Comparing Cross-Scale Resilience Properties Through Data Modelling of State Space

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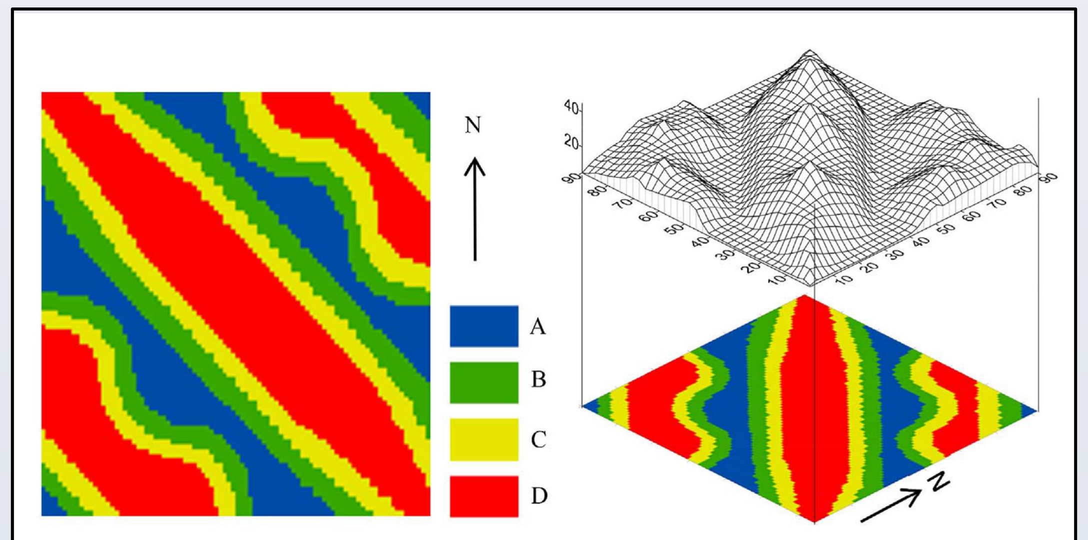
1. Issues with comparing patterns and inferring resilience properties

Patterns can be represented by different ontologies, like points, lines, and areas

A particular ontology is often associated with a specific conceptual paradigm, along with its scale of applicability

Comparing patterns should integrate multiple ontologies and their particular scalar extents (and use different paradigms)

This is especially true when trying to compare patterns and link them to their resilience properties – resilience properties are cross-scalar.



Topography as gradient surface and patch.
Wu, Q., F. Guo, H. Li, and J. Kang. 2017. Measuring landscape pattern in three dimensional space. ***Landscape and Urban Planning*** 167: 49-59.

2. Responses to these issues:

The solution of the familiar: we stick to a particular conceptual paradigm

The curse of standardization: we work at one particular scale

The sublimation of process: we focus on how a particular pattern changes with scale

The sublimation of pattern: we concentrate only on the particular scale for which a statistical property peaks

3. An alternative: data modeling of cross-scale resilience properties in state space

Combines different representations of pattern and accounts for the processes that generate resilience properties

Incorporates multiple conceptual paradigms and explanatory variables operating across different scalar extents and resolution

Fosters a multivariate interpretative framework (versus approaches that sublimate pattern and process)

Has a deep theoretical and methodological lineage in ecology

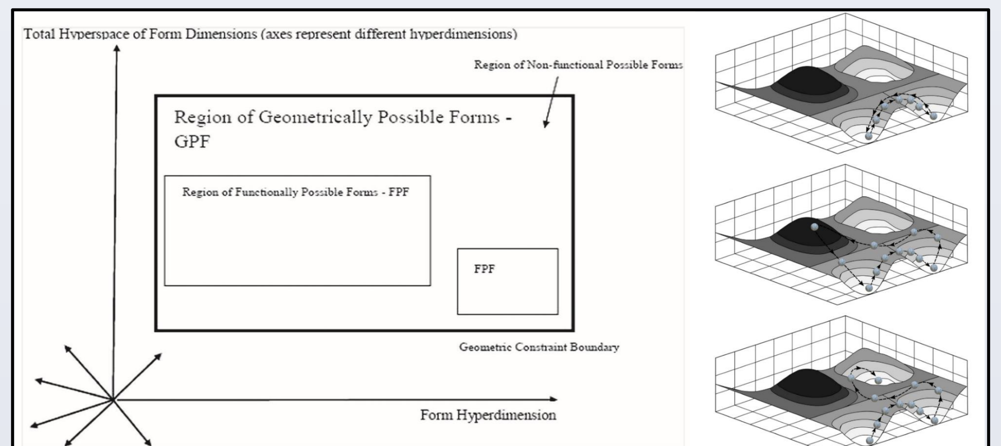
4. Data modeling? State space?

Data modeling: a means of making the phenomena under study more accessible for analysis

Modeling patterns: combining different representations of pattern to represent the phenomena, a strategy of overfitting versus underfitting

State space: a multidimensional volume defined by observations of the phenomena and their dynamical properties

Dimensionality: the number of axes



State space concepts
Inkpen, R., and K. Hall. 2016. Using morphospaces to understand tafoni development. ***Geomorphology*** (left).

Lamothe, K. A., K. M. Somers, and D. A. Jackson. 2019. Linking the ball-and-cup analogy and ordination trajectories to describe ecosystem stability, resistance, and resilience. ***Ecosphere*** (right).

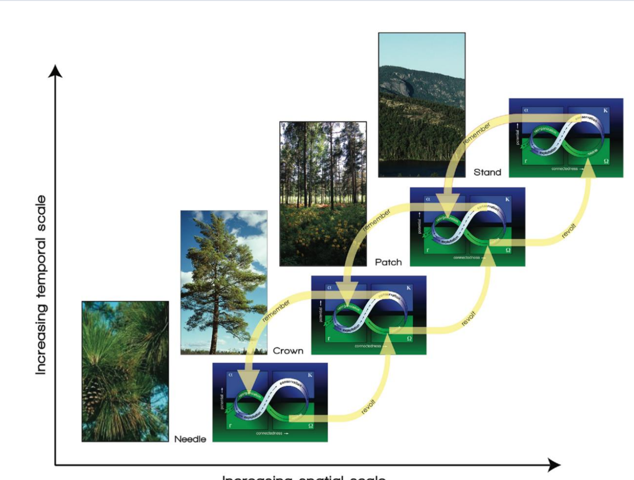
5. What is cross-scale resilience?

A small number of key structuring processes shape ecosystems

These key structuring processes are specified in adaptive cycles that link to form panarchies

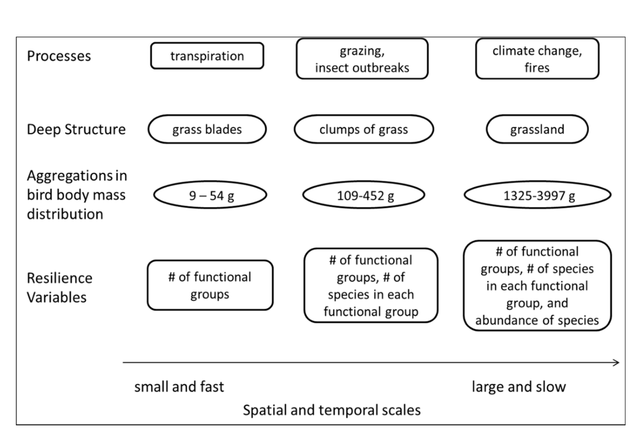
Variables representing processes in each adaptive cycle are hierarchically-nested and vary within and across scales

These variables forms the basis for comparing patterns and linking resilience properties to them across scales.



Adaptive cycles and panarchies for forest resilience properties

Allen, C.R., Angeler, D.G., Garmestani, A.S., Gunderson, L.H., and Holling, C.S. 2014. Panarchy: theory and application. ***Ecosystems.***



Variables for forest resilience in three adaptive cycles

Sundstrom, S., D. Angeler, A. Garmestani, J. García, and C. Allen. 2014. Transdisciplinary Application of Cross-Scale Resilience. ***Sustainability.***

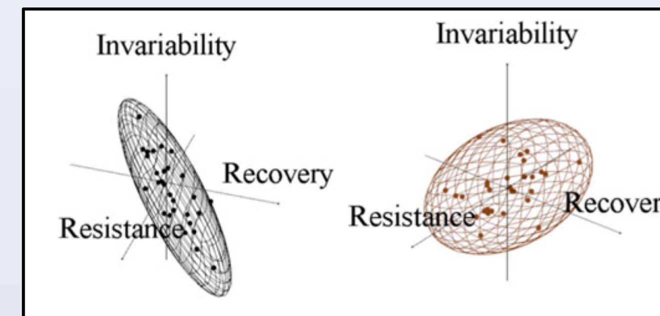
6. Comparing patterns and their resilience properties in state space

The variance structure of cross-scaled data conveys differences in observations as well as their resilience properties

Resilience is multidimensional: it consists of two (or more) properties, typically resistance and resilience.

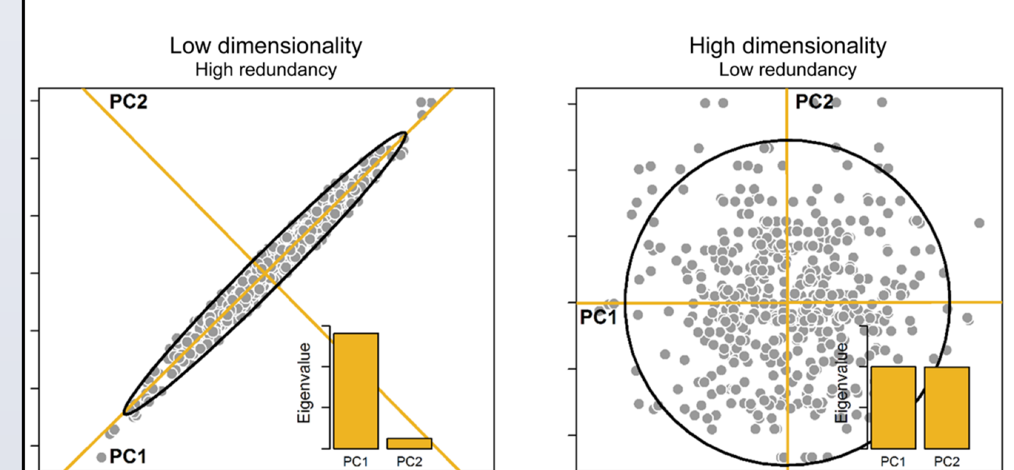
Resistance and resilience can be expressed as non-independent dimensions, or axes, in state space

Low dimensions capture resistance, higher dimensions capture resilience



Resilience properties as dimensions of state space

Donohue, I., O. L. Petchey, et al. 2013. On the dimensionality of ecological stability. ***Ecology Letters.***

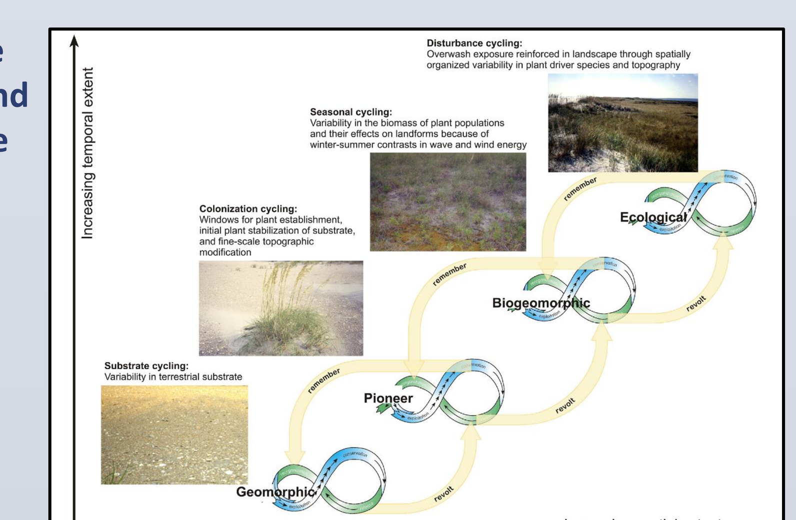


Dimensionality as analytical strategy
Stevens, R. D., and J. S. Tello. 2018. A latitudinal gradient in dimensionality of biodiversity. ***Ecography.***

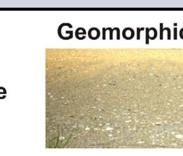
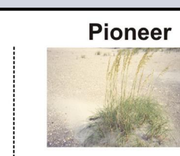
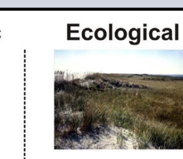
Instructions for cross-scale data modelling: an example using dune topography

Question: How do barrier island dune topographies and their resilience properties co-vary among many different islands?

1. **Conceptualize the adaptive cycles and panarchies for the system under study.**



2. **Define measureable variables for each adaptive cycle.**

	Geomorphic	Pioneer	Biogeomorphic	Ecological
Adaptive cycle				
Cross-scale variables	Elevation relative to sea level	Frequency distribution of elevation	Patch structure of elevation	Continuous surface properties of elevation

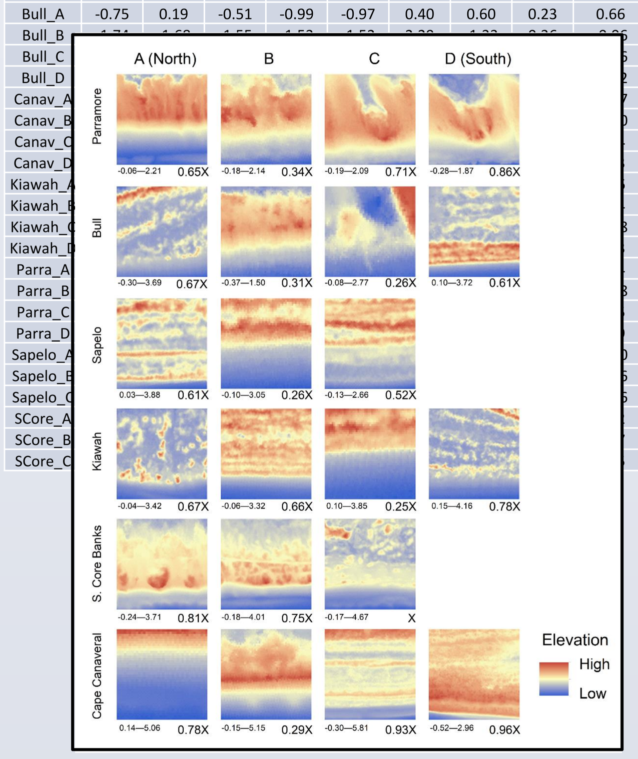
Stallins, J. A., and D. Corenblit. 2018. Interdependence of geomorphic and ecologic resilience properties. ***Geomorphology*** 305: 76-93.

3. **These variables should span the resistance defining the 'template' of the pattern to the resilience arising from adaptive components.**

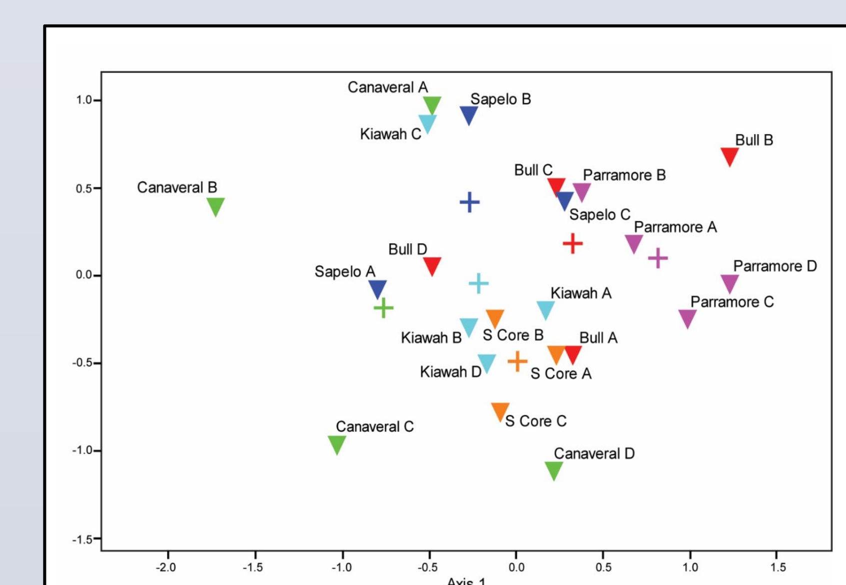
Cross-scale variables and their properties					
	Component of topography	**Property**	**Pattern geometry**	**Spatial explicitness**	**Variables**
Descriptive statistics	Position of land relative to marine inputs	Geomorphic resistance	Global summary; aggregate mean field measures	Low	Mean, maximum elevations, 25th, 50th, 75th percentiles
Patch metrics	Formation of dune landforms via vegetation	Geomorphic resistance and emergence of biogeomorphic resilience	Patches of interval-ranged elevation	Intermediate	Indices to describe patch shape, area, diversity, and structure
Gradient-based metrics	Landscape Interactivity of landforms and vegetation	Biogeomorphic resilience	Continuous surface properties	High	Spatial autocorrelation; plot size; skewness and kurtosis of elevation

4. **Collect data and assemble variables.**

	Elevational descriptive statistics					Patch Indices								Landscape continuous surface properties			
Island site	Mean	Max	25th	50th	75th	LPI	LSI	SHAPE	CONTAG	IJI	SIDI	PAFRAC	AI	Moran's	Size	Skewness	Kurtosis
Bull_A	-0.75	0.19	-0.51	-0.99	-0.97	0.40	0.60	0.23	0.66	-0.35	-0.91	1.57	-0.39	1.40	0.28	2.20	2.27
Bull_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.19	-1.99	-0.09	0.99	-0.88	-1.09	-0.66	-0.90
Bull_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.72	-0.14	0.14	-0.22	0.50	-1.37	1.47	0.56
Bull_D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.87	0.15	0.33	-0.87	0.48	0.11	0.58	-0.27
Canav_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.95	1.01	-1.04	-0.77	-0.34	-1.57	1.34	-0.28
Canav_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.92	2.03	0.75	-1.80	-0.85	-1.13	-0.55	-0.73
Canav_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.21	1.06	0.77	-0.69	1.23	1.24	0.09	0.24
Canav_D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.25	-0.75	0.08	0.43	1.01	1.52	-1.65	1.78
Kiawah_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.28	-1.24	0.45	-0.37	1.00	0.20	1.36	1.14
Kiawah_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.08	-0.09	0.94	-0.12	0.42	0.24	-1.62	-0.33
Kiawah_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.15	1.09	1.60	-0.71	-1.89	-1.35	0.03	-1.25
Kiawah_D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.35	-0.82	0.34	-0.43	1.50	0.79	1.22	1.75
Parra_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.54	-0.05	-1.11	1.50	-1.42	0.28	-0.70	-1.11
Parra_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.36	0.06	-0.79	0.61	-0.95	-0.95	-0.53	-0.60
Parra_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.20	-1.49	-2.16	1.79	-0.19	0.53	-1.03	-0.38
Parra_D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.92	-0.80	-1.94	1.89	-0.62	1.08	-0.35	-0.84
Sapelo_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.98	0.36	0.50	-1.58	1.08	-0.03	-0.11	0.32
Sapelo_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.81	1.27	0.35	-0.91	-1.20	-1.33	-0.07	-1.10
Sapelo_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.64	0.13	-0.93	0.23	-0.85	-0.29	-0.05	-0.67
SCore_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.04	-0.30	-0.65	0.90	0.04	0.53	-0.35	0.25
SCore_B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.60	1.04	0.24	0.30	-0.27	0.68	-0.58	-0.41
SCore_C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.37	0.37	0.65	0.24	0.80	1.64	-0.04	0.59



5. **Perform dimensionality reduction (ordination) to obtain variance structure of data and the location of observations in state space.**



6. **Use the loadings of variables on the axes of state space to affirm and assign resilience properties to observations.**