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

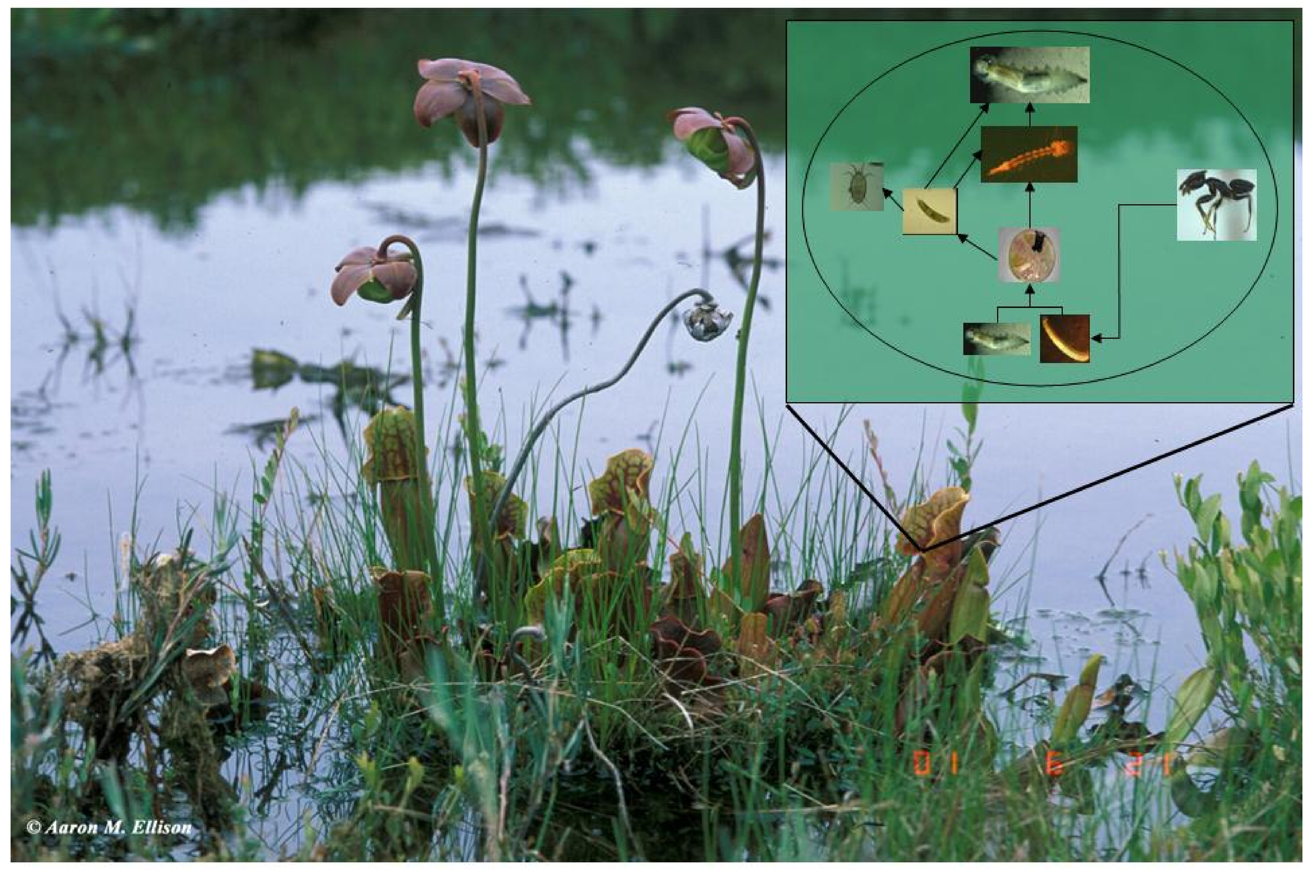


Figure 1: Pitcher plant and food web.

The model and simulations

The general model for alternative stable states:

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

- 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:

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

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

$$PAR = c \sin(2\pi f) \tag{4}$$

$$w_t = e^{-\beta w_0 t} \tag{5}$$

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

Component	Equation
Nutrient Release	$n_t = \frac{w_t x_t}{c}$

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

Parameter	Min	Max
w (prey mass)	0	10
β (decomp rate)	0.001	0.011
d (inflection point)	-5	5

Table 2: Parameter ranges for simulations.

Results

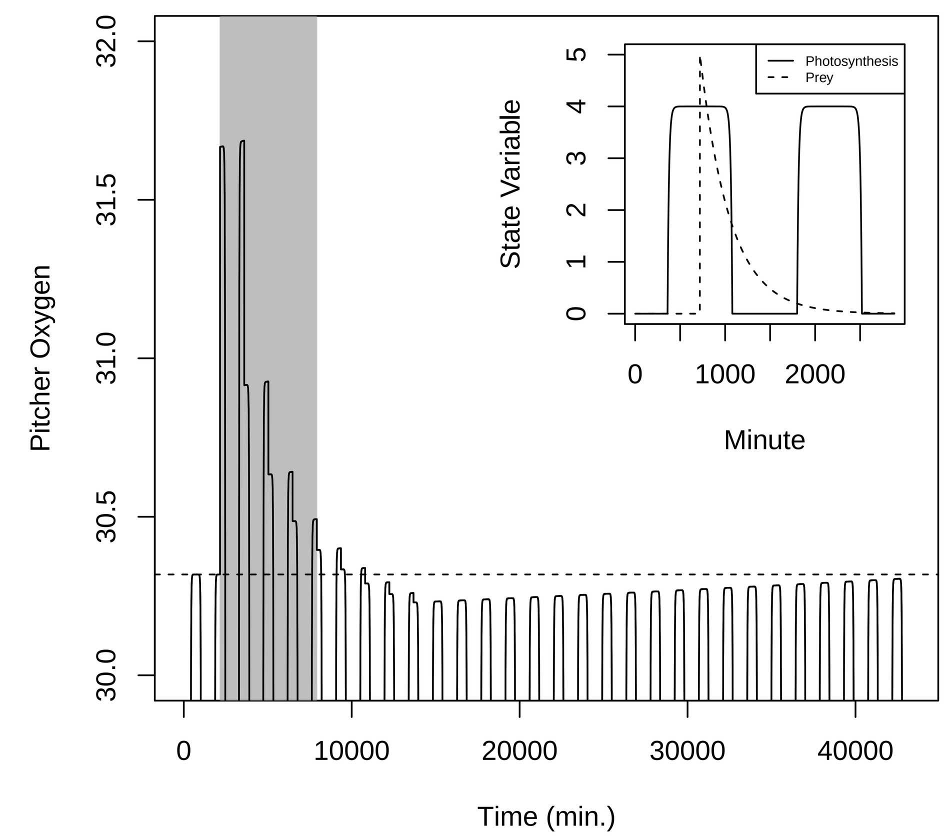
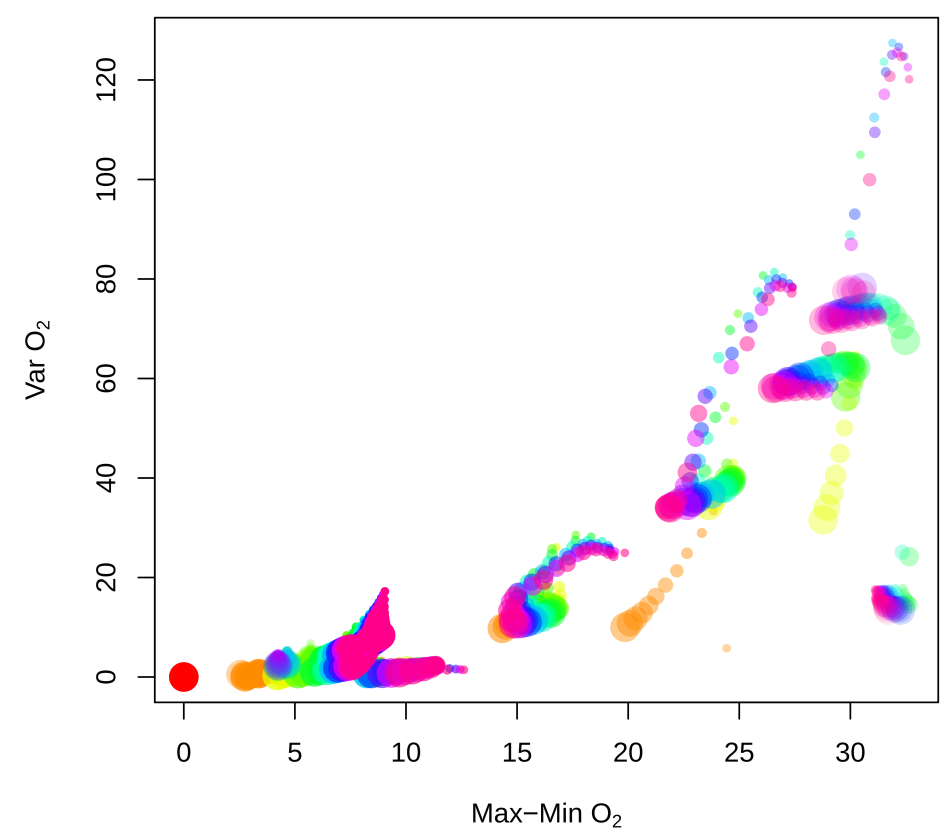


Figure 2: The pitcher plant micro-ecosystem model exhibited several behaviors similar to those of real *S. purpurea* pitcher plants, including: diurnal cycling of O_2 and 48 hours to complete decomposition of prey (inset plot), altered O_2 production with prey addition (grey region), hysteresis occurs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



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.

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.

References

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

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