Non-random dispersal strategies in multi-trophic communities

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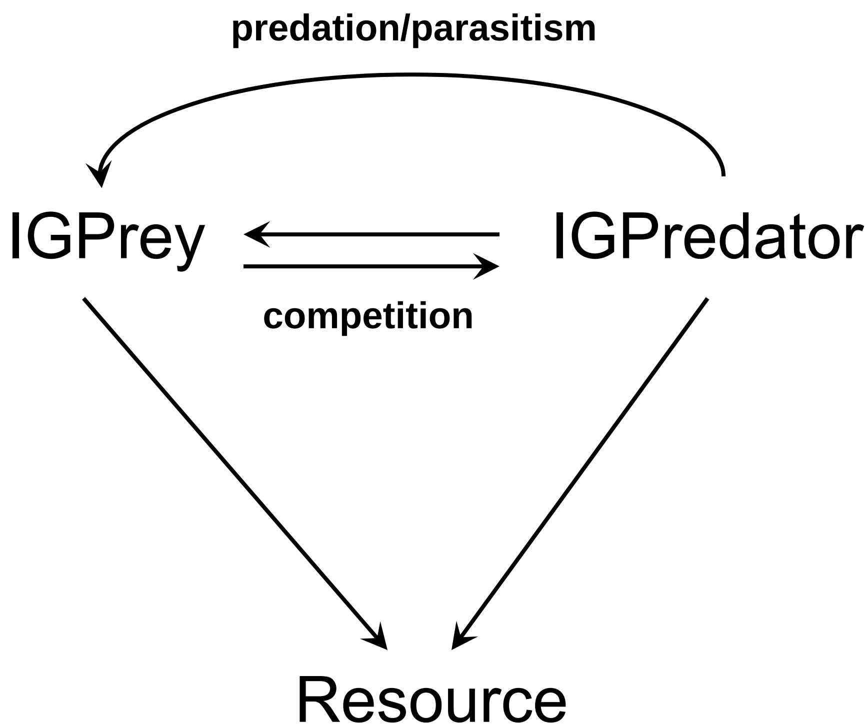
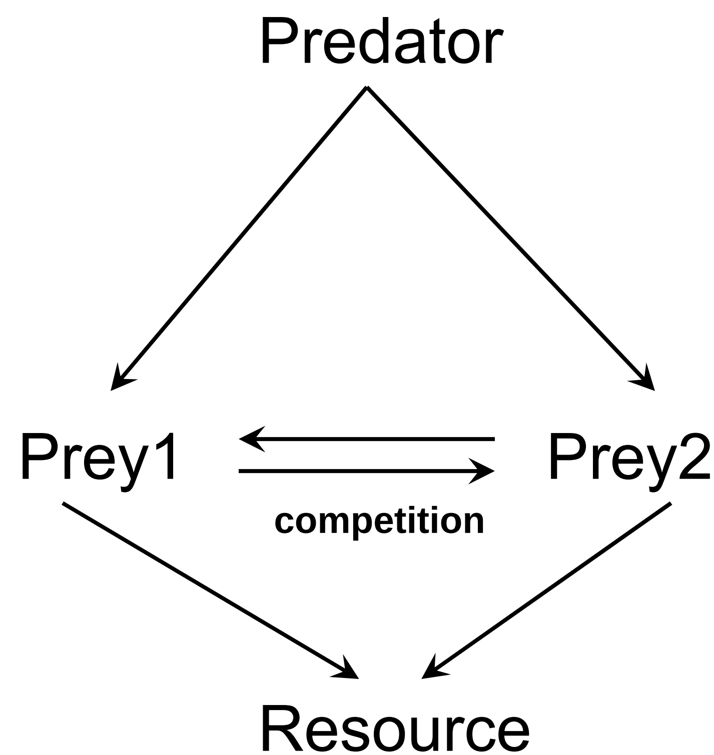
Non-random dispersal strategies in multi-trophic communities

1. **Ecological effects of non-random dispersal**: coexistence and species distributions

2. **Implications of ecological effects**: evolution of dispersal

Multi-trophic interactions





Intraguild predation

Selective predation

Local coexistence of consumers

Local niche partitioning:

trade-off between competitive ability and predator susceptibility

Trade-off depends on resource or predator traits:

resource productivity

predator mortality

Productivity (Mortality)	Interaction	Outcome
Low (High)	Exploitative competition (R* rule)	**Superior competitor**
Intermediate	Competition-predation trade-off (resource partitioning)	**Coexistence**
High (Low)	Predation (P* rule)	**Inferior competitor**

Spatial variation in resource productivity/predator mortality

$\Rightarrow$ Inter-specific segregation

Effects of dispersal --- ?

Spatial dynamics: intraguild predation

$$\frac{dR_j}{d\tau} = r_j R_j(1 - R_j) - a_1 R_j C_{1j} - \delta a_2 R_j C_{2j}$$

IGPrey

$$\frac{dC_{1j}}{d\tau} = a_1 R_j C_{1j} - C_{1j} - \delta\alpha C_{1j} C_{2j} - \beta_1 E_j(m_1) C_{1j} + \beta_1 I_j(m_1)$$

$$\frac{dC_{2j}}{d\tau} = \delta\Big(a_2 R_j C_{2j} - C_{2j} + f\alpha C_{1j} C_{2j} - \beta_2 E_j(m_2) C_{2j} + \beta_2 I_j(m_2)\Big)$$

IGPredator

$j = 1...n$

$m_i =$ dispersal strategy

Spatial variation in resource productivity (r_j)

Spatial dynamics: selective predation

$$\frac{dR_j}{d\tau} = r_j R_j(1 - R_j) - \delta_1 a_1 R_j C_{1j} - \delta_2 a_2 R_j C_{2j}$$

Superior
competitor

$$\frac{dC_{1j}}{d\tau} = \delta_1\Big(a_1 R_j C_{1j} - C_{1j} - \alpha_1 C_{1j} P_j - \beta_1 E_j(m_1) C_{1j} + \beta_1 I_j(m_1)\Big)$$

$$\frac{dC_{2j}}{d\tau} = \delta_2\Big(a_2 R_j C_{2j} - C_{2j} - \alpha_2 C_{2j} P_j - \beta_2 E_j(m_2) C_{2j} + \beta_2 I_j(m_2)\Big)$$

Inferior
competitor

$$\frac{dP_j}{d\tau} = f_1 \alpha_1 \delta_1 C_{1j} P_j + f_2 \alpha_2 \delta_2 C_{2j} P_j - P_j - \beta_P E_j(m_P) P_j + \beta_P I_j(m_P)$$

$$j = 1 \ldots n$$

$m_i =$ dispersal strategy

Spatial variation in resource productivity (r_j)

Dispersal strategies

1. Dispersal in response to fitness

2. Dispersal in response to density

3. Dispersal in response to habitat quality

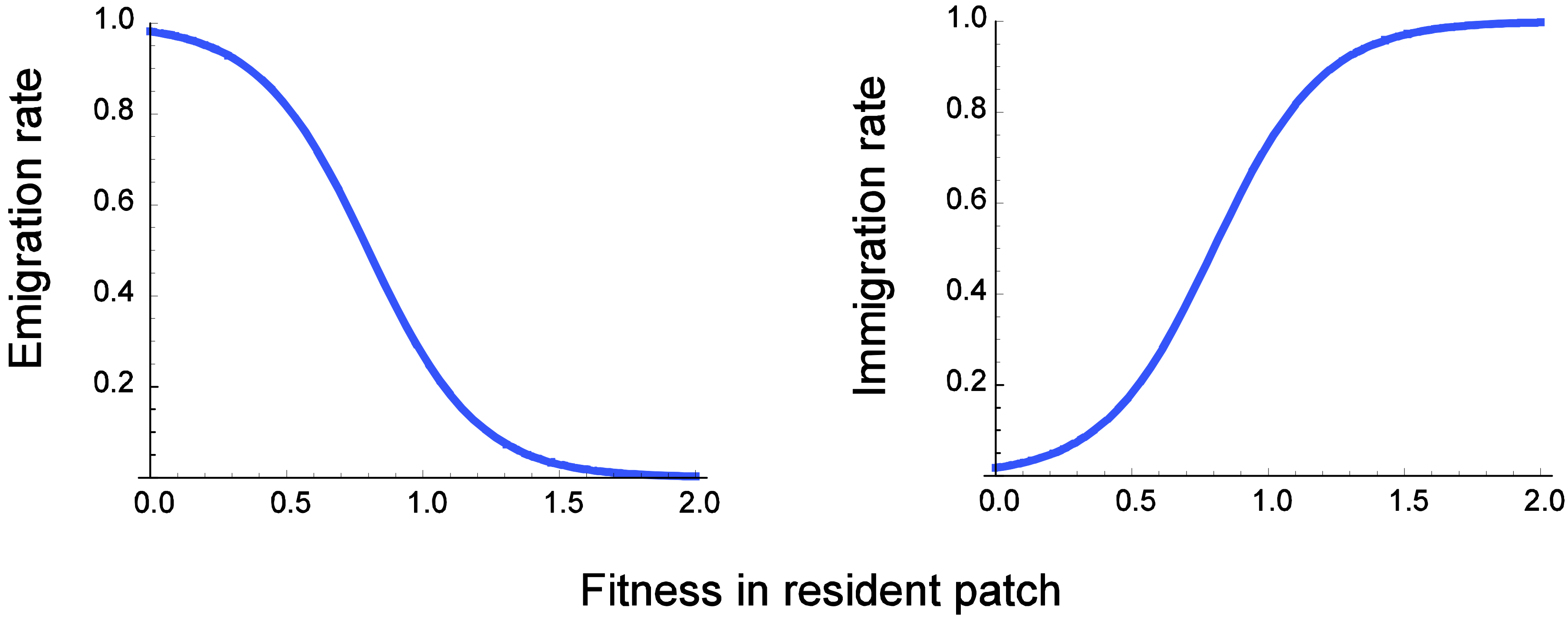
4. Random

Dispersal in response to fitness differences

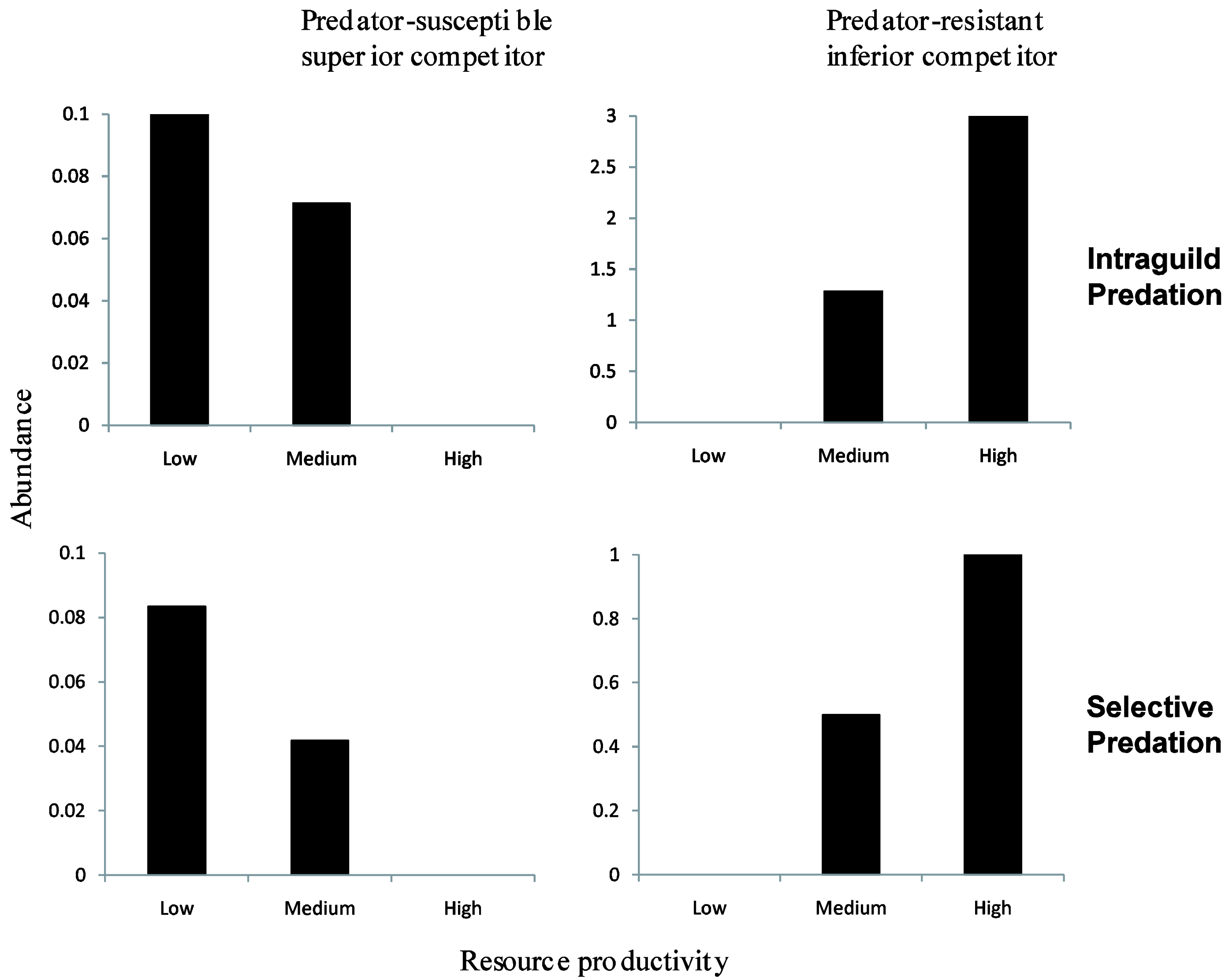
Net movement from areas of lower to higher fitness

Fitness = per capita growth rate

Dispersal in response to fitness differences



Fitness-dependent dispersal



Inter-specific segregation

Optimal dispersal strategy:

Complete information on spatial variation in fitness

Biologically realistic strategies:

Incomplete information on spatial variance in fitness

Biologically realistic dispersal strategies

1. Dispersal in response to density

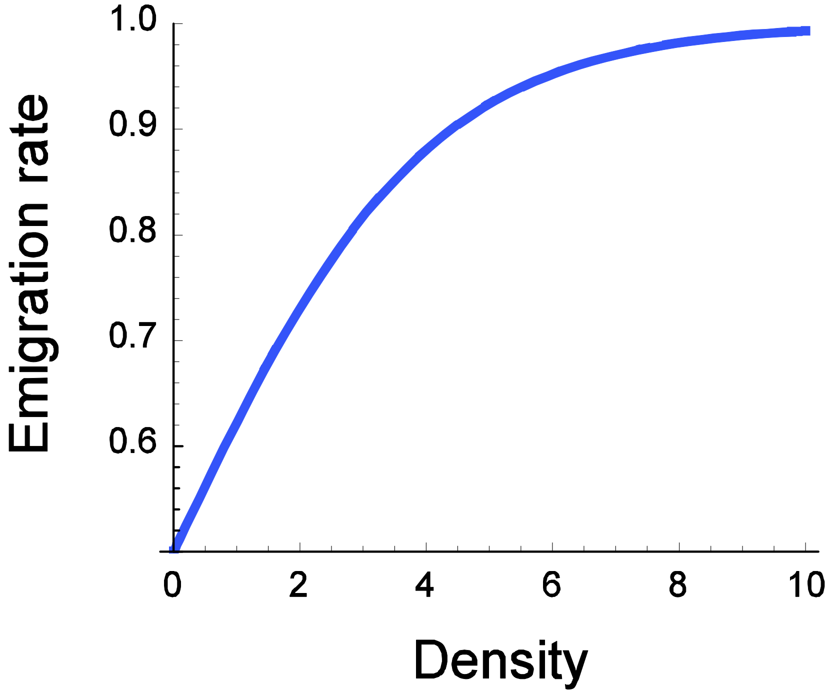
2. Dispersal in response to habitat quality (resource productivity)

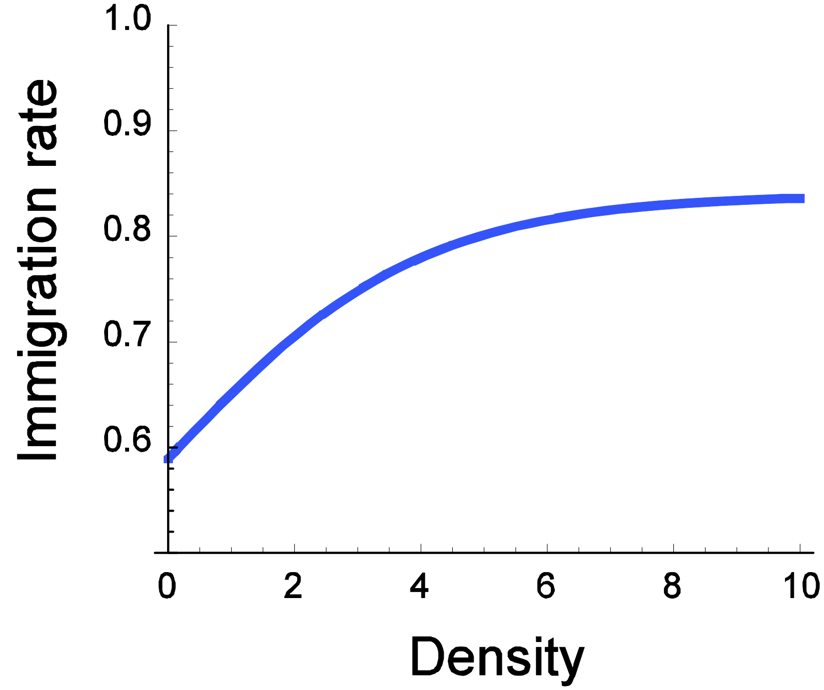
Dispersal in response to density

1. Emigration in response to density of conspecifics and heterospecifics

2. Random immigration (information limitation)

Dispersal in response to density

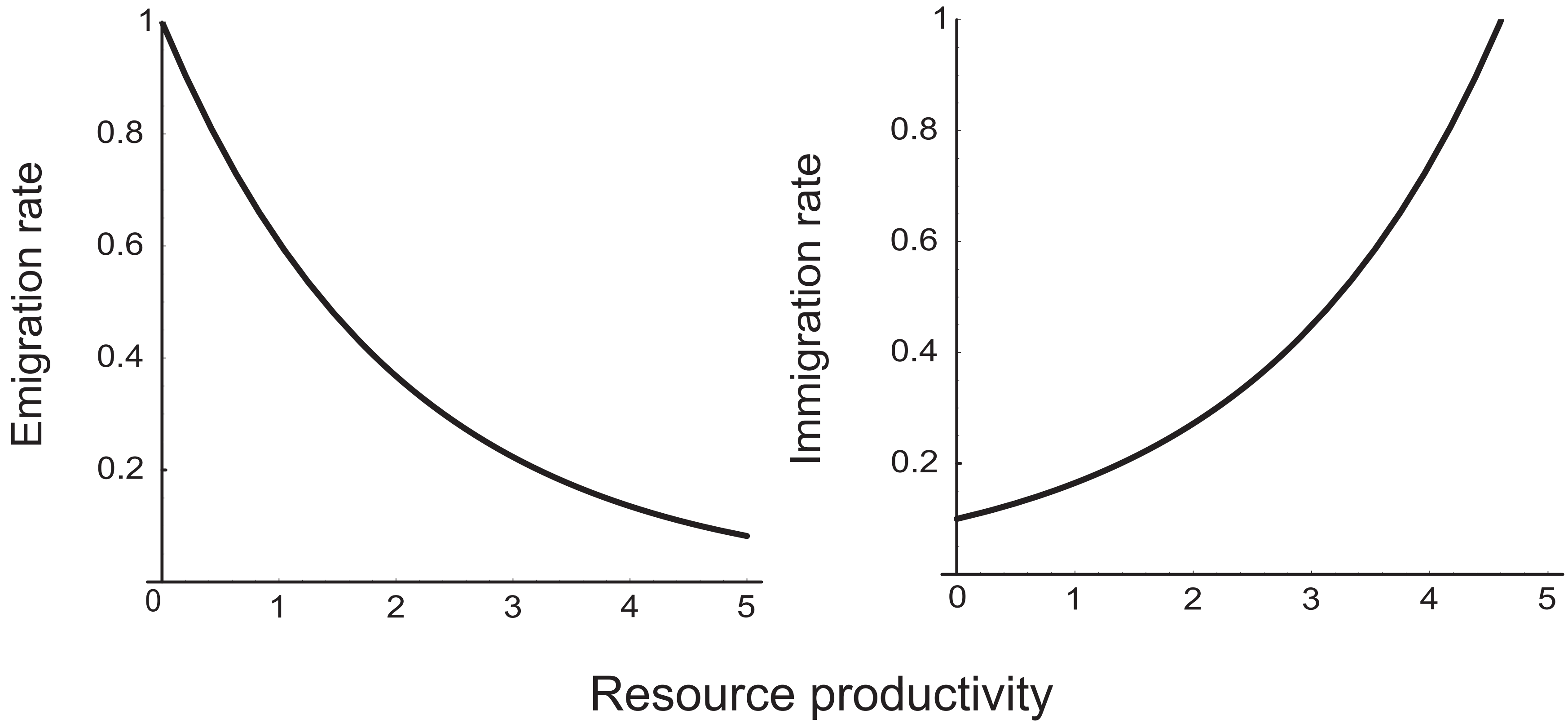




Dispersal in response to habitat quality

Emigration and immigration in response to habitat quality (resource productivity)

Dispersal in response to habitat quality



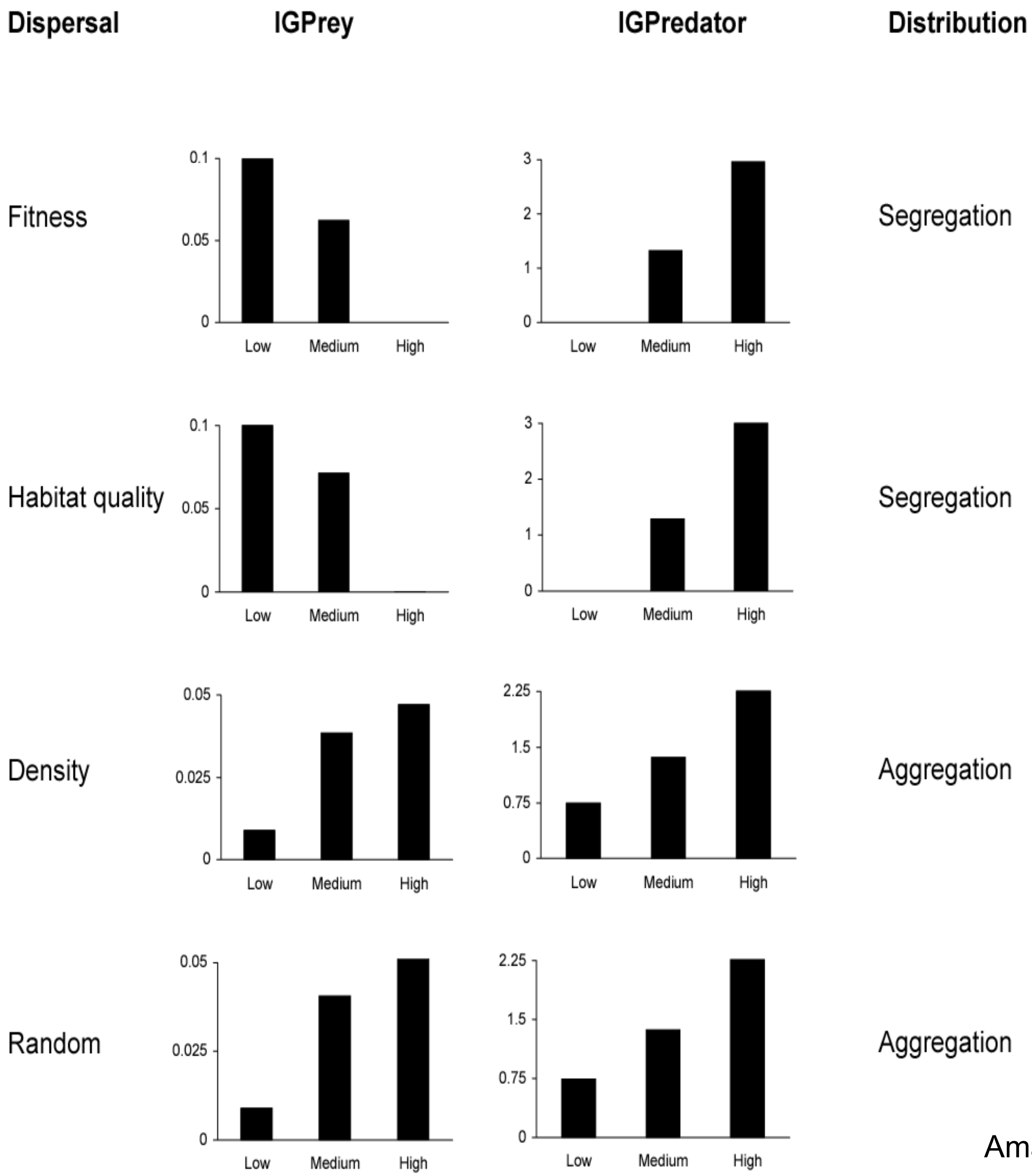
Comparative analysis of dispersal strategies

Fitness	**Density**	Random
(Optimal)	**Habitat quality**	

Three-patch model of dispersal

	Patch 1	Patch 2	Patch 3
Productivity	Low	Intermediate	High
	$r < r_{C2}$	$r_{C2} < r < r_{C1}$	$r > r_{C1}$
Outcome (no dispersal)	Superior competitor	Coexistence	Inferior competitor

Intraguild predation



Amarasekare (2007)

Dispersal strategies: puzzling outcomes

Movement to higher productivity habitats $\longrightarrow$ segregation to high and low productivity habitats

Movement away from higher density habitats $\longrightarrow$ aggregation to high density habitats

Density $\Rightarrow$ less optimal outcome than productivity

Cues for dispersal: density vs. productivity

Density: consumer attribute, indicates strength of competition and predation

Productivity: resource attribute, provides no information on competition or predation

Difference in trophic constraints

IGPrey: resource acquisition vs. predator avoidance

(density)

IGPredator: resource acquisition (resource productivity)

Dispersal in response to density $\Rightarrow$ net movement from higher to lower productivity

IGPrey: net movement from **lower to higher** fitness

IGPredator: net movement from **higher to lower** fitness

Optimal dispersal for IGPrey, suboptimal dispersal for IGPredator $\Rightarrow$ suboptimal outcome for both species

Dispersal in response to productivity ⇒ net movement into high productivity areas

IGPrey: net movement from **higher to lower** fitness

IGPredator: net movement from **lower to higher** fitness

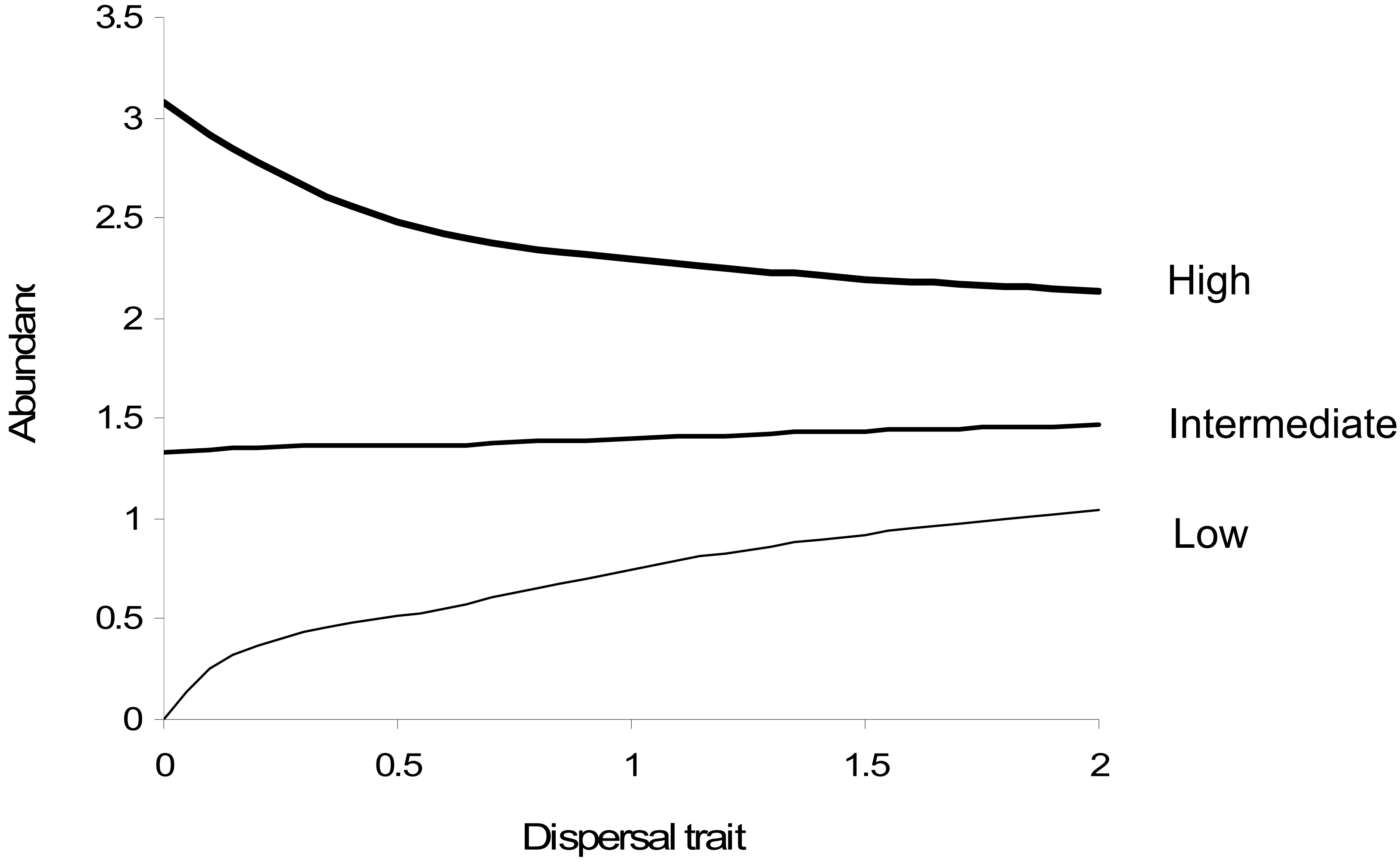
Suboptimal dispersal for IGPrey, optimal dispersal for IGPredator ⇒ optimal outcome for both species

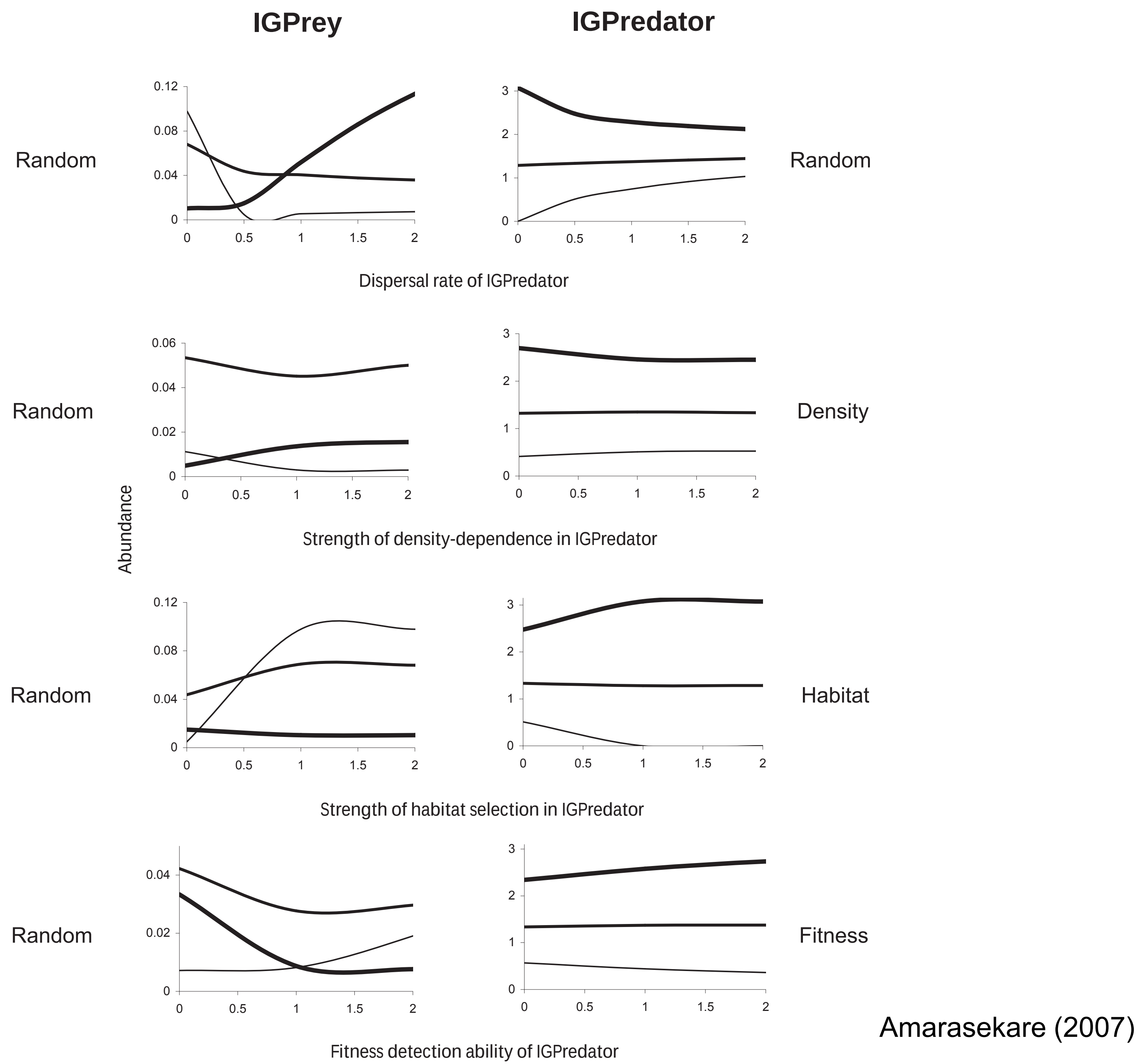
Asymmetry in dispersal effects and responses

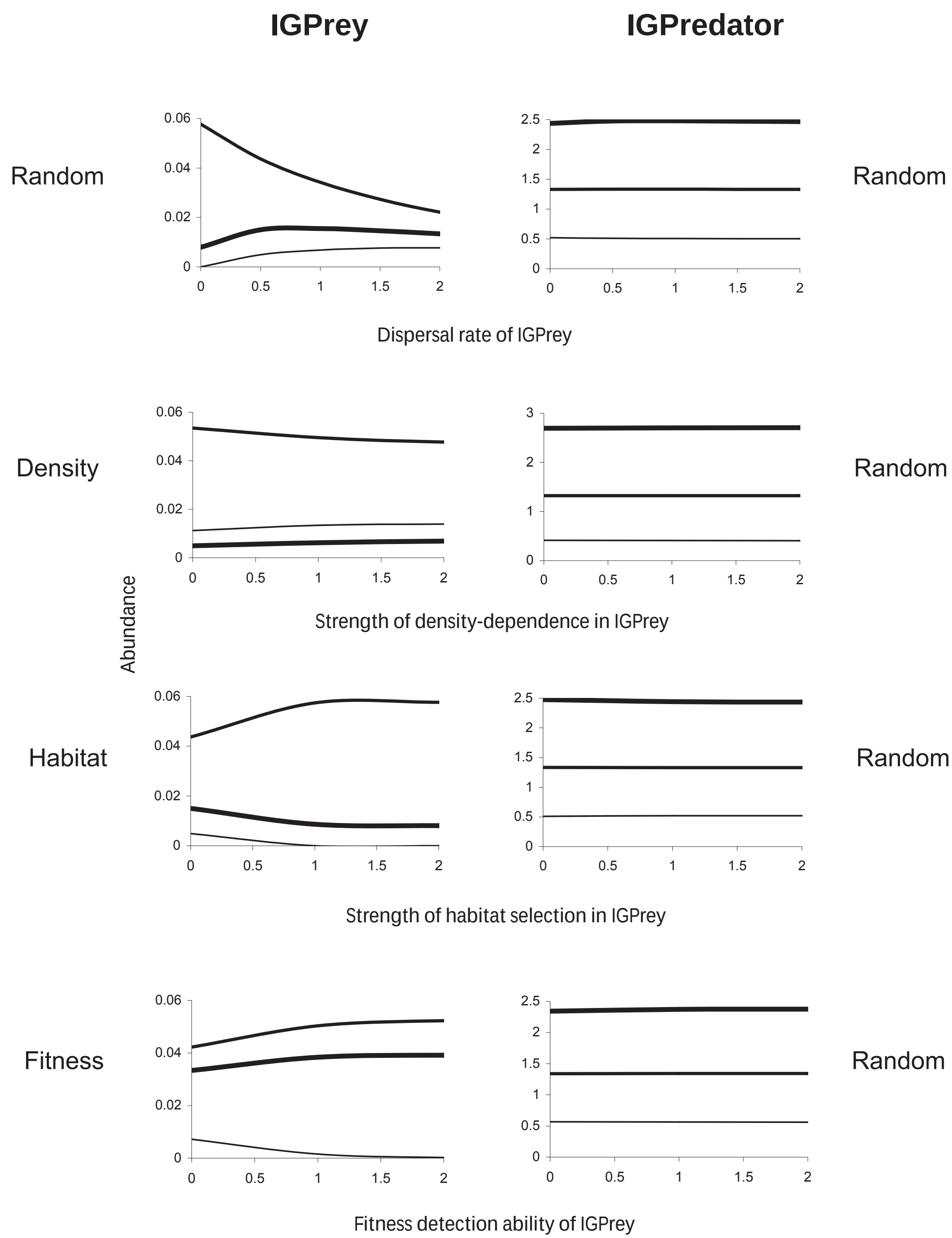
IGPredator's dispersal has a strong effect on the IGPrey,

IGPrey's dispersal has no effect on the IGPredator

Abundance-dispersal relationships




IGPrey
IGPredator
Random
Random
Dispersal rate of IGPredator
Random
Density
Strength of density-dependence in IGPredator
Abundance
Random
Habitat
Strength of habitat selection in IGPredator
Random
Fitness
Fitness detection ability of IGPredator
0.12
0.08
0.04
0.06
0.02
0
0.5
1
1.5
2
3
Amarasekare (2007)



Amarasekare (2007)

Asymmetry in response to dispersal

IGPrey strongly affected by dispersal strategy and dispersal behavior of IGPredator,

IGPredator unaffected by dispersal strategy and dispersal behavior of IGPrey

Dispersal in response to density: optimal for IGPrey, suboptimal for IGPredator

IGPredator has large effect on IGPrey $\Rightarrow$ suboptimal dispersal in IGPredator imposes large fitness cost on IGPrey

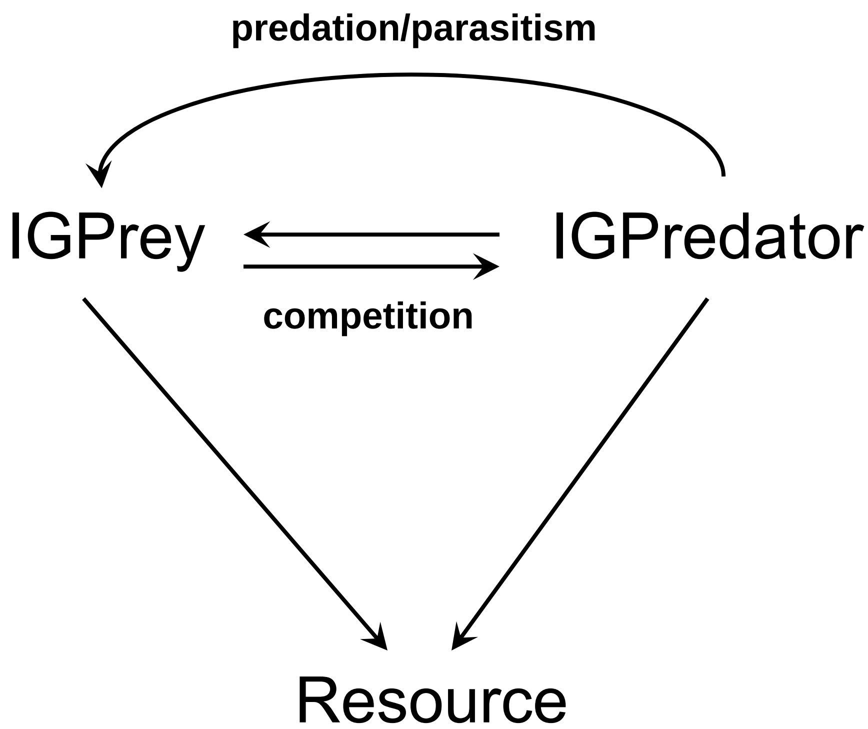
Dispersal in response to density $\longrightarrow$ suboptimal outcome for both species

Dispersal in response to productivity:
suboptimal for IGPrey, optimal for IGPredator

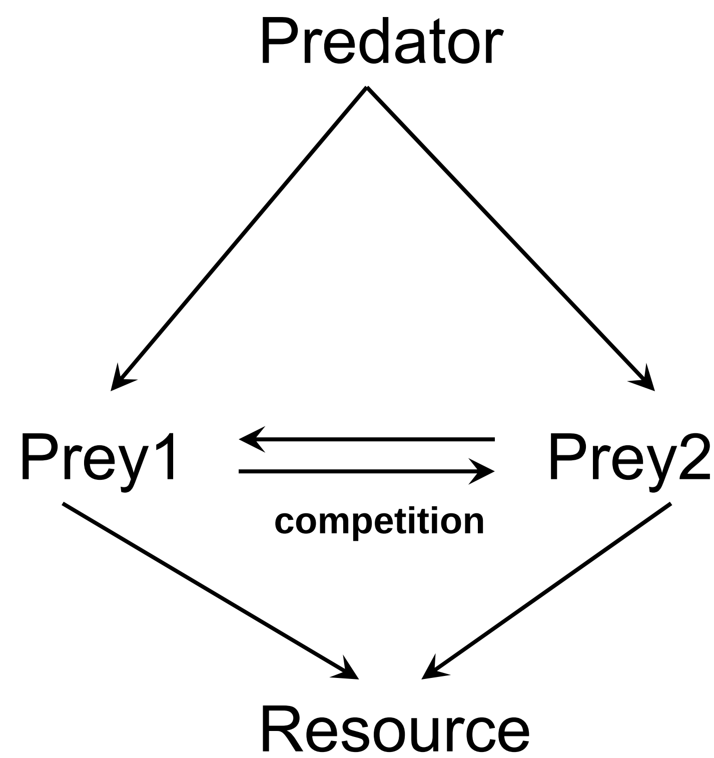
IGPrey has no effect on IGPredator $\Rightarrow$
suboptimal dispersal in IGPrey imposes no fitness cost on IGPredator

Dispersal in response to productivity $\longrightarrow$
optimal outcome for both species

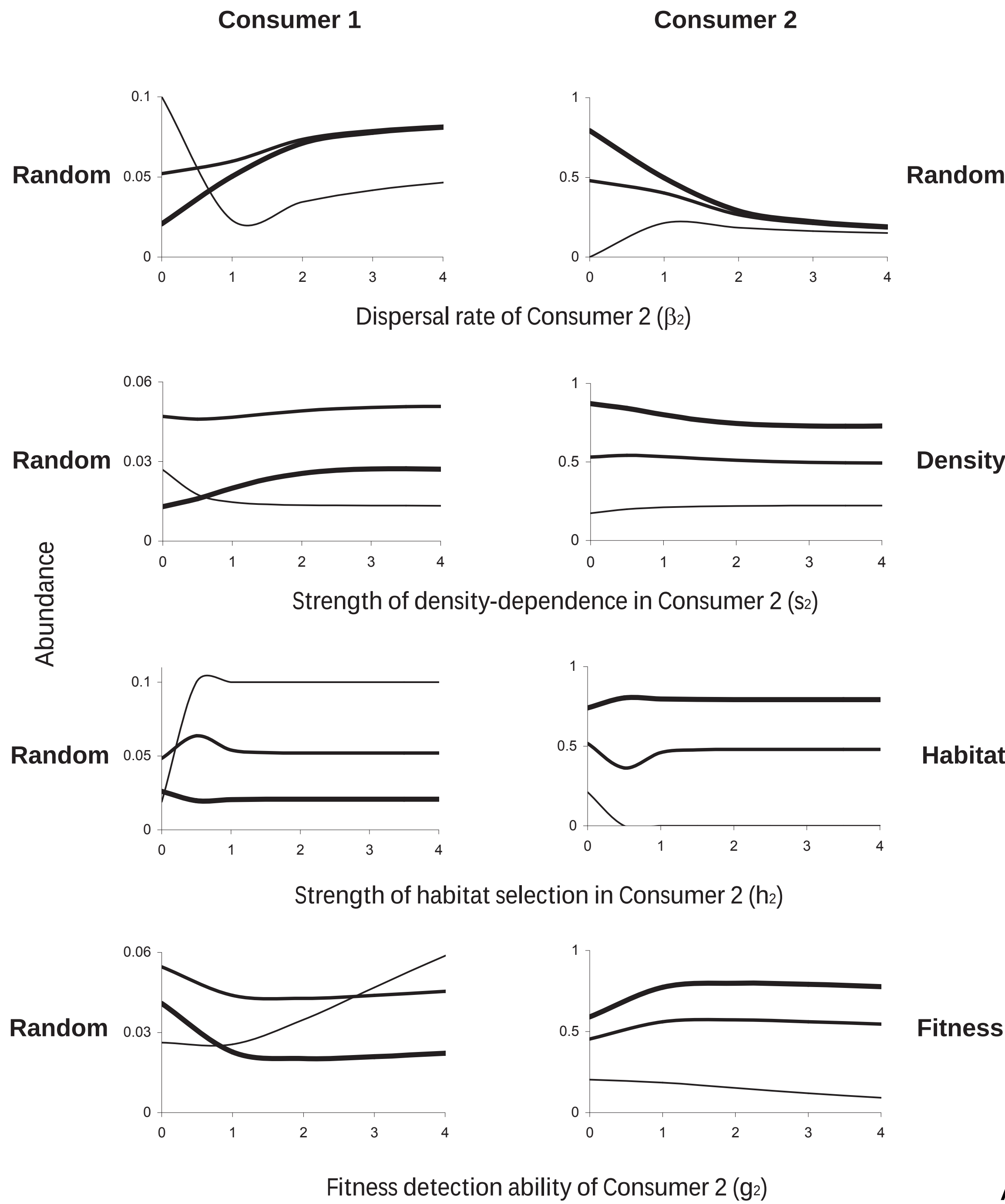
Multi-trophic interactions



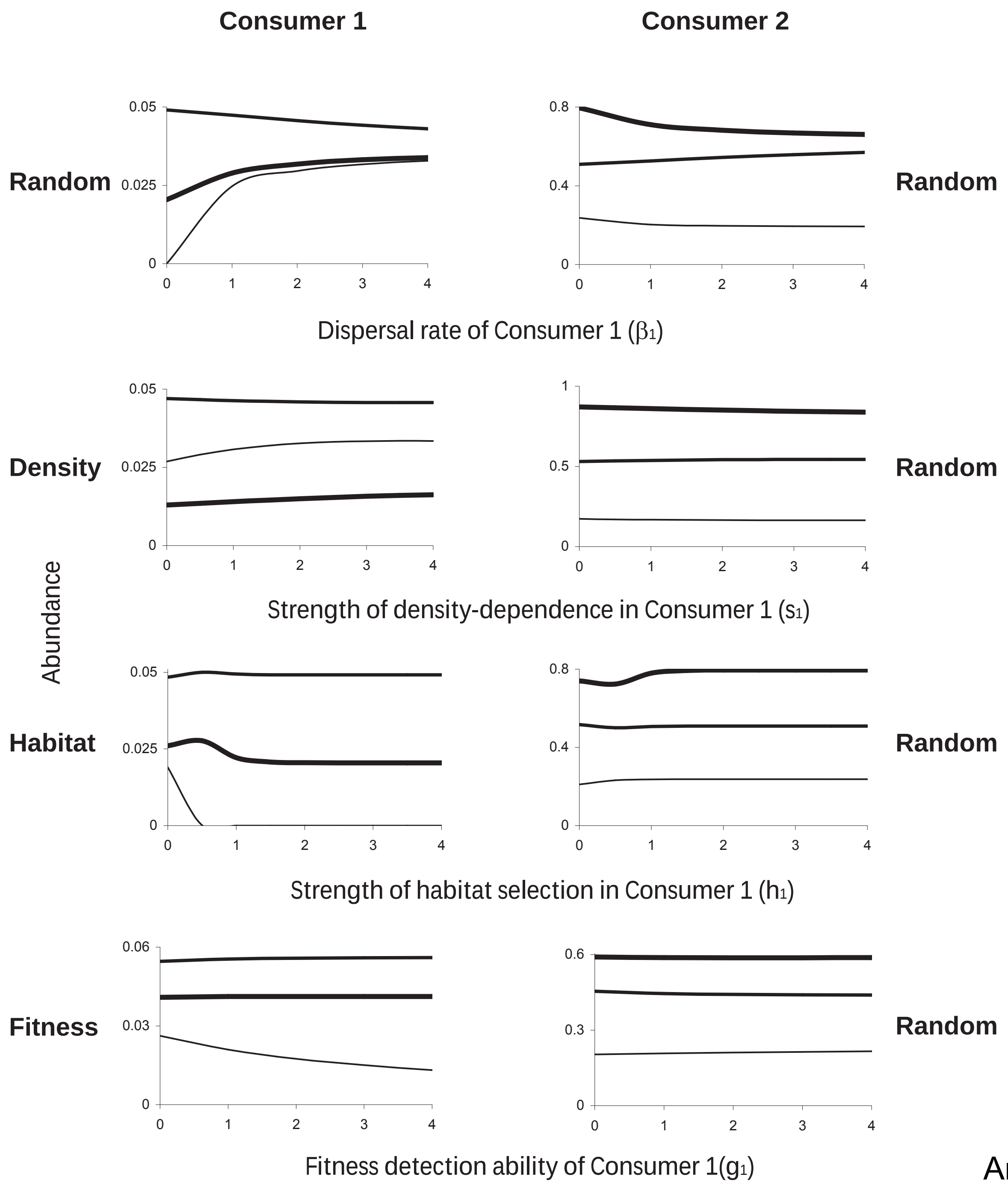
Intraguild predation



Selective predation



Amarasekare (2009)



Amarasekare (2009)

Non-random dispersal strategies in multi-trophic communities

1. **Trophic constraints**: density better for sup. competitor, productivity better for inf. competitor

2. Same dispersal cues $\Rightarrow$ optimal dispersal for one species, suboptimal dispersal for the other

3. **Asymmetry**: inf. competitor's dispersal has large effect on the sup. competitor but not vice versa

4. Optimal dispersal for inf. competitor $\Rightarrow$ optimal outcome for both species

Non-random dispersal strategies in multi-trophic communities

1. **Trophic constraints** determine fitness benefits of dispersal strategies

2. **Dispersal asymmetries**: predator-resistant consumer’s dispersal has disproportionate effect on coexistence and species distributions

3. **Keystone dispersers**

Non-random dispersal strategies in multi-trophic communities

1. **Ecological effects of non-random dispersal**: coexistence and species distributions

2. **Implications of ecological effects**: evolution of dispersal

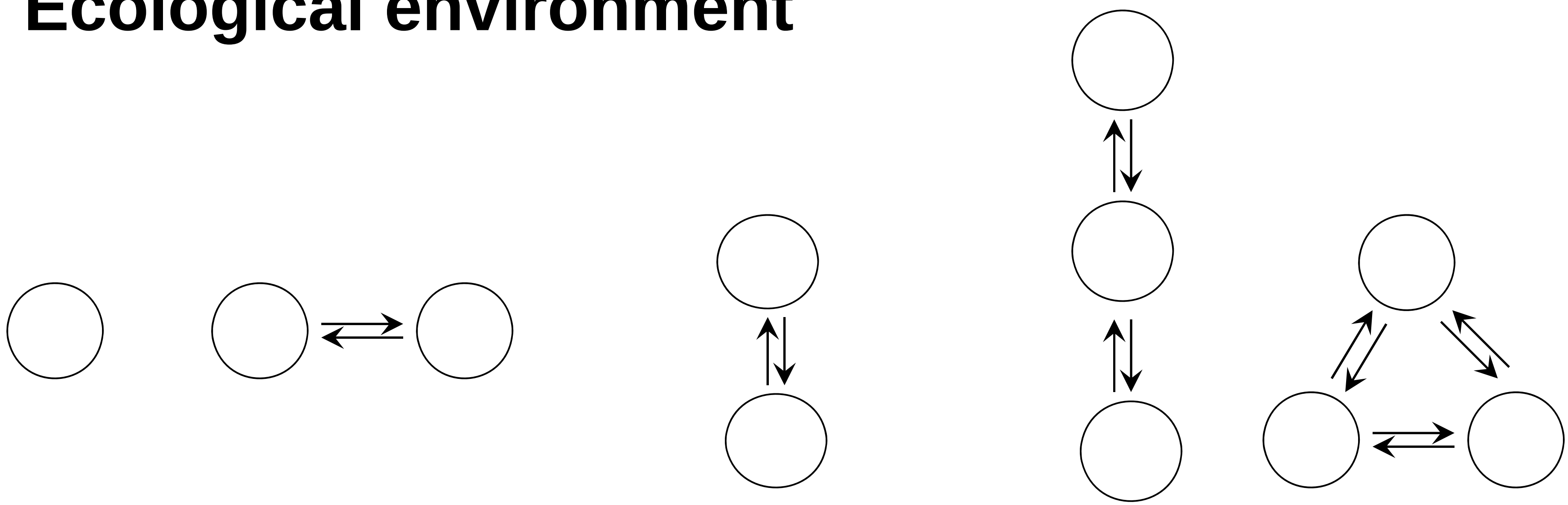
Evolution of random dispersal

Variable environments

- Local extinction (disturbances)
- Risk spreading (fluctuations)

Evolution of dispersal: current status

Ecological environment



Single species

Competition

Resource-consumer

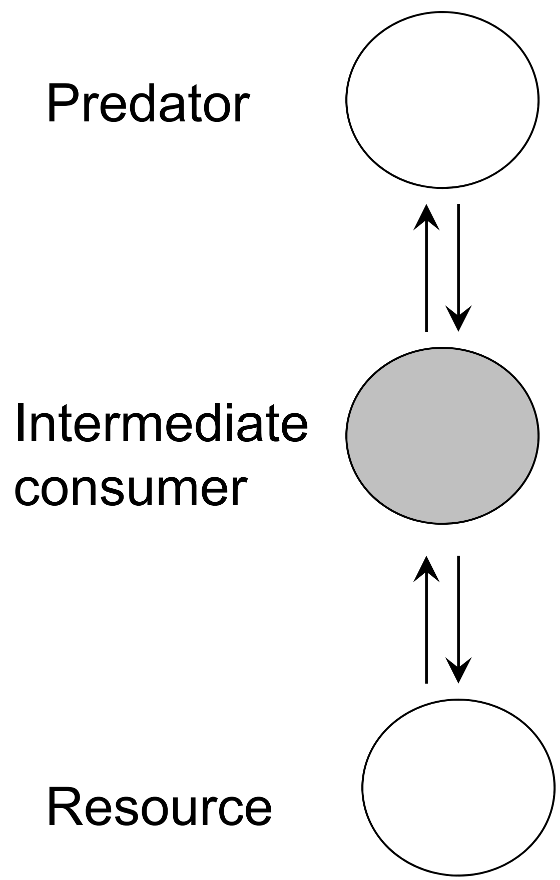
Resource-consumer-natural enemy

Food web

Well-studied

Poorly-studied

Evolution of dispersal in multi-trophic communities



- Tri-trophic interaction
- Dispersal of intermediate consumer
- Resource acquisition vs. predator avoidance

Tritrophic interaction: local dynamics

$$\frac{dR}{d\tau} = rR(1-R) - RC$$

$$\frac{dC}{d\tau} = a_C RC - \delta C - CP$$

$$\frac{dP}{d\tau} = a_P CP - P$$

Resource productivity (r)

Consumer mortality (δ)

Attack rates (a_C, a_P)

Tritrophic interaction: asymptotic behavior

Resource-consumer community

$$R^\star = \frac{\delta}{a_C}$$
$$C^\star = r\big(1 - \frac{\delta}{a_C}\big)$$

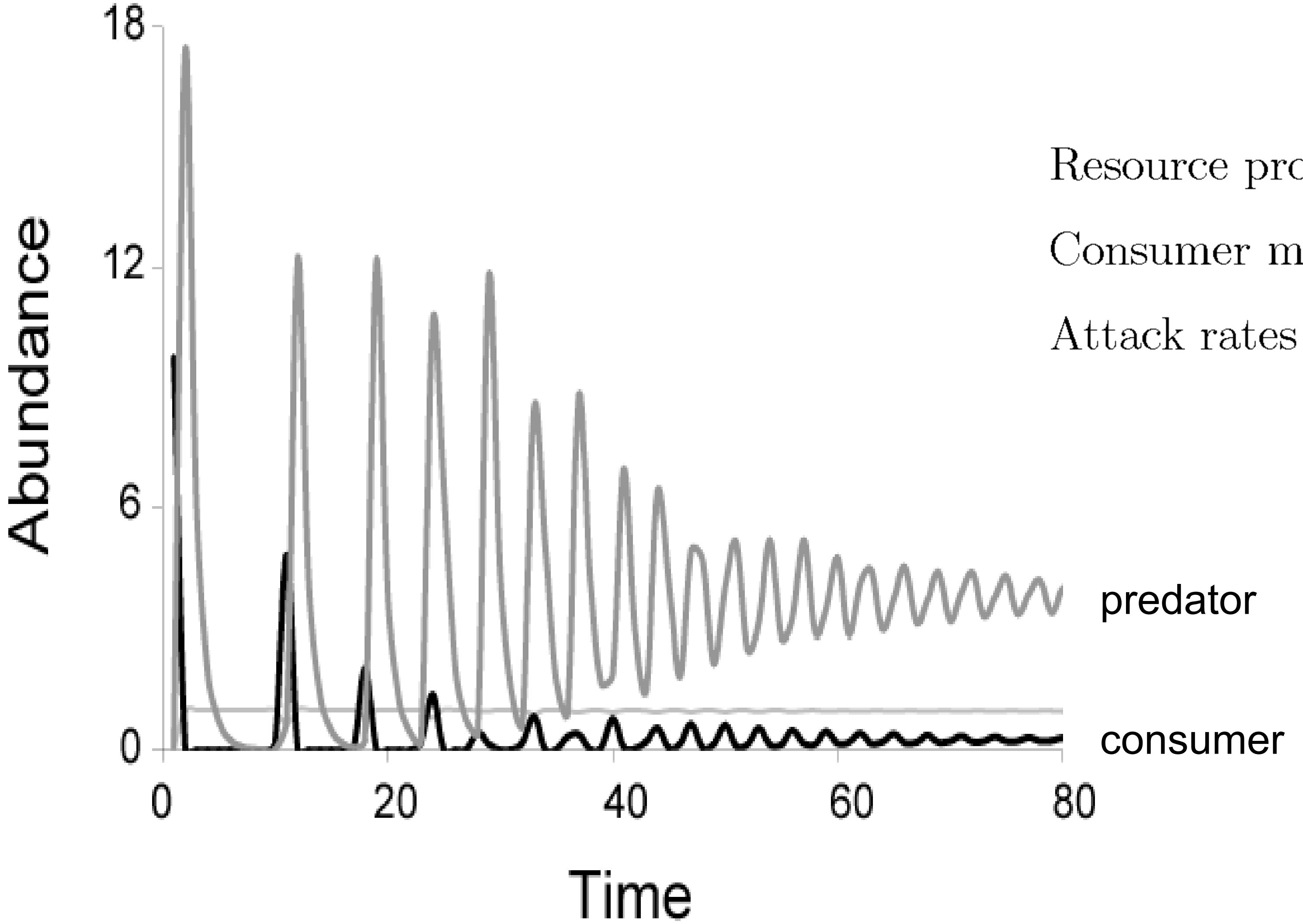
Consumer's equilibrium abundance depends on resource productivity

Resource-consumer-predator community

$$R^\star = 1 - \frac{1}{r a_P}$$
$$C^\star = \frac{1}{a_P}$$
$$P^\star = a_C\big(1 - \frac{1}{r a_P}\big) - \delta$$

Consumer's equilibrium abundance independent of resource productivity

Tritrophic interaction: transient behavior



Resource productivity (r)

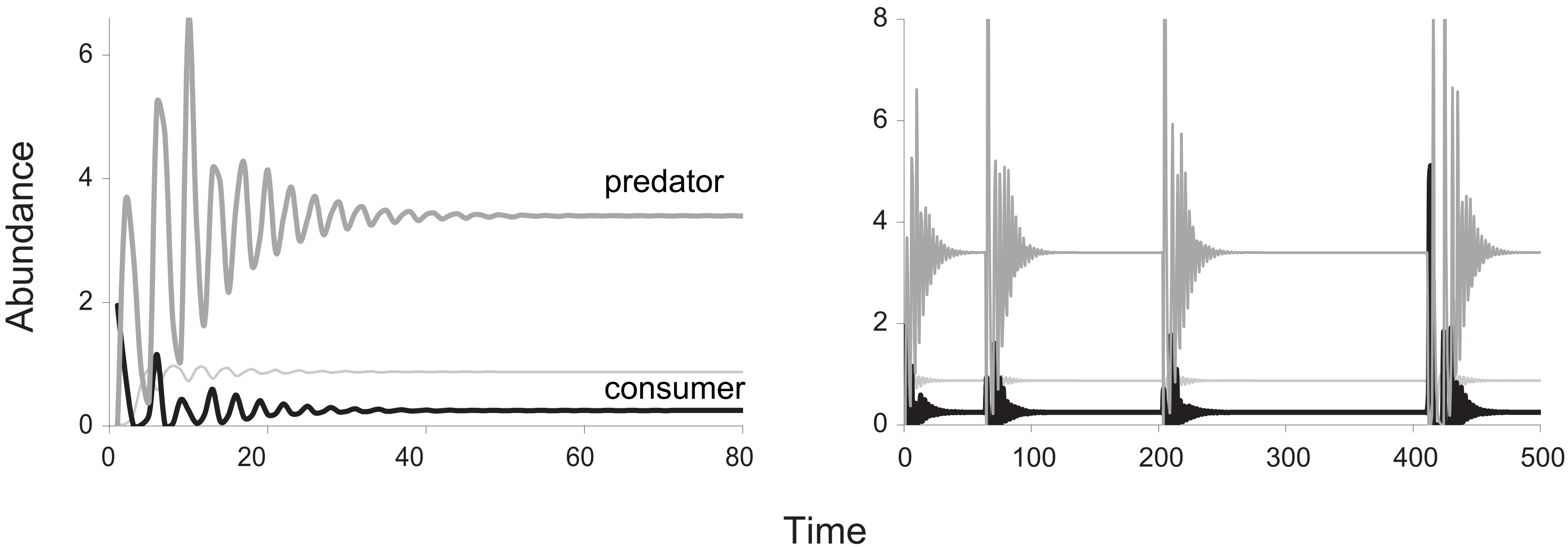
Consumer mortality (δ)

Attack rates (a_C, a_P)

Population fluctuations due to predator colonization

Community assembly

Extinction-colonization dynamics



Transient fluctuations

Persistent fluctuations

Consequences of predator-induced population fluctuations

1. Consumer extinction at low abundances

2. Temporal variation in fitness (per capita growth rate)

Evolution of random dispersal

Variable environments

- Local extinction
- Risk spreading

Evolution of consumer dispersal

Ecological selective environment

Spatial variation:

Productivity of basal resource
(spatial structure and dynamics)

Temporal variation:

Extinction-colonization dynamics of predator
(temporal variation in fitness)

Tritrophic interaction: spatial dynamics

$$\frac{dR_j}{d\tau} = r_j R_j (1 - R_j) - R_j C_j$$

$$\frac{dC_j}{d\tau} = a_C R_j C_{1j} - \delta C_j - C_j P_j - \beta_c C_j + \frac{\beta_C}{2} \sum_{k=1}^{2} C_k$$

$$\frac{dP_j}{d\tau} = a_P C_j P_j - P_j$$

$$(j, k = 1, 2)$$

Per capita dispersal rate (β)

Spatial variation in resource productivity (r_j)

Spatial structure: resource productivity

1. Resource productivity variation high

Predator cannot invade one patch
Predator's spatial structure: **source-sink**

2. Resource productivity variation low

Predator can invade both patches
Predator's spatial structure: **source-source**
Spatial variation in predator abundance

Predator's spatial structure: selective environment in the absence of temporal variation

Productivity variation	Predator's spatial structure	Consumer abundance	Consumer dispersal
Low	**Source-source**	$C_1^* = C_2^*$	**Neutral**
High	**Source-sink**	$C_1^* < C_2^*$	**Selected against**

Temporal variation: extinction-colonization dynamics in predator

- Random local extinction of predator
- Periodic recolonization
- Extinction-colonization dynamics independent in the two patches $\Rightarrow$

  asynchronous fluctuations in abundance

Ecological selective environment for the evolution of dispersal

Resource productivity → Predator's spatial structure → **Spatial variation in consumer's fitness**

Predator's extinction-colonization dynamics → Asynchronous fluctuations → **Temporal variation in consumer's fitness**

Evolution of consumer dispersal

Case 1

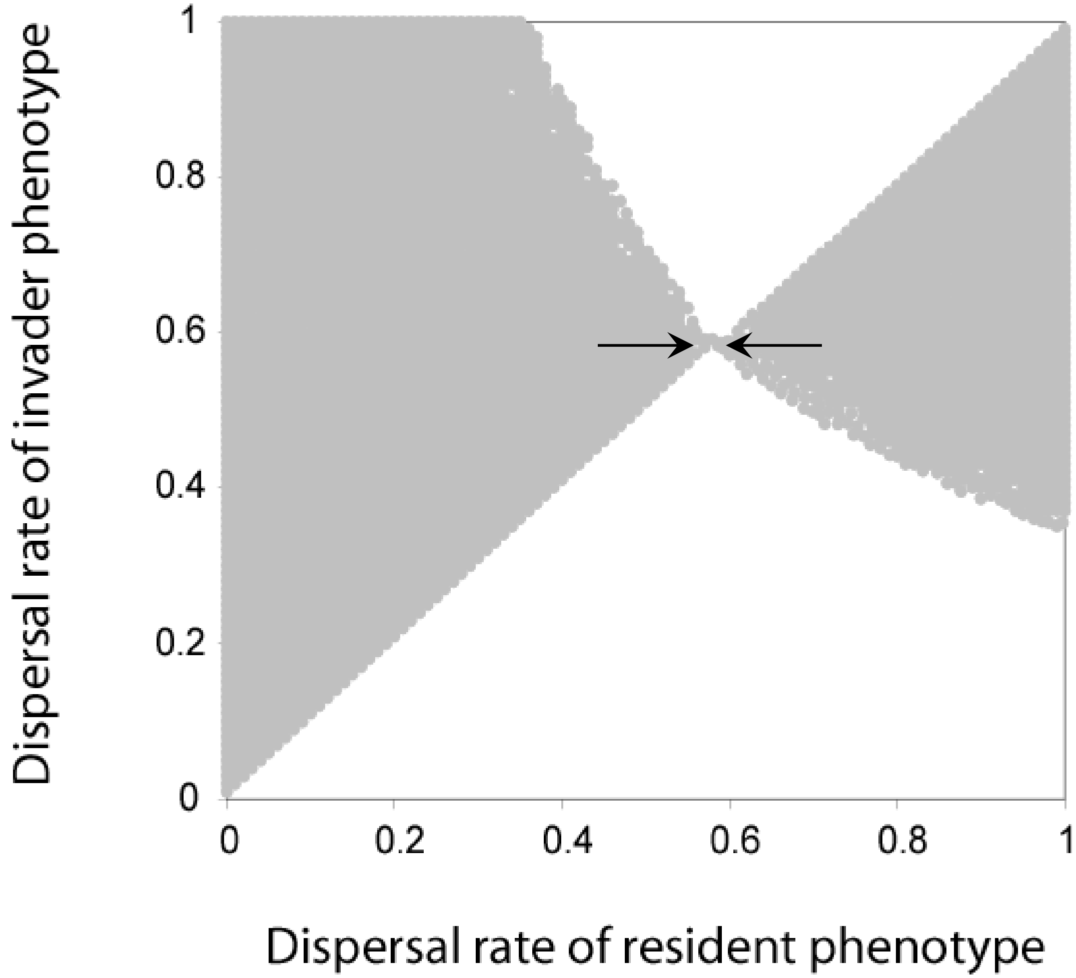
Resource productivity variation is low

Predator can invade both patches

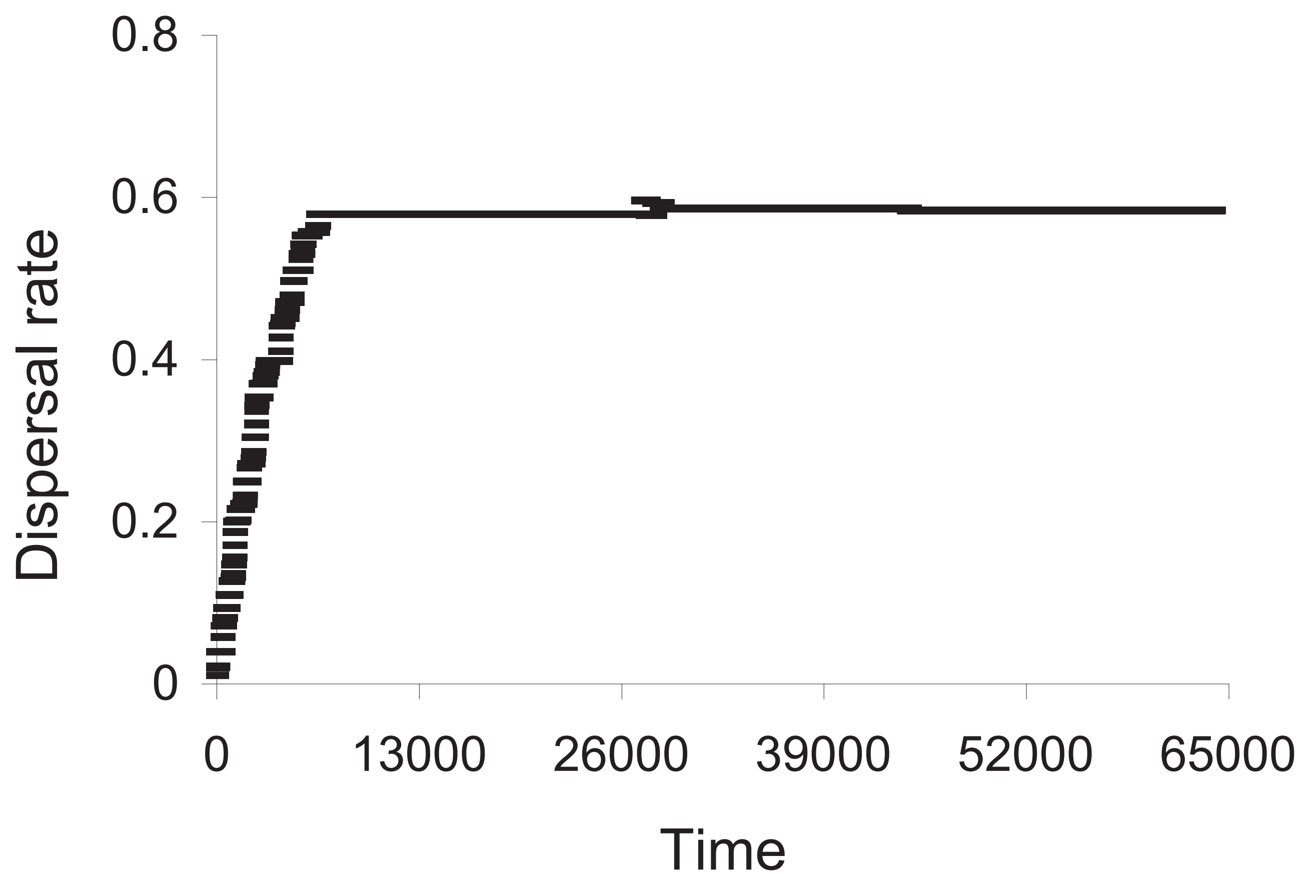
Spatial variation: neutral dispersal

Temporal variation: ?

Consumer dispersal: evolutionarily stable dispersal rate



Consumer dispersal: dispersal monomorphism



Evolution of consumer dispersal

Case 2

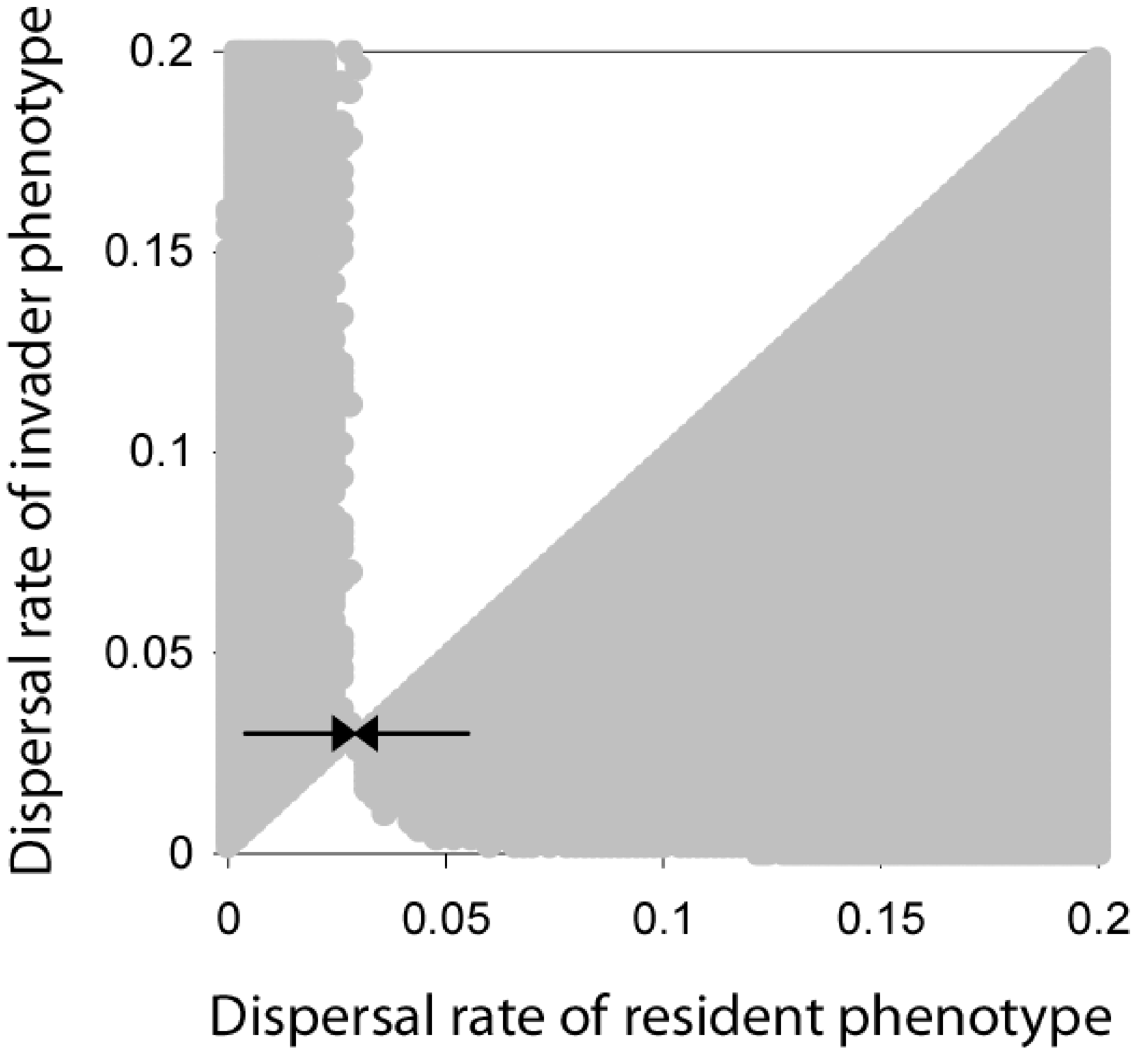
Resource productivity variation is high

Predator can invade only one patch

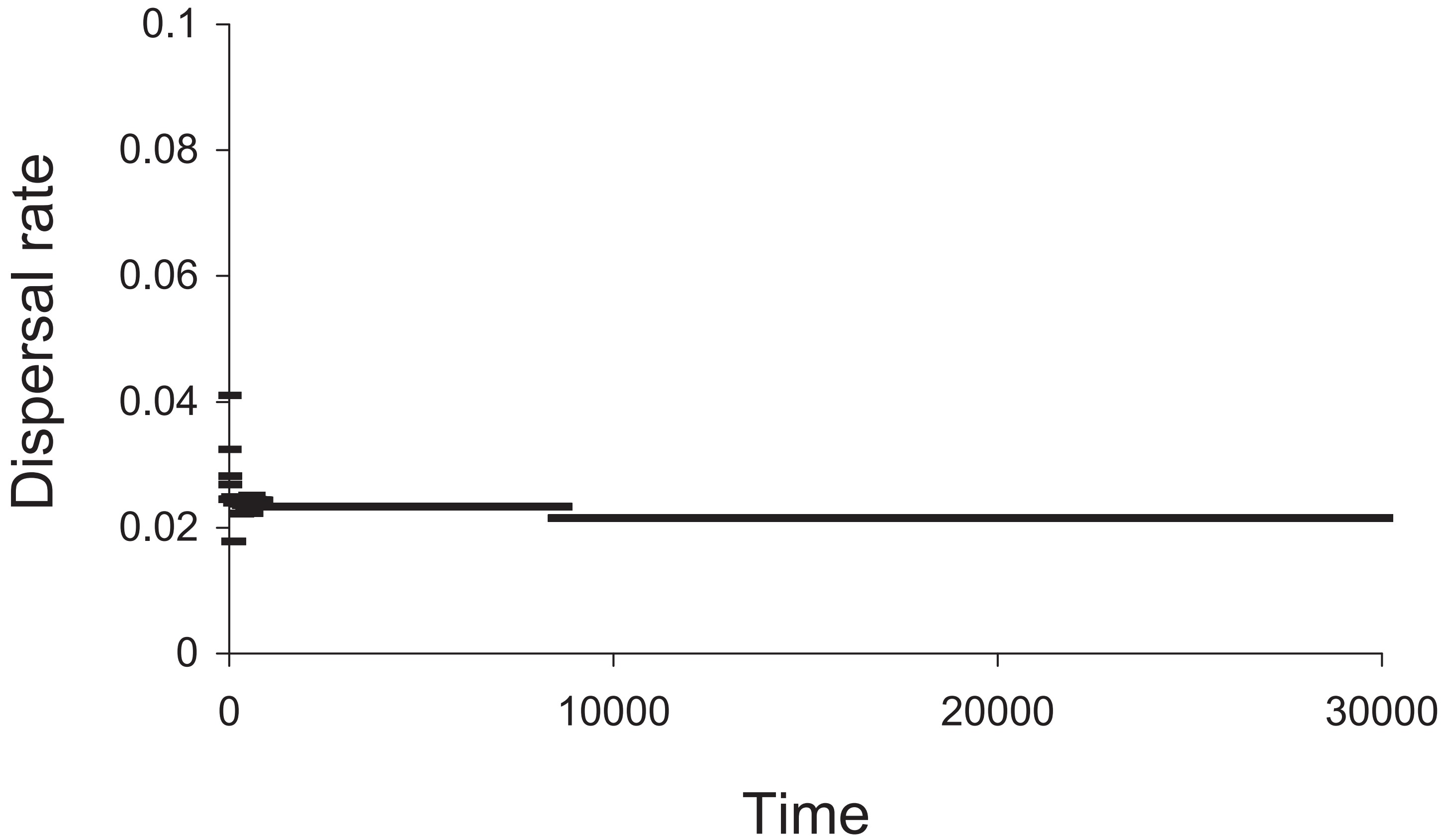
Spatial variation: dispersal is selected against

Temporal variation:?

Consumer dispersal



Consumer dispersal: dispersal monomorphism



Ecological dynamics constrain evolution of polymorphism

Consumer overexploitation in predator-occupied patch ⇒ dispersal is advantageous

Low resource productivity in predator-free patch ⇒ high dispersal disadvantageous

Spatial structure precludes evolution of high dispersal phenotype

Evolution of consumer dispersal

Case 2

Resource productivity variation is high

Predator can invade only one patch

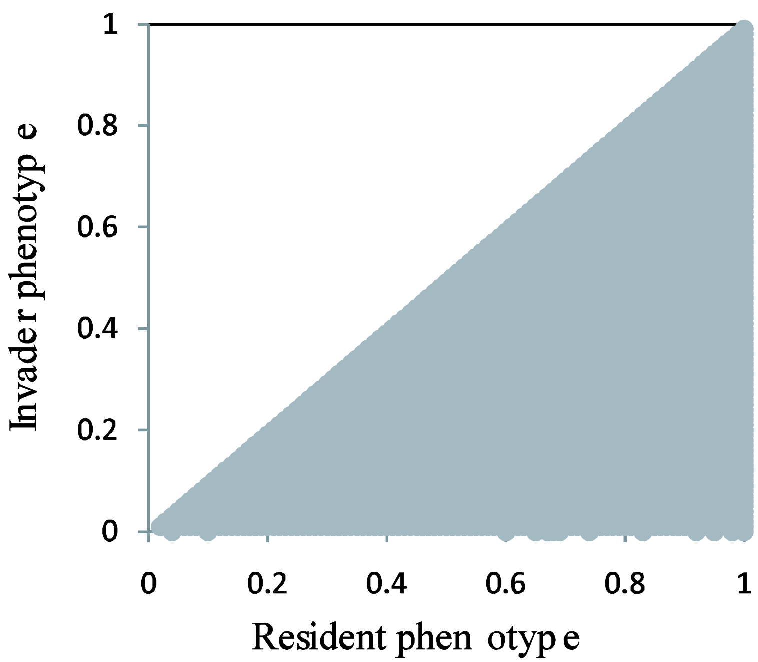
Spatial variation: dispersal is selected against

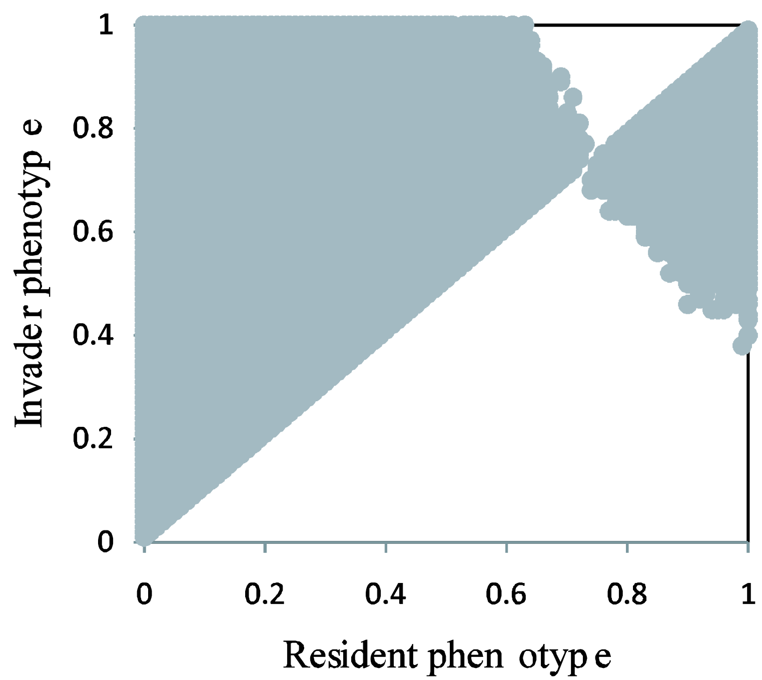
Temporal variation: dispersal monomorphism (ESS)

Evolution of non-random dispersal

Dispersal in response to resource productivity

Dispersal in response to predator density





ESS: zero dispersal

ESS: intermediate dispersal rate

Random vs. non-random dispersal

ESS: random dispersal

Mutants dispersing in response to productivity cannot invade

Mutants dispersing in response to predator density displace random resident

Evolution of dispersal in multi-trophic communities

1. Community composition:
   Selective environment

2. Community dynamics:
   Constraints on evolution

Evolution of dispersal: future directions

Random vs. non-random dispersal in foodwebs

(Intraguild predation, selective predation)