Alternative States in Tidepool Metacommunities

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INTRODUCTION

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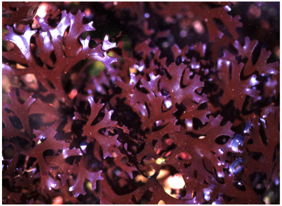

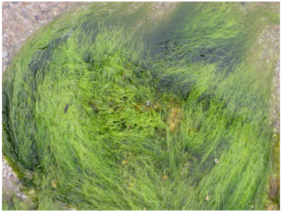

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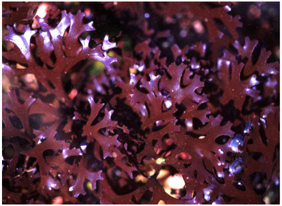

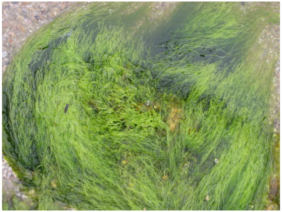

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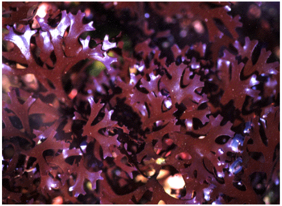

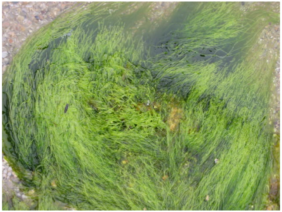

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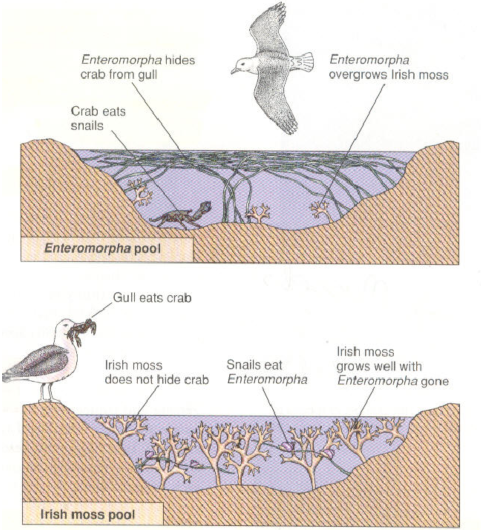


Our Study

Develop a model of tide pool dynamics to answer the following questions:

- Do alternative stable states exist when modelling a single tide pool?
- Under what conditions?
- What dynamics occur when considering two or more pools?
- What are the dynamics of pool colonization?

One Pool, Three Species

Only explicitly model *Enteromorpha*, *Littorina*, and *Carcinus*:

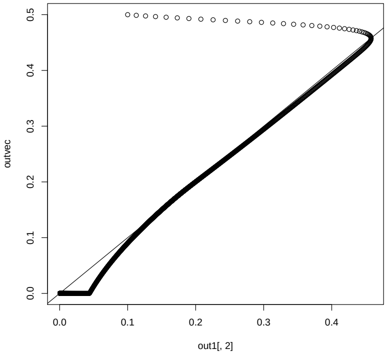
$$\frac{\mathrm{d}E}{\mathrm{d}t} = r_E E(1 - E) - \alpha_{LE} EL$$

$$\frac{\mathrm{d}L}{\mathrm{d}t} = r_L L(1 - L) - \alpha_{CL} LC$$

$$\frac{\mathrm{d}C}{\mathrm{d}t} = r_C C(1 - C) - \frac{d_C}{1 + \alpha_{EC} E} C$$

One Pool, Simplified

- *Enteromorpha* population dynamics occur on a much faster time scale than *Littorina* and *Carcinus* (months vs. years)
- Reasonable to assume that *Enteromorpha* reaches equilibrium instantaneously



One Pool, Simplified

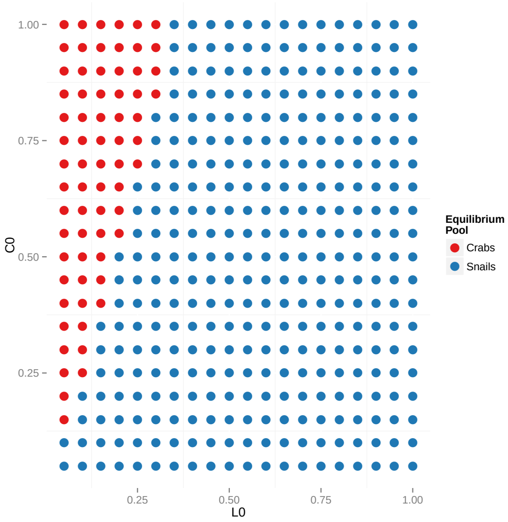
$$\frac{\mathrm{d}L}{\mathrm{d}t} = r_L L(1-L) - \alpha_{CL} LC$$

$$\frac{\mathrm{d}C}{\mathrm{d}t} = r_C C(1-C) - \frac{d_C}{1+\alpha_{EC}E^*(L)} C$$

$$E^*(L) = \max(0, 1 - \frac{\alpha_{LEL}}{r_E})$$

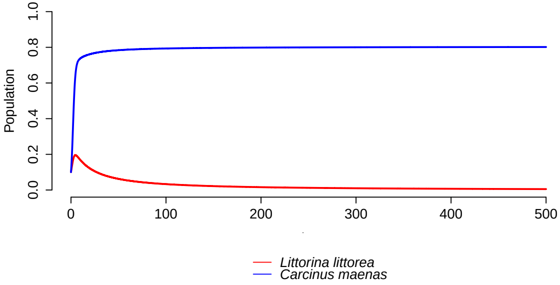
One Pool, Simplified

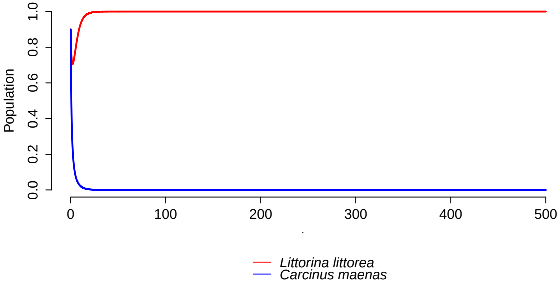
$r_E = .25$
$r_L = .25$
$r_C = .75$
$d_C = 1$
$\alpha_{LE} = .75$
$\alpha_{CL} = 1$
$\alpha_{EC} = 1$



One Pool, Simplified

$r_E = .25$
$r_L = .25$
$r_C = .75$
$d_C = 1$
$\alpha_{LE} = .75$
$\alpha_{CL} = 1$
$\alpha_{EC} = 1$



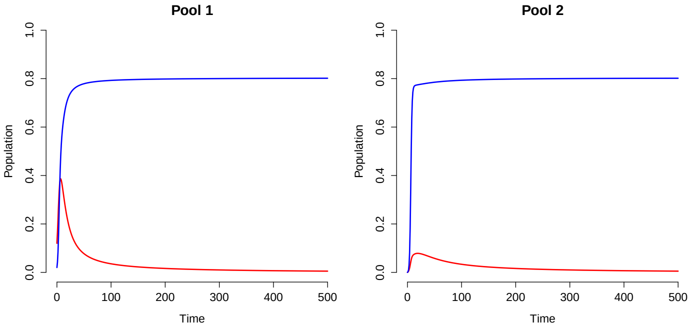


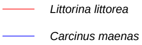
Two Pools

$$\frac{\mathrm{d}L_1}{\mathrm{d}t} = r_L L_1(1 - L_1) - \alpha_{C_1 L_1} L_1 C_1 + i_L(\rho L_2 - L_1)$$
$$\frac{\mathrm{d}C_1}{\mathrm{d}t} = r_C C_1(1 - C_1) - \frac{d_C}{1 + \alpha_{EC} E^*(L_1)} C_1 + i_C(\rho C_2 - C_1)$$
$$\frac{\mathrm{d}L_2}{\mathrm{d}t} = r_L L_2(1 - L_2) - \alpha_{C_2 L_2} L_2 C_2 + i_L(\frac{1}{\rho} L_1 - L_2)$$
$$\frac{\mathrm{d}C_2}{\mathrm{d}t} = r_C C_2(1 - C_2) - \frac{d_C}{1 + \alpha_{EC} E^*(L_2)} C_2 + i_C(\frac{1}{\rho} C_1 - C_2)$$

$$\rho = \frac{\text{size of pool 2}}{\text{size of pool 1}}$$

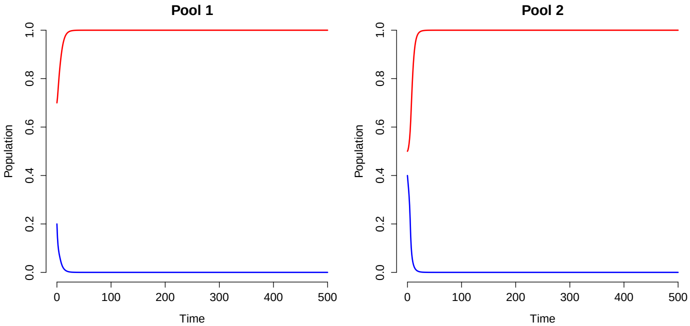
Two Pools: Varying Initial Conditions





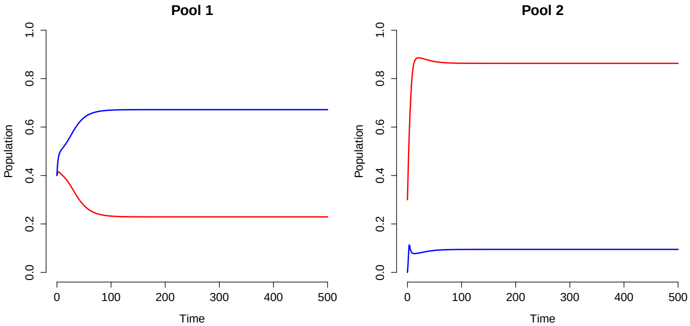
L1	0.12
L2	0
C1	0.02
C2	0
rho	1
ic	0.05
il	0.01

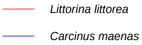
TWO POOLS: VARYING INITIAL CONDITIONS



L1	0.7
L2	0.5
C1	0.2
C2	0.4
rho	1
ic	0.05
il	0.01

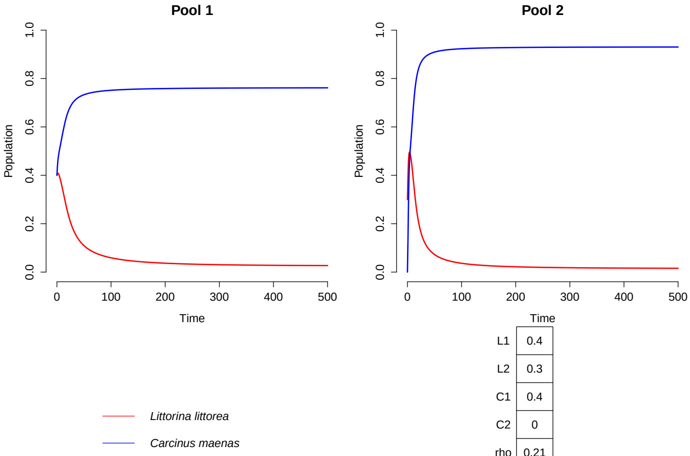
Two Pools: Varying Initial Conditions





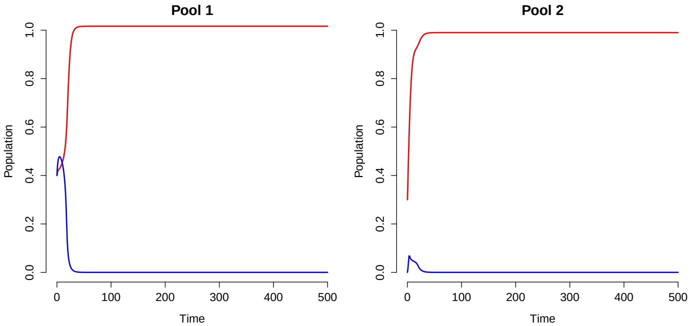
L1	0.4
L2	0.3
C1	0.4
C2	0
rho	1
ic	0.05
il	0.01

Two Pools: Varying Pool Sizes



L1	0.4
L2	0.3
C1	0.4
C2	0
rho	0.21
ic	0.05
il	0.01

Two Pools: Varying Pool Sizes

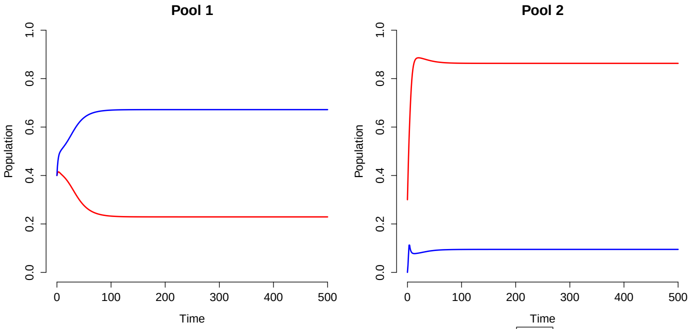


Littorina littorea

Carcinus maenas

L1	0.4
L2	0.3
C1	0.4
C2	0
rho	1.7
ic	0.05
il	0.01

Two Pools: Varying Pool Sizes

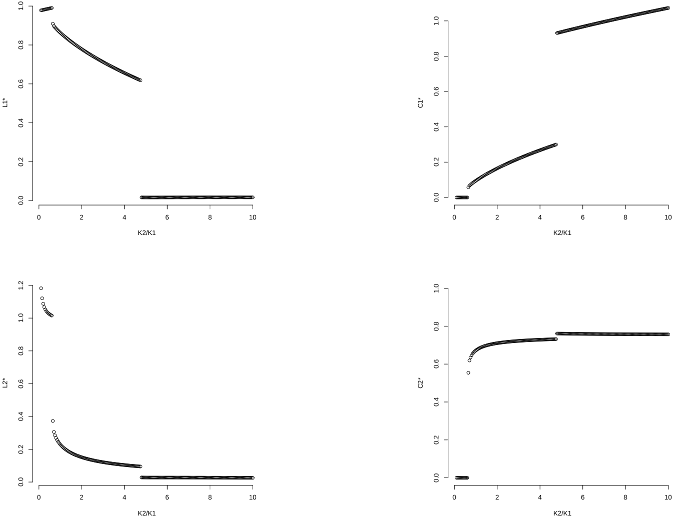


Littorina littorea

Carcinus maenas

L1	0.4
L2	0.3
C1	0.4
C2	0
rho	1
ic	0.05
il	0.01

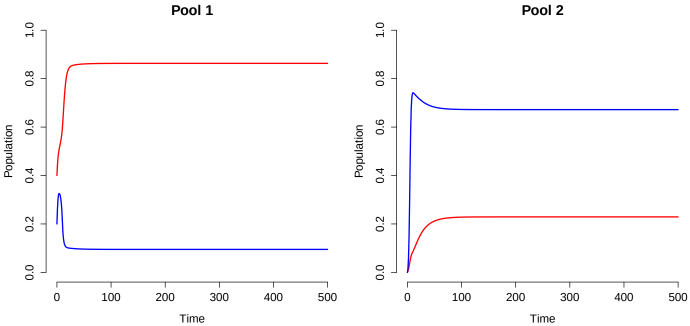
Two Pools



Colonizing Empty Pools

- If one pool is extinguished how does recolonization happen?

Colonizing Empty Pools: Coexistence

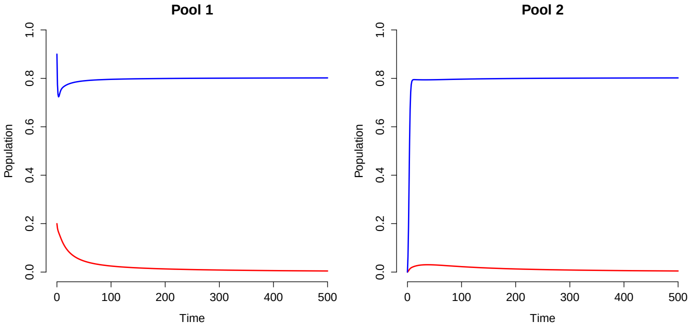


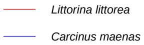
Littorina littorea

Carcinus maenas

L1	0.4
L2	0
C1	0.2
C2	0
rho	1
ic	0.05
il	0.01

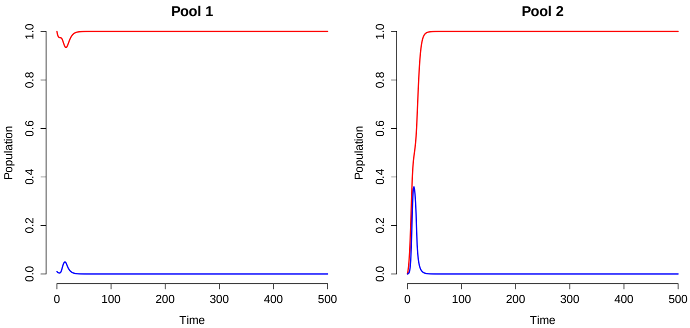
Colonizing Empty Pools: Carcinus Domination

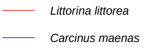




L1	0.2
L2	0
C1	0.9
C2	0
rho	1
ic	0.05
il	0.01

Colonizing Empty Pools: Littorina Domination





L1	1
L2	0
C1	0.01
C2	0
rho	1
ic	0.05
il	0.01

Future Directions

- Possible expansions of the model for future work

Future Directions: n Pools

$$\frac{\mathrm{d}L_i}{\mathrm{d}t} = r_L L_i(1 - L_i) - \alpha_{C_i L_i} L_i C_i + i_L(L)$$

$$\frac{\mathrm{d}C_i}{\mathrm{d}t} = r_C C_i(1 - C_i) - \frac{d_C}{1 + \alpha_{EC} E^*(L_i)} C_i + i_C(C)$$

Future Directions: ∞ Pools

$$\frac{\mathrm{d}L_1}{\mathrm{d}t} = r_L L_1(1 - L_1) - \alpha_{C_1 L_1} L_1 C_1 + i_L(\rho L_2 - L_1)$$
$$\frac{\mathrm{d}C_1}{\mathrm{d}t} = r_C C_1(1 - C_1) - \frac{d_C}{1 + \alpha_{EC} E^*(L_1)} C_1 + i_L(\rho C_2 - C_1)$$
$$\frac{\mathrm{d}L_2}{\mathrm{d}t} = r_L L_2(1 - L_2) - \alpha_{C_2 L_2} L_2 C_2 + i_L(\frac{1}{\rho} L_1 - L_2)$$
$$\frac{\mathrm{d}C_2}{\mathrm{d}t} = r_C C_2(1 - C_2) - \frac{d_C}{1 + \alpha_{EC} E^*(L_2)} C_2 + i_L(\frac{1}{\rho} C_1 - C_2)$$

$$\rho = \rho(L_1, L_2, C_1, C_2)$$

Future Directions: Alterations to Littorina

- Structuring Littorina to include larvae population
- Including sea immigration term

Conclusions

- The system has bistability, even for one pool!
- For two pools we can have both coexistence or domination for either species
- There is a critical phase transition for pool state as the size ratio of pools increases
- Except under extreme conditions, Carcinus colonize first
- Carcinus will dominate in the long term, so another mechanism must be maintaining diversity (snail age structure? Sea immigration?)

Conclusions

- Lubchenco (1978) *Plant Species Diversity in a Marine Intertidal Community: Importance of Herbivore Food Preference and Algal Competitive Abilities* The American Naturalist Vol. 112, No. 983 pp. 23-29