Temporal scales of coupled ecosystem processes provide a benchmark for alternate ecosystem states

Photosynthesis and decomposition in a model micro-ecosystem

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Background and Overview

- Ecosystem dynamics can lead to sudden, recalcitrant state changes,
- Here, we further develop and apply an ecosystem model based on the food web of the carnivorous plant, *Sarracenia purpurea*, to simulate oxygen production and explore the impact of simultaneously altering key parameters,
- We found three main results:
  1. The micro-ecosystem model reproduced key behaviors of the real pitcher plant food web
  2. Sensitivity analysis revealed parameter combinations that produce alternative ecosystem states
  3. Differences in photosynthesis and decomposition rates lead to both alternative states and hyesteresis,
- These results support previous findings that the timing of processes can lead to shifts in ecosystem state.

Methods

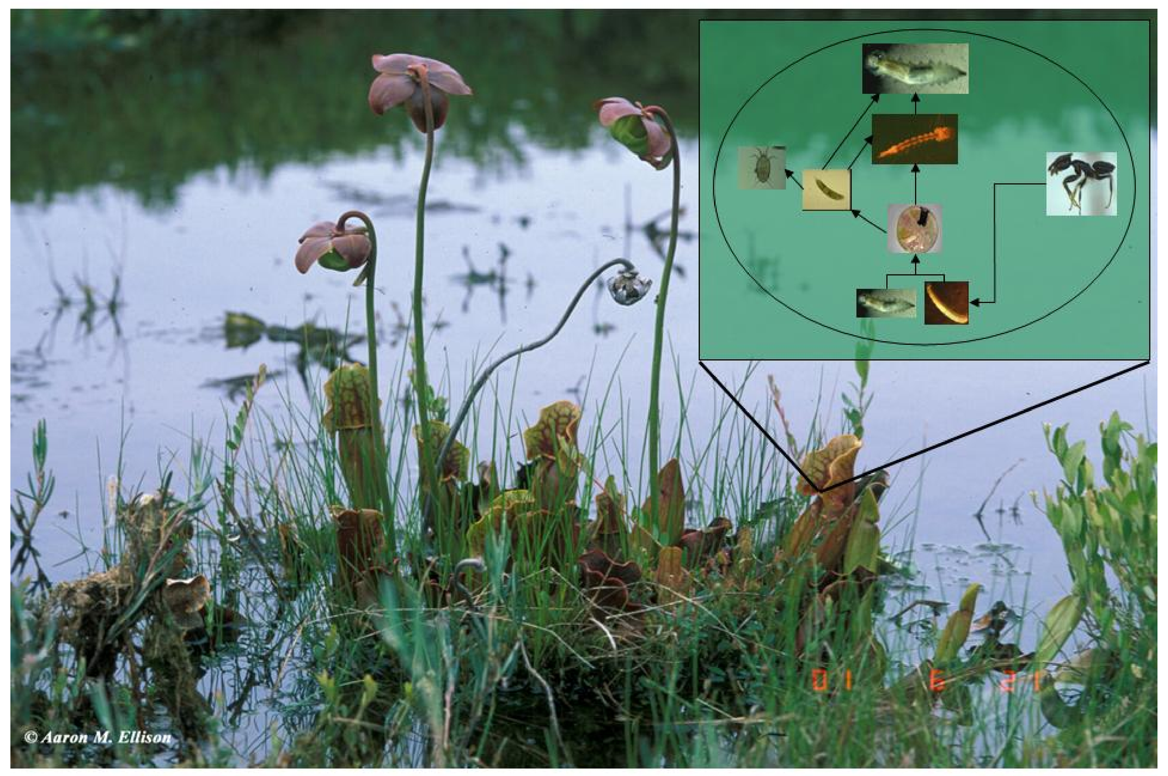

Figure 1: Pitcher plant and food web.

Pitcher Plant Micro-Ecosystem Model

A general model that produces alternative ecosystem states can be represented as: $\frac{dx}{dt} = a - bx + rf(x)$. Where, x = observed variable, a = positively correlated state variable, b = negatively correlated state variable, $rf(x)$ = positive feedback loop, where r controls the rate and $f(x)$ determines the shape of the state transition.

Component	Equation
Oxygen	$x_{t+1} = a_t A_t - \left\{ m + a_t \frac{w+t}{K+w_t} \right\} + D_t(x_t)$
Photosynthesis	$A = A_{max} \left\{ 1 - e^{-0.3(PAR-LCP)} \right\}$
PAR	$PAR = c \sin(2\pi f)$
Decomposition	$w_t = e^{-\beta w_0 t}$
Oxygenation	$a_t + 1 = a_t \left\{ \frac{a'_{max} - a'_{min}}{1+e^{-sn_t-d}} + a'_{min} \right\}$
Nutrient Release	$n_t = \frac{w_t x_t}{c}$

Table 1: The *S. purpurea* micro-ecosystem model.

Sensitivity Analysis Simulations

Because the micro-ecosystem model is a coupled, non-linear dynamic equation, we conducted simulations in which we variaed three key parameters in the model: w the prey mass added, β the decomposition rate and d the inflection point of the nutrient augmentation function.

Results

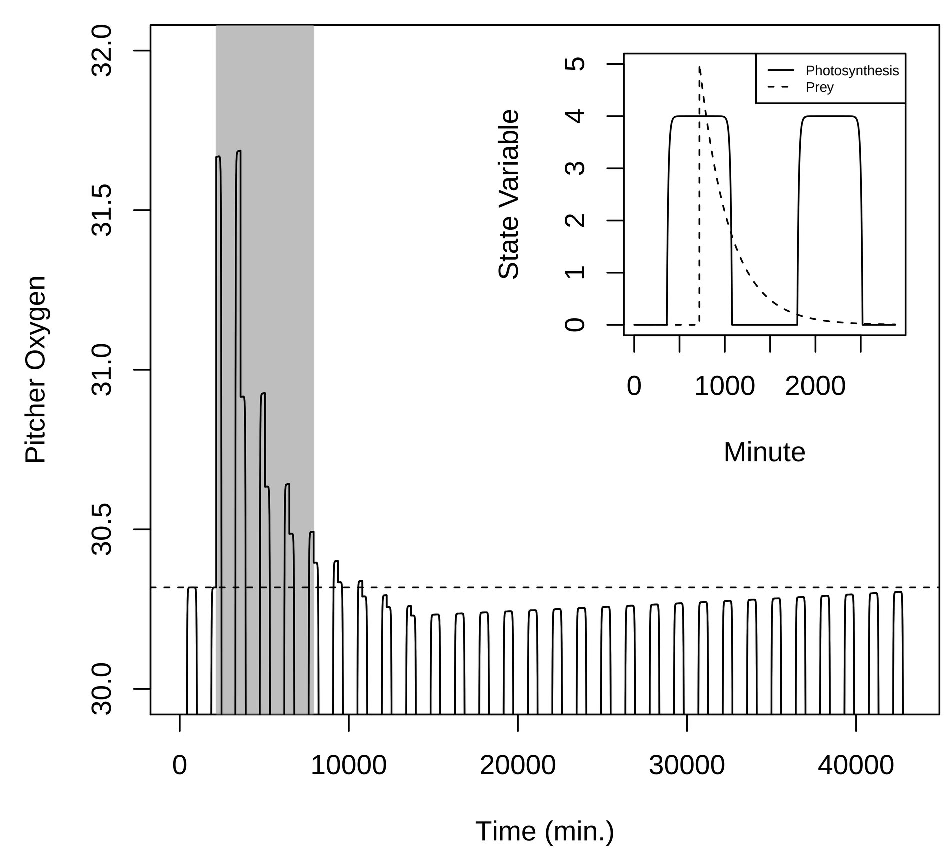

Figure 2: The pitcher plant micro-ecosystem model exhibited several behaviors similar to those of real *S. purpurea* pitcher plants, including: dirunal cycling of O_2 and 48 hours to complete decomposition of prey (inset plot), altered O_2 production with prey addition (grey region), hysteresis occurs when prey addition stops (time = 9360 min).

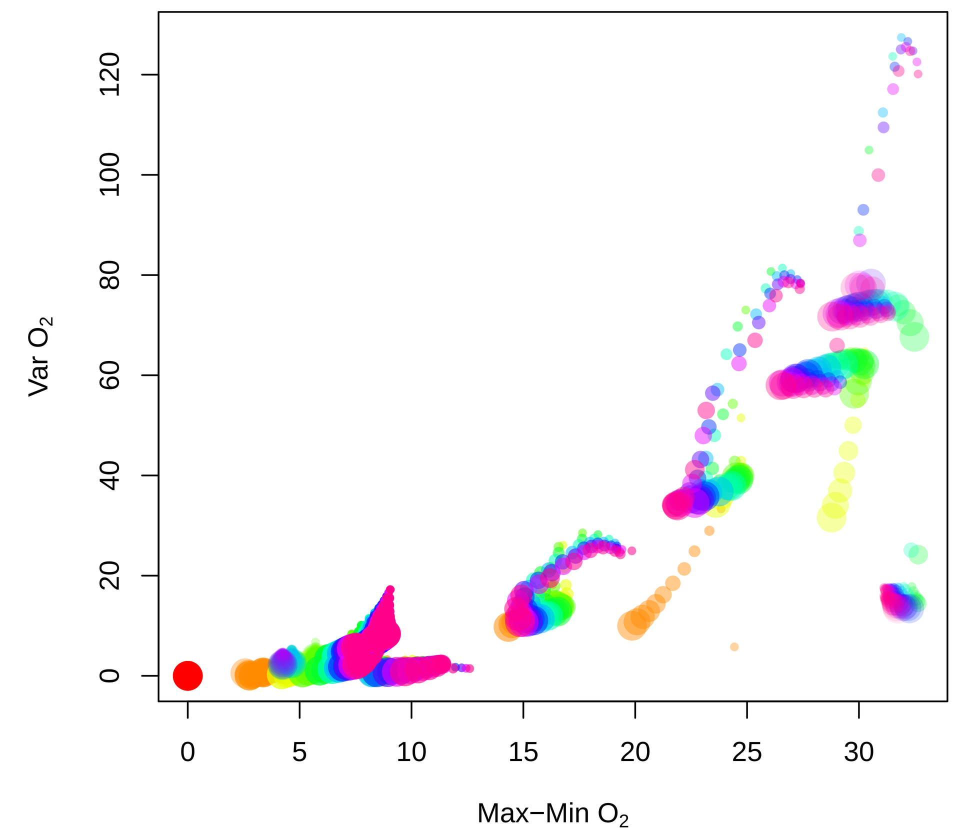

Figure 3: The variance and range of the O_2 dynamics were affected by prey mass (w) added (color: red = 0 to blue=10), the decomposition rate (β) (size: smallest = 0.001 to largest = 0.011) and the inflection point (d) of O_2 augmentation (opacity: lightest = -5 to darkest = 5).

Conclusions

- Exploration of the parameter space for the model supports the presence of alternative states and the potential for tipping points resulting from the impact of the rate of decomposition and photosynthesitic augmentation.
- These results suggest that identifying the flow of important components (e.g., nutrients) among compartments in ecosystems and using snap-shot data to compare the temporal scale of these flow rates can help to detect systems prone to critical transitions.
- We are currently developing a toolbox for exploring ecosystems models using a web-based dynamic modeling framework available at: https://github.com/HarvardForest/ecoapps.

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