Spatial Organization of Biological Soil Crusts in Drylands

Daniel Kozar

UC Davis - Hydrologic Sciences Graduate Group

Spatial Ecology Group

Biological Soil Crusts

- Biological soil crusts, or BSCs, are complex communities living in the soils surface of drylands

- Composition varies but is largely determined by aridity gradient

Cyanobacteria → Lichens → Bryophytes (Mosses)

Aridity ←

Biomass →

- Play key roles in environmental processes:

Nutrient cycling

Hydrology

Erosion and soil stability

Interactions with vegetation

(a)

(b)

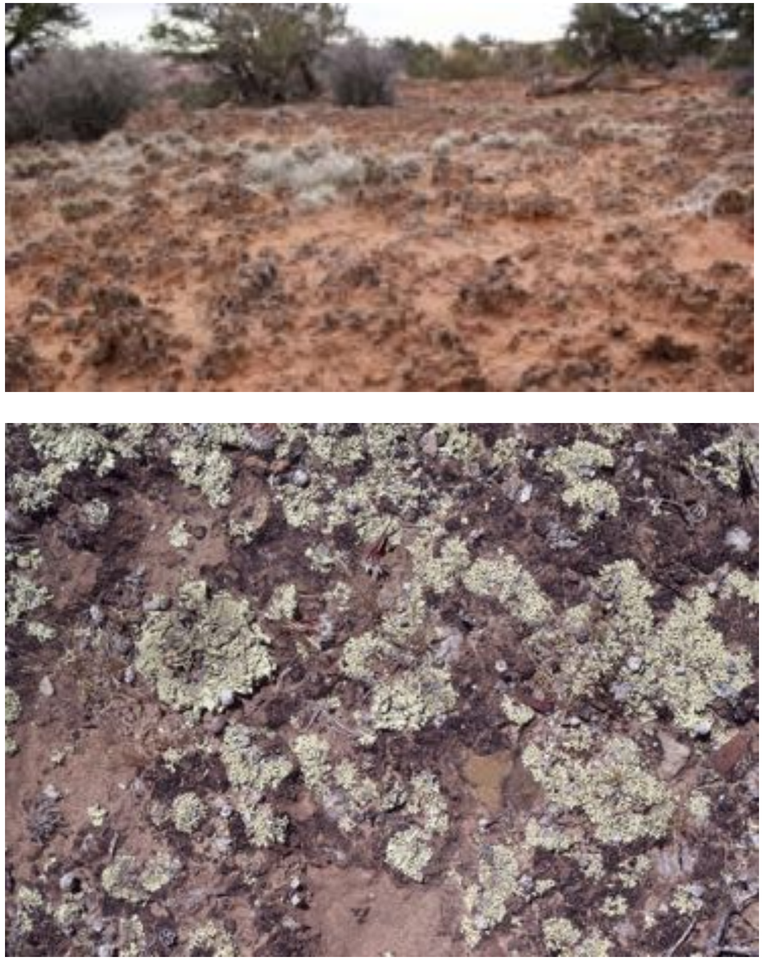


Figure 1: Biological soil crusts in (a) typical dryland landscape and (b) close up of late successional crust (Garcia-Pichel Lab/ANBG)

Why study them?

- Functional role, and interaction with vegetation is suggested to vary along aridity gradients
- In the face of changes in precipitation regime and stress due to climatic changes, BSCs likely play key role in ecosystem state change in drylands
- Hysteresis may mean recovery after shift near to impossible
- Researchers often use spatial organization of vegetation in drylands to understand early warning signs of state change

  BSCs are conspicuous constituents in space

  Likely respond to changes in stress earlier than vegetation

  Why not include spatial information about BSCs to our advantage as well?

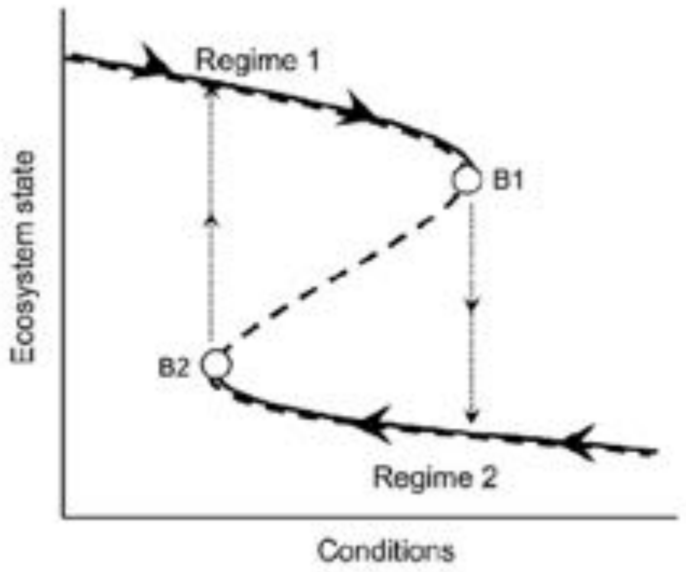


Figure 2: Conceptual diagram of hysteresis loop. Dryland state change in light of climate change (Ocean Tipping Points)

Methods

Combined approach:

- Two dimensional spatially implicit system
- Spatially explicit system using water balance
  Excess entropy
- Only consider BSCs as one state

Two Dimensional System

Amended two species competition-mutualism model

$$\frac{dV}{dt} = r_v V \frac{(K_V - V + \alpha_{VB} B)}{K_V} \qquad \text{(Vegetation)}$$

$$\frac{dB}{dt} = r_B B \frac{(K_B - B + \frac{\alpha_{VB}}{\beta} V)}{K_B} \qquad \text{(BSC)}$$

$$\beta = \frac{\alpha_{VB}}{\alpha_{BV}}$$

$$\alpha_{VB} = \alpha_{VB_0} \frac{B + 1001}{C + e^{(0.1B)}}$$

Spatially Explicit Ecohydrological Model

Amended from McGrath et al., 2012 which models vegetation on hillslopes forming tiger bush

$$\frac{dw_i}{dt} = P_i + R_i - Q_i - E_i - \sum T_n$$

$$I_i = P_i + R_i - Q_i = \frac{p_i l v}{\Delta x^2 \Delta t_r}[1 + \sum_{k=1}^{i=1} \prod_{j=1}^{k} (1 - p_j)]$$

$$T_i = T_{max} \int g_c(r) f_c(r) dr$$

$$E_i = \sum_1 k \beta_k \frac{D}{t_e}$$

$$K_i = K_0 + K_v \int g_f(r) f_f(r) dr - K_{BSC} \int g_{BSC}(r) f_{BSC}(r) dr$$

$$p_i = min(K_i / P, 1)$$

Growth of each constituent dependent on transpiration rates in each cell

Entropy Density in Space

Information measures useful in two-dimensional space in order to identify structure

Method outlined in Feldman & Crutchfield, 2003

Similar to calculation in one-dimensional systems except for order of sampling

In space, each state is extracted in order from cell of interest or "spin"

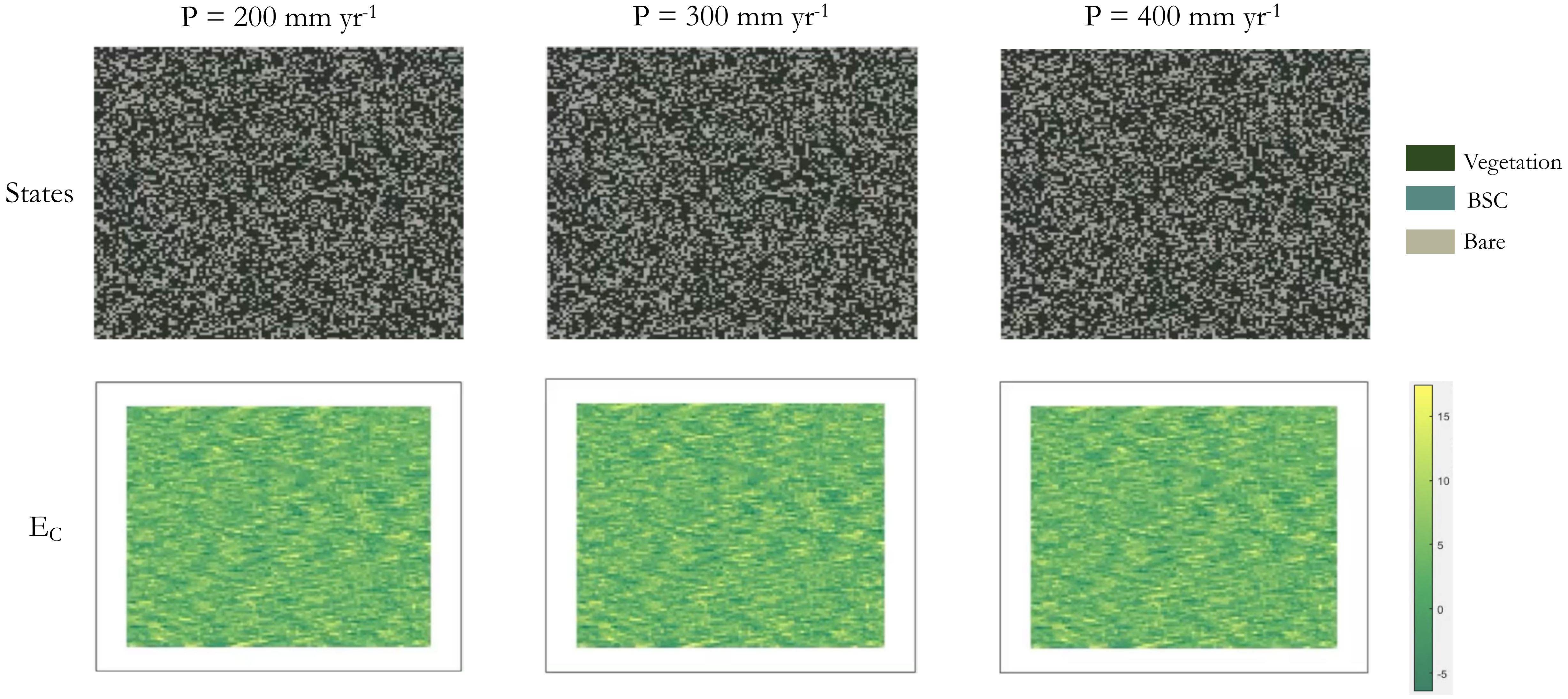
9	7	5	3	1	X				
					2	4	6	8	10

$$H(L) = -\sum_{x \in X} Pr(x) log_2 Pr(x)$$

$$h_\mu = \lim_{L \to \infty} \frac{H(L)}{L}$$

$$E_c = \sum_{L=1}^{\infty} [h_\mu(L) - h_\mu]$$

Results – Spatially Explicit Model



Results – Spatially Implicit Model

Partial derivatives to obtain Jacobian at fixed-points:

$$\frac{\partial f}{\partial V} = r_V - 2\frac{r_V}{k_V}V + \frac{r_C \alpha_{VB}}{K_V}B \qquad \frac{\partial g}{\partial V} = \frac{r_B \alpha_{VB}}{K_B \beta}B$$

$$\frac{\partial f}{\partial B} = \frac{r_C \alpha_{VB}}{K_V}V \qquad \frac{\partial g}{\partial B} = r_B - 2\frac{r_B}{k_B}B + \frac{r_C \alpha_{VB}}{K_B \beta}V$$

$$\left(f = \frac{dV}{dt}, g = \frac{dB}{dt}\right)$$

Fixed points:

(0,0)
$(0,K_B)$ → Stability?

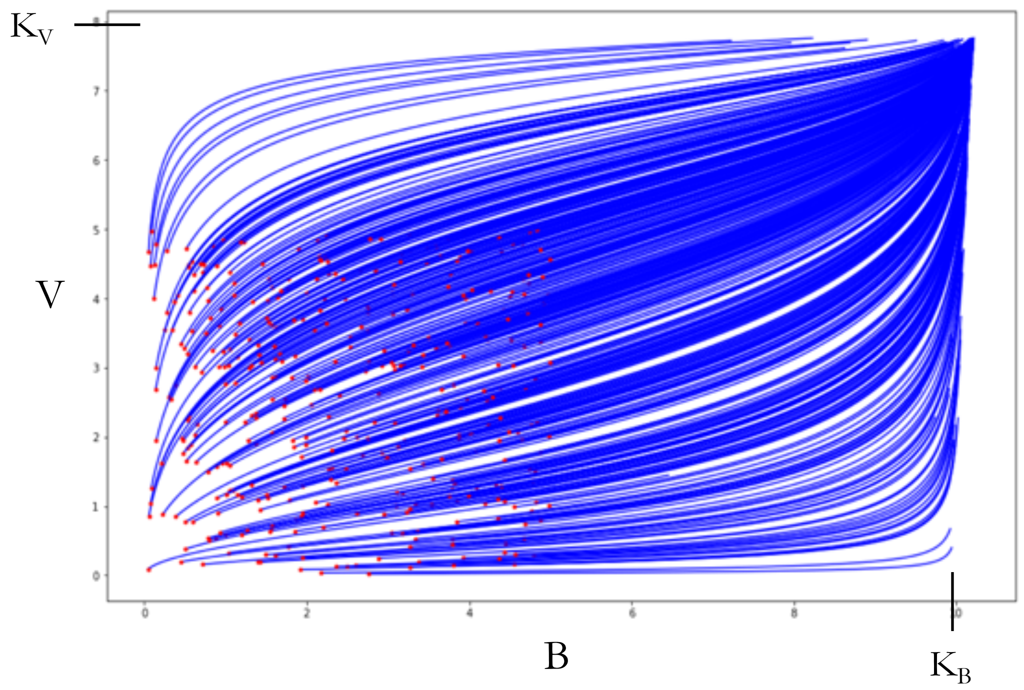


Figure 3: Phase portrait analysis suggests that regardless of interaction direction and strength, both populations will reach respective carrying capacity given positive nonzero initial conditions

Preliminary Findings & Future Work

Spatial complexity of landscape peaks during initial self-organization

Adding BSC component suggested to not affect vegetation self-organization

Spatial complexity moves throughout landscape with patterns, but magnitude varies little with stress, suggesting that the complexity of the system only varies during initial self-organization rather than along aridity gradient

Will assess asymptotic population behavior in spatially explicit model in comparison to implicit model

Will assess mean entropy rates over time along aridity gradient

Thank you!

Questions or comments greatly appreciated