The Critical Role of Movement in Big and Small Ecosystems

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Premise

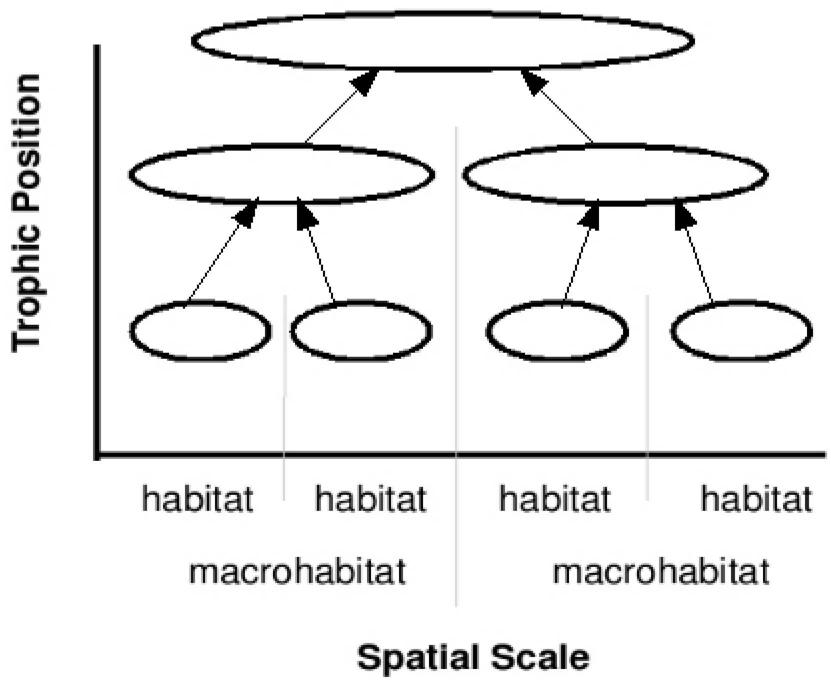
Empirical arguments suggest that one of the fundamental building blocks (modules) of food webs is inherently spatial and therefore behooves us to consider the role of adaptive movement.

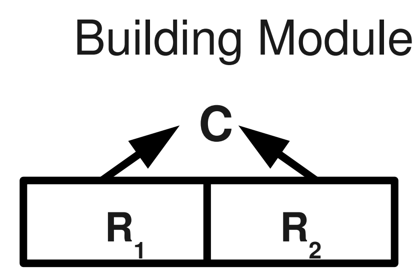
Adaptive movement within this framework:

> governs structural responses of food webs both within and across ecosystems

> in a spatially expansive world, adaptive consumer movement is a potent stabilizer. This comes from the rapid temporal response to spatial and temporal variability.

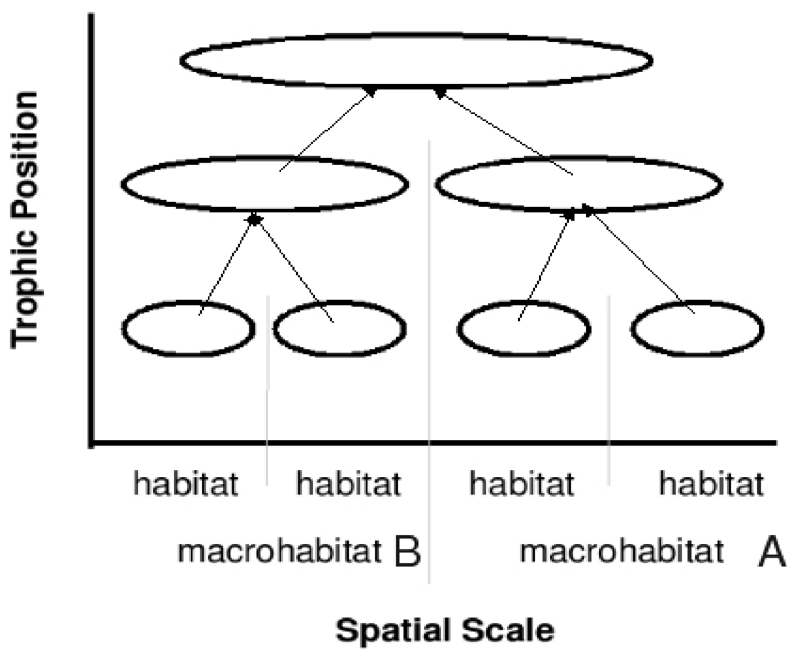
Body Size and Food web Structure

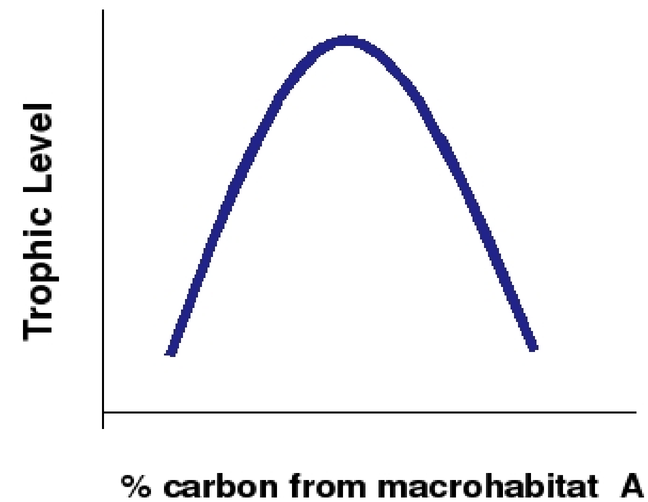




Mobility and trophic position tend to increase with body size (e.g., Peters 1983, Cohen et al. 2003)

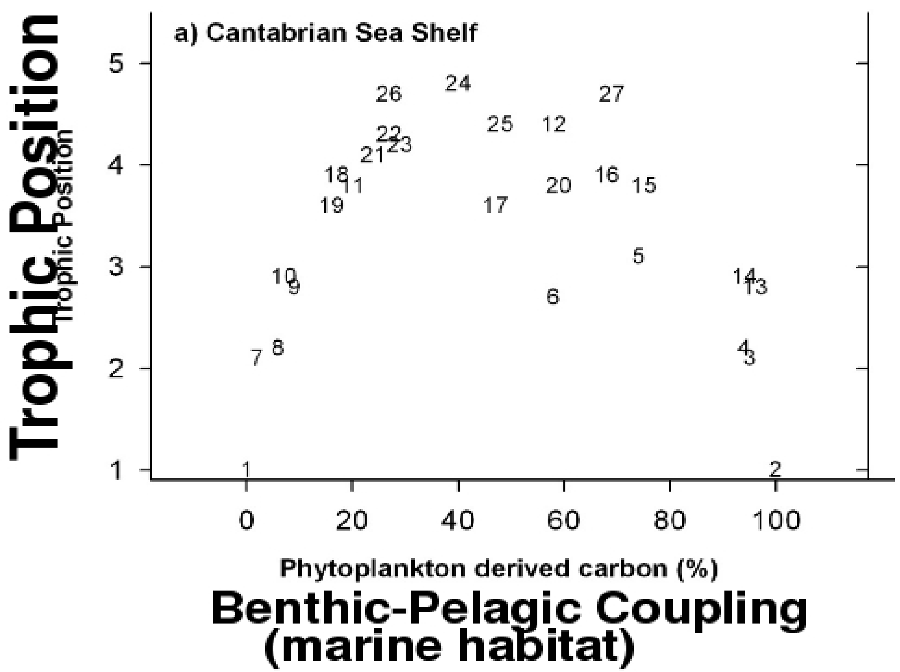
Prediction: Hump-shaped Carbon Flux in Spatial Food Webs

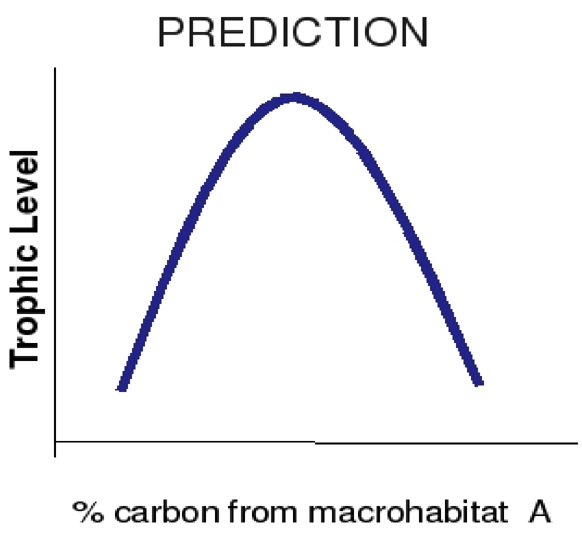




If we follow carbon from a habitat (say macro) we expect that organisms low in the food web have distinct carbon signals & higher trophic level organisms integrate carbon from multiple habitats.

Empirical Signatures of this Module

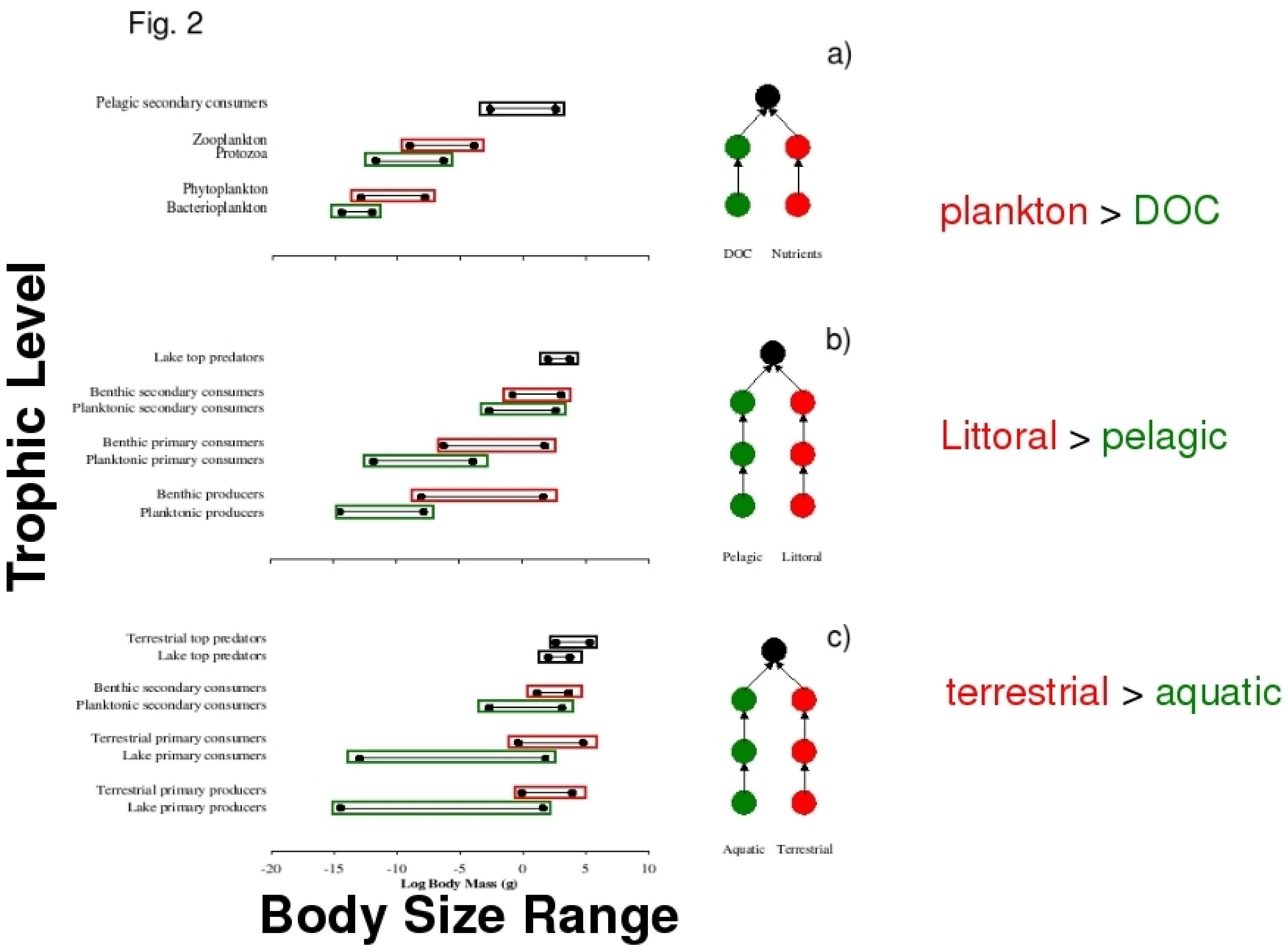




Found this consistently across 8 food webs from both aquatic and terrestrial ecosystems. (Rooney et al. 2006 Nature)

*Network theorists have found this module (motif) to be over-represented. (e.g., Milo et al. 2002)

Module Repeats Across Scales

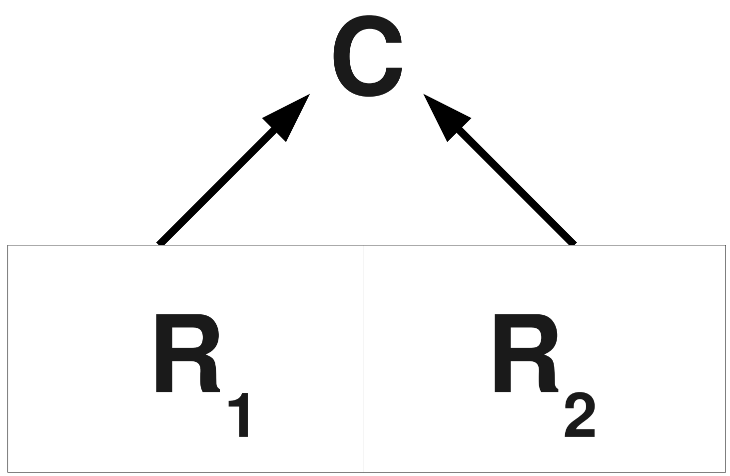


Summary

Mobile generalists couple resources in different habitats in space.

Module ubiquitous within webs.

Module repeats across scales.



A 2-patch spatial C-R-R model

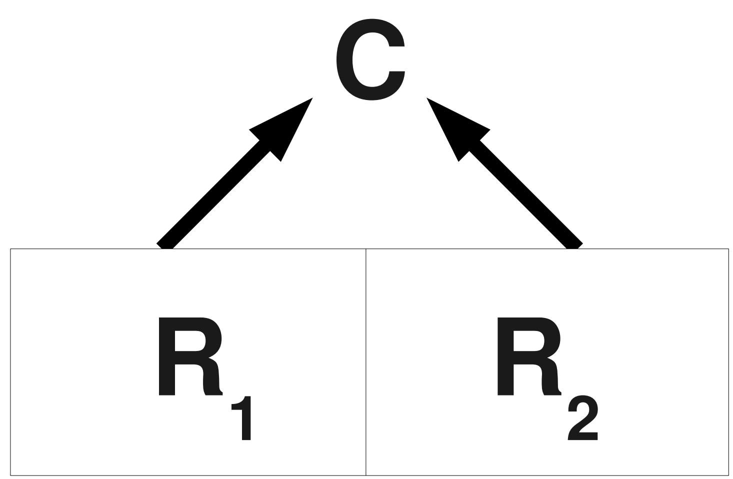
(movement is rapid relative to growth rates)

$$\frac{dR_i}{dt} = G_{R,i}\left(R_i\right) - aC_{F,i}R_i - aC_{F,j}QR_i$$

$$\frac{dC_{F,i}}{dt} = \frac{1}{\varepsilon^2} D\left(W_i C_{F,j} - W_j C_{F,i}\right) + \frac{1}{\varepsilon}\left(-aC_{F,i}R_i - aC_{F,i}QR_j + \frac{1}{h}C_{H,i}\right)$$
$$+\left(eaC_{F,i}R_i + eaC_{F,i}QR_j - mC_{F,i}\right)$$

$$\frac{dC_{H,i}}{dt} = \frac{1}{\varepsilon}\left(aC_{F,i}R_i + aC_{F,i}QR_j - \frac{1}{h}C_{H,i}\right) - mC_{H,i}$$

W_i is the relative density dependent preference function which defines the probability that an individual prefers patch i relative to patch j



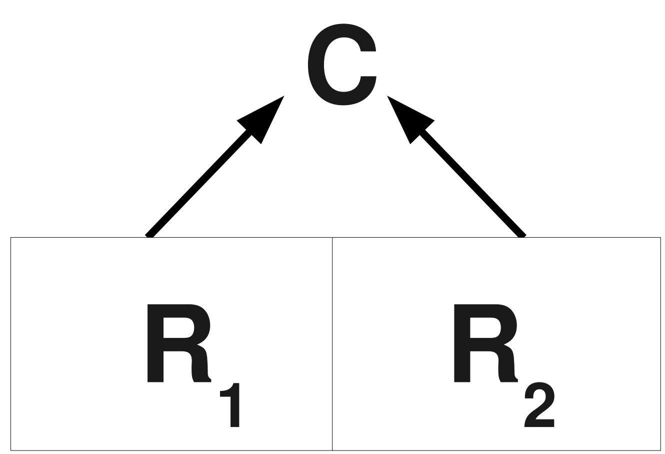
Becomes a spatially implicit model with a parameter (Q) that sets the spatial scaling of the C-R1-R2 interactions

$$\frac{dR_i}{dt} = G_{R,i}(R_i) - \frac{S_i aCR_i}{1 + S_i ahR_i + S_j ahR_j}$$

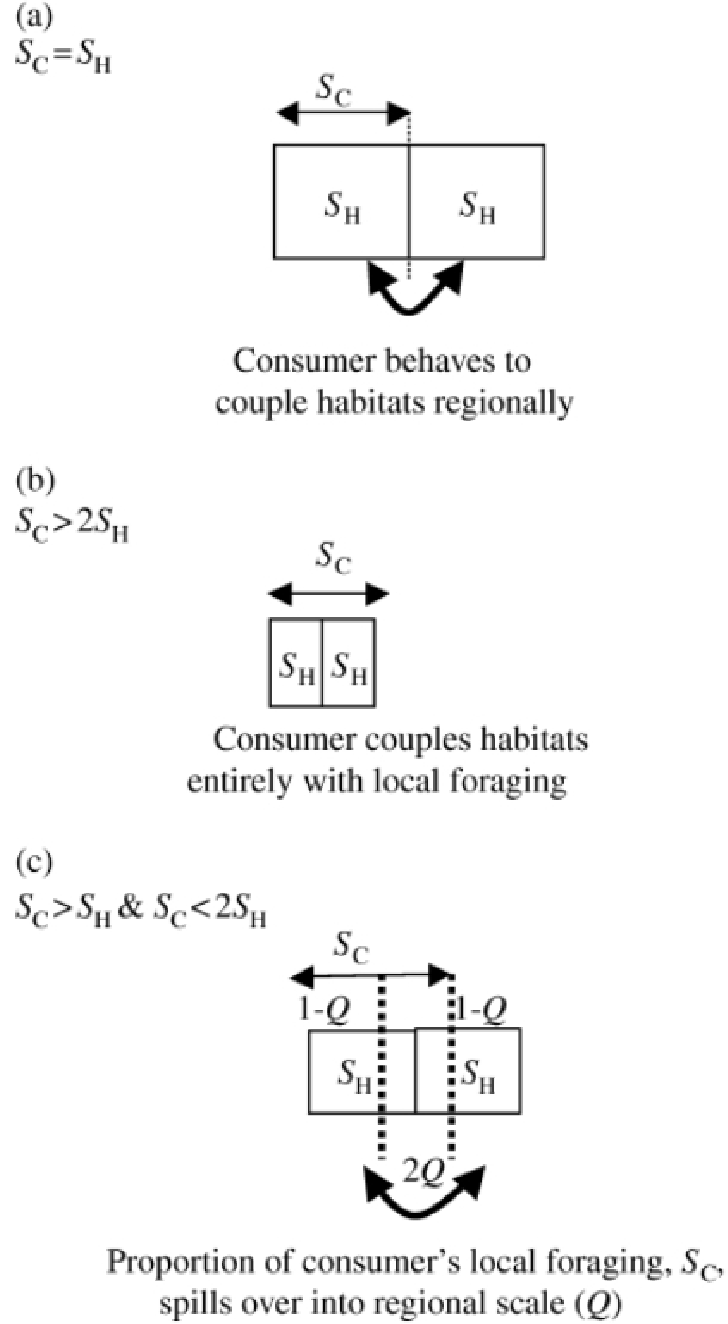
$$\frac{dC}{dt} = e\left(\frac{S_i aCR_i + S_j aCR_j}{1 + S_i ahR_i + S_j ahR_j}\right) - mC$$

where

$$S_i = Q + (1 - Q)W_i.$$



Scaling C-R-R interactions in Space:



Case (i)

Spatially expansive

Q=0

Case (ii)

Spatially compressed

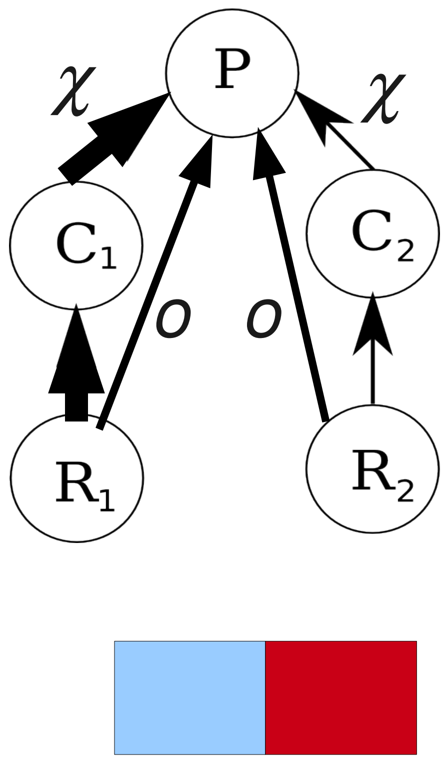
Q=1

Case (iii)

0<Q<1

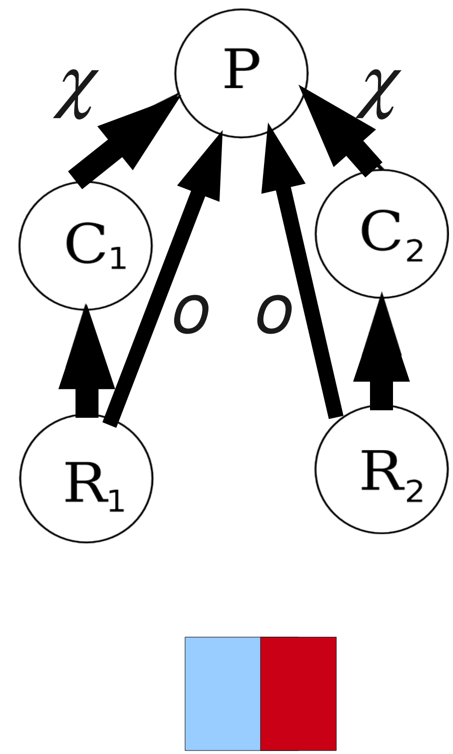
Consider the following food web

- assume Predator, P, has a preferred habitat
- “flexibility” in the compartmental coupling (χ) and omnivory (o)



Spatially expansive

Q=0



Spatially constrained

Q=1

Under different spatial scaling, what are the implications of this “adaptive” ability:

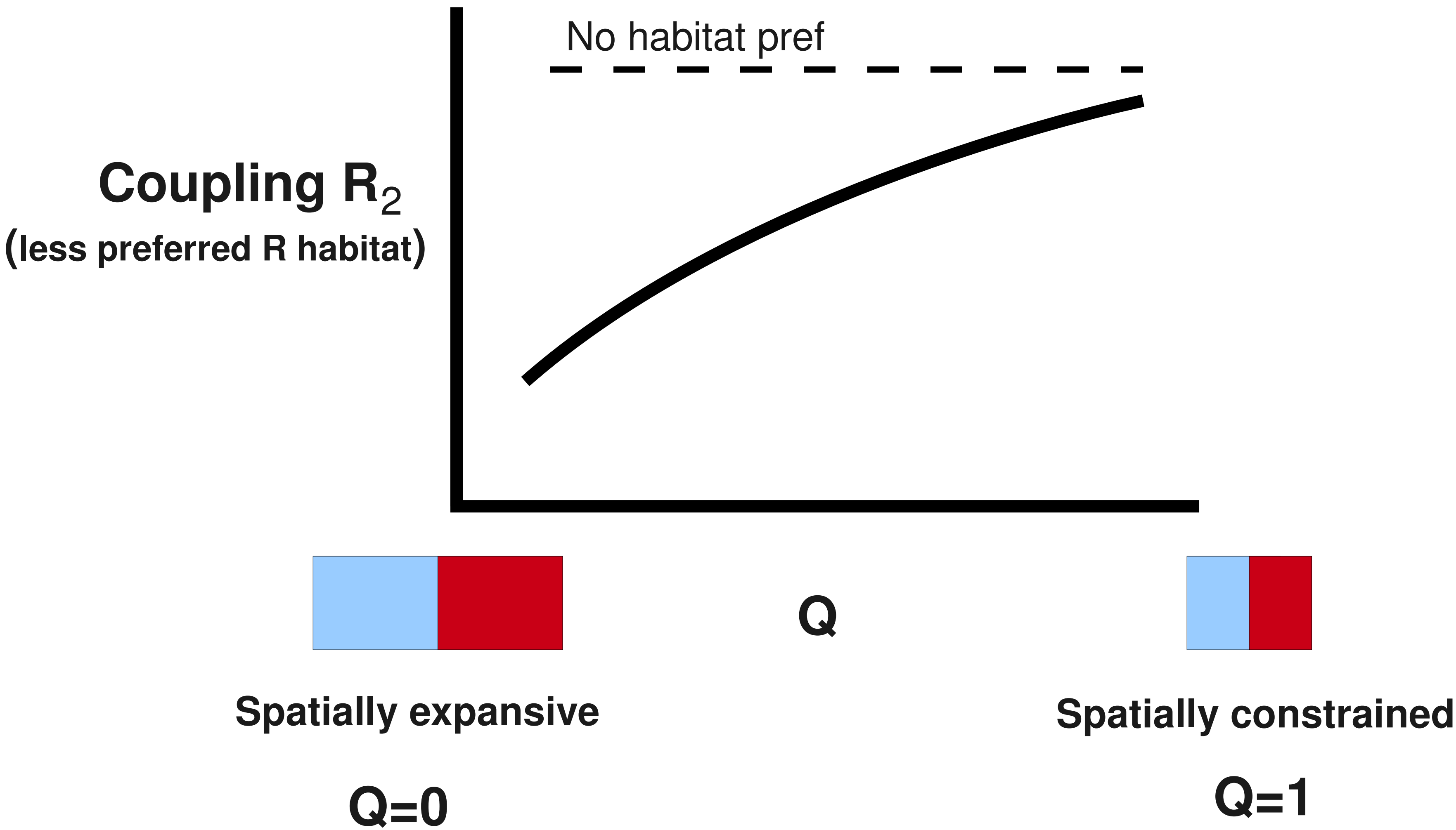
(i) for food web structure, &;

(ii) stability

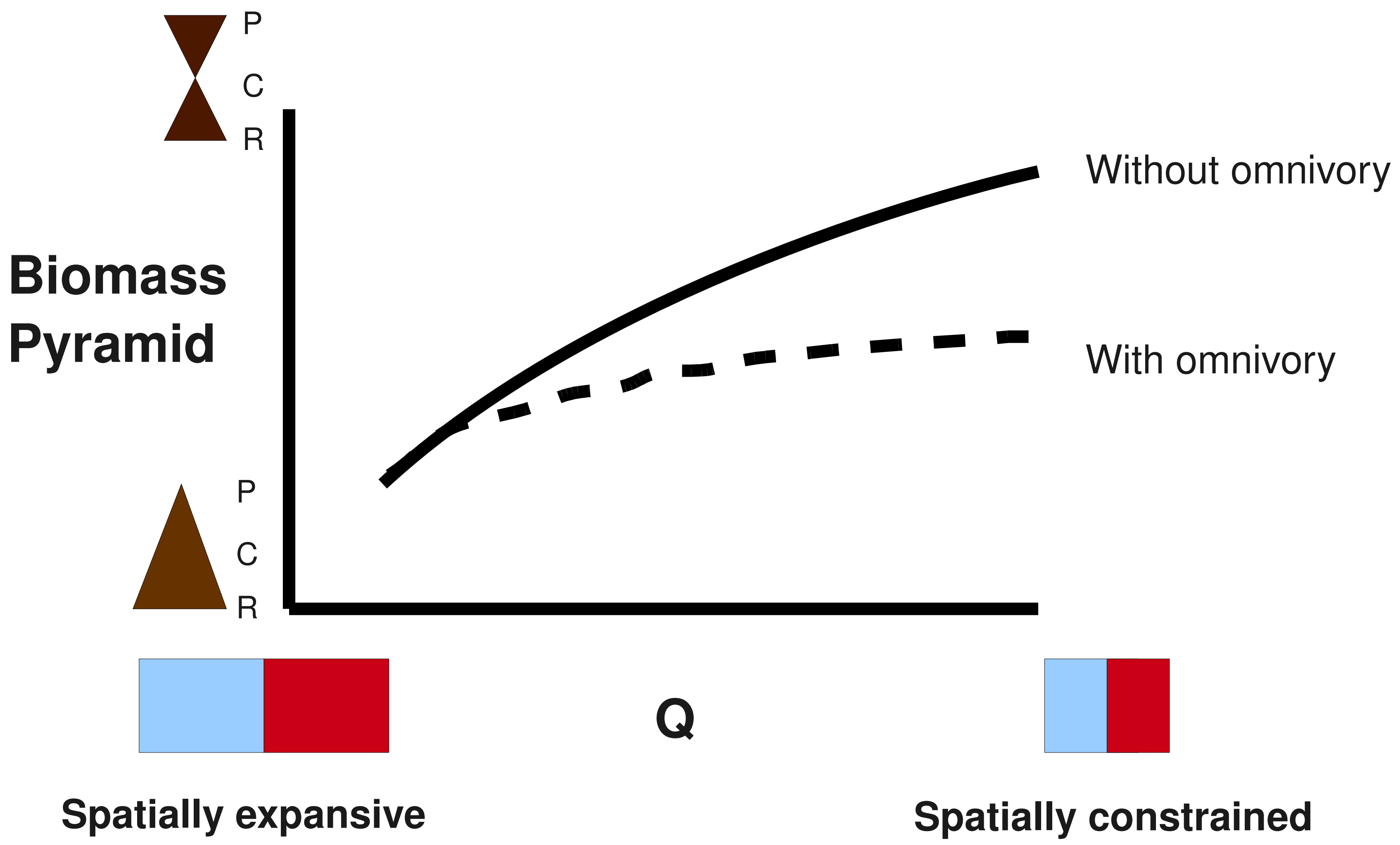
Strength of Compartmental Coupling

Coupling = consumption rate of R_2 / total consumption

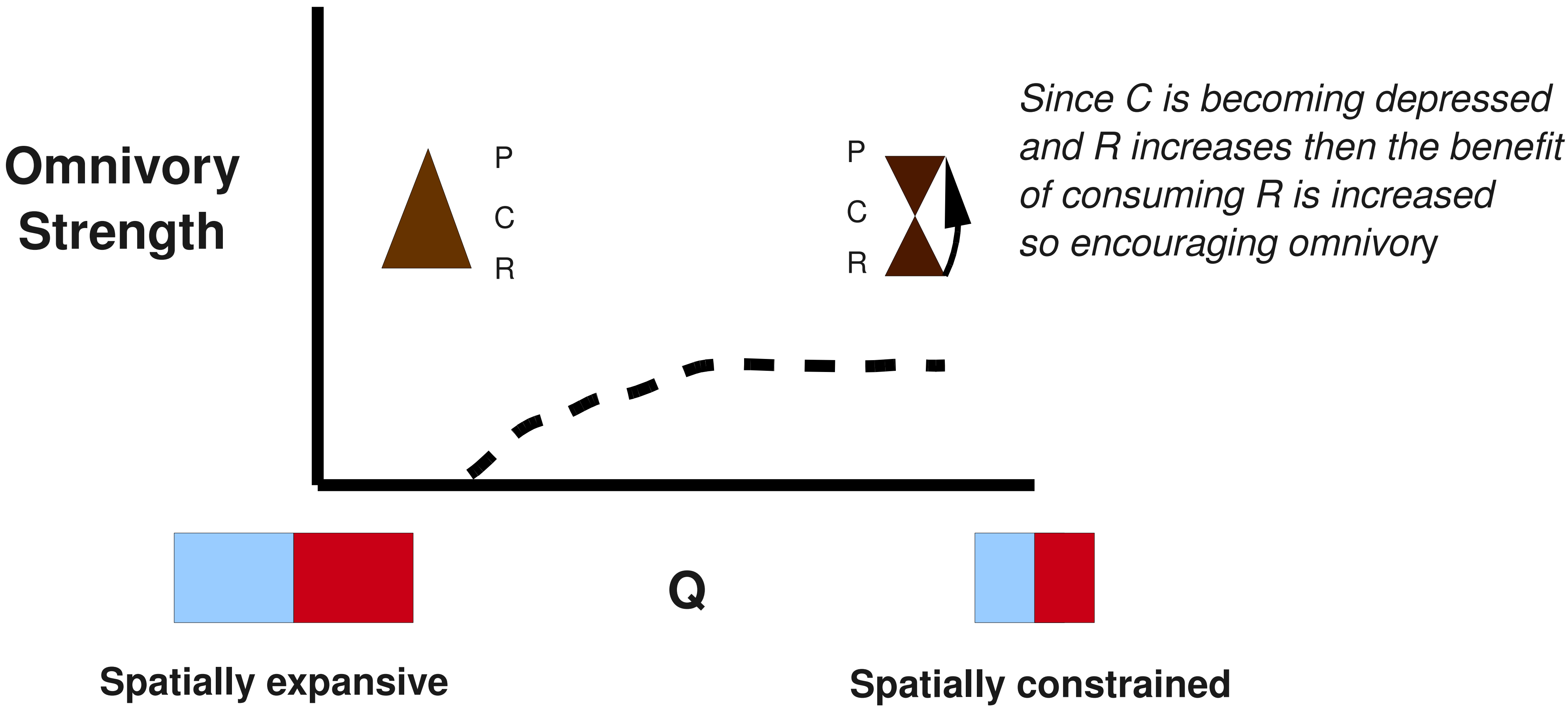
Coupling always increases as long as $W_1 / W_2 > 1$ where W_1 is the preferred habitat compartment



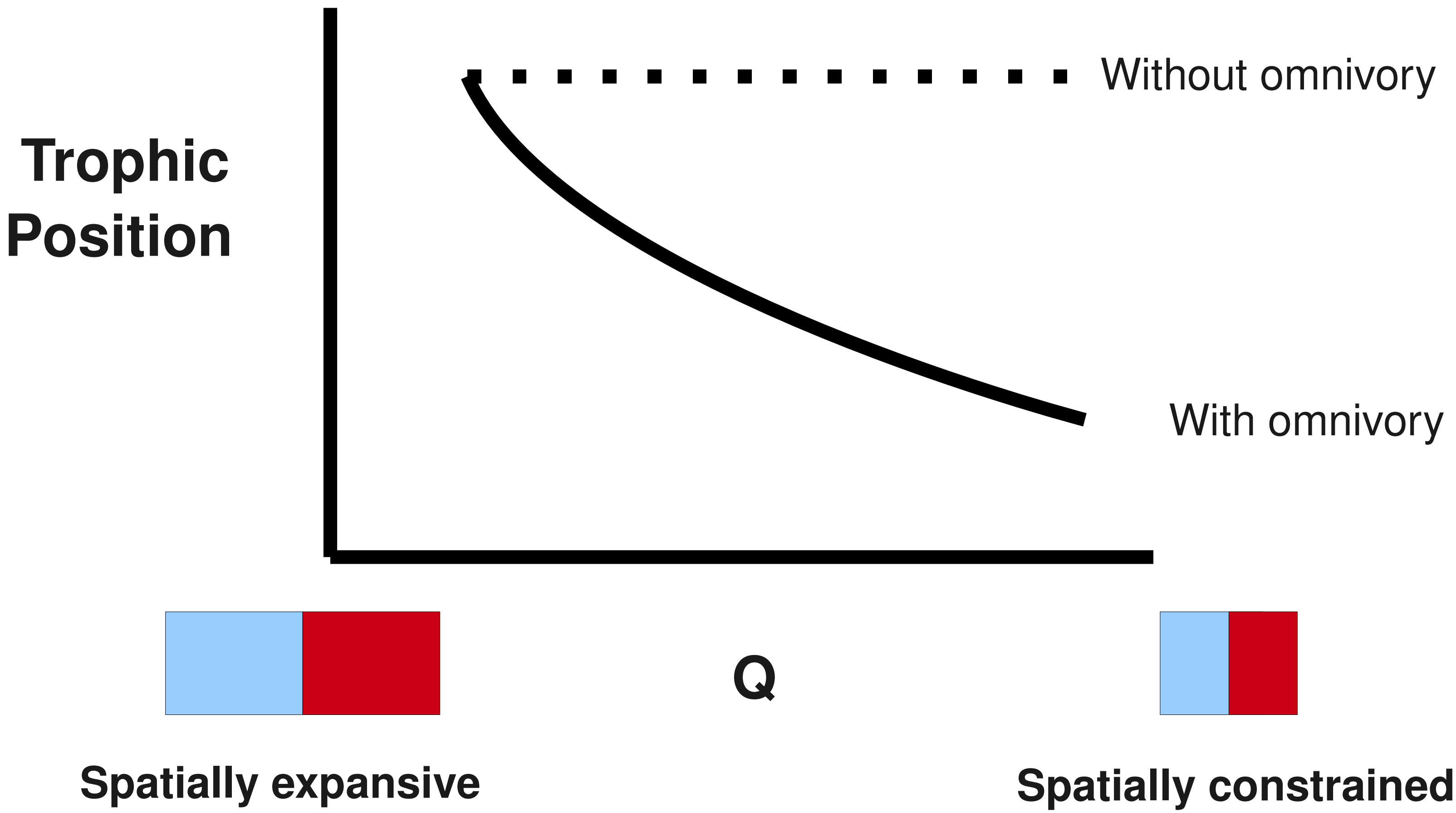
Trophic Control



Strength of Omnivory



Food Chain Length



Summary: Structure

1) Coupling ↑ with ↓ ecosystem size

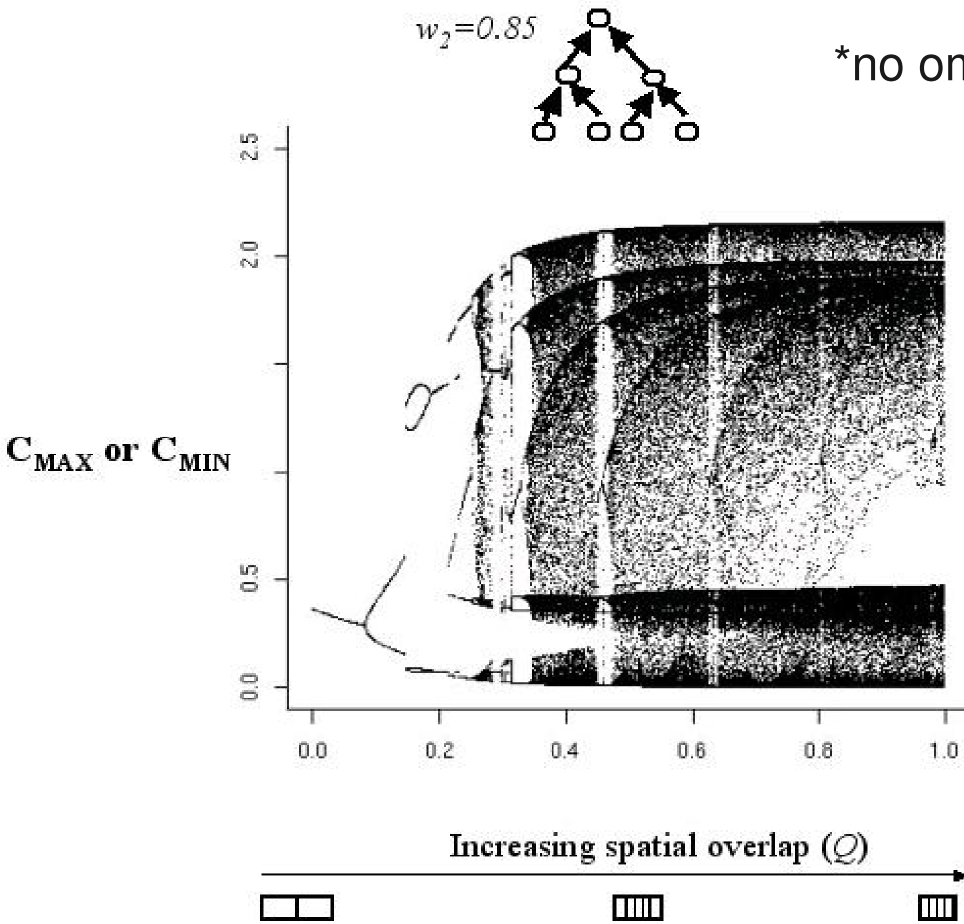
2) Trophic control ↑ with ↓ ecosystem size

3) Omnivory ↑ with ↓ ecosystem size

4) Food chain length ↓ with ↓ ecosystem size

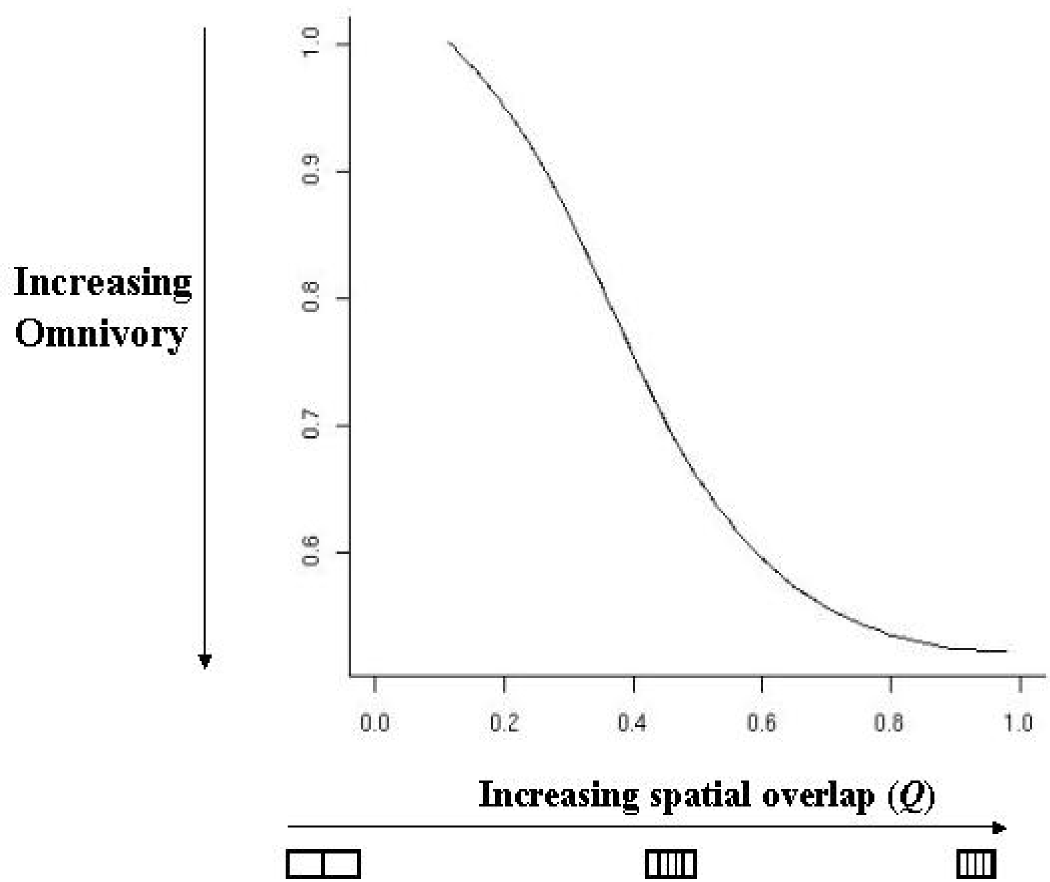
Mobile Predators and Stability

*no omnivory



Stability with ecosystem size OR
Coupling is destabilizing in small systems

Omnivory as a stabilizing response to spatial constraints (compression)



Omnivory can act to stabilize in spatially contrained ecosystems

Summary: Stability

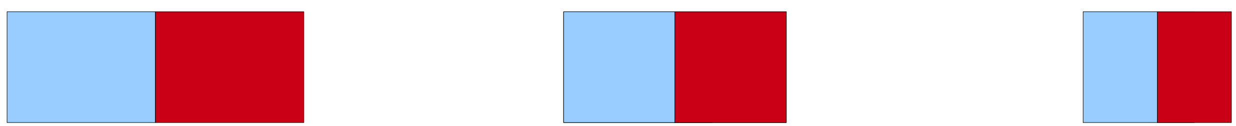
1) mobile foragers are potent stabilizers in a spatially expansive ecosystem

2) spatial constraints drives destabilization
   - effectively lose spatial decoupling and adaptive movement capable of rapidly integrating variance
   - strong interactions synchronize pathways

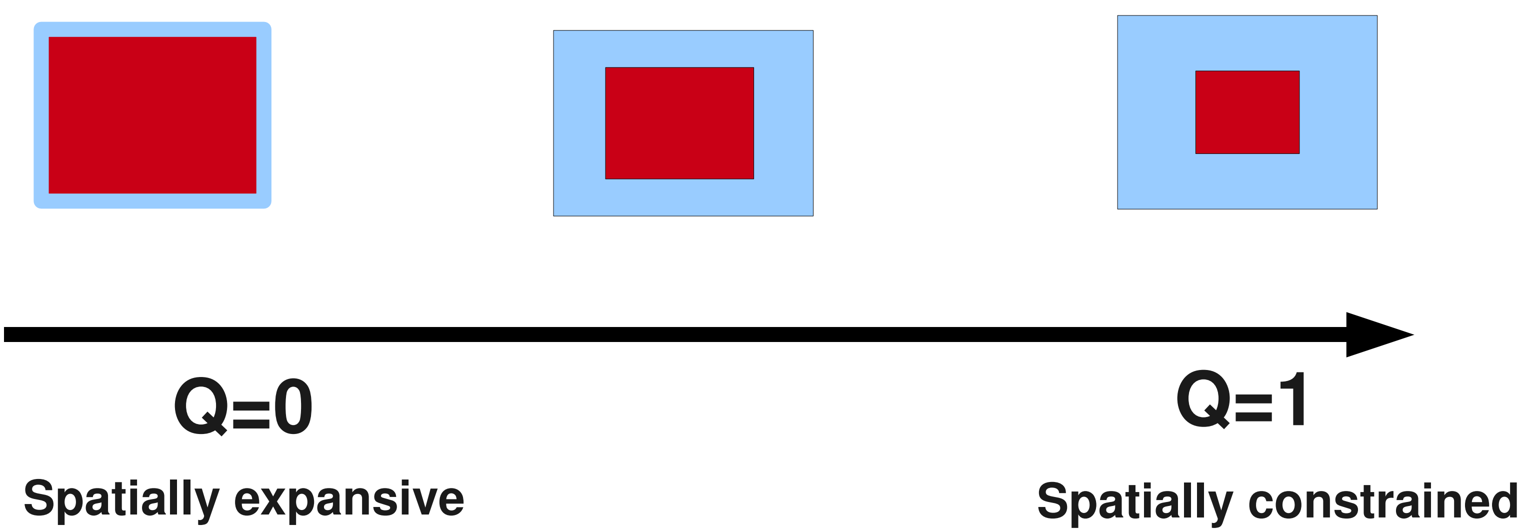
3) ecological space (*omnivory*) can act as a stabilizing agent in spatially constrained ecosystems
   (*ecological space*)

Empirical Results: 2 ways of looking at Q

1) ecosystem size changes

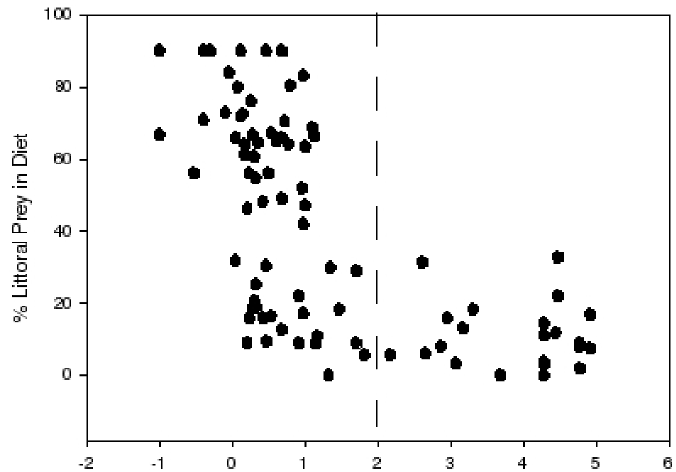


2) relative habitat size changes



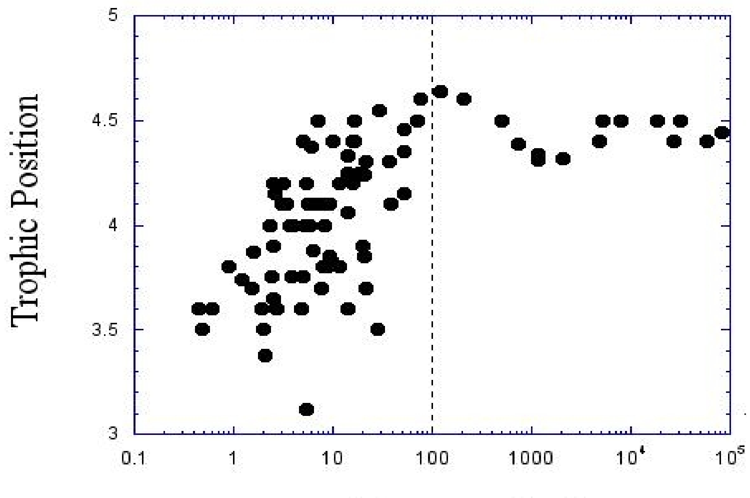
Structure and Ecosystem Size

Coupling

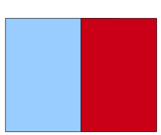


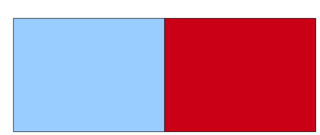
Coupling ↑ with ↓ ecosystem size

FCL



FCL ↓ with ↓ ecosystem size



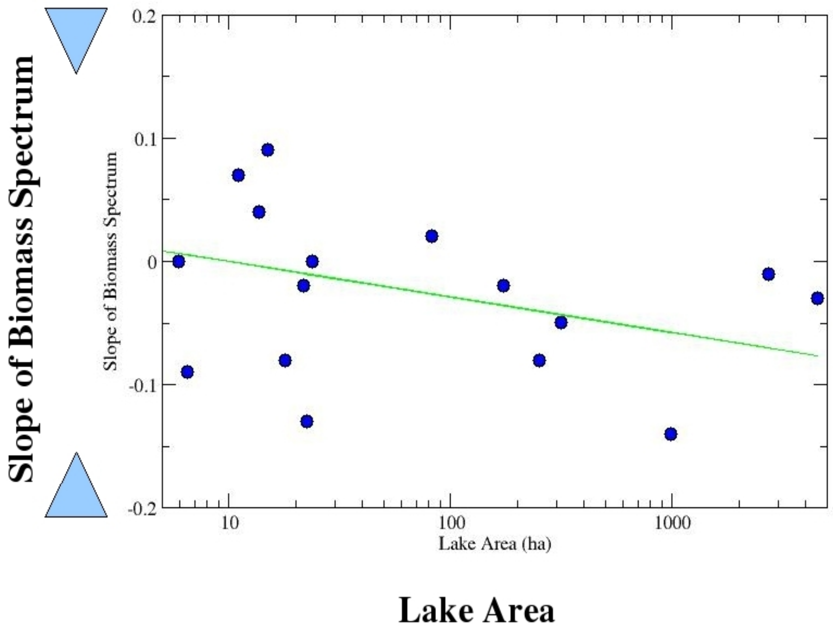


McCann et al. 2005.
Ecol. Letts.

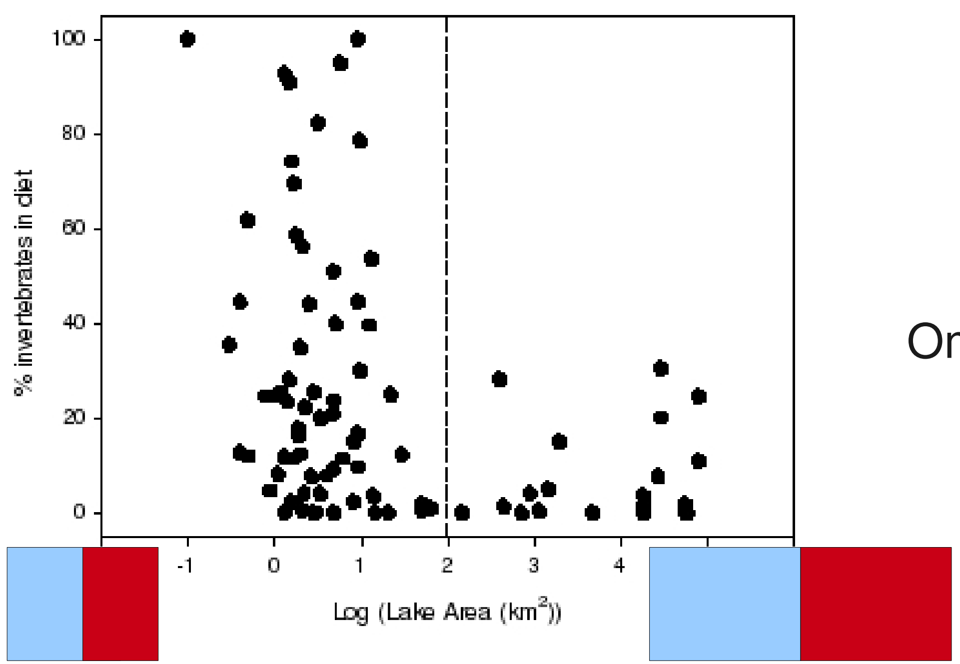
Cyr and Peters 1996 CJFAS

TC ↑ with ↓ ecosystem size

TC



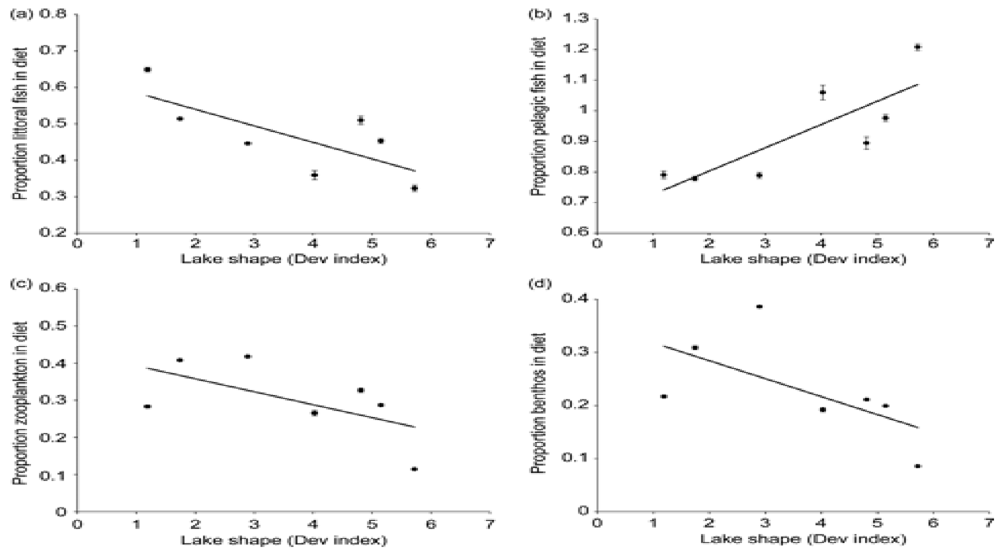
Omnivory



Omnivory ↑ with ↓ size

Structure and Relative Littoral Habitat

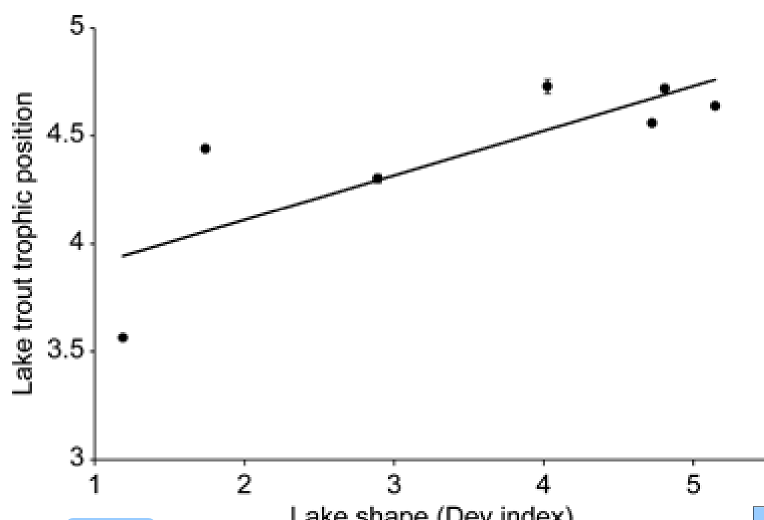
Coupling



Pelagic Omnivory

Benthic Omnivory

FCL



Dolson et al. Oikos 2009

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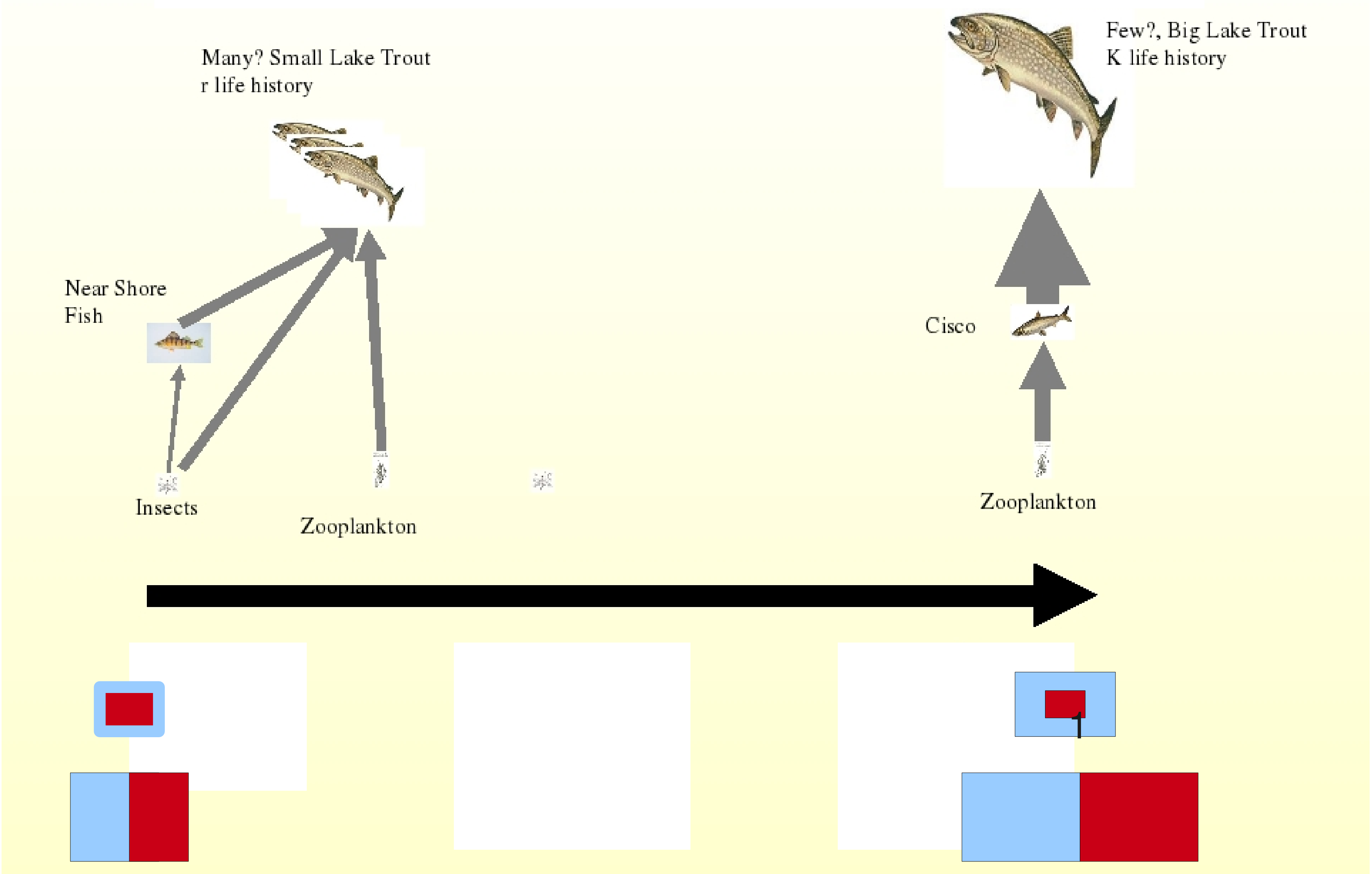
Empirical Summary: Across Ecosystems



Spatially constrained

Spatially expansive

Summary

Empirical arguments suggest that one of the fundamental building blocks (modules) of food webs is inherently spatial C-R1-R2 where adaptive movement/foraging:

(i) governs structural responses of food webs across a gradient in ecosystem size and shape;

(ii) governs the structural response within a given food web to varying prey density

(iii) in a spatially expansive world, consumer adaptive movement is a potent stabilizer. This comes from the rapid temporal response to spatial and temporal variability.