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

Ron Corstanje, Joanna Zawadzka, Delia Ivanoff, and Kathleen Pietro

09 Apr 2018

www.cranfield.ac.uk
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

\[ y(t) = f(x, \zeta, \omega, C, d) \]

- \( \zeta \) is the damping factor
- \( \omega \) is the natural frequency
- \( C \) is the initial slope
- \( d \) is the final equilibrium
Putting this into practice
Operationalising Resilience

Soil Resilience Category
- Adaptive
- Exhibiting CSD
- Fragile Type 1
- Fragile Type 2
- Resilient

Variance

Autocorrelation

Non-propagating
Propagating

Stable

Damping

0 0.25 0.50 0.75 1.00

0.0 0.5 1.0

-0.5

0 50 100 Kilometres

North
So where are the STA’s in this?
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

The Adaptive Cycle

Exemplars of the outcome from the datamining exercise
Spatial Analysis of a non-stationary process
Modelling this a non-stationary process
Verification of models vs patterns
Verification of models vs patterns
Verification of models vs patterns
The adaptive cycle

High resilience, greatest uncertainty

Stable, low resilience

High but decreasing 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.