Method of predicting reference condition biota affects the performance and interpretation of ecological indices

Charles P. Hawkins[1], Yong Cao[1], & Brett Roper[2]

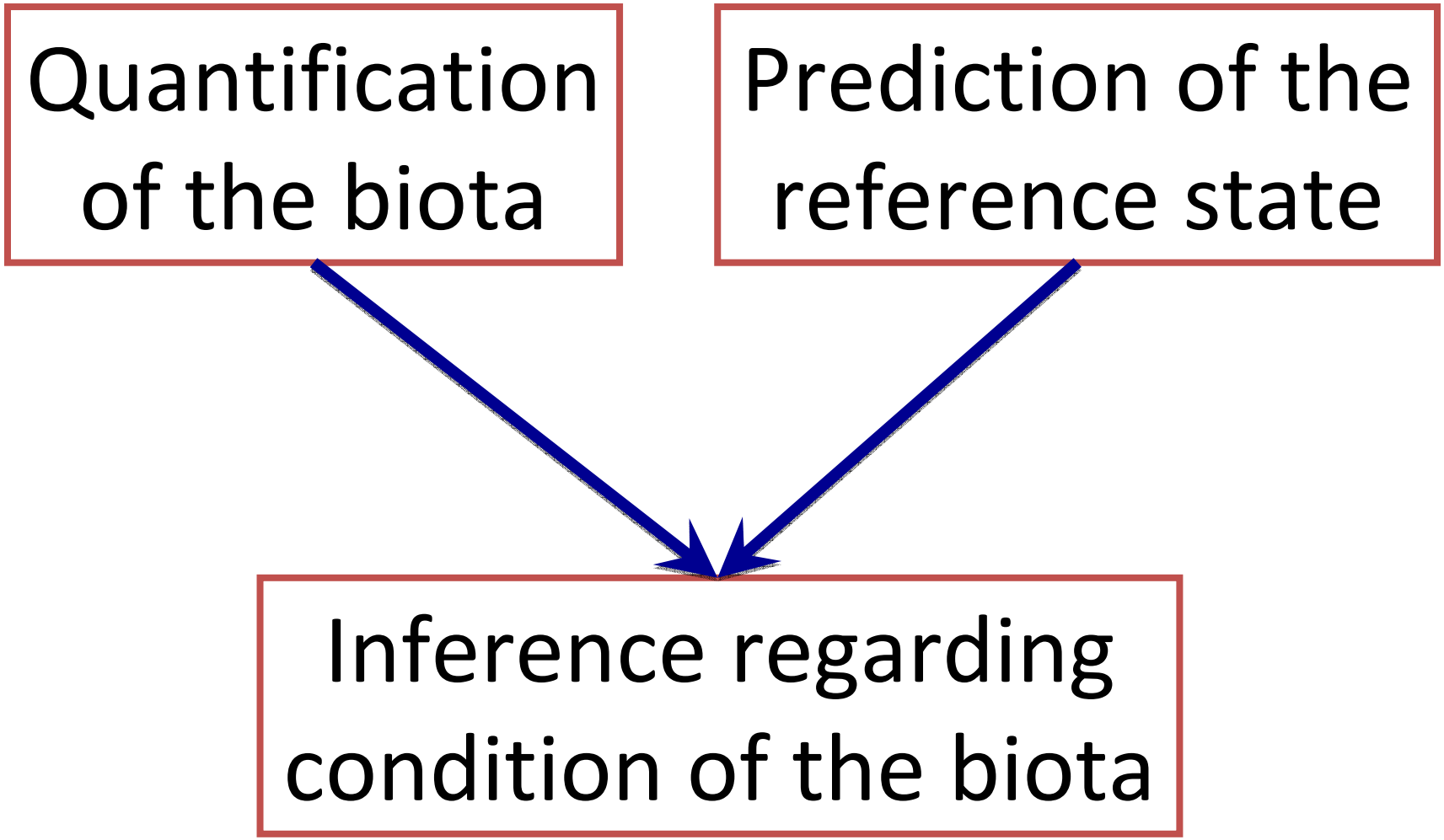
[1]Department of Watershed Sciences
Utah State University, Logan, UT

[2]Fish and Aquatic Ecology Unit
Forestry Sciences Lab, USDA Forest Service
Logan, UT 84321

Desirable Index Properties

1. Relevant – e.g., biological integrity.
2. Interpretable
3. Accurate - responds to ecosystem alteration in expected ways.
4. Precise enough to detect ecologically significant departures from reference conditions.

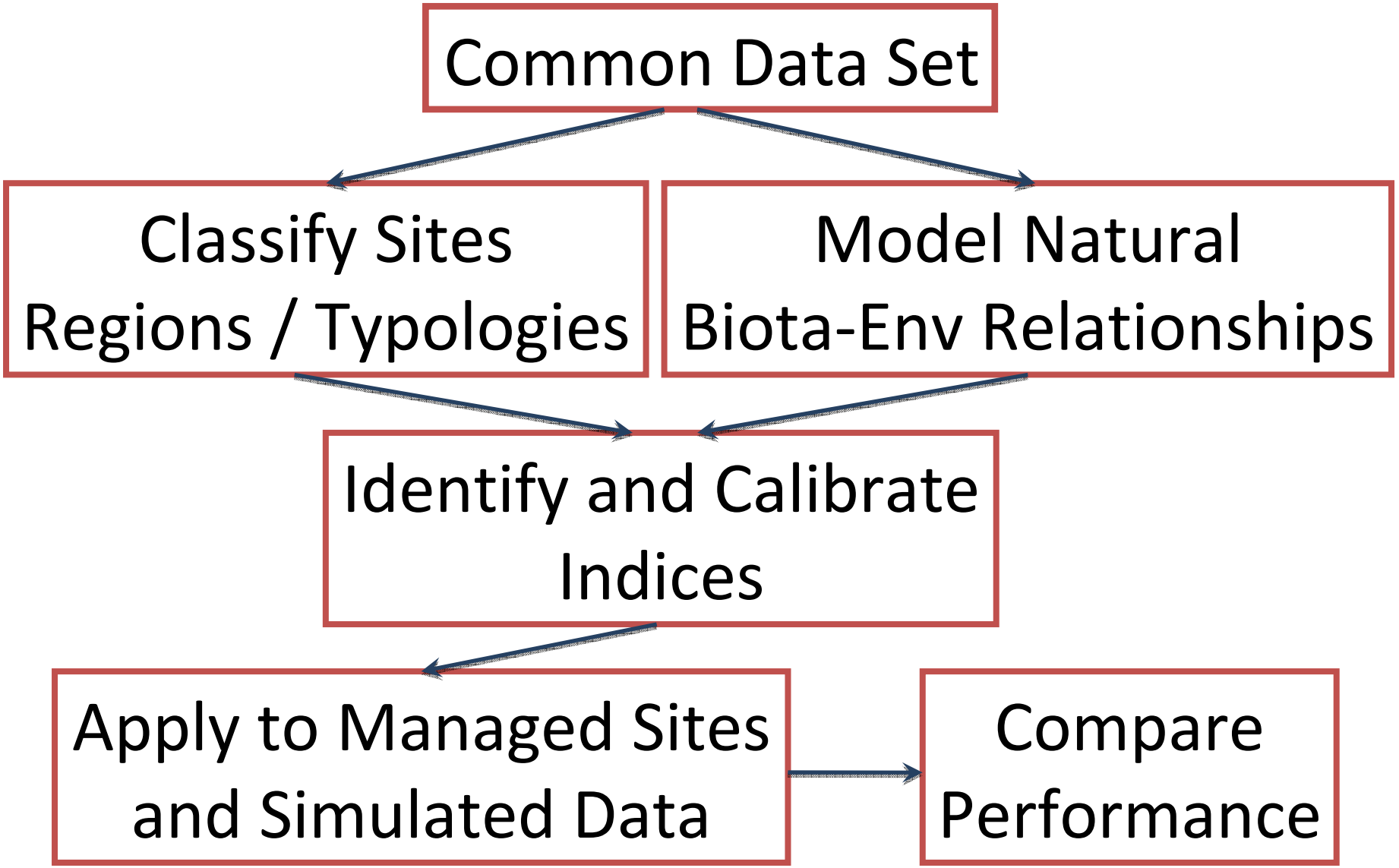
Ecological Assessments Depend on Two Coupled Elements



Previous Evaluations of Index Performance

Index Type & Prediction Method were usually confounded

What to do?


Common Data Set
Classify Sites
Regions / Typologies
Model Natural
Biota-Env Relationships
Identify and Calibrate
Indices
Apply to Managed Sites
and Simulated Data
Compare
Performance

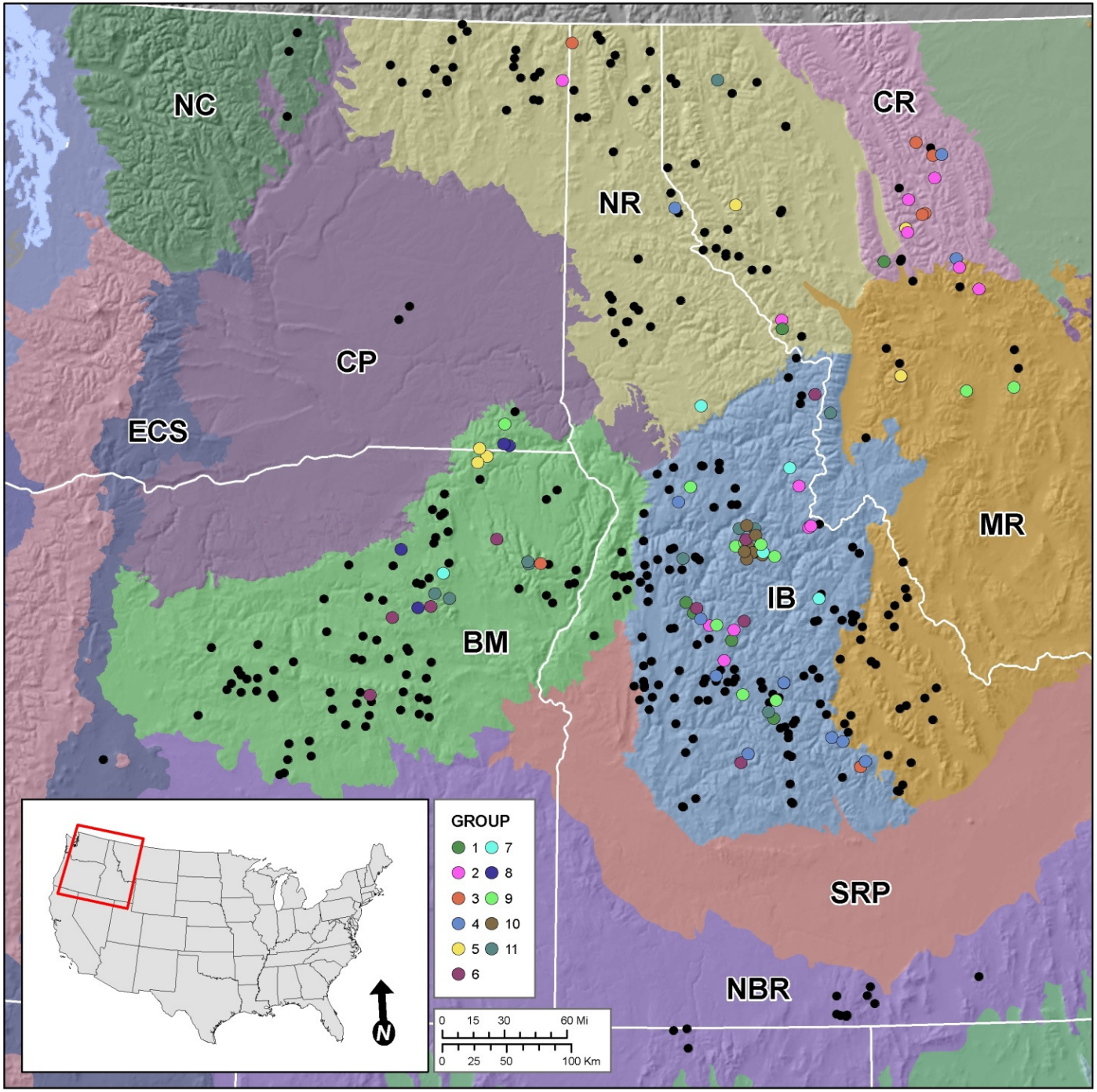
PIBO Project:

94 high-quality reference sites.

255 managed sites.

Targeted riffle collections.

300 count samples.



Compared Two Index Types

1. MMIs: based on 37 candidate metrics previously used in the region.

2. O/E: proportion of expected taxa

8 Index-Prediction Combinations

1. MMIs:
   A. 1 class (null – same prediction everywhere)
   B. Multiple Linear Regression of MMI A
   C. MLR on individual metrics
   D. Classification and Regression Trees (CART) on metrics
   E. Random Forests regression on metrics
2. O/E:
   A. Null - same prediction everywhere
   B. Discriminant Functions model – traditional
   C. Random Forests model

Assessing Performance

1. Precision:
   A. Standard deviation (SD) of reference site values.
   B. 10^{th} percentile of reference site values.
2. Accuracy
   A. R^2 of Random Forests regressions of post-index reference site values on environmental gradients.
   B. Response to known (simulated) alteration of 13 reference sites.
3. Responsiveness:
   A. Mean index value of managed sites.
   B. Student's *t* value for *t*-test between reference and managed sites.
4. Sensitivity:
   A. % of managed sites with index values < 10^{th} percentile of reference site values.

MMI Development

- If metrics modeled, use regression residuals as response ‘metric’.
- Quantify discrimination of reference and test sites.
- Select most discriminatory of correlated metrics.
- Standardize MMIs by dividing by reference site means (i.e., standardized reference mean = 1).

MMIs and Natural Variation (14 natural environmental factors)

Index	# metrics	R^2
MMI-A (null)	13	NA
MMI-B (MMI-A & MLR)	13	0.15
MMI-MLR	12	0 - 0.27
MMI-CART	8	0 - 0.49
MMI-RF	9	0 - 0.16

Simulating Impairment

1. 13 reference quality sites with large collections (up to 2300 individuals).
2. $Y_i = X_i[1-C(1-tv_i)]$.
   A. X_i = number of individuals of taxon *i* in unaltered sample.
   B. C = level of stress (9 levels, 0 to 3.2).
   C. tv_i = tolerance value of taxon *i* (0 to 10/6.5).
   D. Y_i = number of individuals of taxon *i* in stressed sample.
3. Sampled 300 individuals from each large collection following stress and estimate MMI and O/E values.

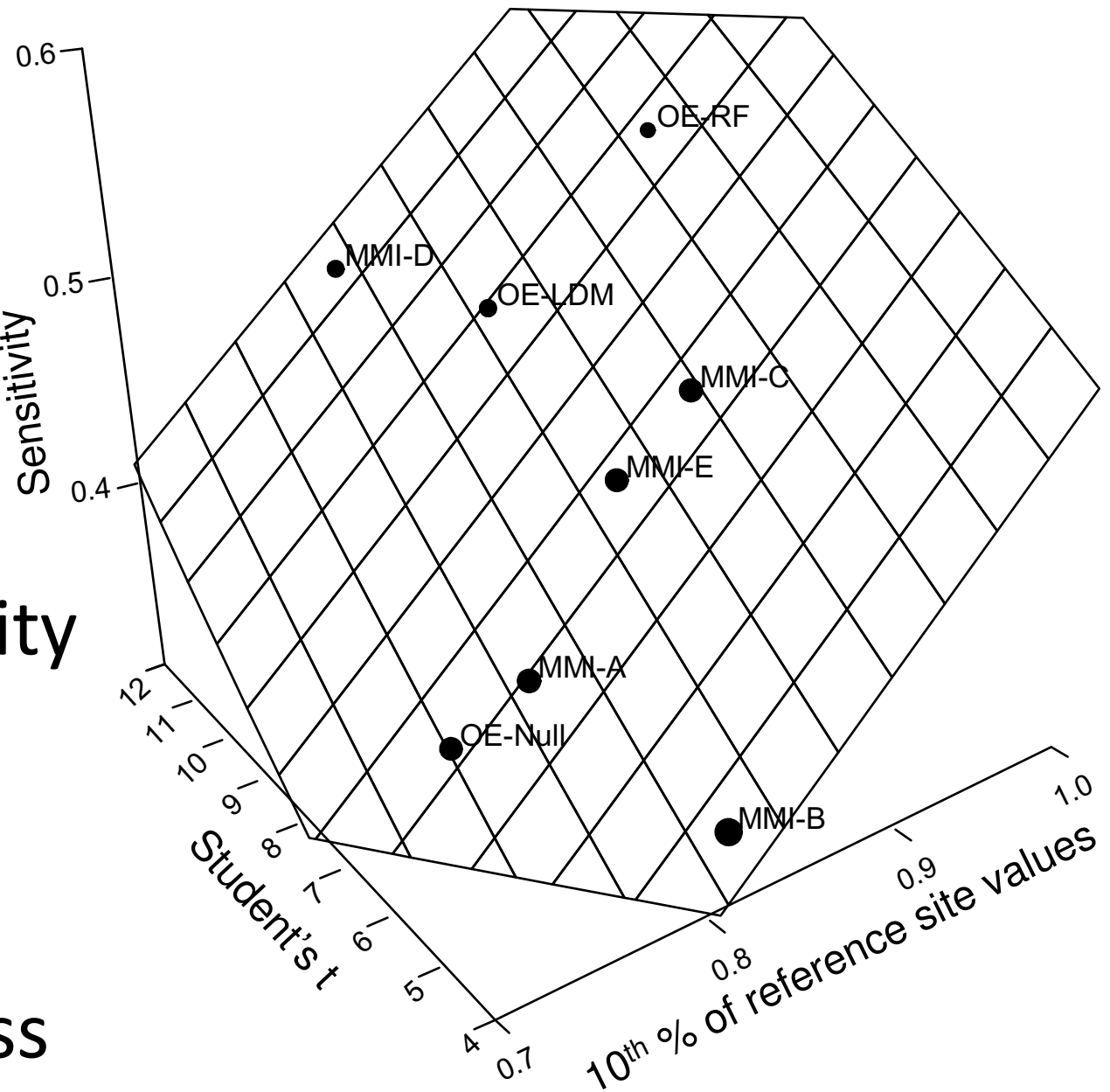
Characterizing Ecological Truth

1. "True" taxa loss = % taxa loss from big sample following simulated stress.
2. Similarity of the stressed big sample assemblage to the reference one:
   A. log abundance data.
   B. Bray-Curtis index (0-1).
3. Hypotheses:
   A. O/E will track taxa loss best.
   B. MMI will track Bray-Curtis best.

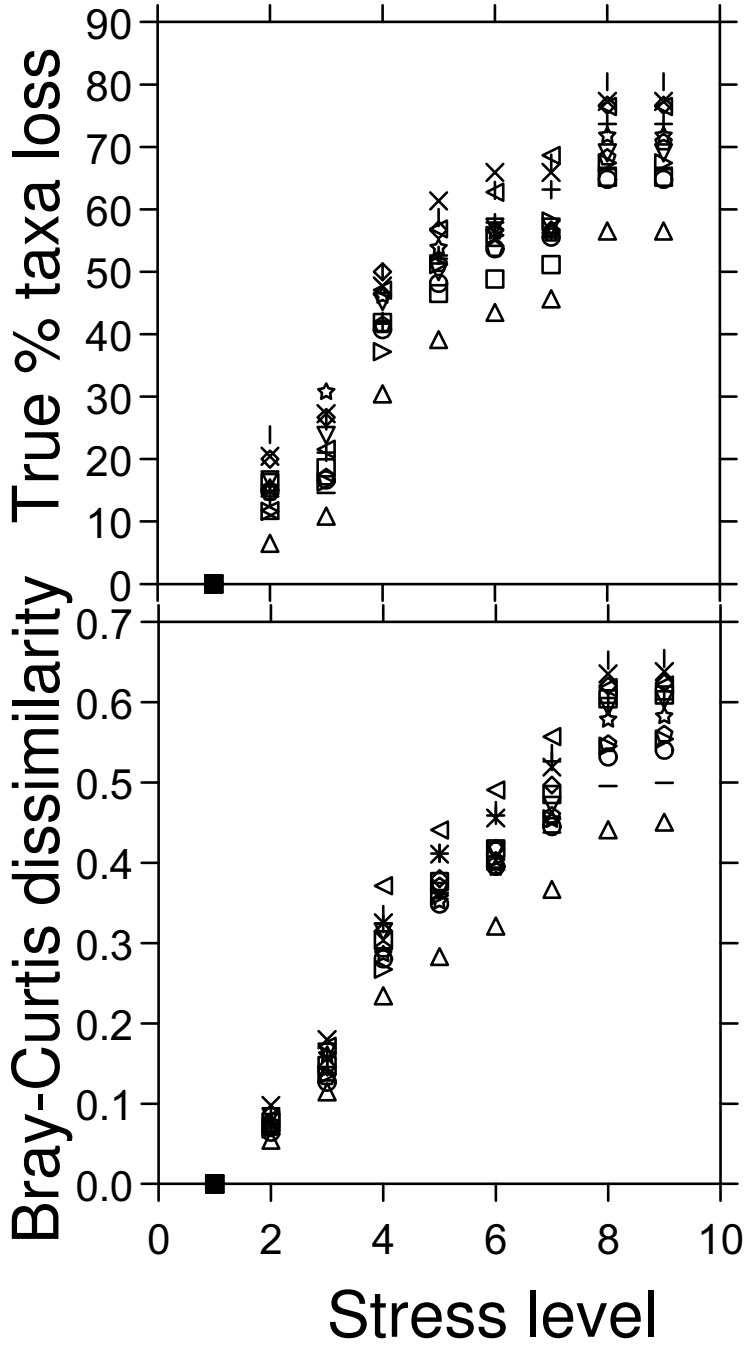
Performance Metrics

Reference Samples			Managed Samples		
Index	SD	10th %	Mean	*t*	Sensitivity
MMI-A (null)	0.14	0.76	0.87	6.92	0.36
MMI-A (MLR)	0.13	0.82	0.92	4.46	**0.32**
MMI-MLR	**0.11**	0.88	0.90	6.97	0.47
MMI-CART	0.14	0.80	**0.80**	**11.23**	**0.49**
MMI-RF	0.12	0.84	0.88	7.17	0.43
O/E-null	0.17	0.76	0.83	7.37	0.33
O/E-DFM	0.13	0.85	0.83	9.90	0.48
O/E-RF	**0.11**	**0.94**	0.88	9.93	**0.55**

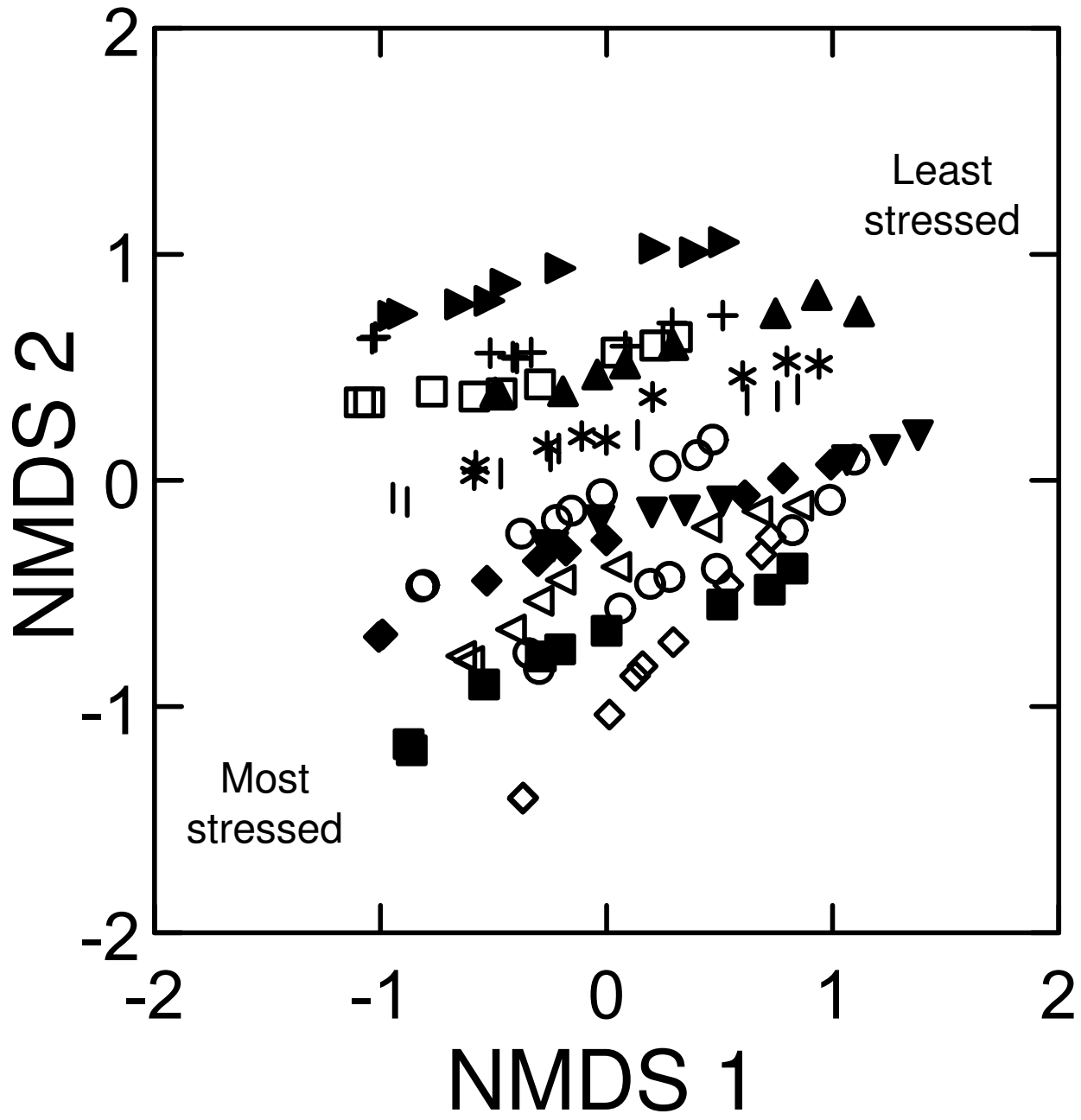
Index sensitivity as a joint function of precision and responsiveness



Stress differentially affected each of the 13 reference sites.

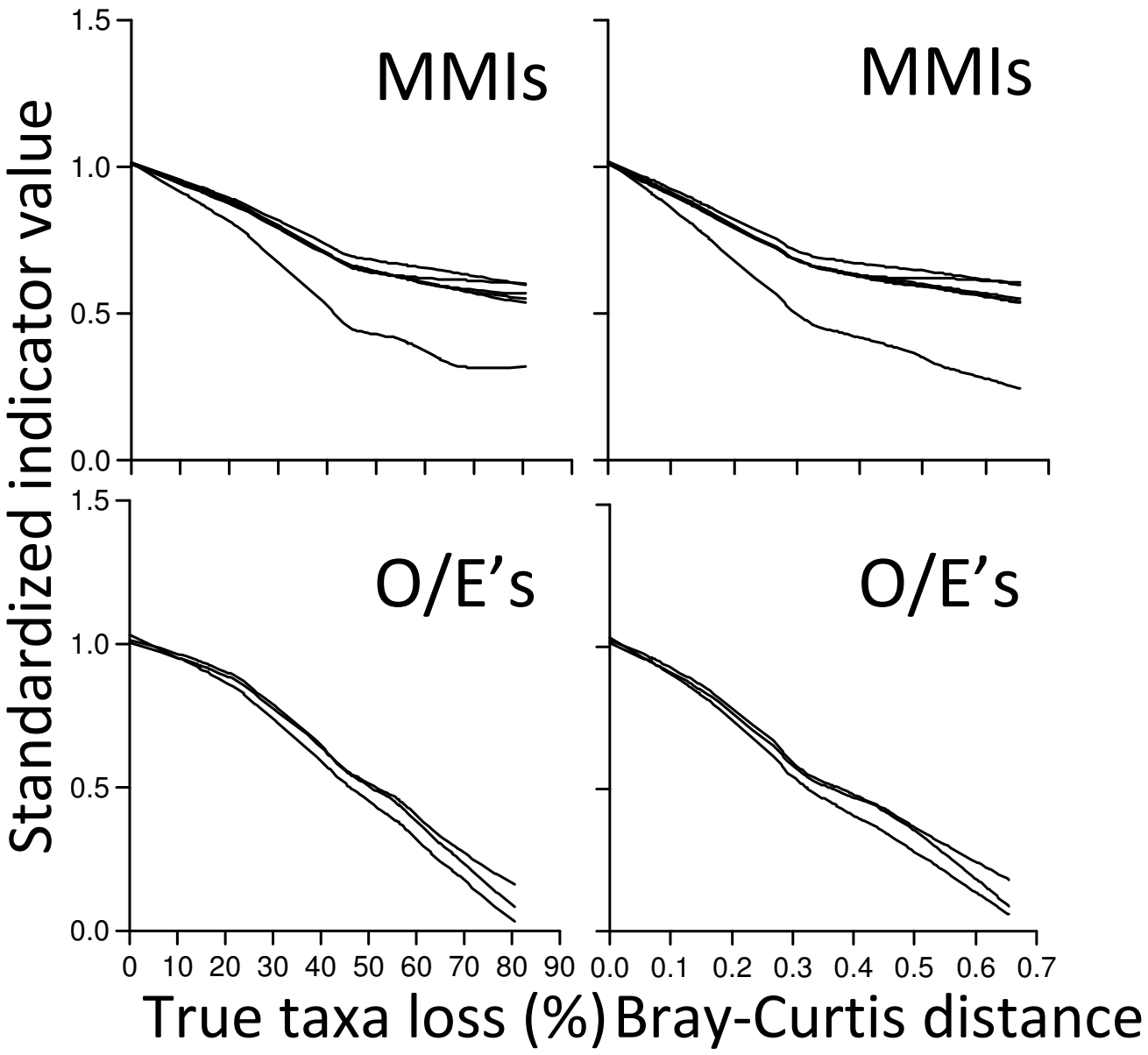


An NMDS ordination shows decreasing similarity with increasing stress.



All MMIs exhibited a plateau effect in response to stress.

O/E indices showed a linear response across the entire stress gradient.



Concluding Remarks

- GOOD - Modeling improves assessments and allows us to avoid ‘one-size-fits-all’ numerical criteria.
- CAUTION - How we develop indices affects their specific behaviors, and we need to understand the implications of those behaviors.
- BAD - The ‘plateau’ behavior of all MMIs was troubling. Perhaps calibrating with a stress gradient will help (sensu Leska Fore and colleagues).
- TRADE OFFS - Modeling greatly improves index sensitivity but it is not “easy”. What are implications for watershed groups, consulting firms, etc.?