Multivariate Analysis of a non-stationary process. Mapping out system resilience.

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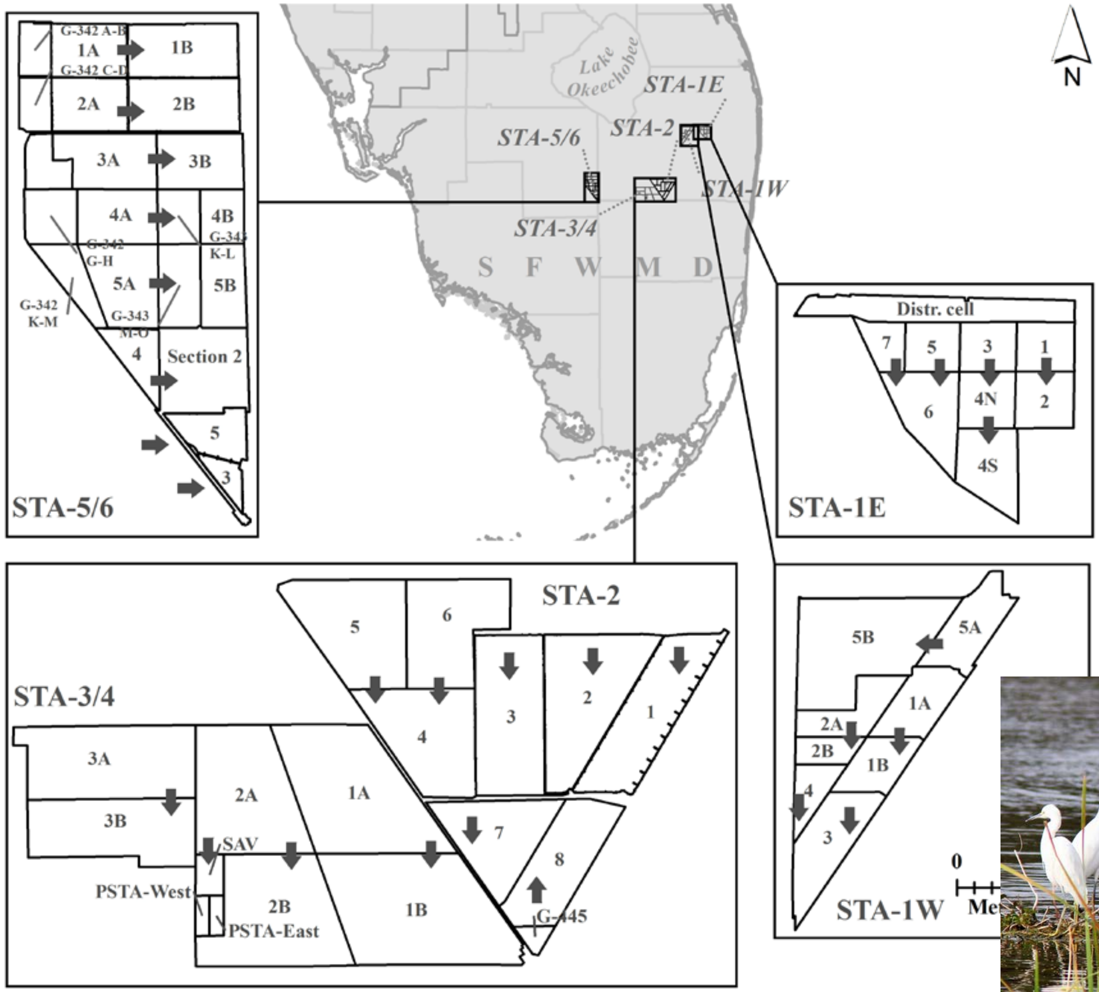
The Everglades Storm Water Treatment Areas: a found ecological experiment in resilience



What do we mean with Resilience?

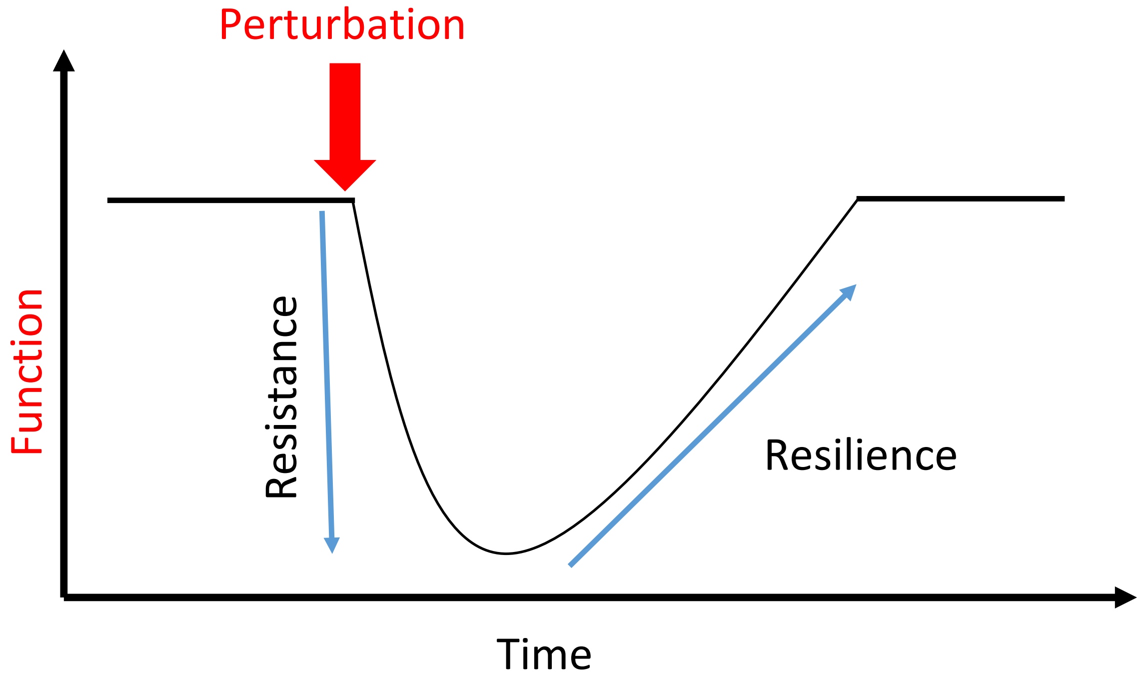
- **Ecological resilience (Holling, 1973)**

Capacity of an ecosystem to tolerate disturbance without switching to a qualitatively different state that is controlled by a different set of processes: ***allows for evolution, adaptation and different species assemblages***

- **Engineering resilience (Pimm, 1984)**

Time taken to return to the pre-disturbance state, ***including original characteristics (major headache in restoration, esp. with climate change)***

What do we mean with Resilience?

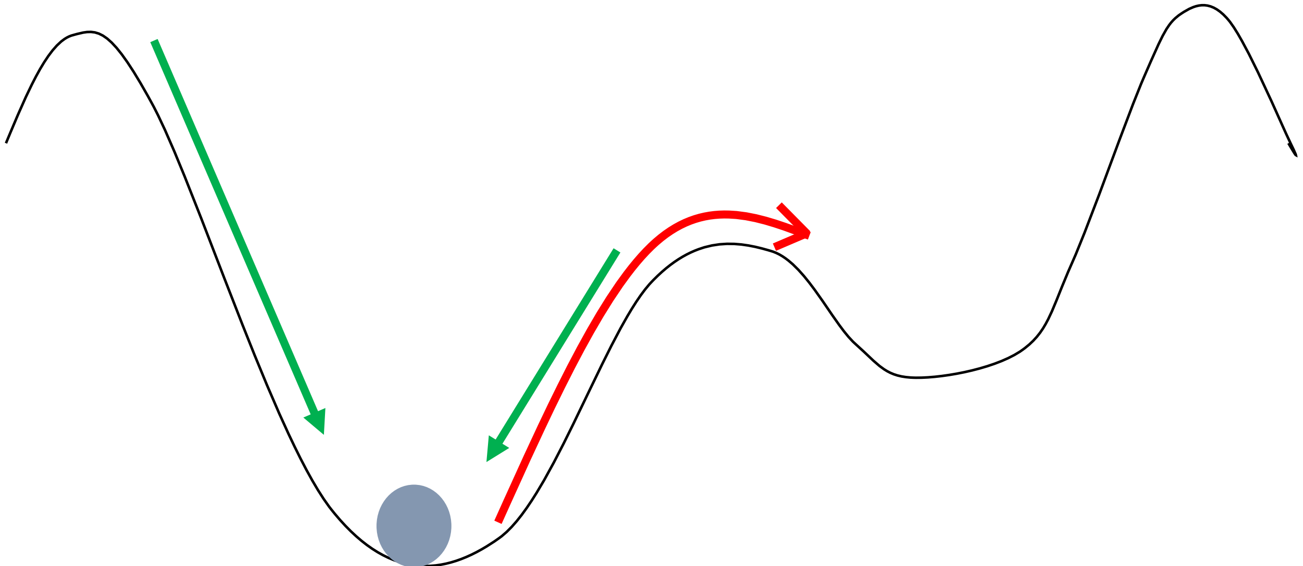


Engineering resilience

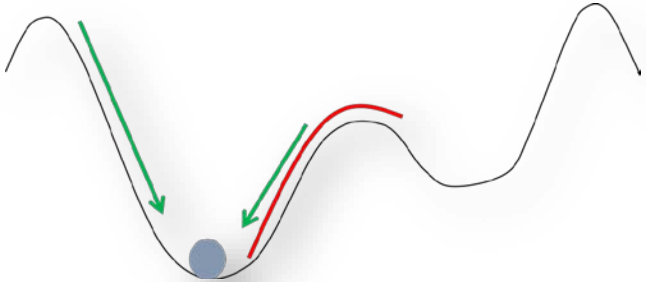
The ability of a system to recover back towards the state it was in prior to disturbance (*Holling 1973. Ann Rev Eco Syst*)

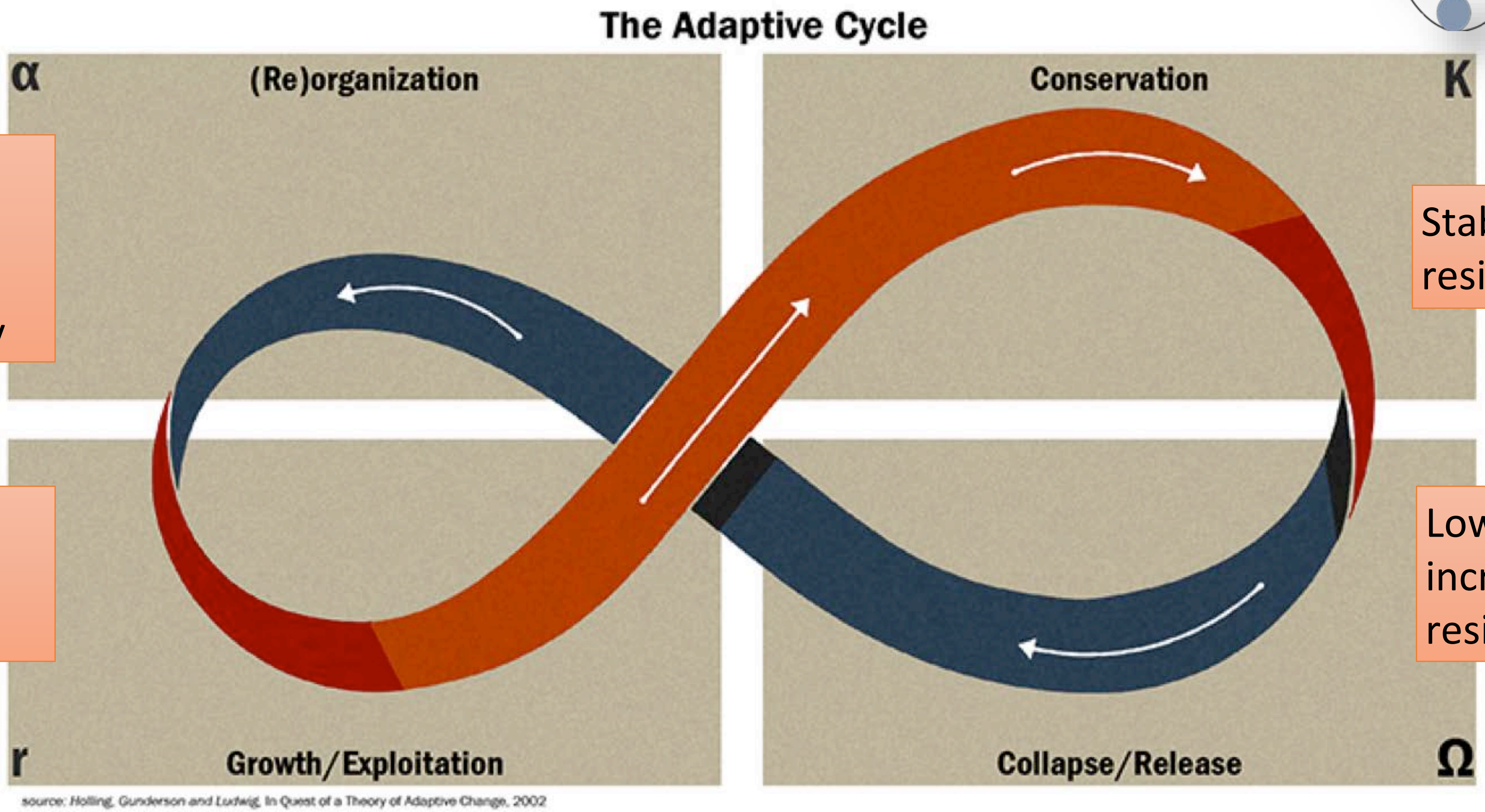
Ecological resilience

The magnitude of disturbance that can be tolerated before the system changes its state (*Pimm 1984 Nature*)



The adaptive cycle





High resilience, greatest uncertainty

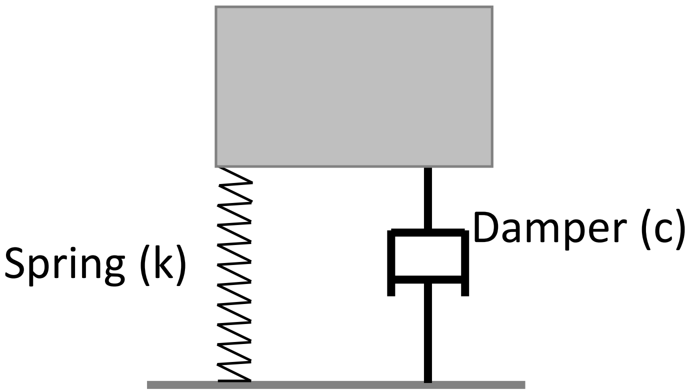
High but decreasing resilience

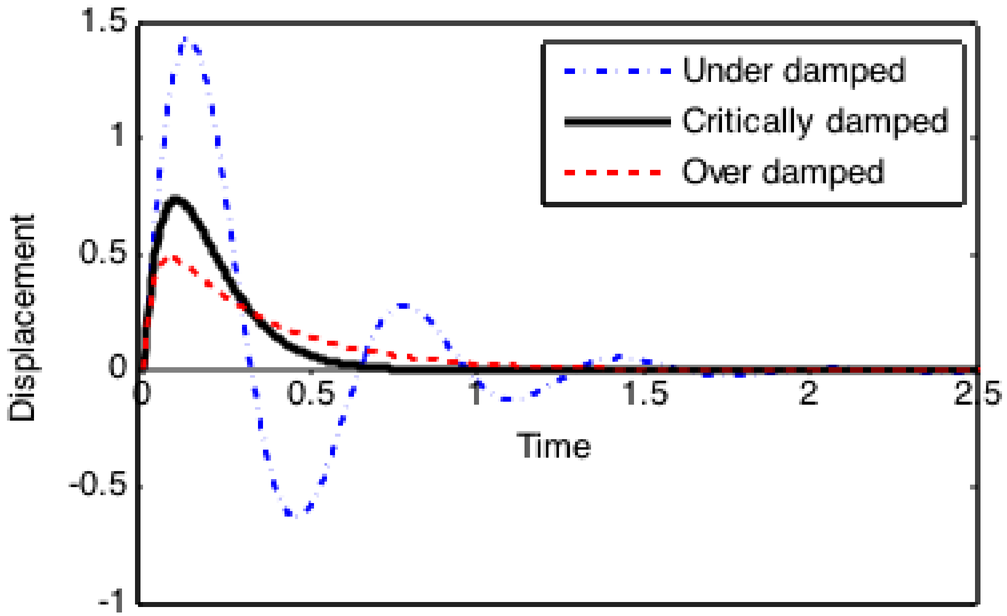
Stable, low resilience

Low but increasing resilience

Damped harmonic motion analogy

A mass on a spring is disturbed from its equilibrium position

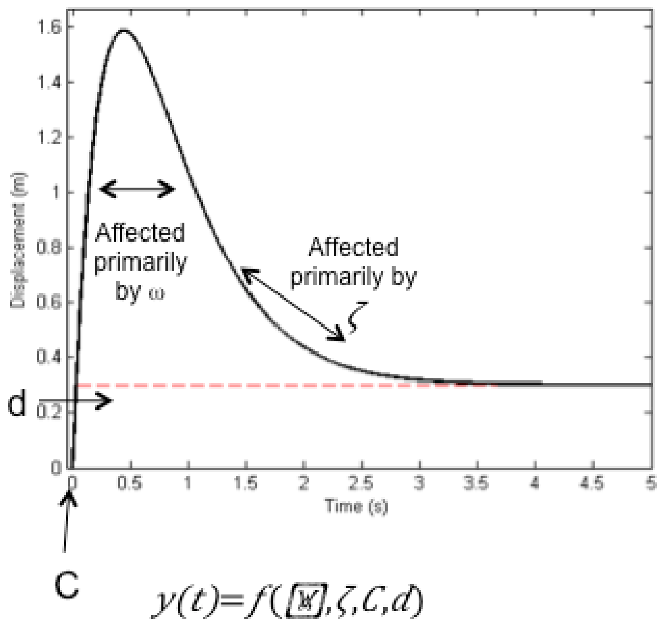




A friction or damping force slowly restores the system to its equilibrium position.

Damping factor: $\zeta = \frac{c}{2\sqrt{km}}$, critically damped when $\zeta = 1$

Damped harmonic motion analogy



$y(t)=f(\boxtimes,\zeta,C,d)$

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ζ is the damping factor
ω is the natural frequency
C is the initial slope
d is the final equilibrium


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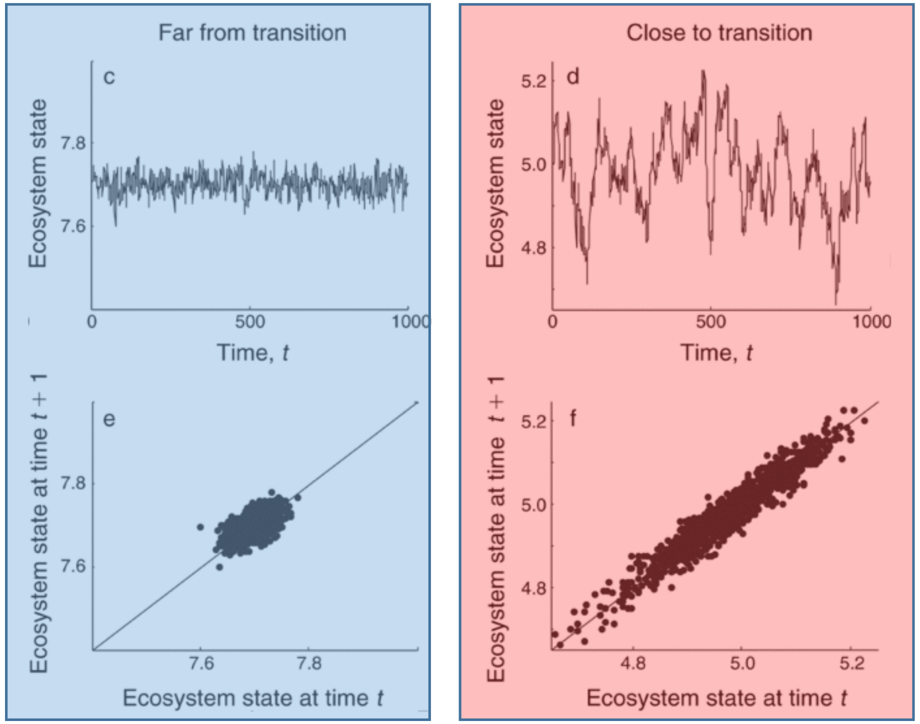
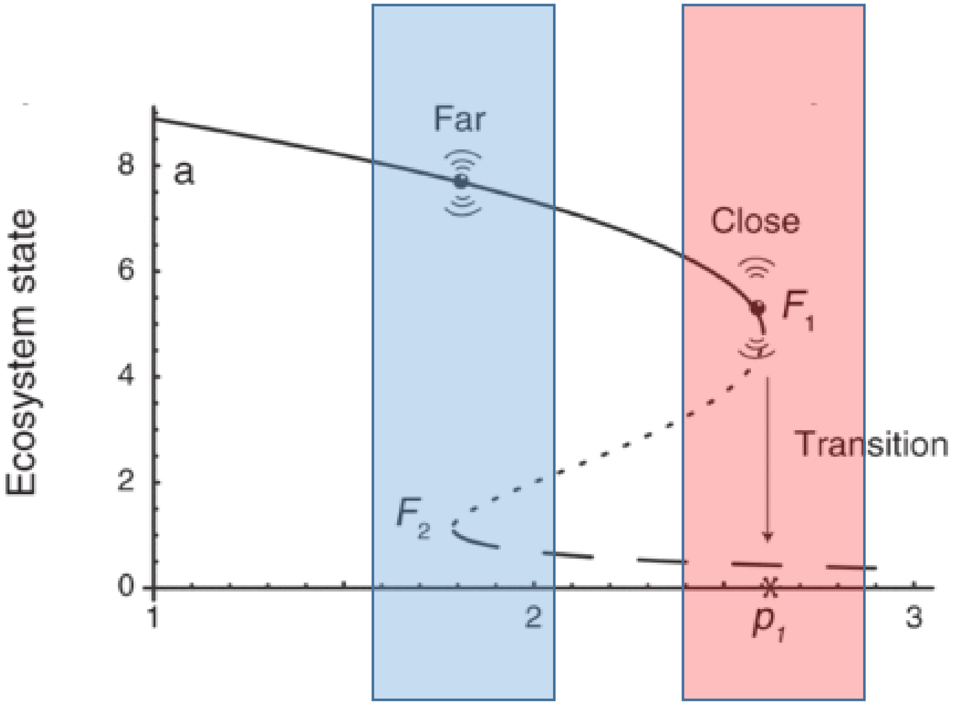
Defining and quantifying the resilience of responses to disturbance: a conceptual and modelling approach from soil science

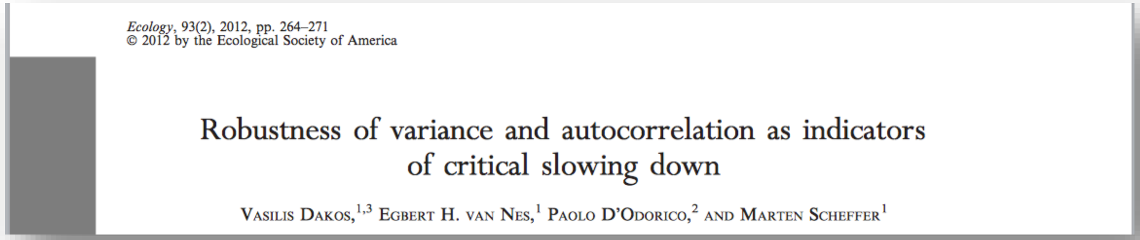
L. C. Todman[1], F. C. Fraser[2], R. Corstanje[2], L. K. Deeks[2], J. A. Harris[2], M. Pawlett[2], K. Ritz[2,3] & A. P. Whitmore[1]

Characteristic[1]	Symbol[2]	A more resilient soil response…	Units[3]
(i) Degree of return	R_v	Returns to a stable level of function closer to a reference level (e.g. the initial level of function or level of a control sample)	U
(ii) Return time-The time taken to reach the new stable level of function	R_t	Reaches the stable level of function more quickly	T
(iii) Rate of return-The rate at which the response tends towards the stable level of function (i.e. related to the gradient of the return period)	R_γ	Has a steeper gradient during return	UT^{-1}
(iv) Efficiency	R_e	Has a smaller area under the response curve i.e. is away from the reference level for less time in total	UT

Putting this into practice



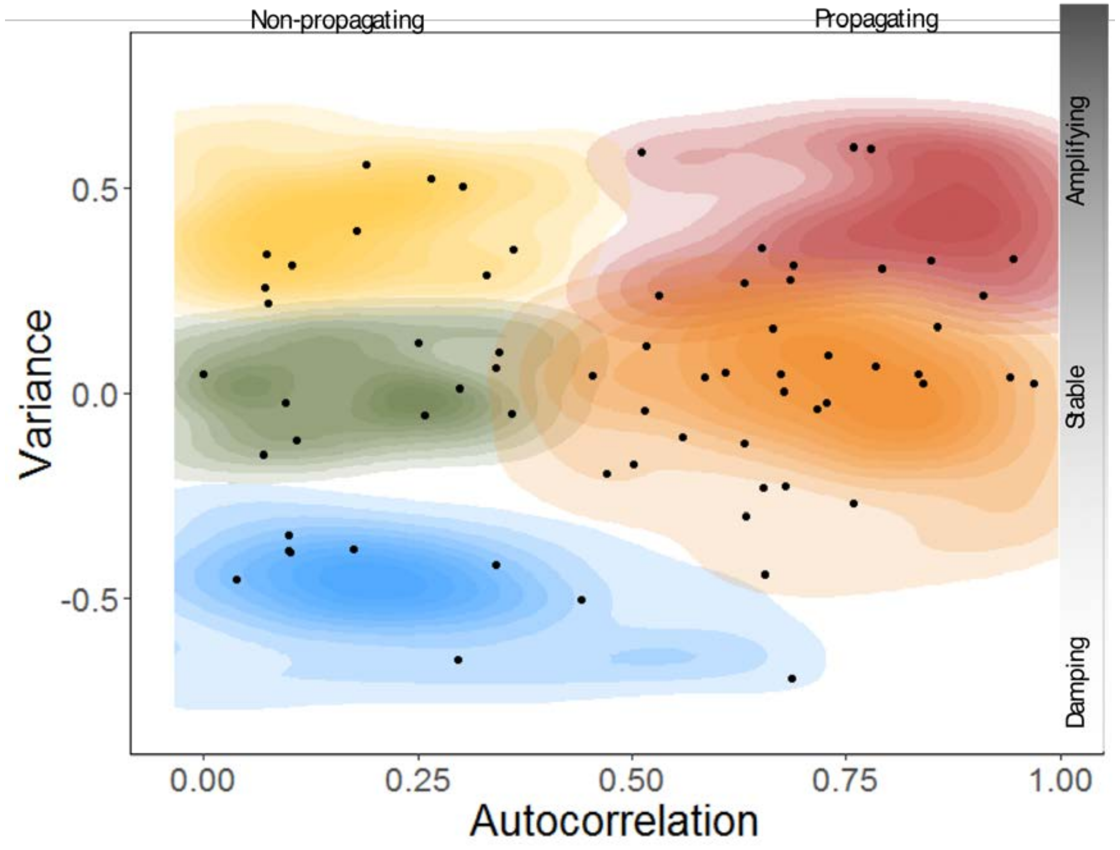


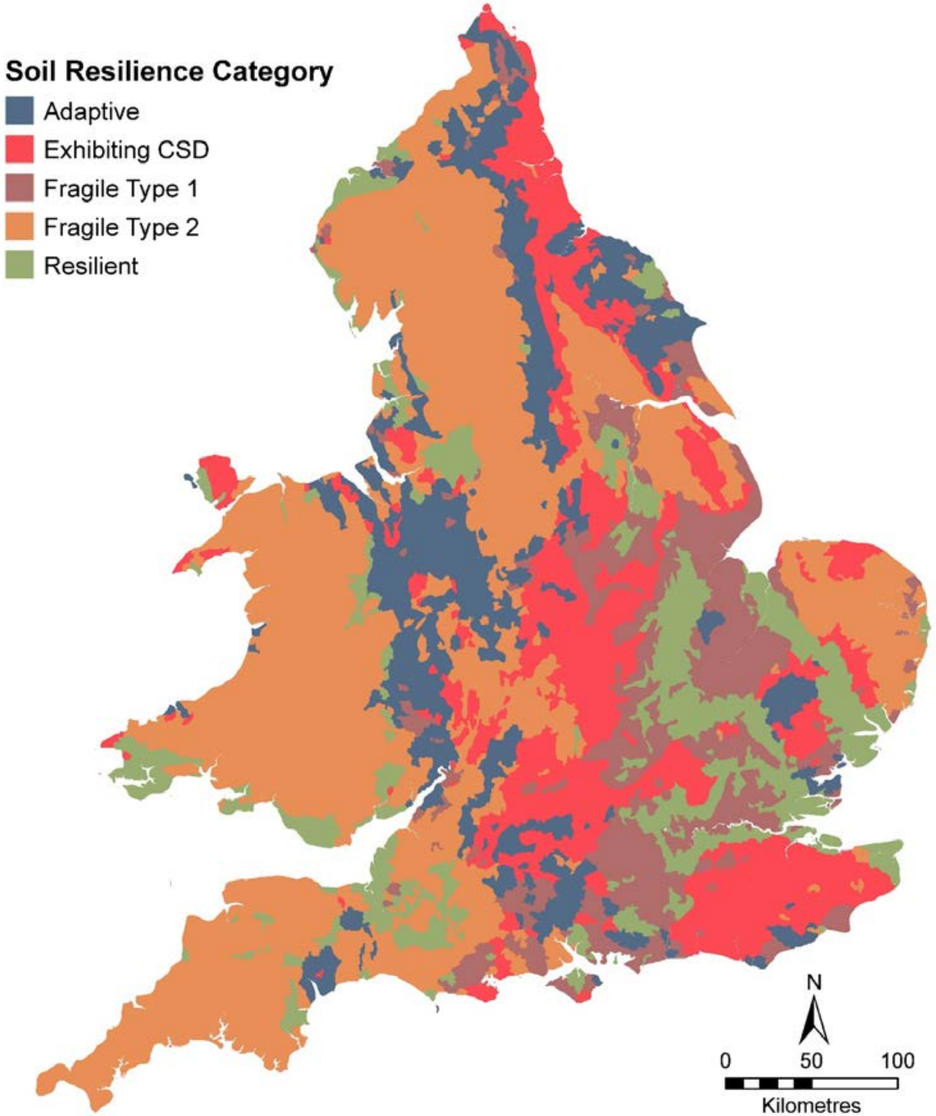

Ecology, 93(2), 2012, pp. 264–271

Robustness of variance and autocorrelation as indicators of critical slowing down

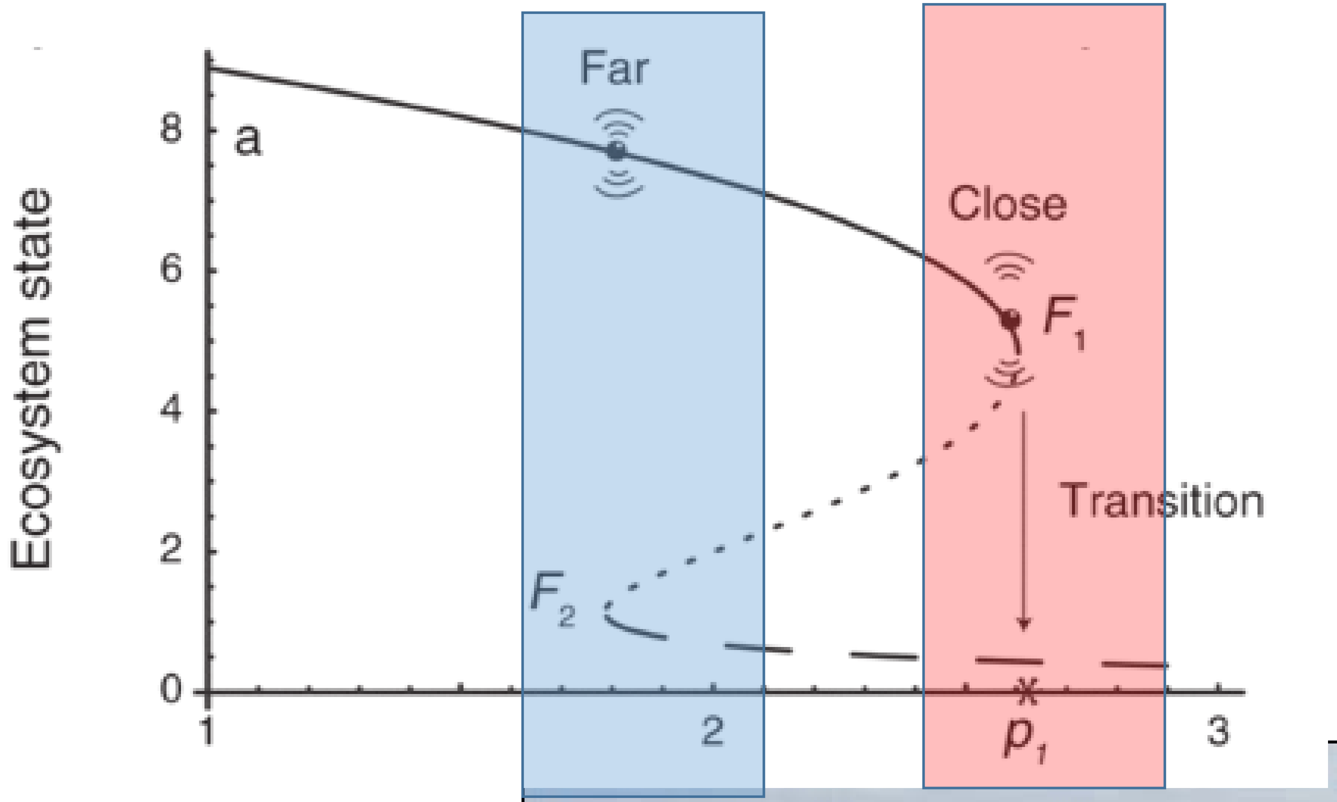
Vasilis Dakos,[1,3] Egbert H. van Nes,[1] Paolo D'Odorico,[2] and Marten Scheffer[1]

Operationalising Resilience





So where are the STA's in this?



National Park Service

The Everglades Storm Water Treatment Areas: a found ecological experiment in resilience

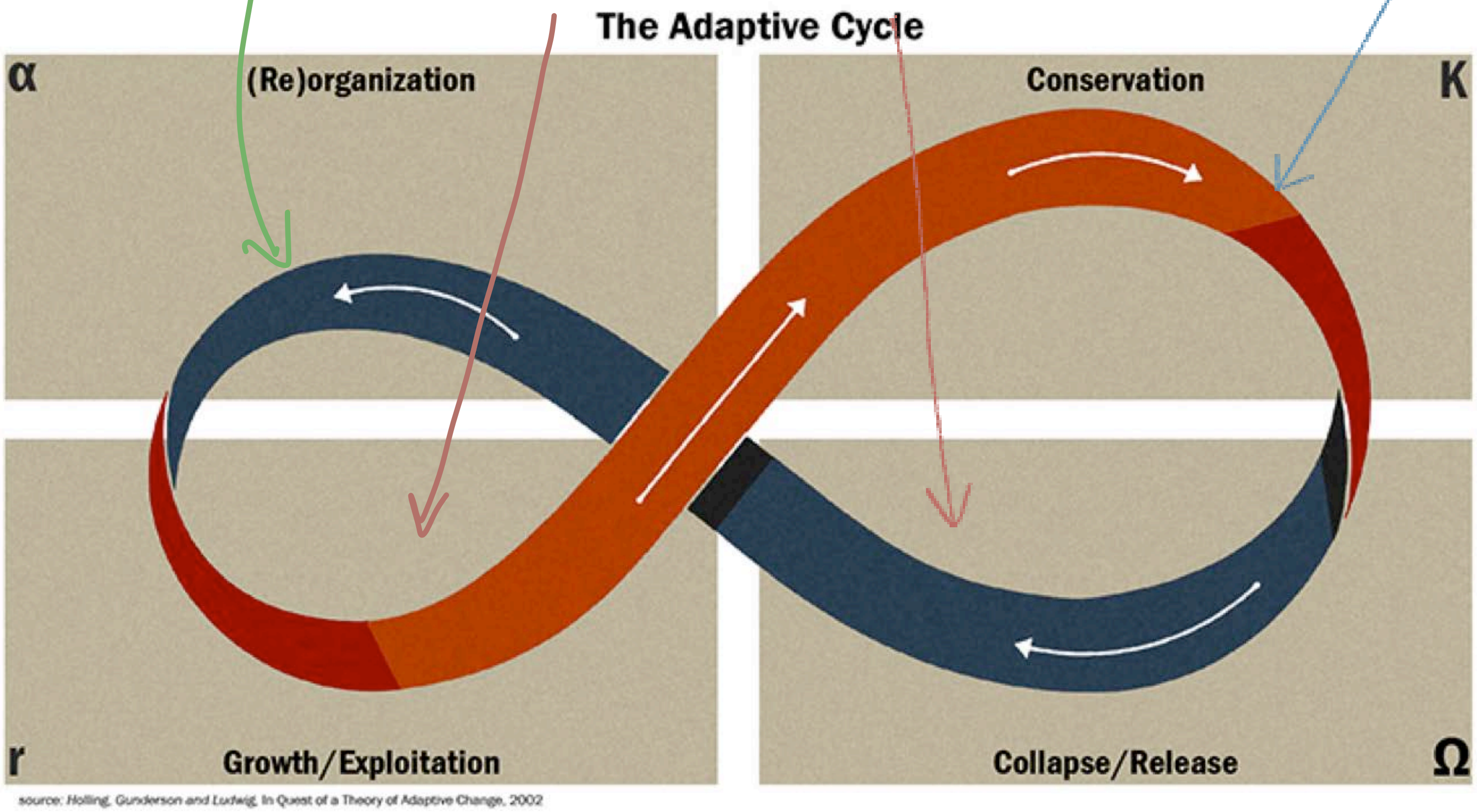
- The general purpose and function of the STAs is to reduce phosphorus (P) in runoff water prior to discharging to the Everglades Protection Area.
- The controls on the P removal process are therefore set by the internal biogeochemical, ecological and physical processes and conditions in each cell.
- They are intrinsically engineered systems, in which the ecosystem is manipulated to obtain a desired outcome (retaining P, removing it from the water column).
- The systems are stochastic, with frequent changes in ecological structure (emergent marsh to open water systems). The systems are also subject to frequent disturbance events (e.g. hurricanes).

If we consider a naïve, but exhaustive dataset over these systems then there may be three board expectations represented in the data:

1) The systems broadly function as engineered systems,
2) The systems are self organizing ecological systems,
3) The systems are entirely stochastic

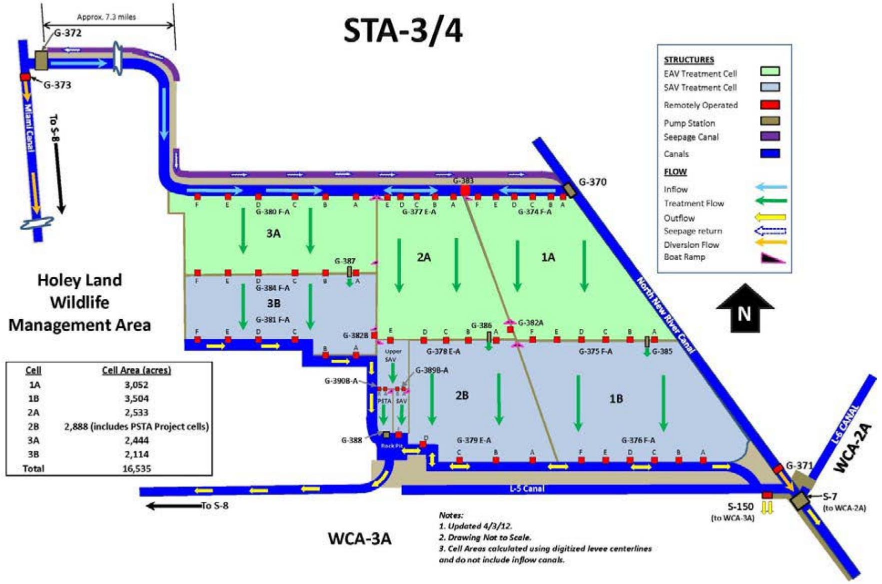
So how does this relate to resilience?

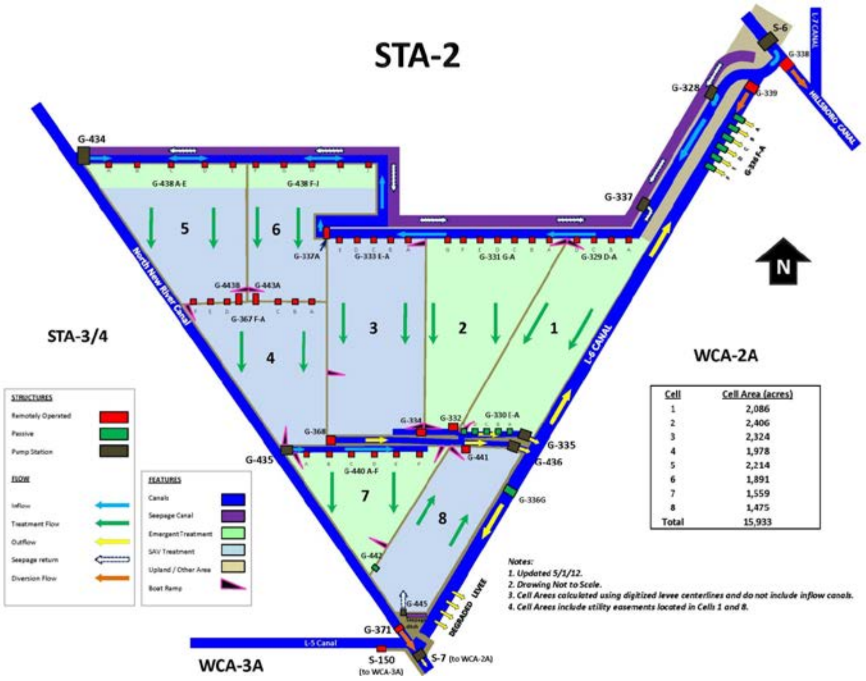
1) The systems broadly function as engineered systems,
2) The systems are self organizing ecological systems,
3) The systems are entirely stochastic

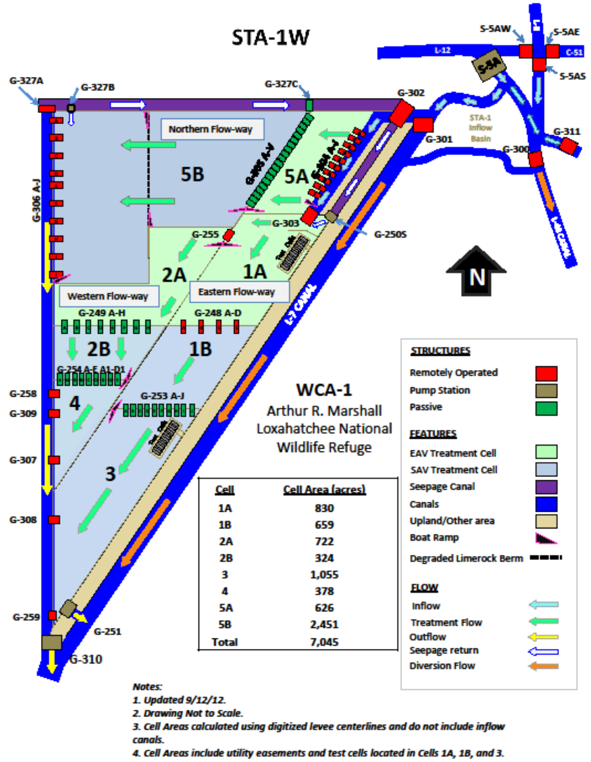


Exemplars of the outcome from the datamining exercise

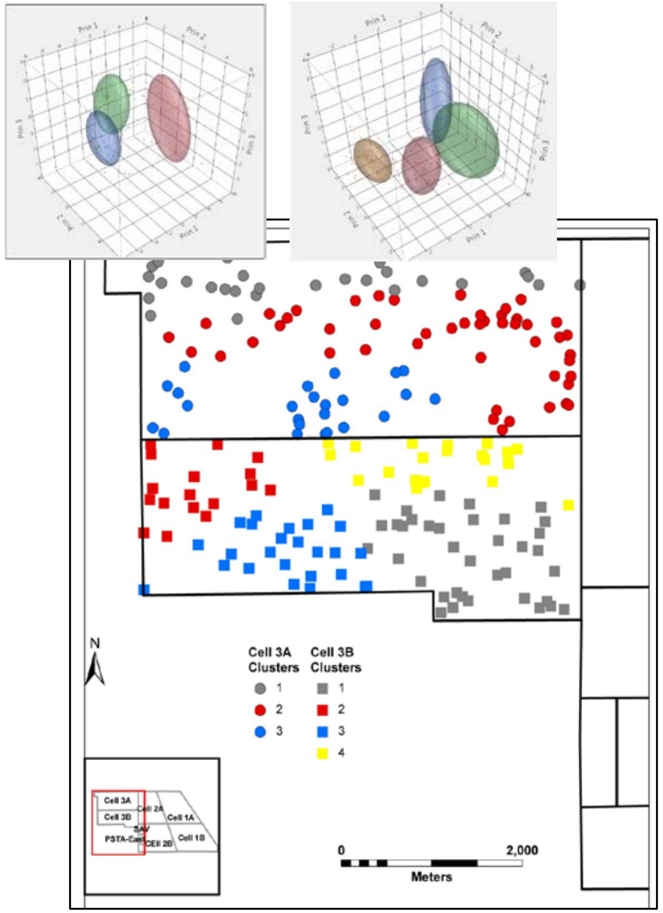
Exemplars

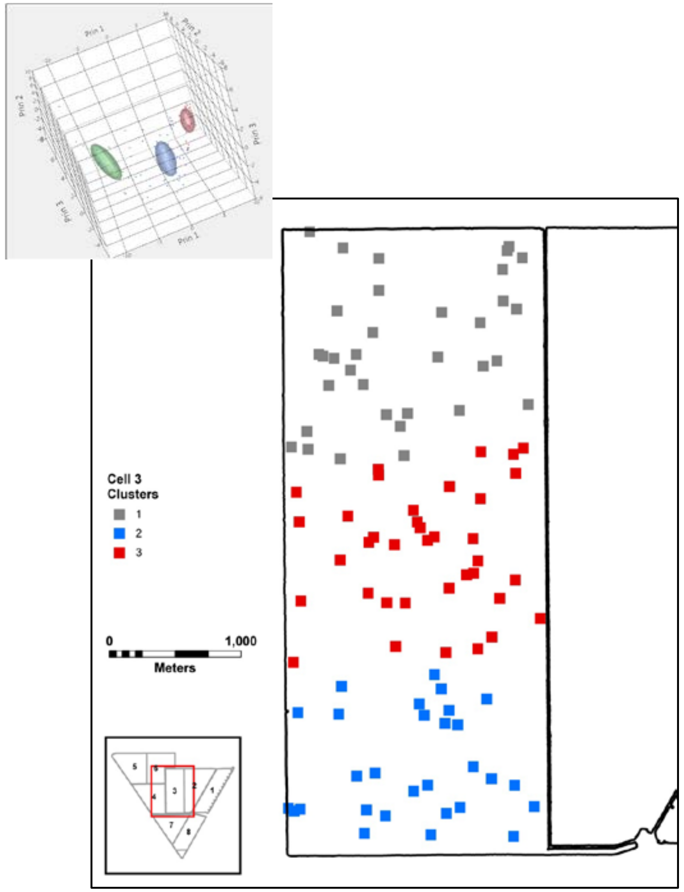


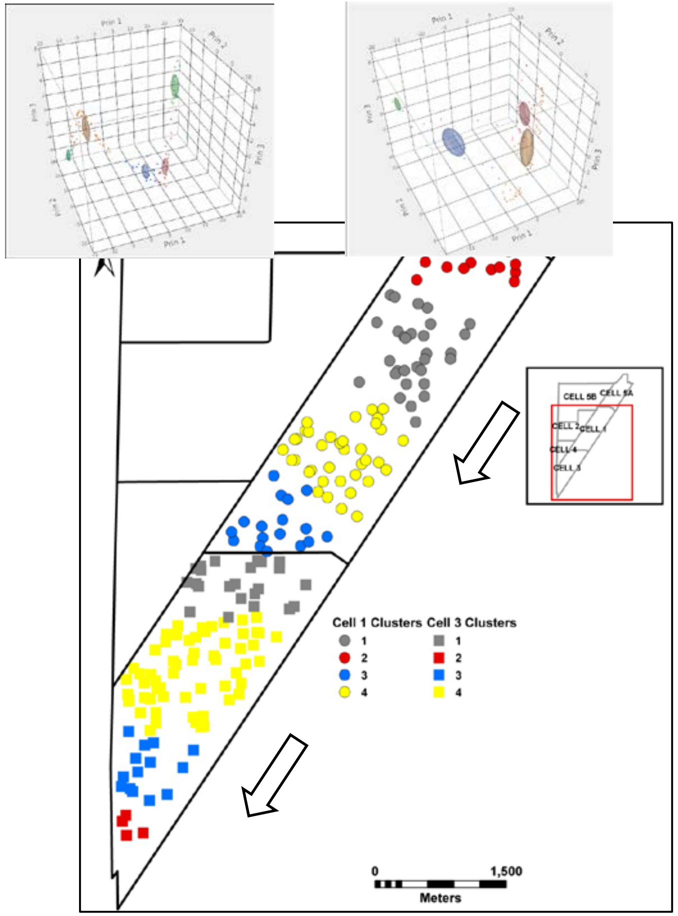




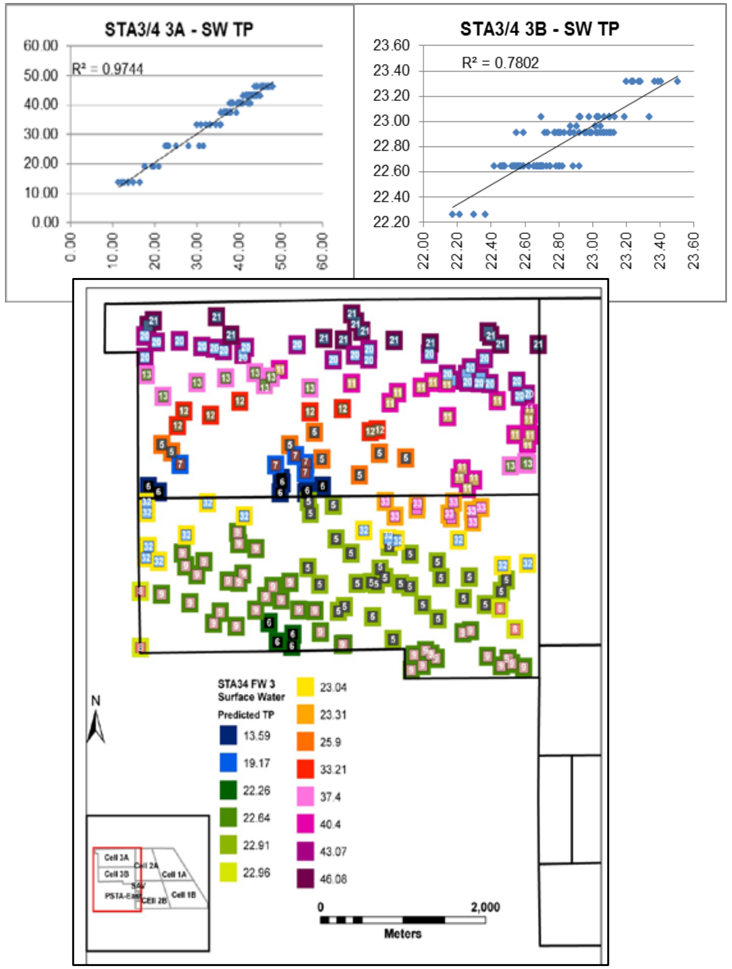
Spatial Analysis of a non-stationary process

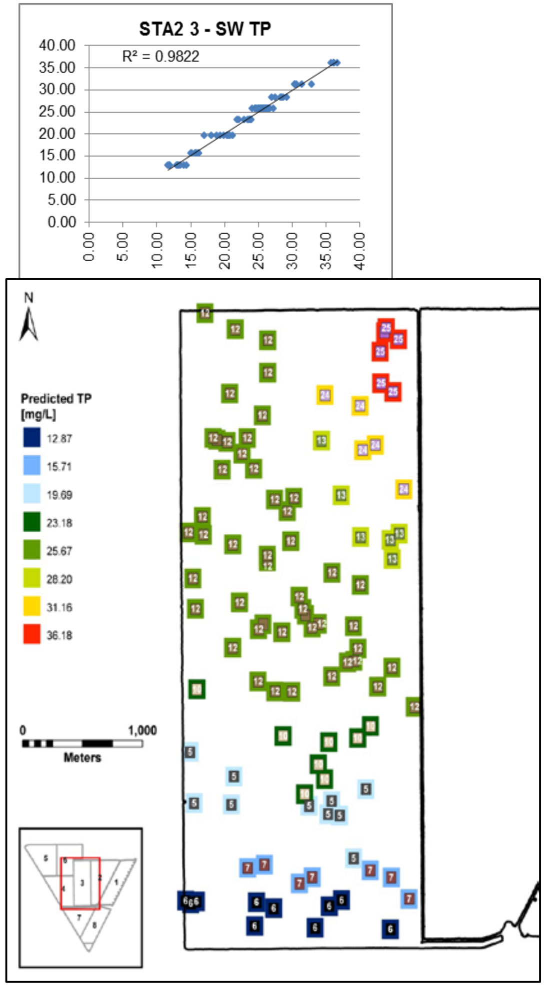


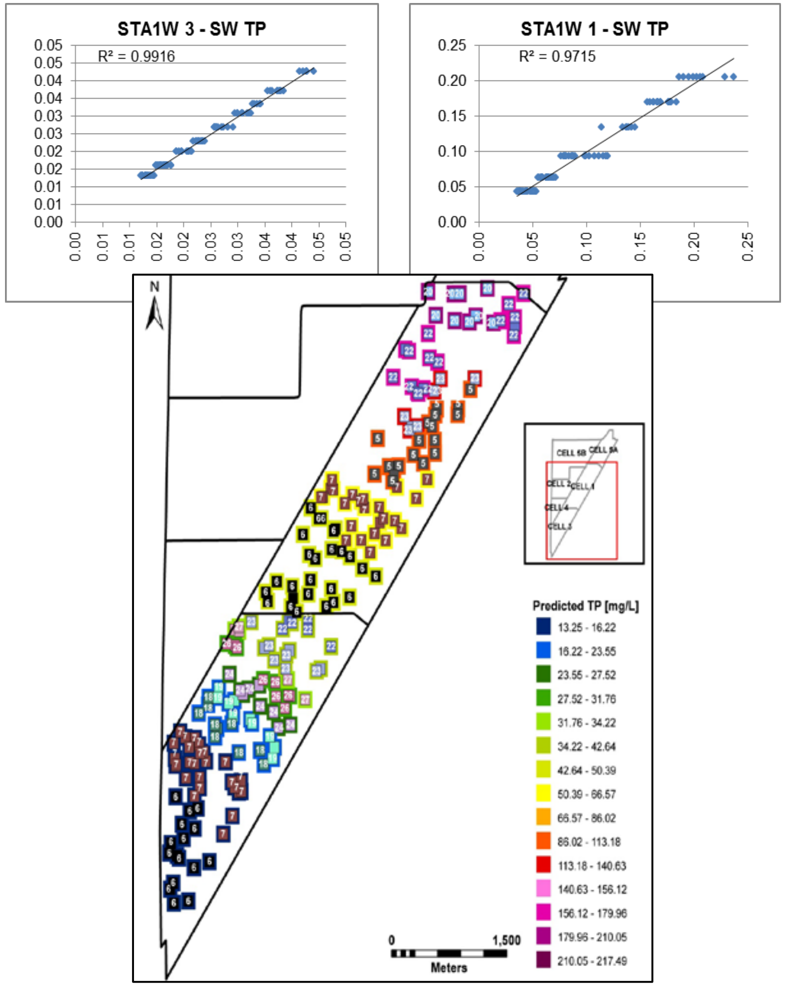




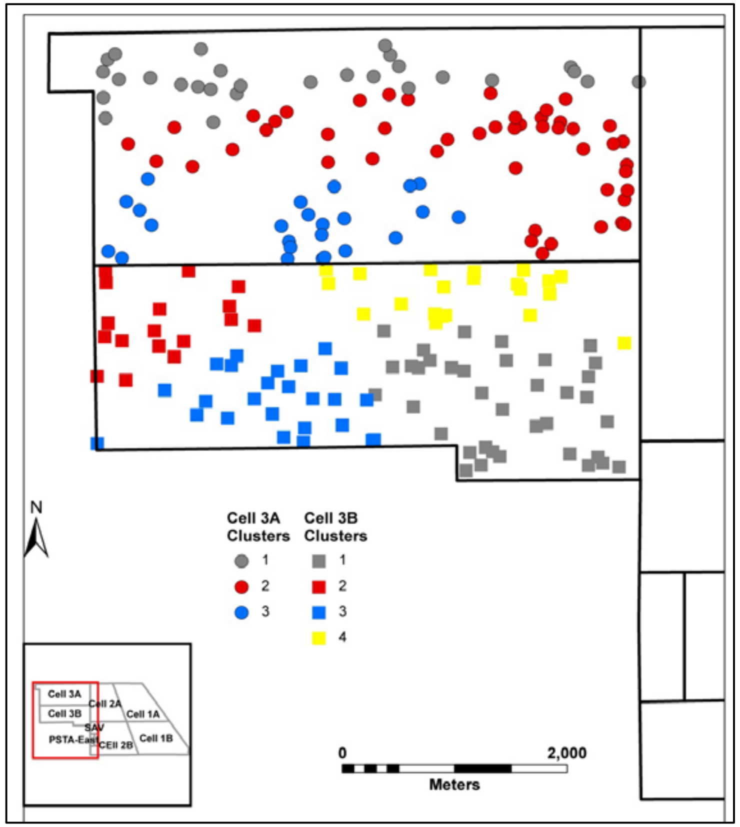
Modelling this a non-stationary process

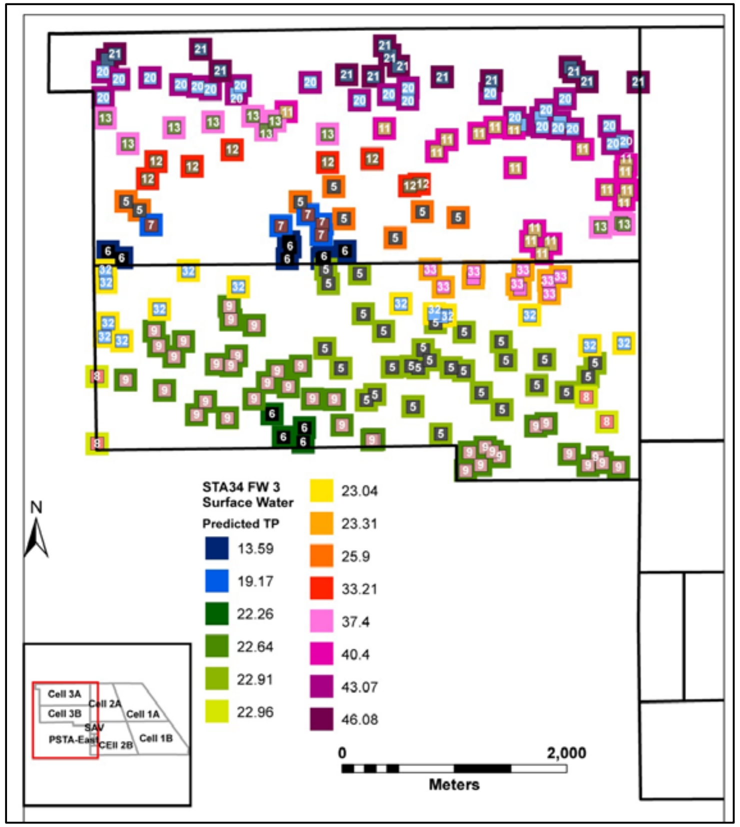






Verification of models vs patterns





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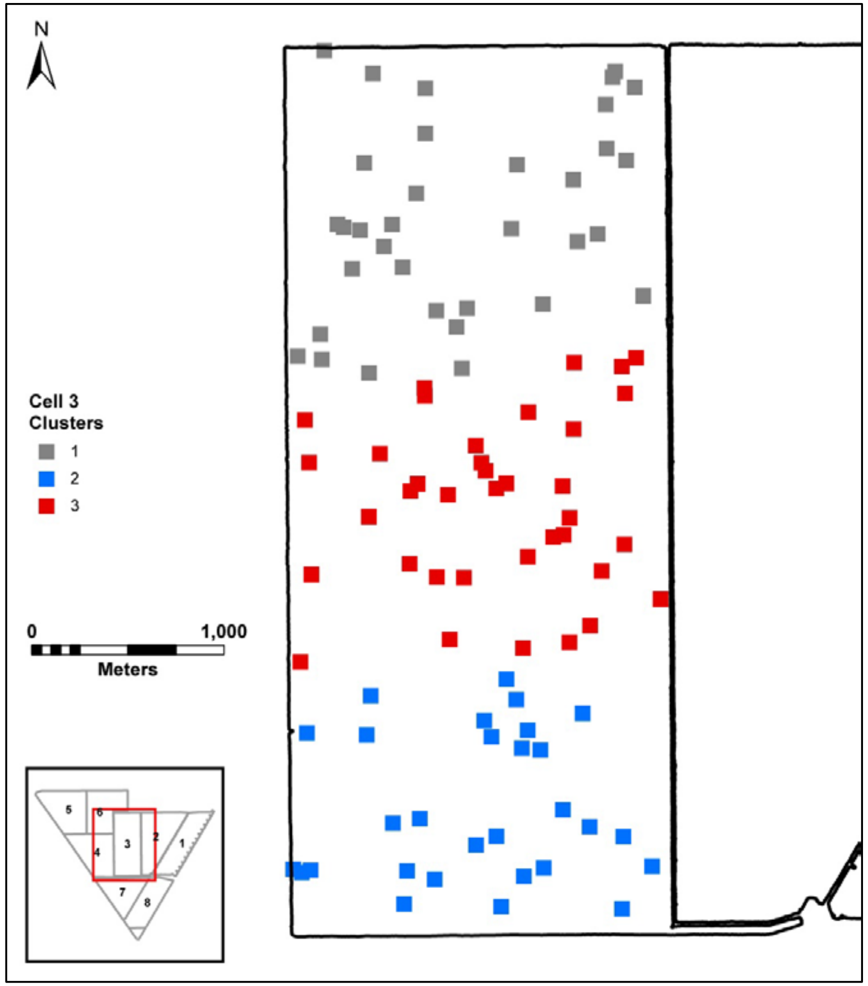

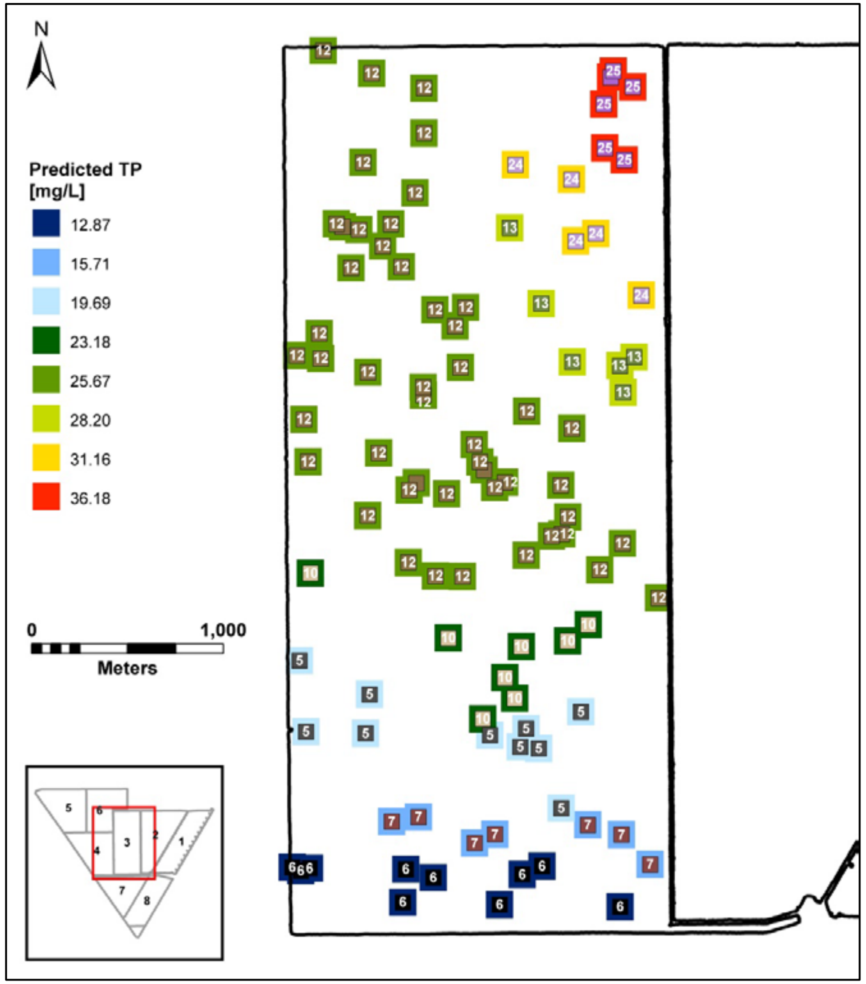

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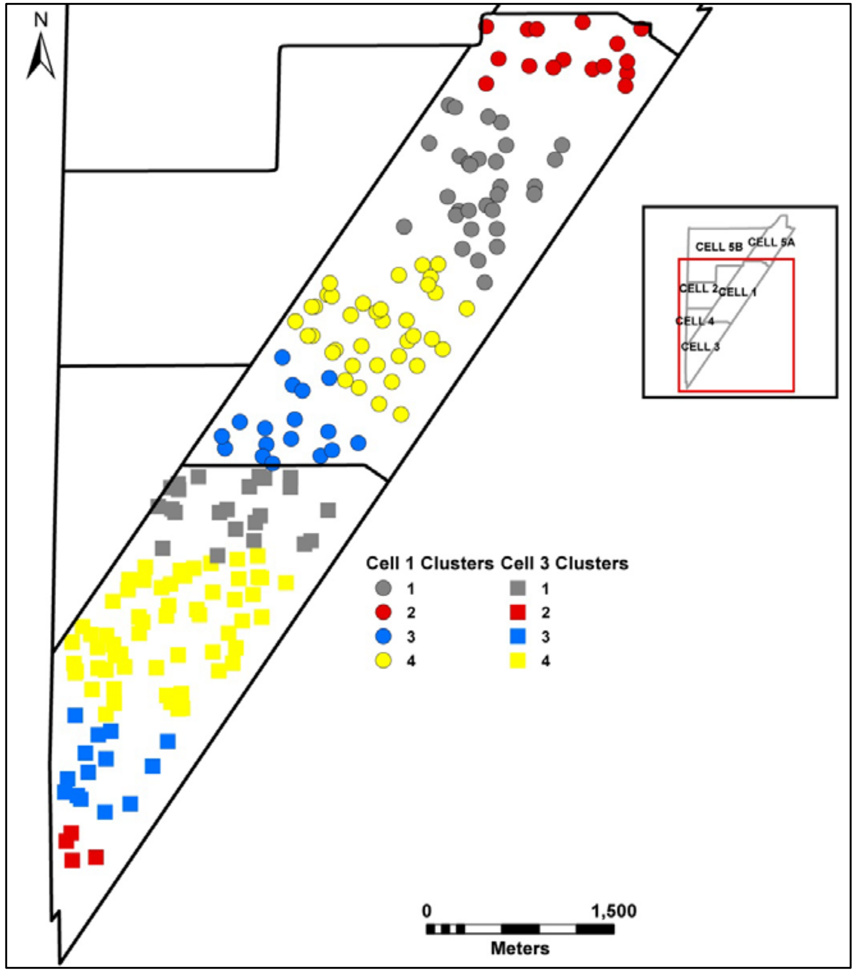
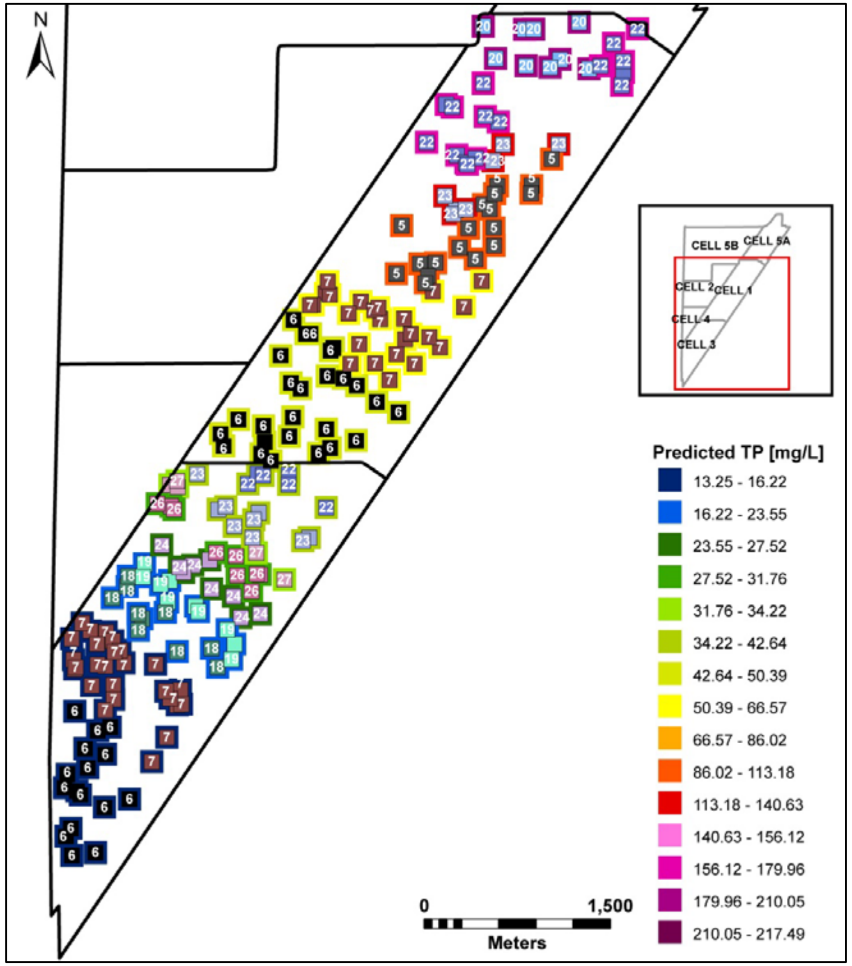
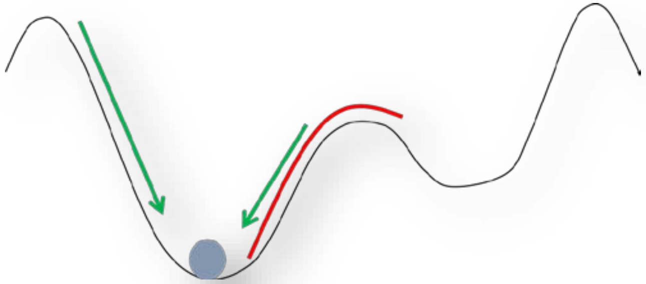


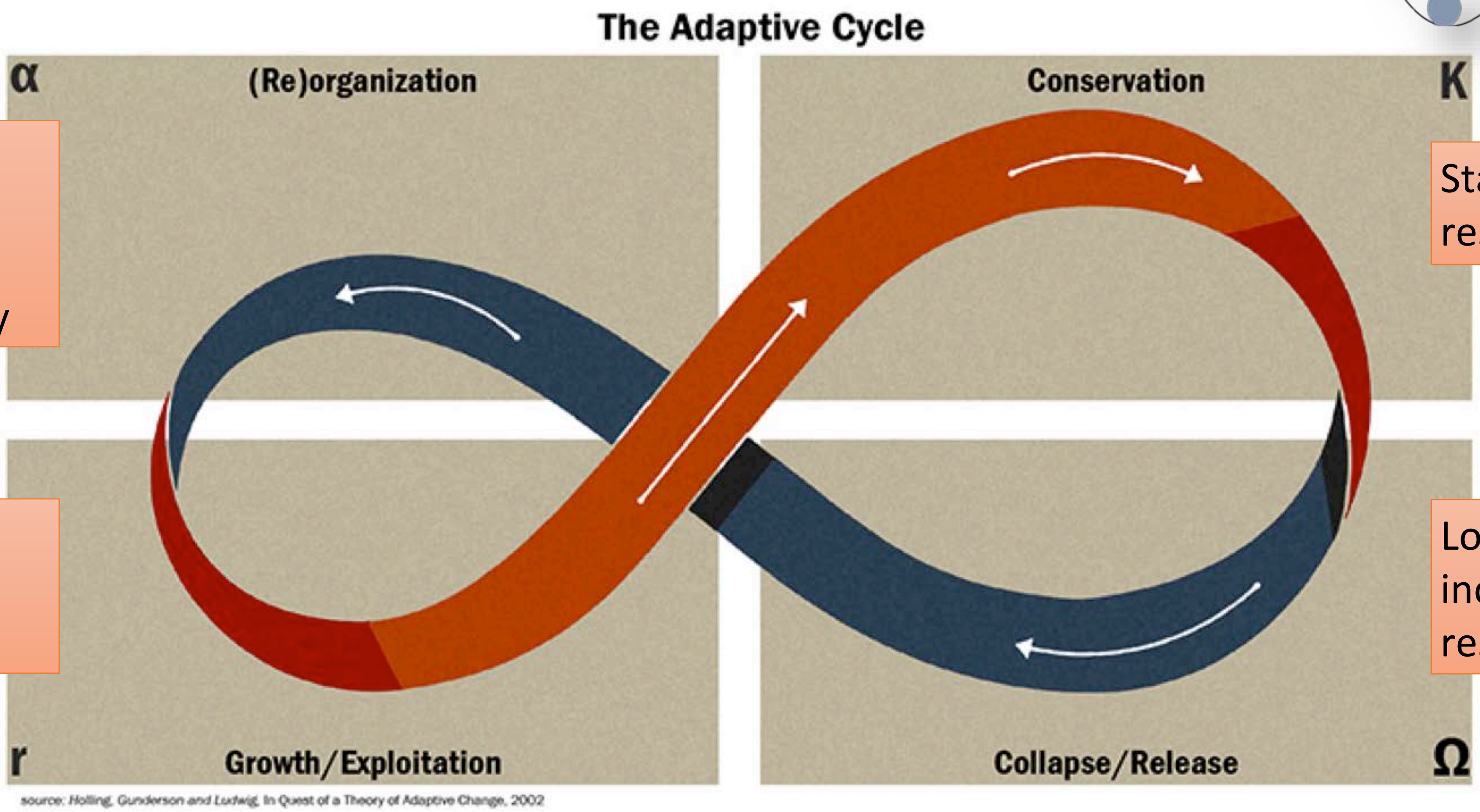


The adaptive cycle



High resilience, greatest uncertainty

High but decreasing resilience



Stable, low resilience

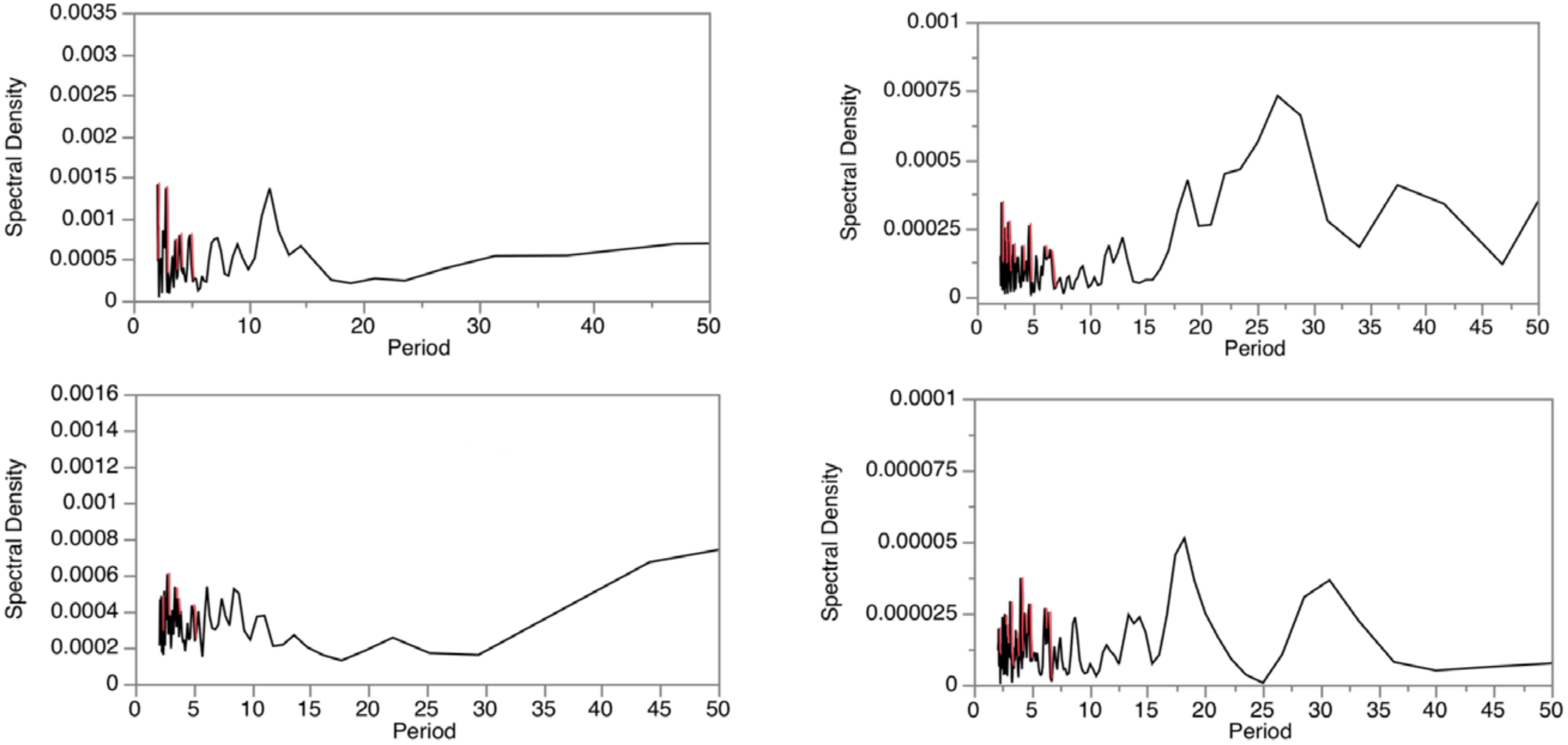
Low but increasing resilience

The Everglades Storm Water Treatment Areas: a found ecological experiment

Temporal Analysis: how resilient are these systems?

STA 2

STA 5/6



The Everglades Storm Water Treatment Areas: a found ecological experiment in resilience

If we now go back to our expectations; three board expectations represented in the data:

1) The systems broadly function as engineered systems,
2) The systems are self organizing ecological systems,
3) The systems are entirely stochastic

Unsurprisingly, they seem to operate as a hybrid of an engineered and self organizing ecological system.