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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Summary

- Community dynamics can lead to sudden, recalcitrant ecosystem state changes (aka. tipping points),
- Here, we further develop and apply the micro-ecosystem model based on the food web of the carnivorous plant, ***Sarracenia purpurea***, to simulate oxygen production of how perturbations lead to ecosystem state changes,
- We found three main results:
  1. The micro-ecosystem model reproduced the gross behavior of the 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 point to a general framework for identifying potential ecosystem state changes.

Methods

The pitcher plant micro-ecosystem

- History of research (Darwin to Sirota)
- Ideal for studying food-web dynamics

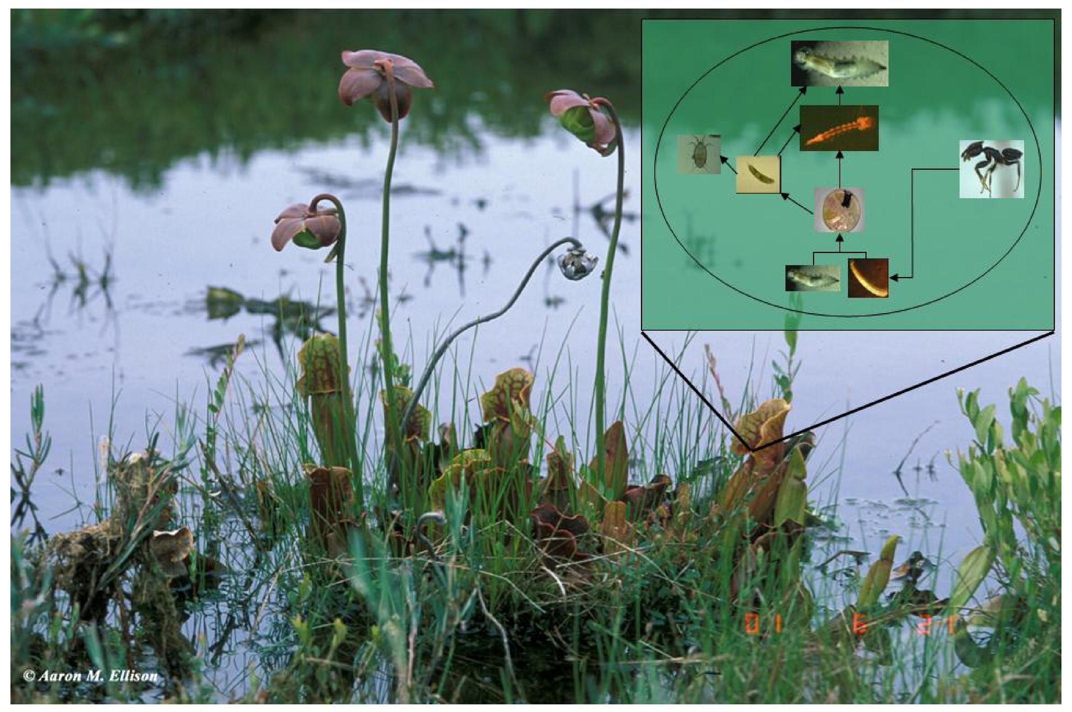


Figure 1: Pitcher plant and food web.

The model and simulations

The general model for alternative stable states:

$$\frac{dx}{dt} = a - bx + rf(x) \quad (1)$$

- 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

The pitcher plant micro-ecosystem model:

$$x_{t+1} = a_t A_t - \left\{ m + a_t \frac{w+t}{K+w_t} \right\} + D_t(x_t) \quad (2)$$

$$A = A_{max} \left\{ 1 - e^{-0.3(PAR-LCP)} \right\} \quad (3)$$

$$PAR = c\sin(2\pi f) \quad (4)$$

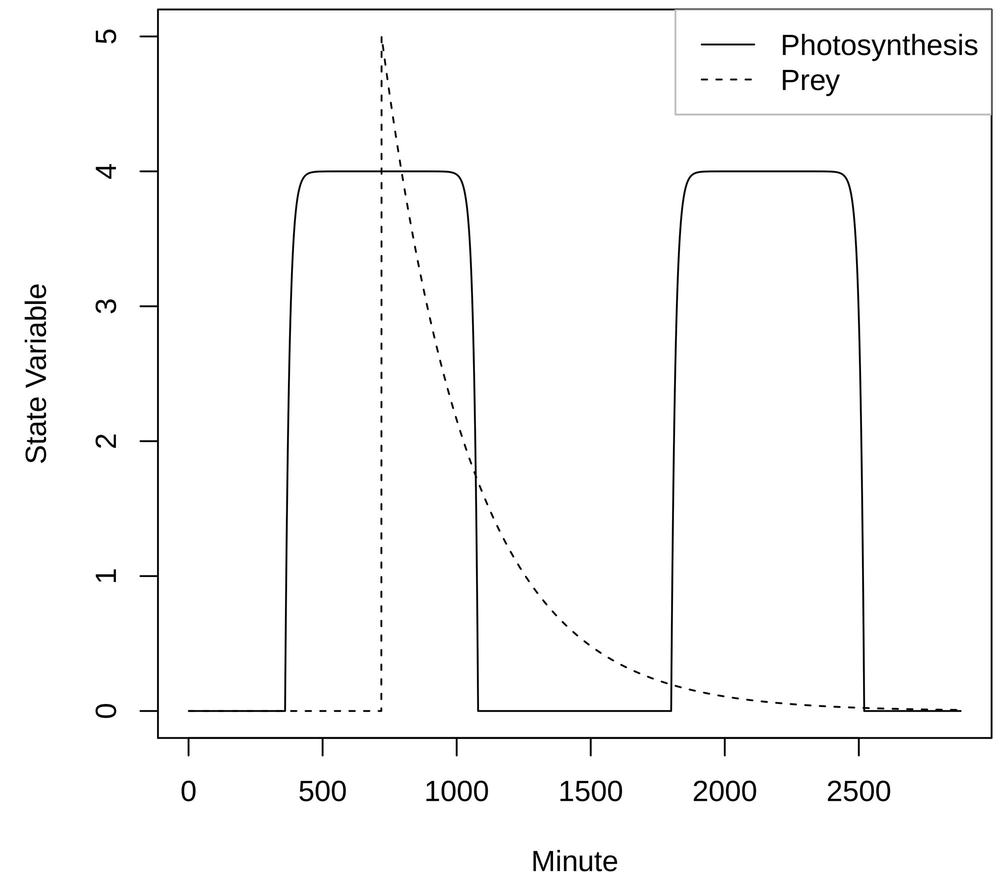
$$w_t = e^{-\beta w_0 t} \quad (5)$$

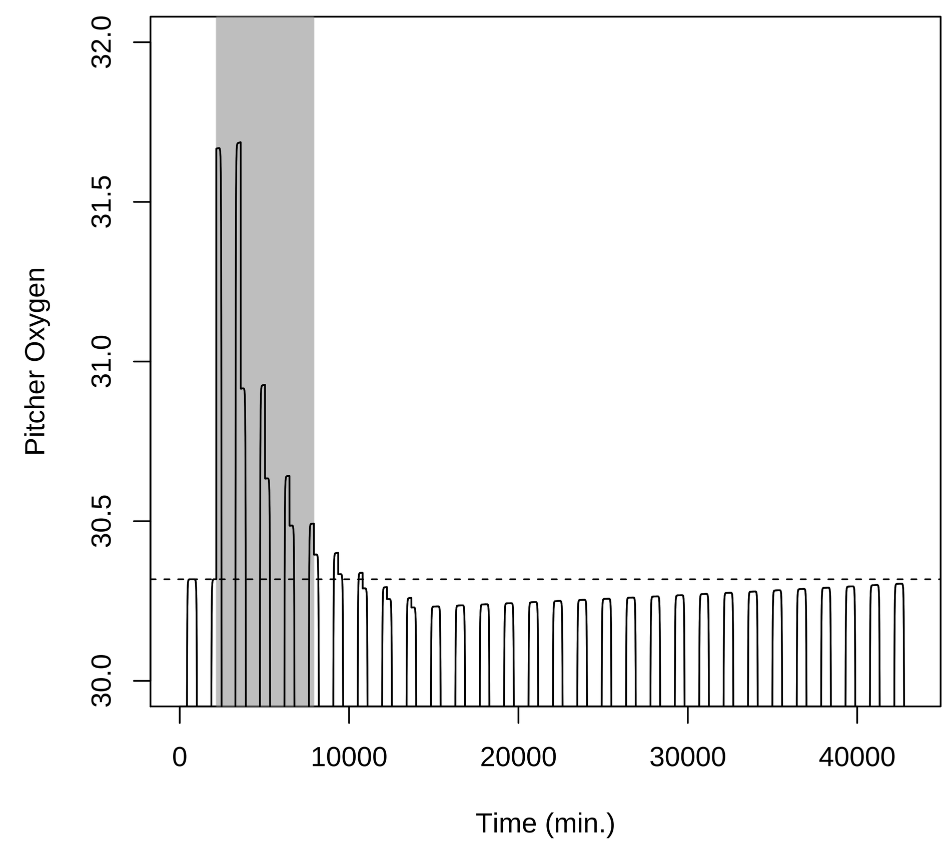
$$a_t + 1 = a_t \left\{ \frac{a'_{max} - a'_{min}}{1 + e^{-sn_t - d}} + a'_{min} \right\} \quad (6)$$

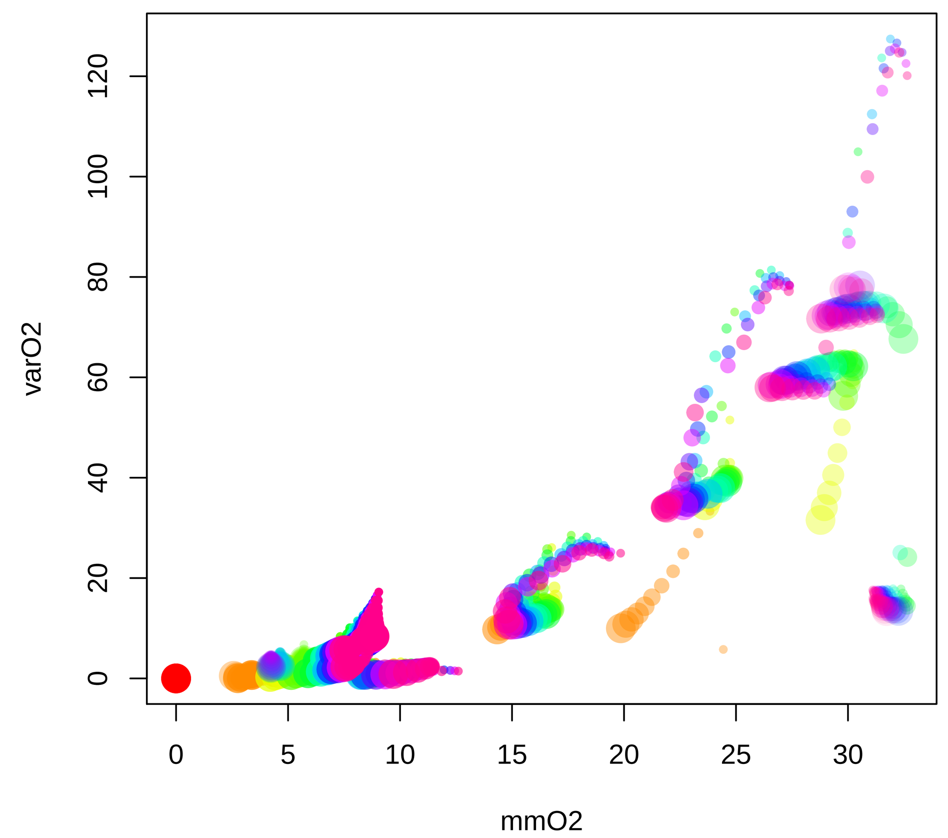
$$n_t = \frac{w_t x_t}{c} \quad (7)$$

Results

The model reproduces the basic features of the pitcher plant system.







Conclusions

- As the rate of decomposition slows such that the release of nutrients overlaps with the next addition of prey, the negative feedback of biological oxygen demand increases.
- The temporal overlap of decomposition among days produces a pattern of hysteresis, as observed in real pitcher plants.
- 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.

Forthcoming

We are currently developing a toolbox for exploring ecosystems models using a web-based dynamic modeling framework. The open-source software and information on how to use the application can be found at: https://github.com/HarvardForest/ecoapps.

[1] A. B. Jones and J. M. Smith. Article Title. *Journal title*, 13(52):123–456, March 2013.

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