Using Simple Models to Explore Complex Dynamics: A case study of Macomona (wedge-shell) and nutrient variations

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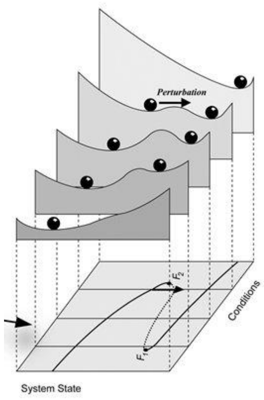
Photo from Waikato Regional Council

Introduction to tipping points:

A dynamical tipping point

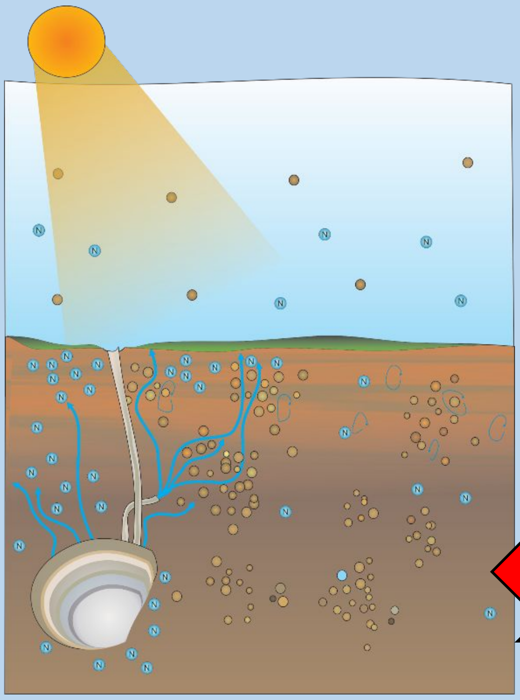
Ecosystem behaviour can be non-linear which means that small changes in environmental conditions can cause disproportionately large changes in response leading to unexpected *regime shifts* or *catastrophic collapses*. It also means that the different states can occur when the environmental conditions are the same (*alternative stable states*).
Multiples stressors (eg, sediment change or nutrient loading) can further accentuate the nonlinearities in the system ultimately leading to loss of resilience and increased susceptibility to change.



http://www.sparcs-center.org/uploads/images/resilience.jpg

A dramatic response forced event

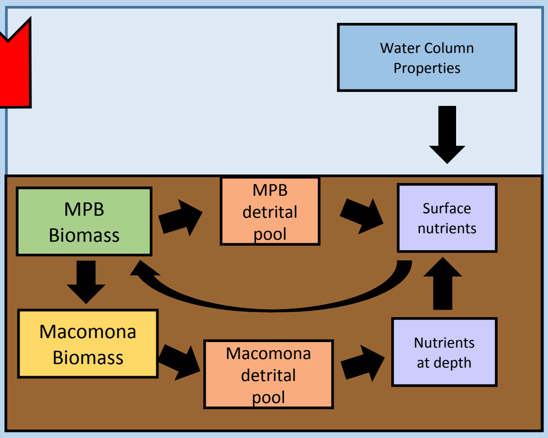
Tipping or regime shifts are not the same as catastrophic changes to ecosystems following extreme events such as e.g. floods or volcanic eruptions.



How are simple models useful for exploring change and assessing risk

1. Defining the conditions leading to a tipping point.
   - E.g. Increase in variability
2. Differentiating between tipping points and a delayed response to change.
3. Determining what happens during a tipping event so that key pathways can be made more resilient.
4. Determining which aspects should be restored, and the potential response to restoration.

The simple system that we have chosen to model is the interaction between *Macomona liliana* and microphytobenthos (MPB). Macomona. Macomona live within the sediments, but feed at the surface. The detritus and nutrients that they produce within the sediments can only reach the surface by porewater movement or Mcaomona pumping behaviour. This can limit the supply of nutrients to MPB



Structure of the model

Microphytobenthos

Light Uptake, Nutrient Uptake

$$G_{MPB} = GR_{MPB}\,\frac{I}{(K_I+I)}\,\frac{N_{MPB}}{(K_N+N_{MPB})}$$

Light

$$I = I_o e^{-kd}$$

Growth, Mortality, Grazing

$$\frac{\partial B_{MPB}}{\partial t} = G_{MPB}B_{MPB}\left(1-\frac{B_{MPB}}{K_{MPB}}\right) - M_{MPB}\left(B_{MPB}-B_{MPB}^{min}\right) - G_{Mac}B_{Mac}\left(1-\frac{B_{Mac}}{K_{Mac}}\right)$$

Macomona

$$G_{Mac} = GR_{Mac}\,\frac{B_{MPB}}{K_{MPB}}$$

Macomona Carrying Capacity
**converted from individual to biomass*

$$K_{Mac} = (21.6 + 0.146MC + 0.005MC^2)$$

Growth, Mortality (Recruitment), Excretion

$$\frac{\partial B_{Mac}}{\partial t} = G_{Mac}B_{Mac}\left(1-\frac{B_{Mac}}{K_{Mac}}\right) - M_{Mac}B_{Mac} - E_{Mac}B_{Mac}$$

Macomona Detritus and Nutrient Pools

Mortality, Breakdown

$$\frac{\partial D_{Mac}}{\partial t} = M_{Mac}B_{Mac} - C_{Mac}D_{Mac}$$

Breakdown, Excretion, Pumping to surface N

$$\frac{\partial N_{Mac}}{\partial t} = C_{Mac}D_{Mac} + E_{Mac}B_{Mac} - P_{Mac}N_{Mac}$$

Microphytobenthos Detritus and Nutrient Pools

Mortality, Breakdown

$$\frac{\partial D_{MPB}}{\partial t} = M_{MPB}B_{MPB} - C_{MPB}D_{MPB}$$

Breakdown, Pumping to surface N

$$\frac{\partial N_{MPB}}{\partial t} = C_{MPB}D_{MPB} + P_{Mac}N_{Mac}$$

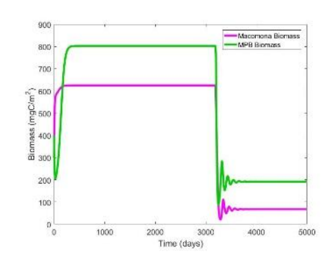
Symbols

MPB=Microphytobenthos
Mac=Macamona
B_{MPB}= MPB Biomass
D_{MPB}= MPB Detritus
N_{MPB}= MPB Surface Nutrient Pool
B_{Mac}= Mac Biomass
D_{Mac}= Mac Detritus
N_{Mac}= Mac Nutrient Pool

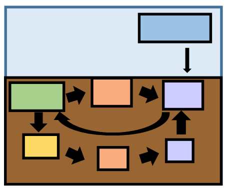
M= Mortality
C= Decomposition rate
K_N = Nutrient uptake rate
K_I= Light uptake rate
k = Light attenuation
K_{Mac}= Mac carrying capacity
K_{MPB}= MPB carrying capacity
P_{Mac}= Pumping and porewater rate

Preliminary results: Alternative States

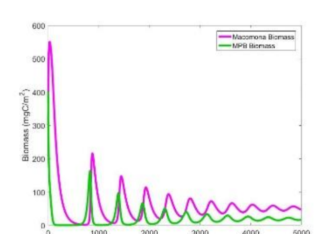
1. High nutrient: Shifting regimes



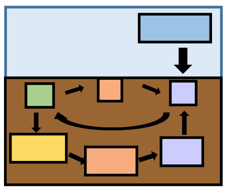
The stable MPB and Macomona biomass is established at the carrying capacity of the system. After some time, the nutrients accumulate at depth and replenishment to the surface is limited by the flushing rate. These nutrients eventually become toxic and cause the Macomona population to collapse. Reduced grazing pressure and nutrient supply means the MPB population establishes at a new level.



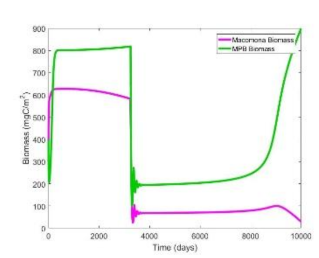
2. Low nutrients: tight non-linear coupling



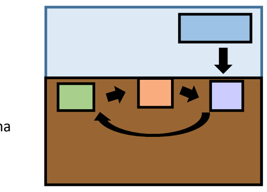
In a low nutrient environment, the MPB quickly use the surface nutrient supply, and their biomass collapses. The Macomona follows after a short time lag. The detrital pool breaks down, and supplies a new source of nutrient, which causes MPB to recover. Gradually through time, the oscillations diminish. Eventually a stable state will be established.



3. Sediment composition change: multiple stressors cause catastrophic shifts



Changes toward muddier sediments feed back into reducing the Macomona carrying capacity. The increasing Macomona detrital pool eventually leads to toxic levels of nutrients at depth, ultimately removing Macomona completely. The MPB re-establishes subsisting on external nutrients and its own regenerated supply.



Parameterising the terms




Next Steps

- Improved parameterisations from field experiments
- Analyse observations to detect similar state changes

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