Detection of Latent Biotic Covariation Embedded in Environmental Gradient Responses

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Summary:

In population ecology, the interaction among organisms and their environment is a predominant topic of interest. It is well known that both abiotic factors and biotic interactions structure ecological communities. However, the relative importance of these factors in controlling community composition is openly debated and may have profound implications for management of communities and our ability to predict community responses to perturbations. There is currently no unified statistical method for simultaneous analysis of biotic and abiotic factors controlling community composition. Thus, we have developed a method to assess community-wide biotic covariation after accounting for individual species responses to environmental gradients (i.e. abiotic factors). The method is capable of detecting positive, negative and mixed community covariation. Results using our method can be used to generate hypotheses on species interactions and drive future experimental work. *This work supported in part by National Science Foundation award #SC004335

Conclusion:

We have developed a method for detecting community biotic covariation based on pairwise species null-model

The **false positive rate is low** and the **detection rate is high** if the following conditions are met:

① There are more sites in the analysis than organisms or taxonomic groups
② The covariation magnitude is greater than the noise magnitude
③ The more covarying pairs of organisms the better the detection rate (1 pair is usually sufficient)
④ The number of independent gradients has little effect on the method's performance

Future work will address hierarchical species covariation and issues with relative abundance data

Sensitivity Analysis

Independent Parameter Sweeps:

Species (**p**)	20, fixed
Sites (**n**)	10 to 120, steps of 10
Gradients (**q**)	1 to 3, steps of 1
Noise Magnitude (**N**)	10^{-6} to 10^{3}, 12 steps
Covariation Magnitude (**M**)	10^{-6} to 10^{3}, 12 steps
Covarying Pairs (**CVP**)	0 to 5, steps of 1

Experiments:

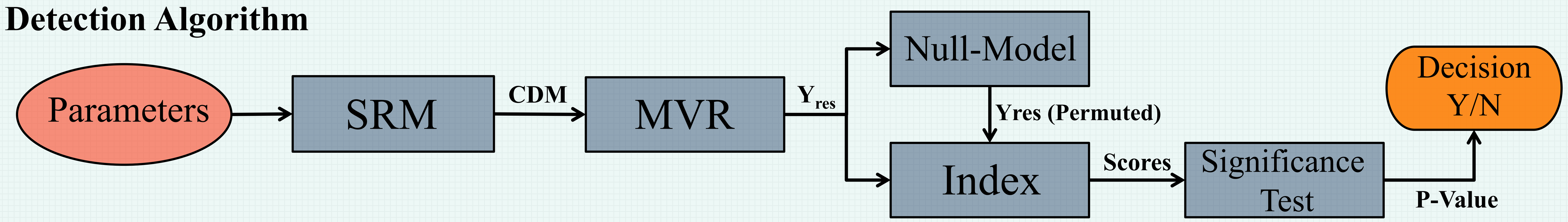
A: False Positive Analysis
680 experiments

B: Positive Community Covariation
25,000 experiments

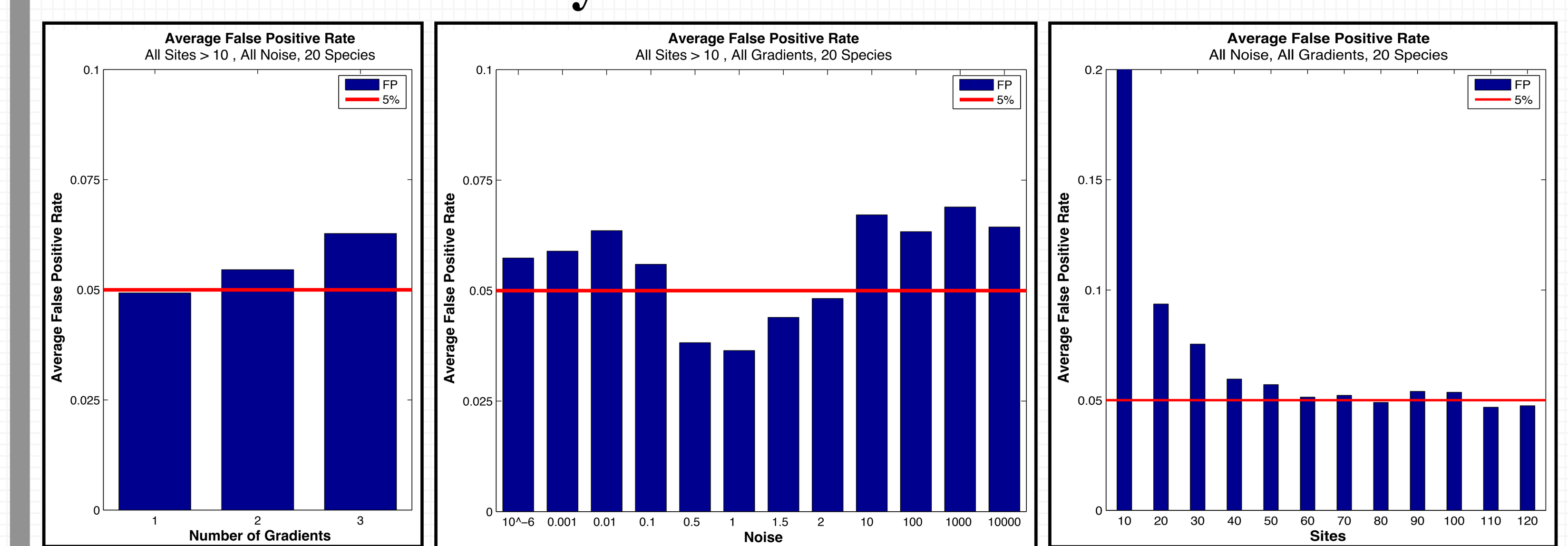
C: Negative Covariation (Not Shown)
25,000 experiments

D: Mixed Covariation (Not Shown)
25,000 experiments

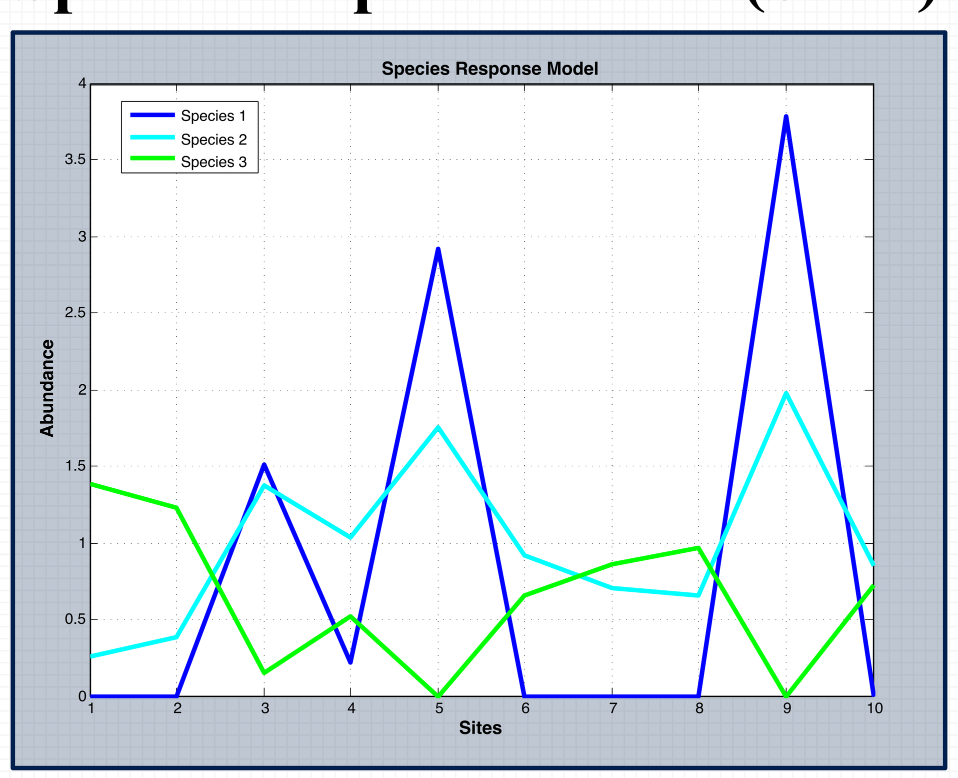
Detection Algorithm



False Positive Analysis



Species Response Model (SRM)



n = 10, **p** = 3, **q** = 1, **N** = 0.001, **M** = 0.01, **CVP** = 1, **Type** = Neg.

$$CDM = X\,B + Y_N + Y_M$$

$$B = \Big[N(0,1)\Big]_{(q+1)\times p} \qquad X = \begin{bmatrix} 1 & \\ 1 & N(0,1) \\ \vdots & \end{bmatrix}_{n\times(q+1)} \qquad Y_N = \Big[N(0,N)\Big]_{n\times p}$$

$$Y_M = \begin{bmatrix} \overbrace{CV_{1,1}\;\; CV_{1,2}}^{CV\,1} & \overbrace{CV_{2,1}\;\; CV_{2,2}}^{CV\,2} & \cdots & \overbrace{CV_{CVP,1}\;\; CV_{CVP,2}}^{CVP} & \begin{matrix}0&0&0\\0&0&0\\0&0&0\\&\cdots&\end{matrix} \end{bmatrix}_{n\times p}$$

$N(0,M)$ $N(0,M)$ $N(0,M)$

Positive: $CV_{1,1} \times (+1)$

Negative: $CV_{1,1} \times (-1)$

Multivariate Regression (MVR)

$$B_{EST} = (X^T X)^{-1} X^T\,CDM$$

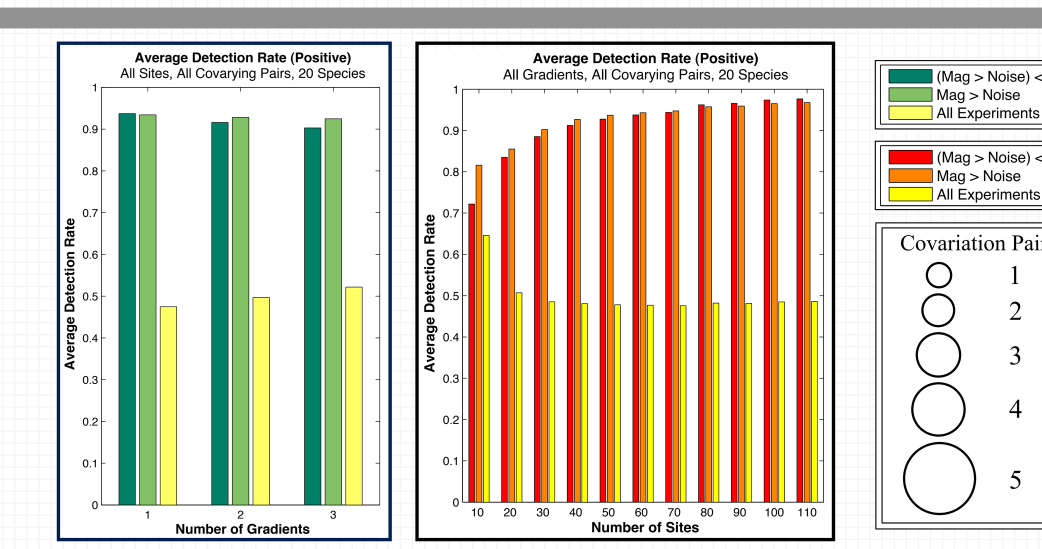
$$Y_{EST} = X\,B_{EST}$$

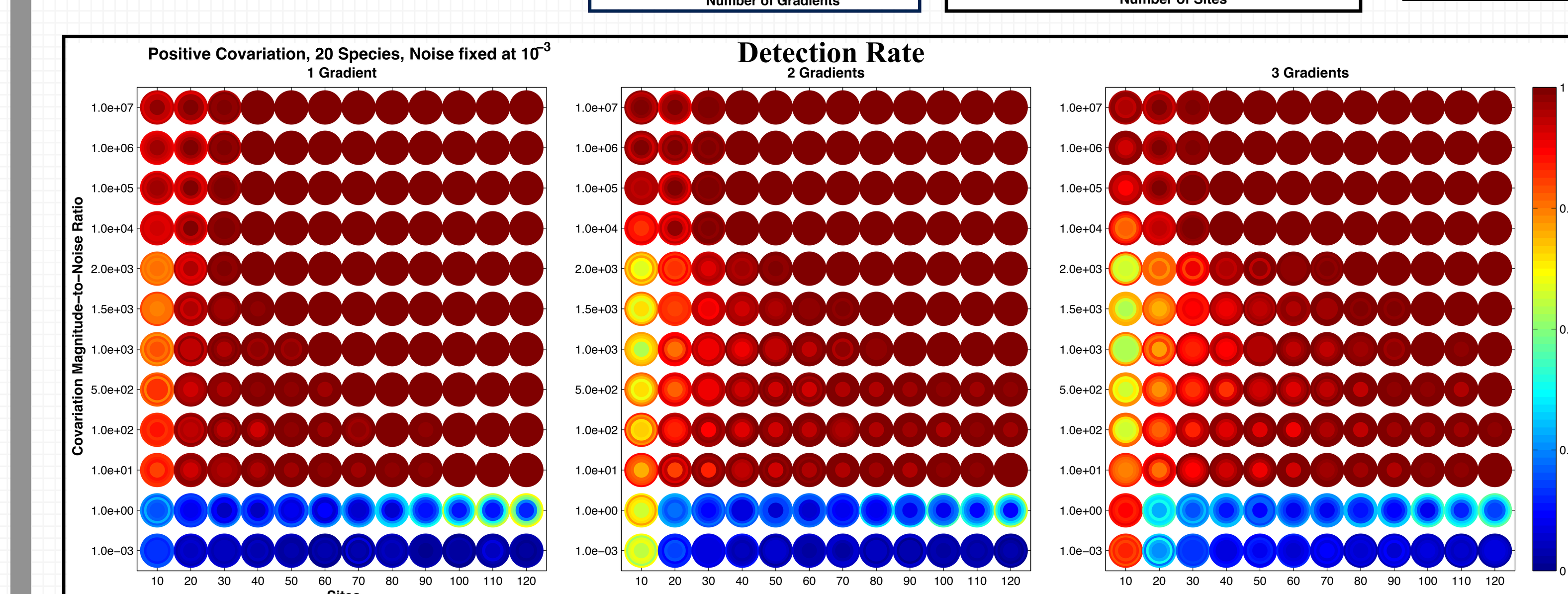
$$Y_{RES} = CDM - Y_{EST}$$

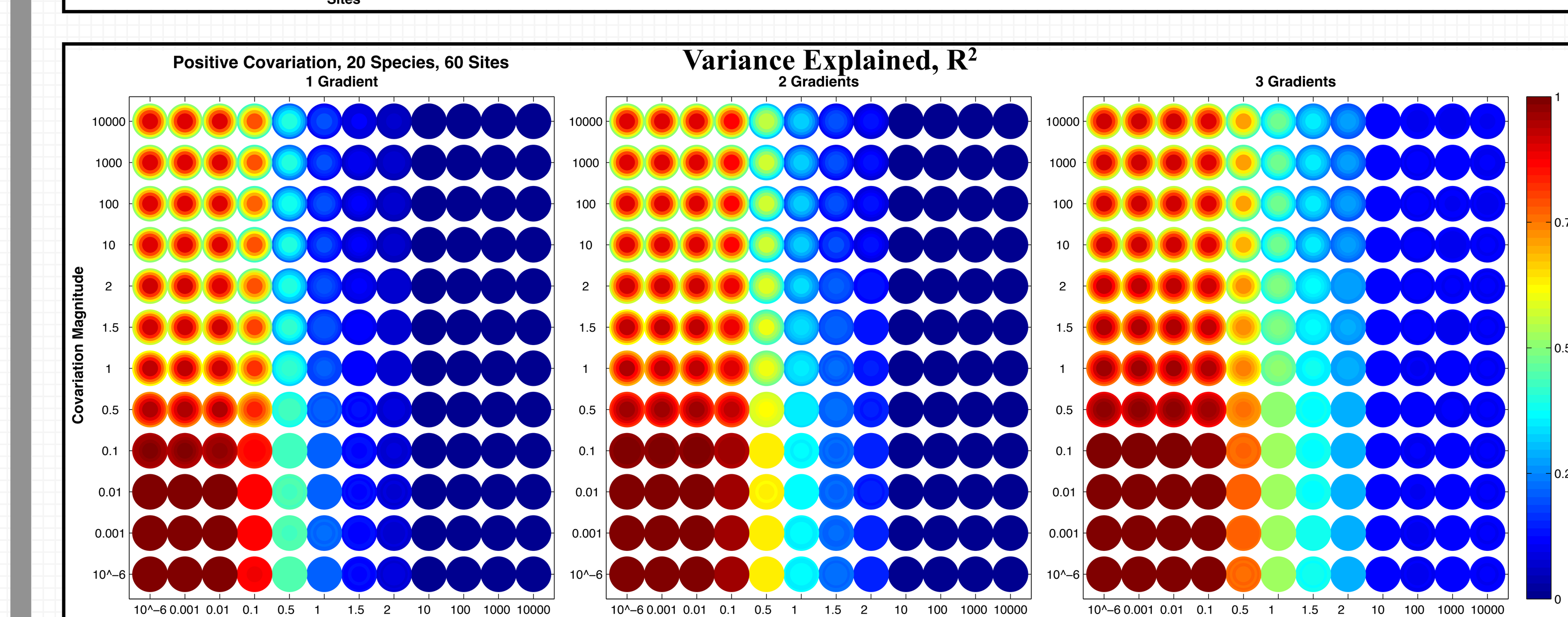
Parameter Definitions

CDM: Community Data Matrix
B: Species Response Parameters
X: Environmental Gradient
$\mathbf{Y_N}$: Noise Matrix
$\mathbf{Y_M}$: Species Covariation Matrix
$\mathbf{B_{EST}}$: Estimated SR Parameters
$\mathbf{Y_{EST}}$: Estimated Species Response
$\mathbf{Y_{RES}}$: Response Residuals
n: Sites
p: Species
q: Gradients
N: Noise Parameter
M: Covariation Parameter
CVP: # of Covarying Pairs
Type: Pos/Neg Covariation

Positive Community Covariation Detection

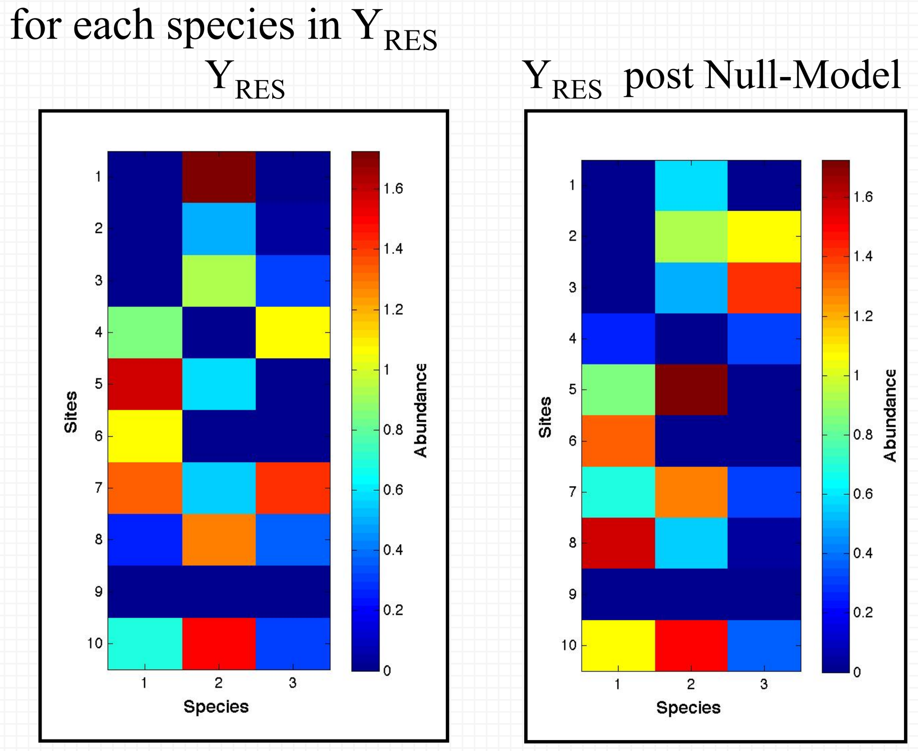






Null-Model

Randomly rearrange nonzero abundances for each species in Y_{RES}



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$\mathbf{I_{YRES}}$: Weighted average of all pairwise species correlations
*Including only sites with mutual non-zero abundance

$$I_{Y_{RES}} = \frac{1}{W_T}\sum_{i=1}^{p-1}\sum_{j=i+1}^{p} W(S_i,S_j)\,\left|corr(S_i,S_j)\right|$$

$$W_T = \sum_{i=1}^{p-1}\sum_{j=i+1}^{p} W(S_i,S_j)$$

S_i, S_j: ↔ CDM(:, i) , CDM(:, j)
Species Abundance Vectors

$$W(S_i,S_j) = w_1 * w_2 * w_3 * w_4$$

Weights:
$\boldsymbol{w_1}$: Covariance²
$\boldsymbol{w_2}$: Correlation²
$\boldsymbol{w_3}$: % of Sites with Mutual Nonzero Abundance
$\boldsymbol{w_4}$: Average of Covarying Pair's Unexplained Variance

Significance Test

$$Test = \frac{Num(I_{Yres(perm)} \geq I_{Yres})}{100} \qquad Decision := \begin{cases} Y & Test \leq 0.05 \\ N & otherwise \end{cases}$$