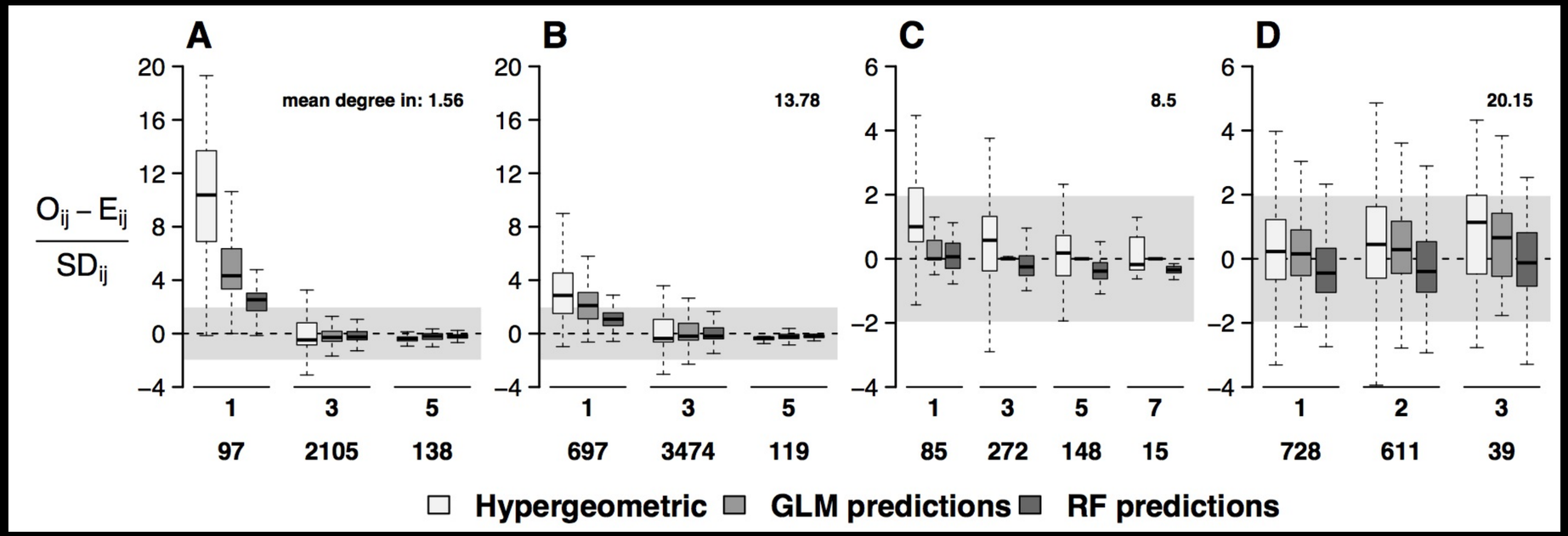

A
B
C
D
mean degree in: 1.56
13.78
8.5
20.15
$\frac{O_{ij} - E_{ij}}{SD_{ij}}$
1
3
5
7
2
97
2105
138
697
3474
119
85
272
148
15
728
611
39
Hypergeometric
GLM predictions
RF predictions

Figure 11

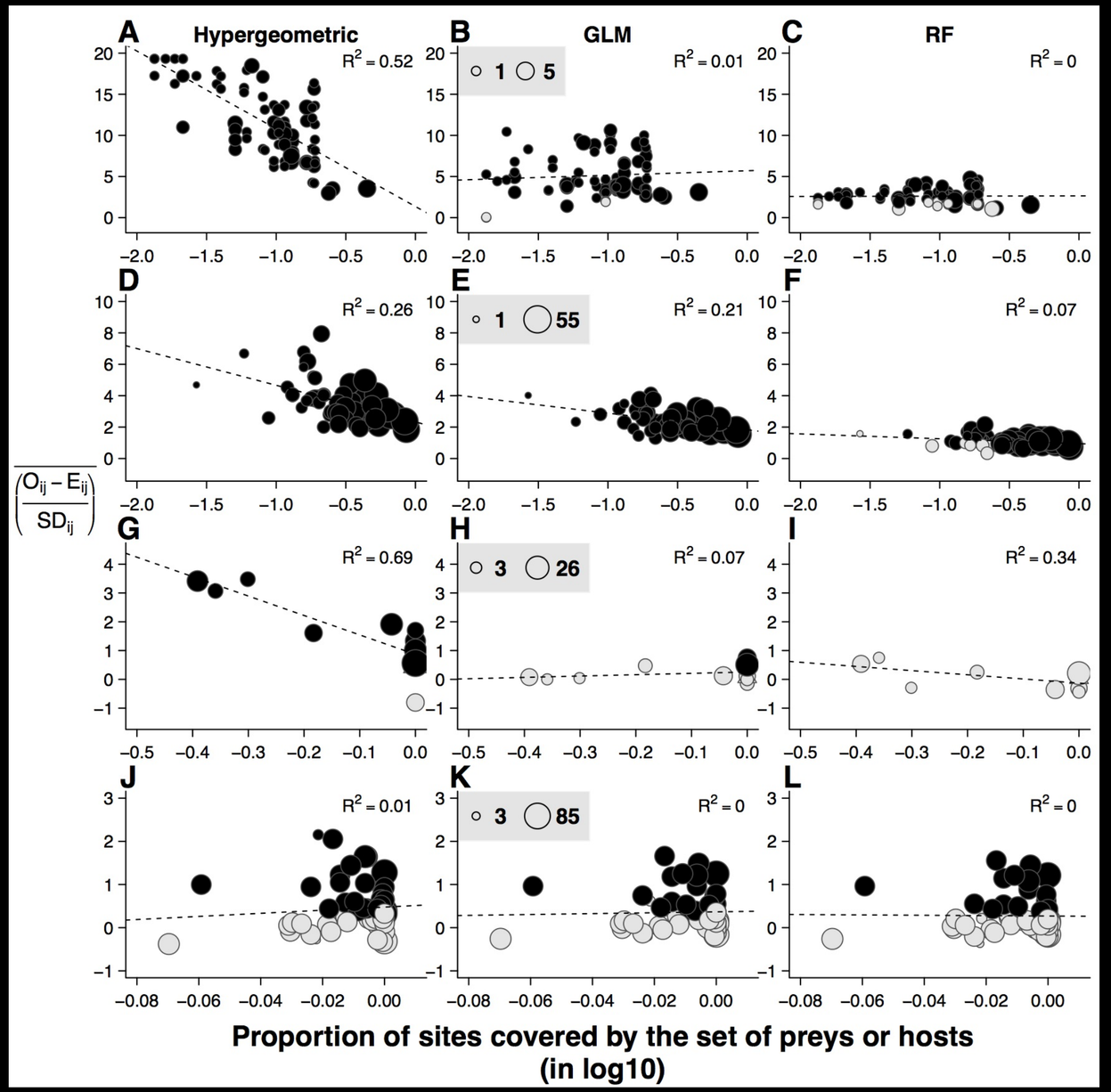

A
Hypergeometric
$R^2 = 0.52$
B
GLM
1 5
$R^2 = 0.01$
C
RF
$R^2 = 0$
D
$R^2 = 0.26$
E
1 55
$R^2 = 0.21$
F
$R^2 = 0.07$
G
$R^2 = 0.69$
H
3 26
$R^2 = 0.07$
I
$R^2 = 0.34$
J
$R^2 = 0.01$
K
3 85
$R^2 = 0$
L
$R^2 = 0$
$\left(\frac{O_{ij} - E_{ij}}{SD_{ij}}\right)$
Proportion of sites covered by the set of preys or hosts
(in log10)

Figure 12

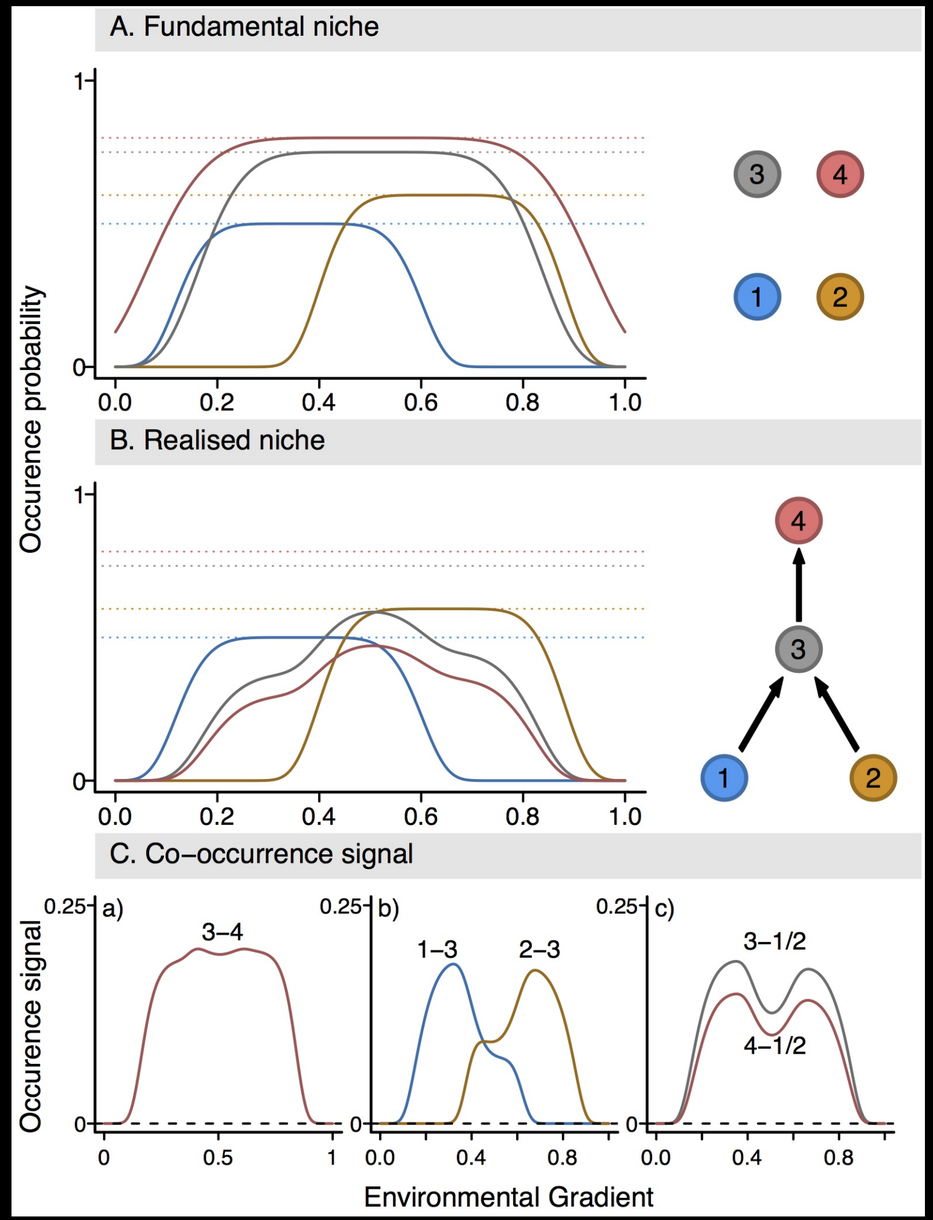

A. Fundamental niche
Occurence probability
1
0
0.0
0.2
0.4
0.6
0.8
1.0
3
4
1
2
B. Realised niche
Occurence probability
1
0
0.0
0.2
0.4
0.6
0.8
1.0
4
3
1
2
C. Co−occurrence signal
Occurence signal
0.25
0
a)
3–4
0
0.5
1
b)
1–3
2–3
0.0
0.4
0.8
c)
3–1/2
4–1/2
Environmental Gradient

Figure 13

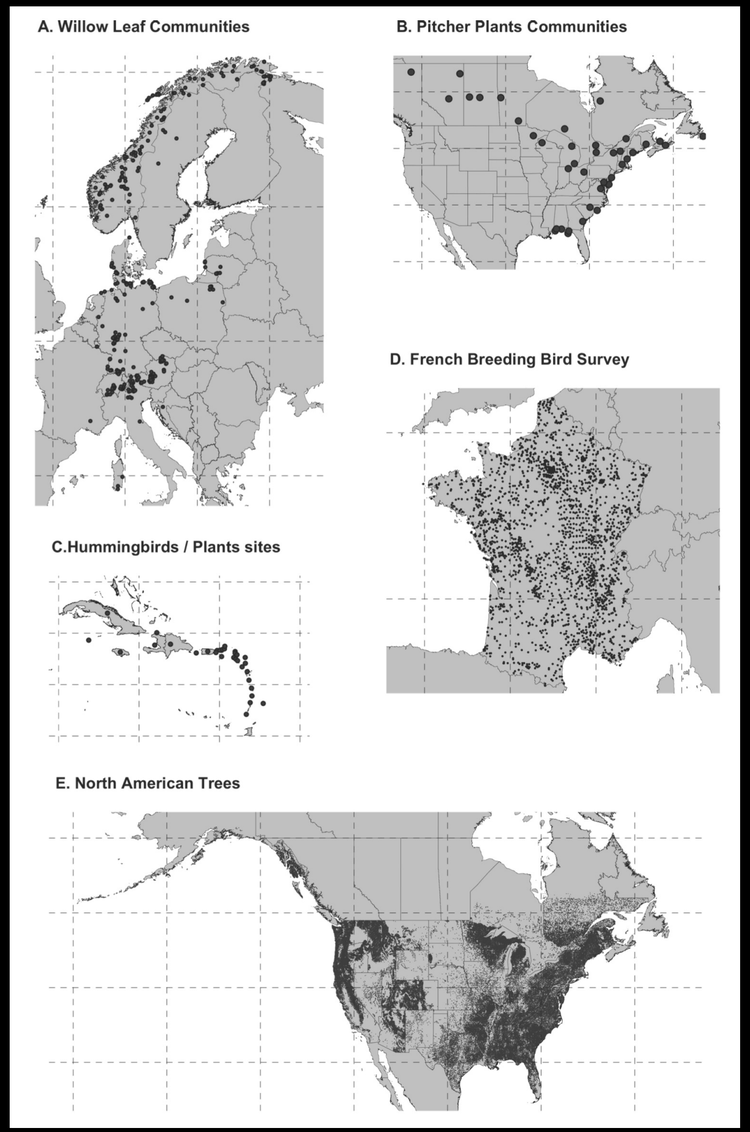

A. Willow Leaf Communities
B. Pitcher Plants Communities
D. French Breeding Bird Survey
C.Hummingbirds / Plants sites
E. North American Trees

Figure 14

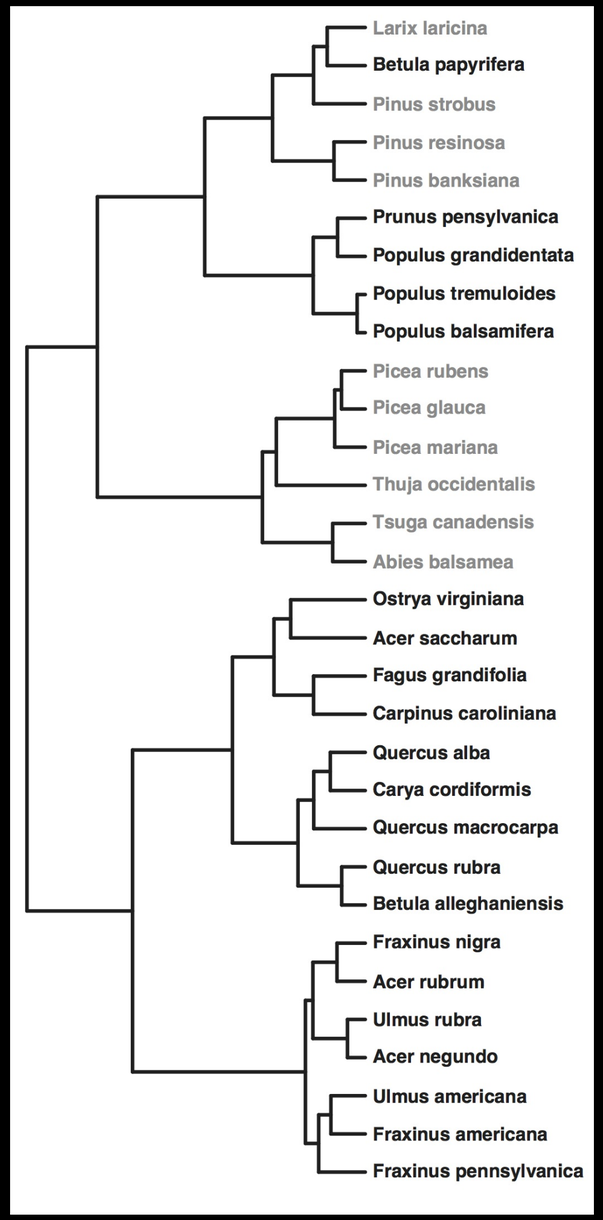
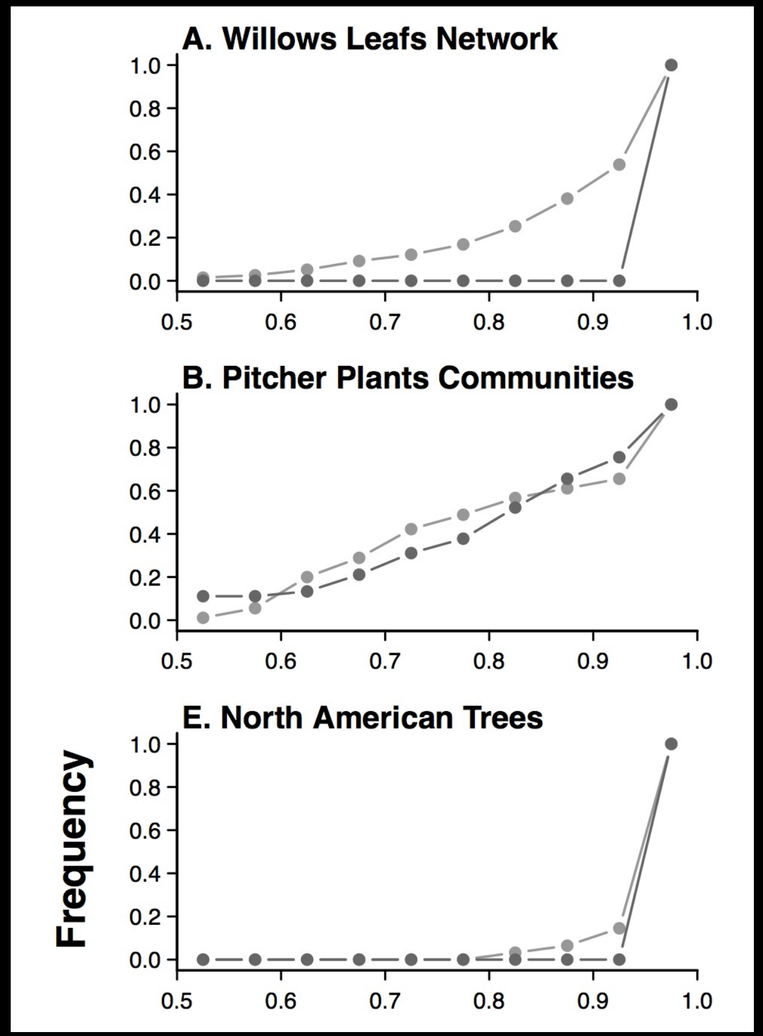

Larix laricina
Betula papyrifera
Pinus strobus
Pinus resinosa
Pinus banksiana
Prunus pensylvanica
Populus grandidentata
Populus tremuloides
Populus balsamifera
Picea rubens
Picea glauca
Picea mariana
Thuja occidentalis
Tsuga canadensis
Abies balsamea
Ostrya virginiana
Acer saccharum
Fagus grandifolia
Carpinus caroliniana
Quercus alba
Carya cordiformis
Quercus macrocarpa
Quercus rubra
Betula alleghaniensis
Fraxinus nigra
Acer rubrum
Ulmus rubra
Acer negundo
Ulmus americana
Fraxinus americana
Fraxinus pennsylvanica

Figure 15


A. Willows Leafs Network
B. Pitcher Plants Communities
E. North American Trees
Frequency
0.0
0.2
0.4
0.6
0.8
1.0
0.5
0.6
0.7
0.8
0.9
1.0

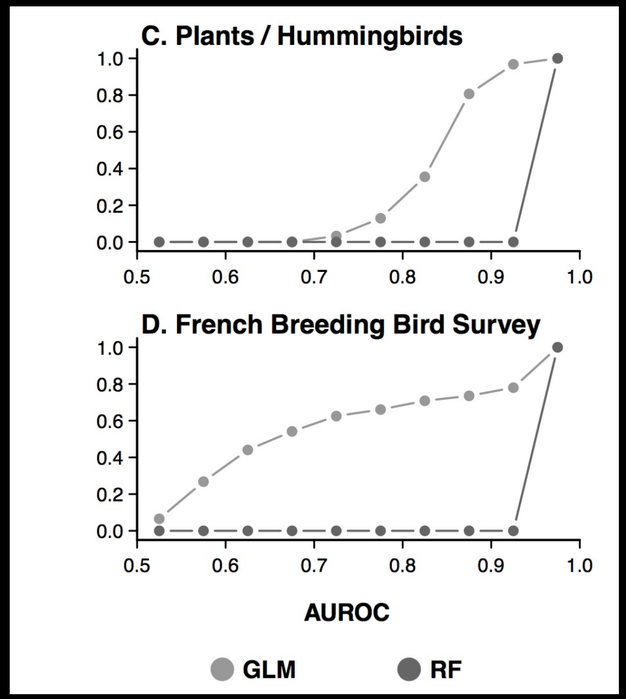

C. Plants / Hummingbirds
D. French Breeding Bird Survey
0.0
0.2
0.4
0.6
0.8
1.0
0.5
0.6
0.7
0.8
0.9
1.0
AUROC
GLM
RF

Figure 16

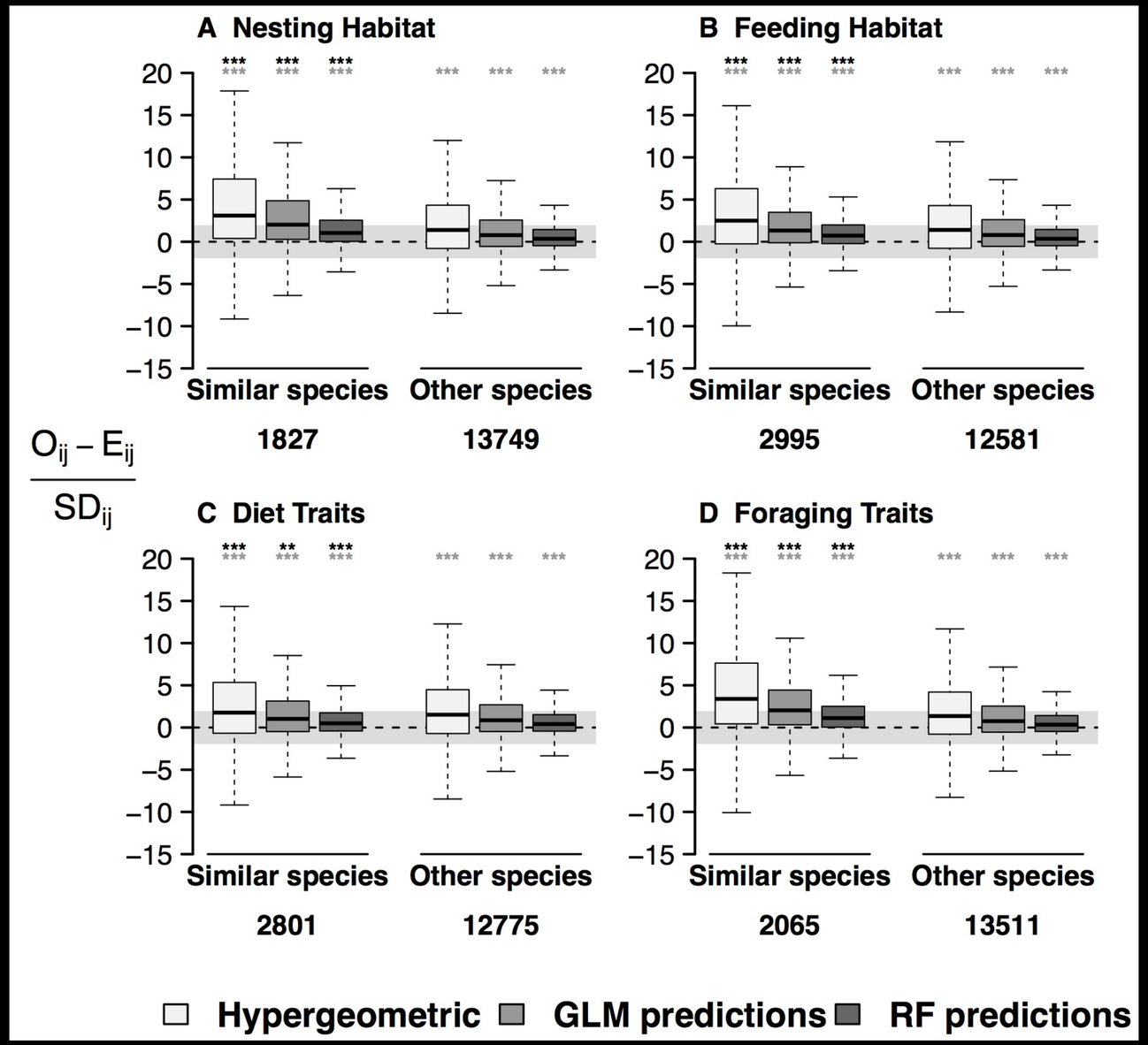

A Nesting Habitat
B Feeding Habitat
C Diet Traits
D Foraging Traits
$\frac{O_{ij} - E_{ij}}{SD_{ij}}$
Similar species
Other species
1827
13749
2995
12581
2801
12775
2065
13511
Hypergeometric
GLM predictions
RF predictions

Figure 17

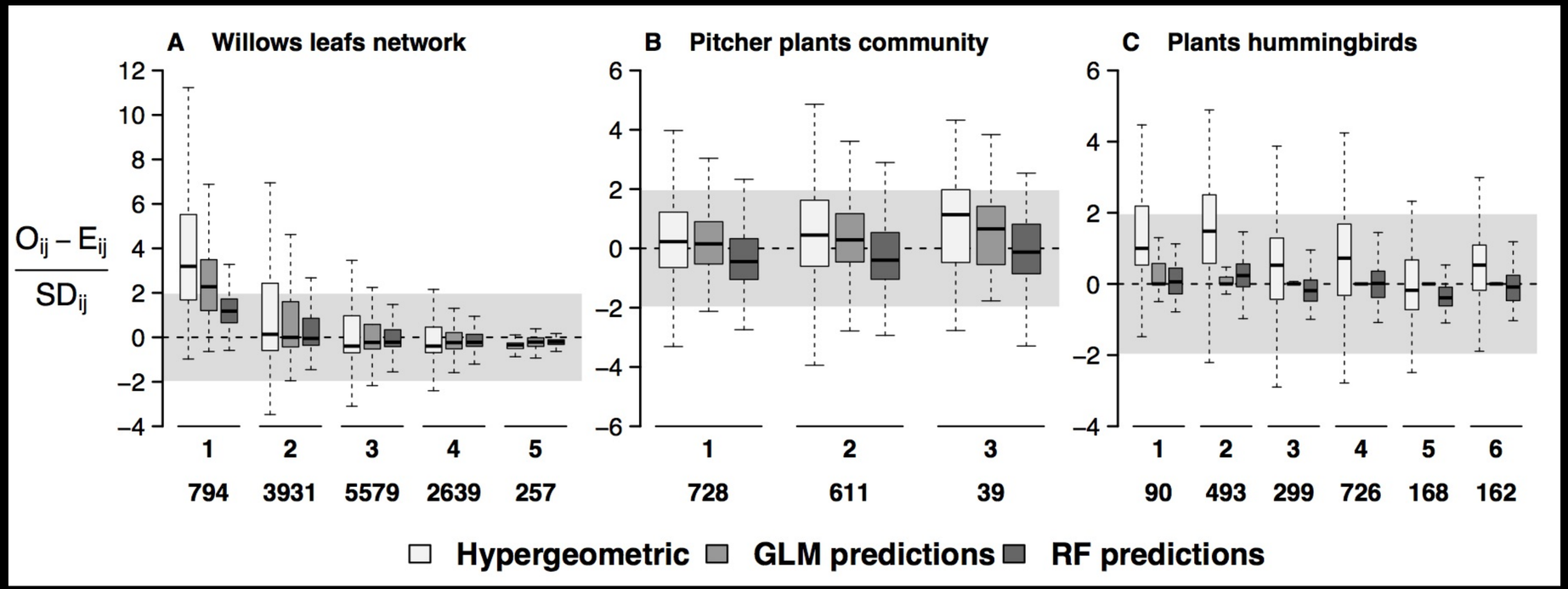

A Willows leafs network
B Pitcher plants community
C Plants hummingbirds
$\frac{O_{ij} - E_{ij}}{SD_{ij}}$
12
10
8
6
4
2
0
−2
−4
6
4
2
0
−2
−4
−6
1 2 3 4 5
794 3931 5579 2639 257
1 2 3
728 611 39
1 2 3 4 5 6
90 493 299 726 168 162
Hypergeometric
GLM predictions
RF predictions

Figure 18

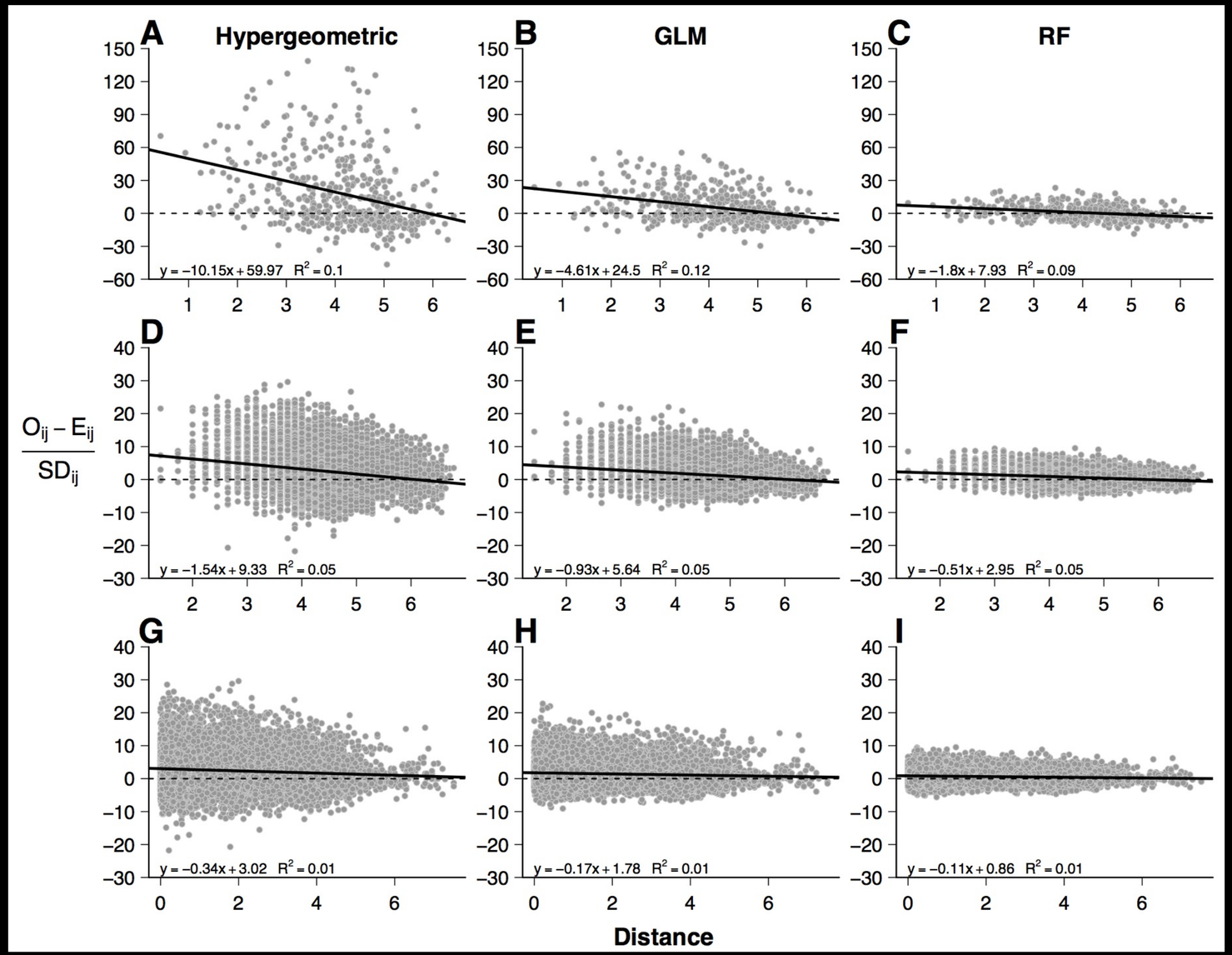

A
Hypergeometric
y = −10.15x + 59.97 R² = 0.1
B
GLM
y = −4.61x + 24.5 R² = 0.12
C
RF
y = −1.8x + 7.93 R² = 0.09
D
y = −1.54x + 9.33 R² = 0.05
E
y = −0.93x + 5.64 R² = 0.05
F
y = −0.51x + 2.95 R² = 0.05
G
y = −0.34x + 3.02 R² = 0.01
H
y = −0.17x + 1.78 R² = 0.01
I
y = −0.11x + 0.86 R² = 0.01
Oij − Eij / SDij
Distance

Figure 19

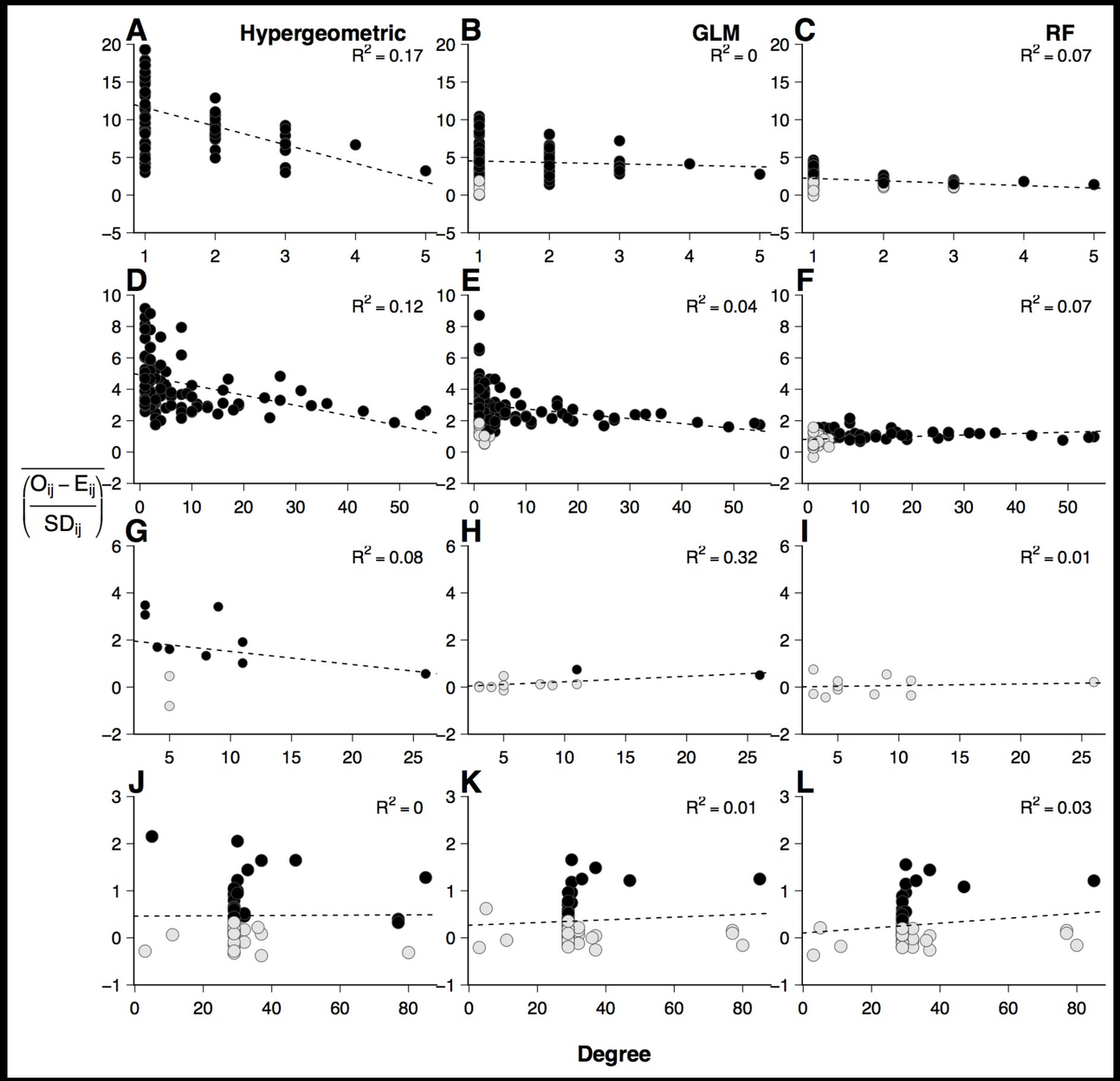

A
Hypergeometric
$R^2 = 0.17$
B
GLM
$R^2 = 0$
C
RF
$R^2 = 0.07$
D
$R^2 = 0.12$
E
$R^2 = 0.04$
F
$R^2 = 0.07$
G
$R^2 = 0.08$
H
$R^2 = 0.32$
I
$R^2 = 0.01$
J
$R^2 = 0$
K
$R^2 = 0.01$
L
$R^2 = 0.03$
$\overline{\left(\frac{O_{ij} - E_{ij}}{SD_{ij}}\right)}$
Degree

Figure 21

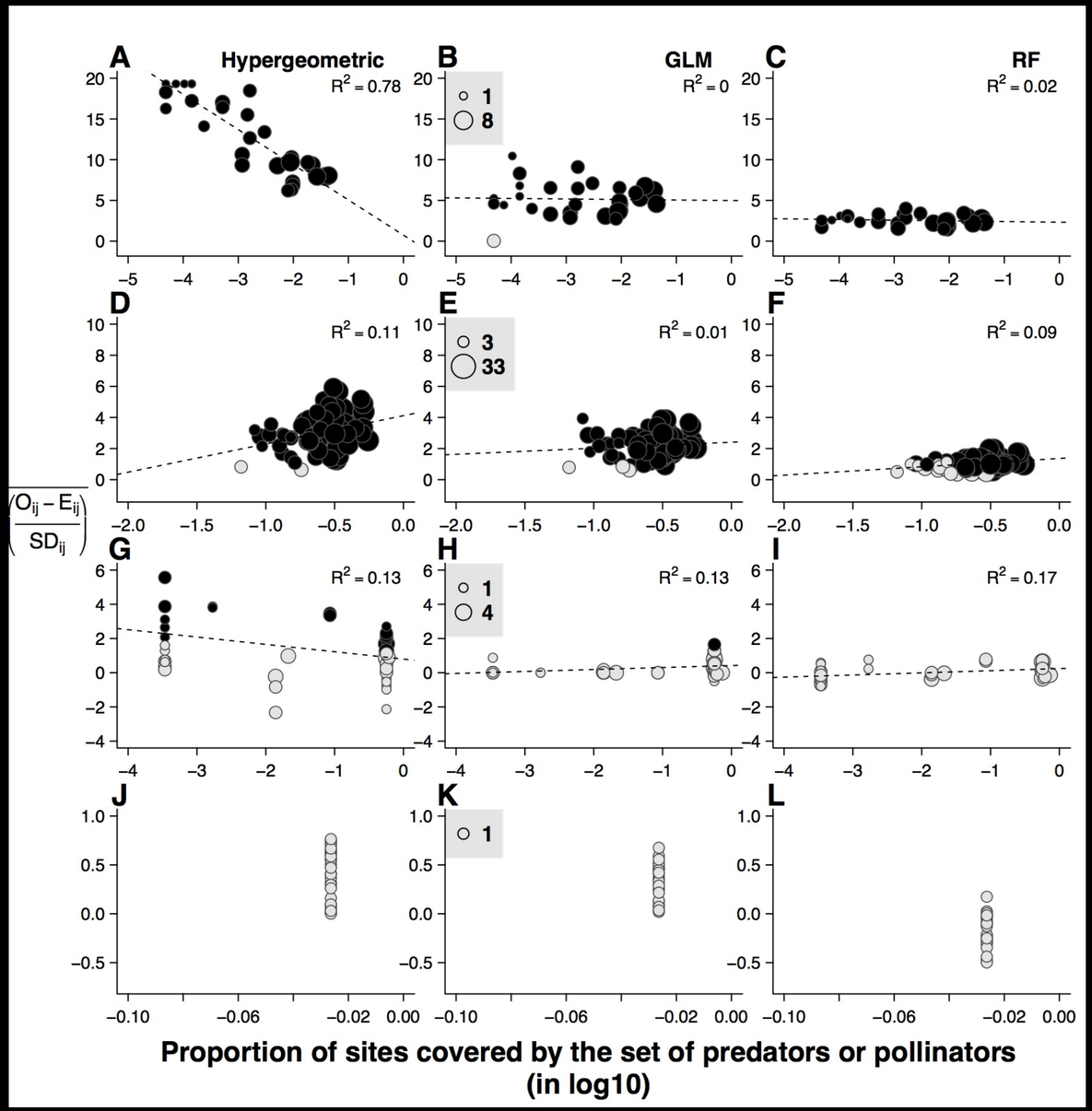

A
Hypergeometric
R^2 = 0.78
B
GLM
R^2 = 0
1
8
C
RF
R^2 = 0.02
D
R^2 = 0.11
E
3
33
R^2 = 0.01
F
R^2 = 0.09
G
R^2 = 0.13
H
1
4
R^2 = 0.13
I
R^2 = 0.17
J
K
1
L
$\left(\frac{O_{ij} - E_{ij}}{SD_{ij}}\right)$
Proportion of sites covered by the set of predators or pollinators (in log10)

Figure 21

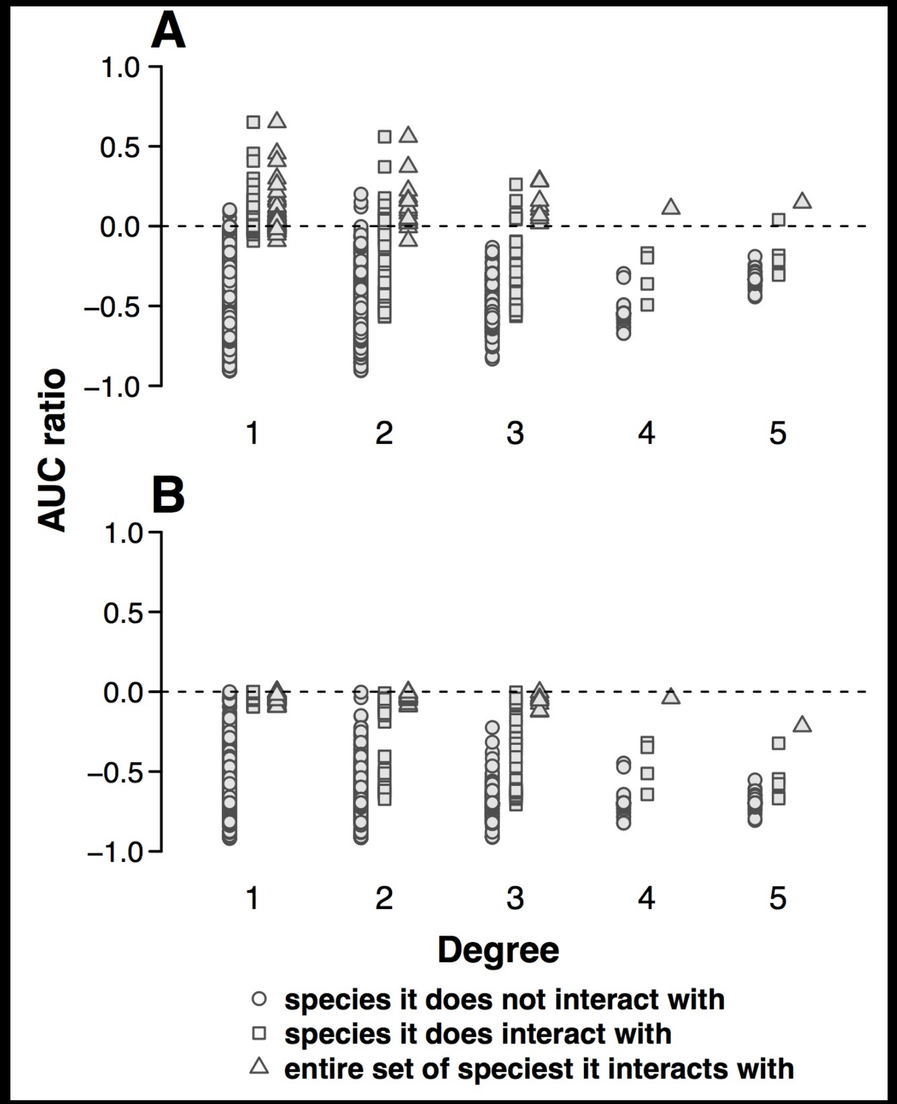
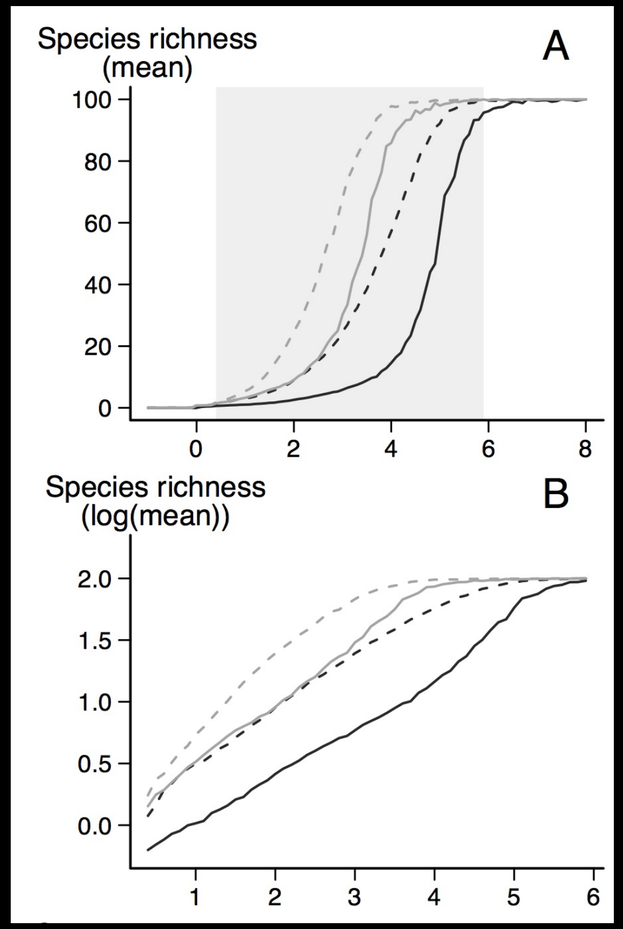
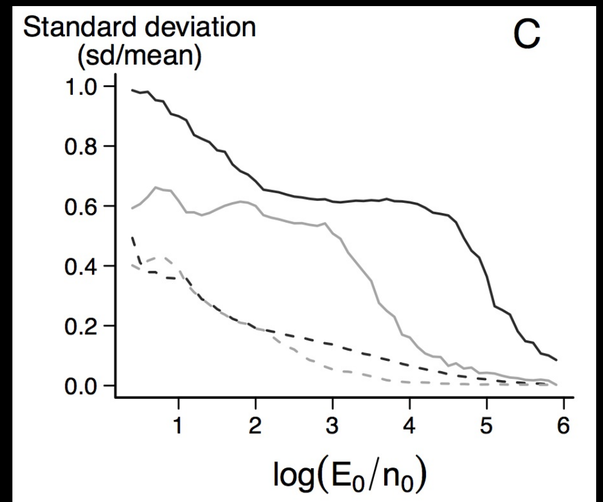

A
B
AUC ratio
1.0
0.5
0.0
−0.5
−1.0
1
2
3
4
5
Degree
species it does not interact with
species it does interact with
entire set of speciest it interacts with

Figure 22





Scenario	MVP	extinction
A	n_0	random
B	n_0	costs-based
C	$n_0 m^{-.75}$	random
D	$n_0 m^{-.75}$	costs-based

Figure 23

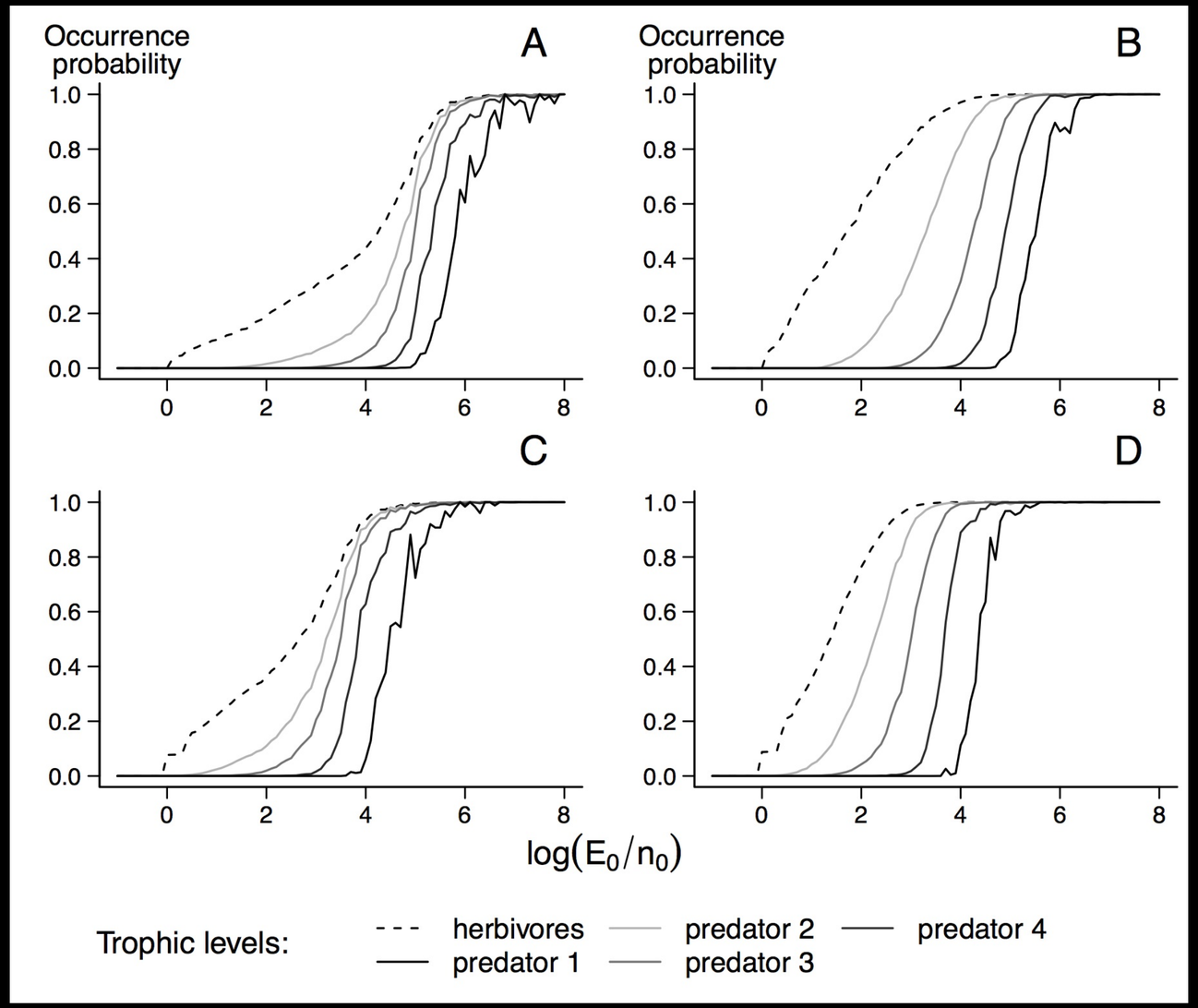

Occurrence probability
A
B
C
D
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
log(E0/n0)
Trophic levels:
herbivores
predator 1
predator 2
predator 3
predator 4

Figure 24

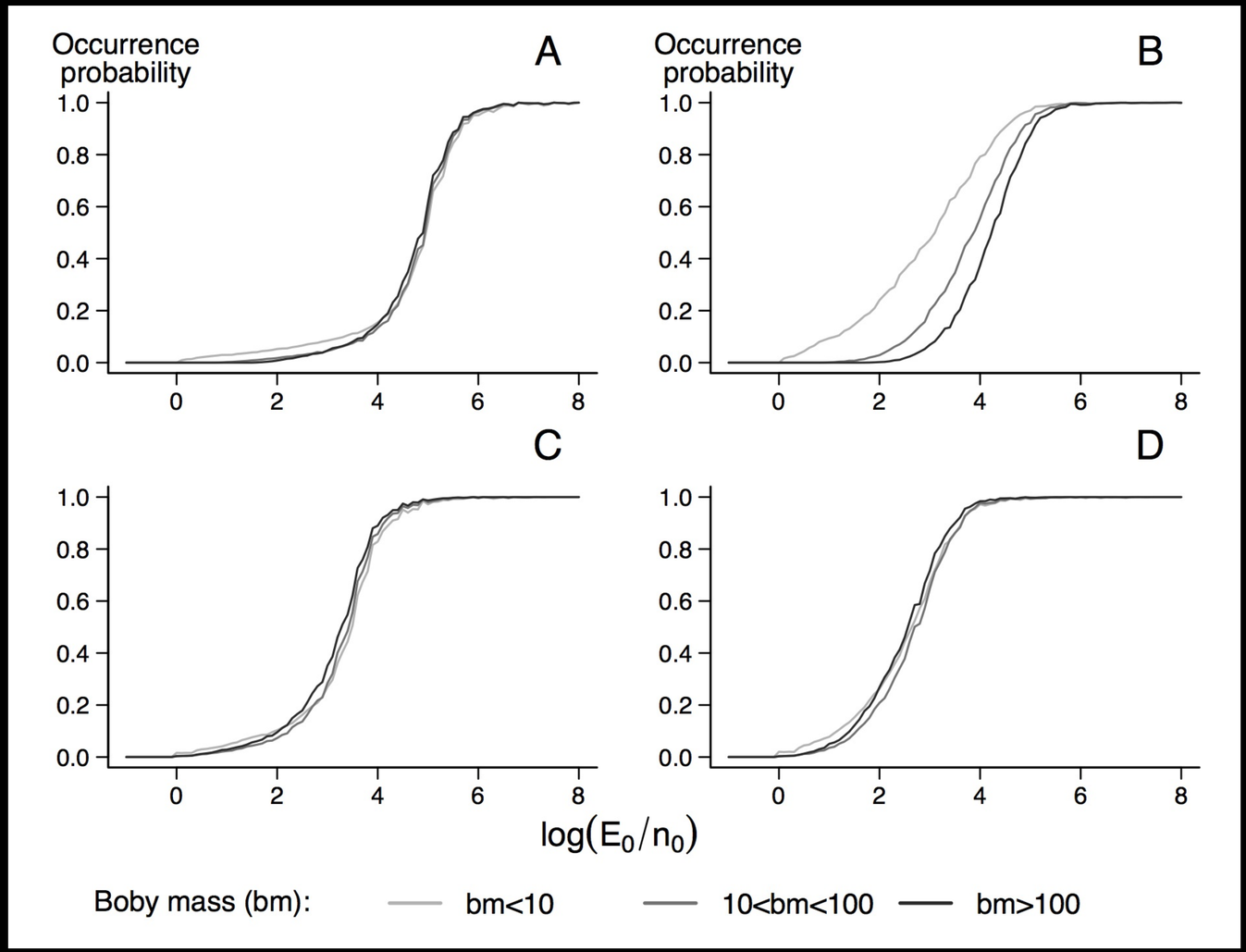
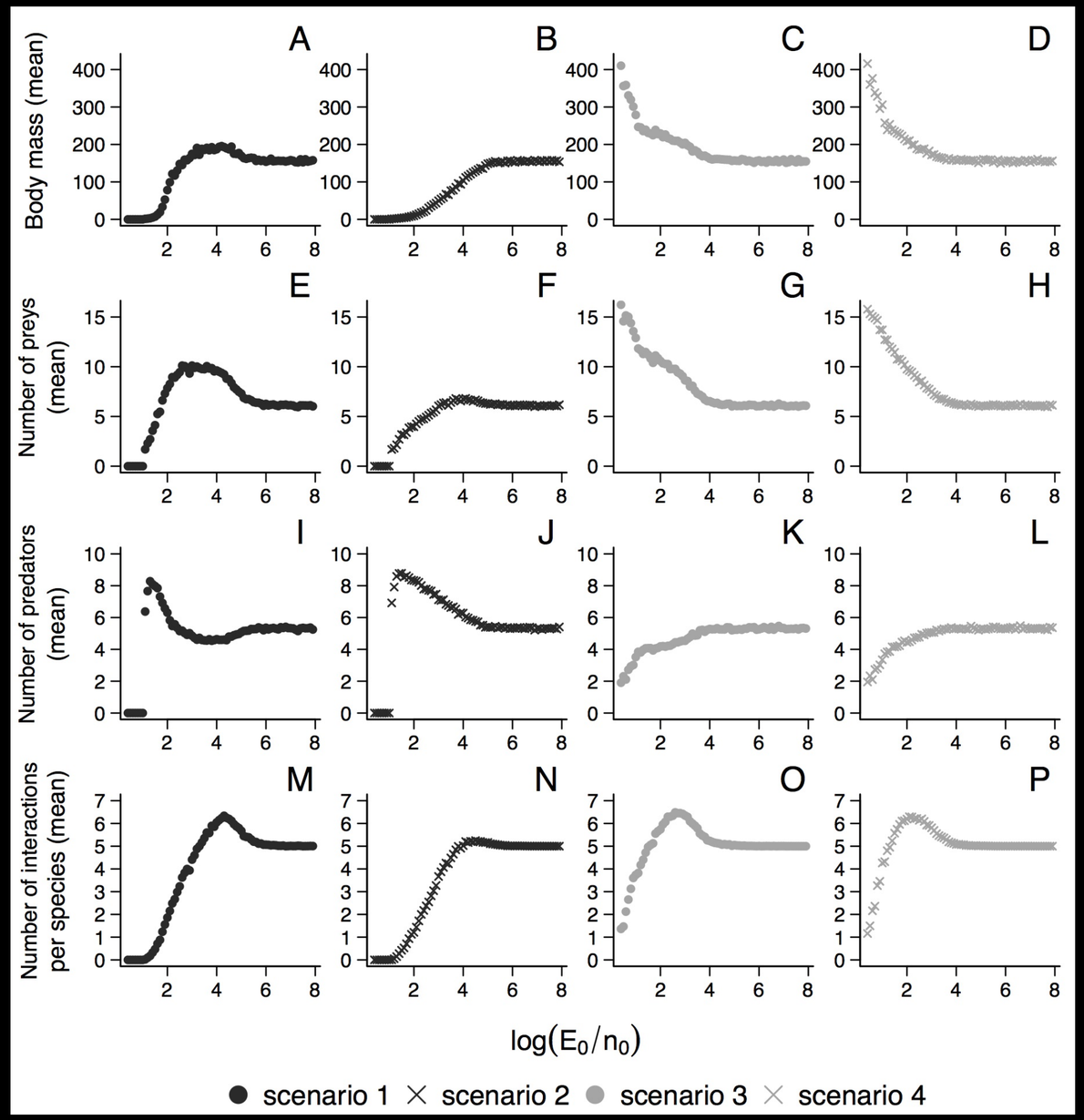

Occurrence probability
A
B
C
D
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
log(E0/n0)
Boby mass (bm):
bm<10
10<bm<100
bm>100

Figure 25


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Body mass (mean)
Number of preys (mean)
Number of predators (mean)
Number of interactions per species (mean)
log(E0/n0)
scenario 1
scenario 2
scenario 3
scenario 4

Phylopic

- Silhouette image found on Phylopic
- Silouhette Ichneumonidae ; credit Melissa Broussard.

Salix data set

Species on slides 120-121:

1- Female of Euura lapponica ovipositing on Salix lapponum ;

2- leaf midrib pea gall induced by Pontania norvegica on Salix borealis ;

3- Larva of Pontania pustulator insid1 e opened leaf midrib bean gall on Salix phylicifolia ;

> 641 site-visits over 29 years, and on 165,424 galls representing 96 herbivore nodes and 52 plant nodes. The dissections and rearings yielded 42,129 natural enemies belonging to 126 species

Null models

Null models

Since 1970 (following Diamond's paper)

Connor et al., 2013, Ecology.

Null models

Since 1970 (following Diamond's paper)

Connor et al., 2013, Ecology.

Pattern-generating models based on randomization of ecological data

Some elements are fixed, others vary randomly.

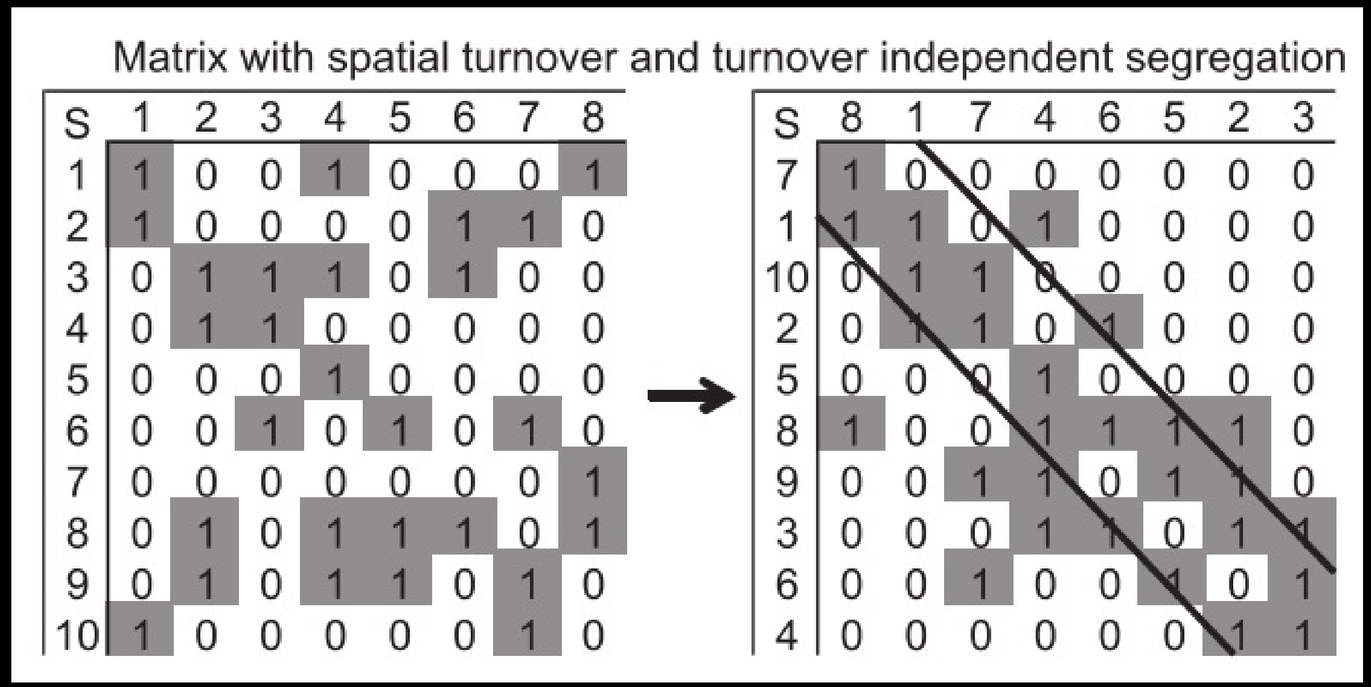
Null models

What would be expected in the absence of a given mechanism?

Detection of pattern in binary presence–absence matrices.

Ulrich & Gotelli, 2013, Oikos

Test 15 indices.



Null models

> Null models of species associations should, thus, be used only to reveal the structure of co-occurrence data.

Difficult to assign to a particular process

MacArthur and Wilson Limits

Releasing the assumption of a constant pool of species is a KEY

MacArthur and Wilson Limits

Releasing the assumption of a constant pool of species is a KEY

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All solutions increase the complexity.