Parasite infection can favor seasonal migration by hosts

Allison Shaw
Dept. of Ecology, Evolution and Behavior

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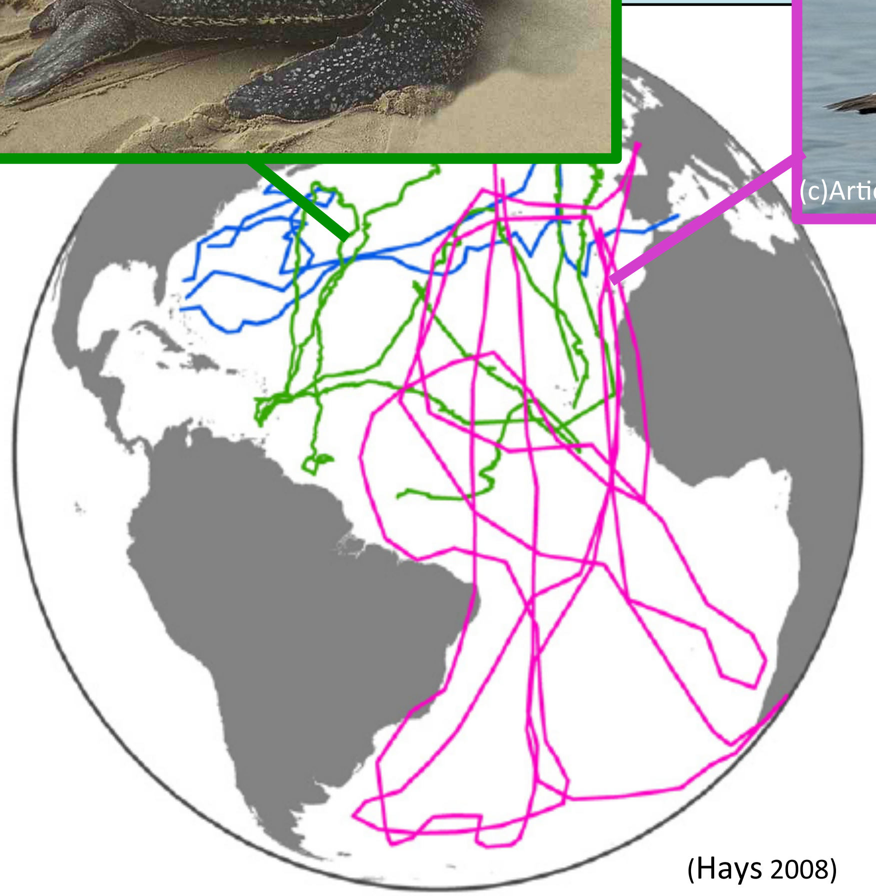
www.virginiaherpetologicalsociety.com


(Hays 2008)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http://seattletimes.nwsource.com/
news/local/links/salmon_reprint.html


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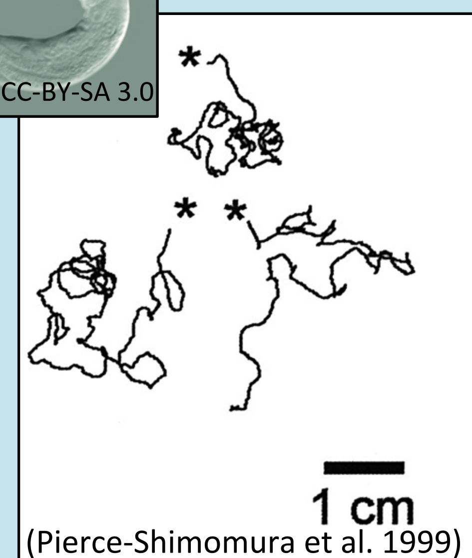

*
* *
1 cm
(Pierce-Shimomura et al. 1999)


(c)Peter Parks,
pbs.org


(c)Johma Luhta, naturepl.com

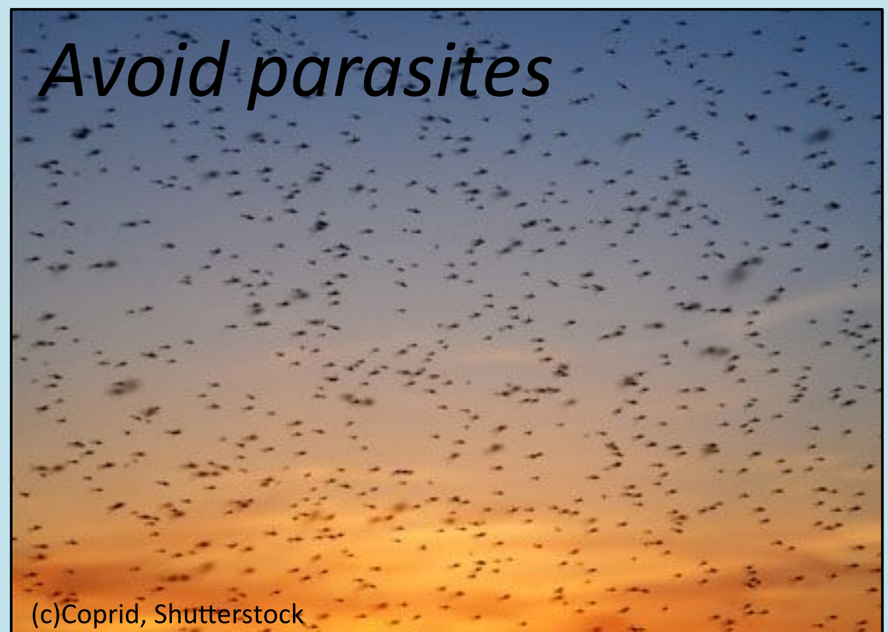

(c)Didier Descouens, CC-BY-SA 4.0

Why move?


Find Food
Avoid predators
(c)Pauk, CC-BY-2.0


Find Mates
(c)Animalparty, CC-BY-2.0

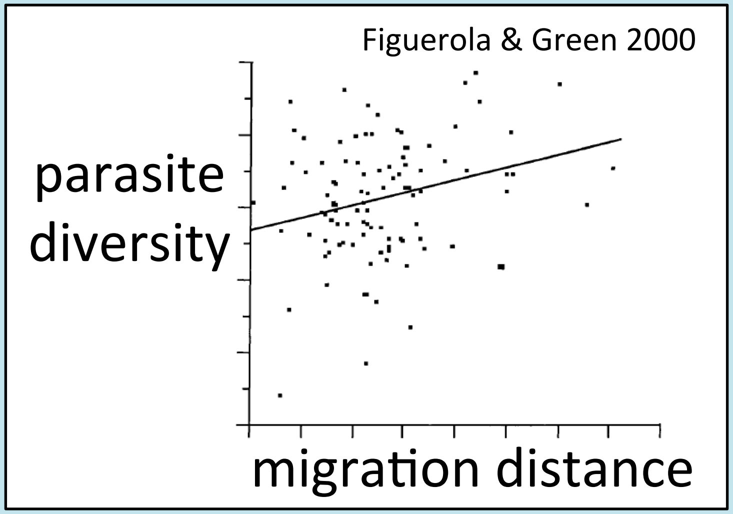

Avoid
climate


Avoid parasites
(c)Coprid, Shutterstock

Infection & movement

Moving helps avoid infection

…or increases parasite exposure



Different movement once infected:

can be driven by hosts

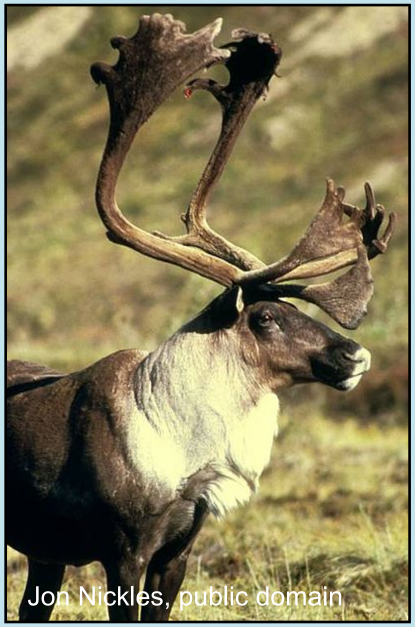
…or by parasite manipulation

Migration and parasites

Migration (round-trip) can reduce parasite infection via:

1. *Migratory escape*: temporarily migrating away from infected areas or individuals

(Loehle 1995)



2. *Migratory culling*: increased mortality of infected individuals during migration

(Bradley & Altizer 2005)

Third infection-related benefit of migration

Some migratory species experience different rates of infection recovery in different environmental conditions:

Flounders (*Platichthys flesus*) migrate between fresh and salt water; their parasites (*Lepeophtheirus pectoralis*) die and detach faster at lower salinities

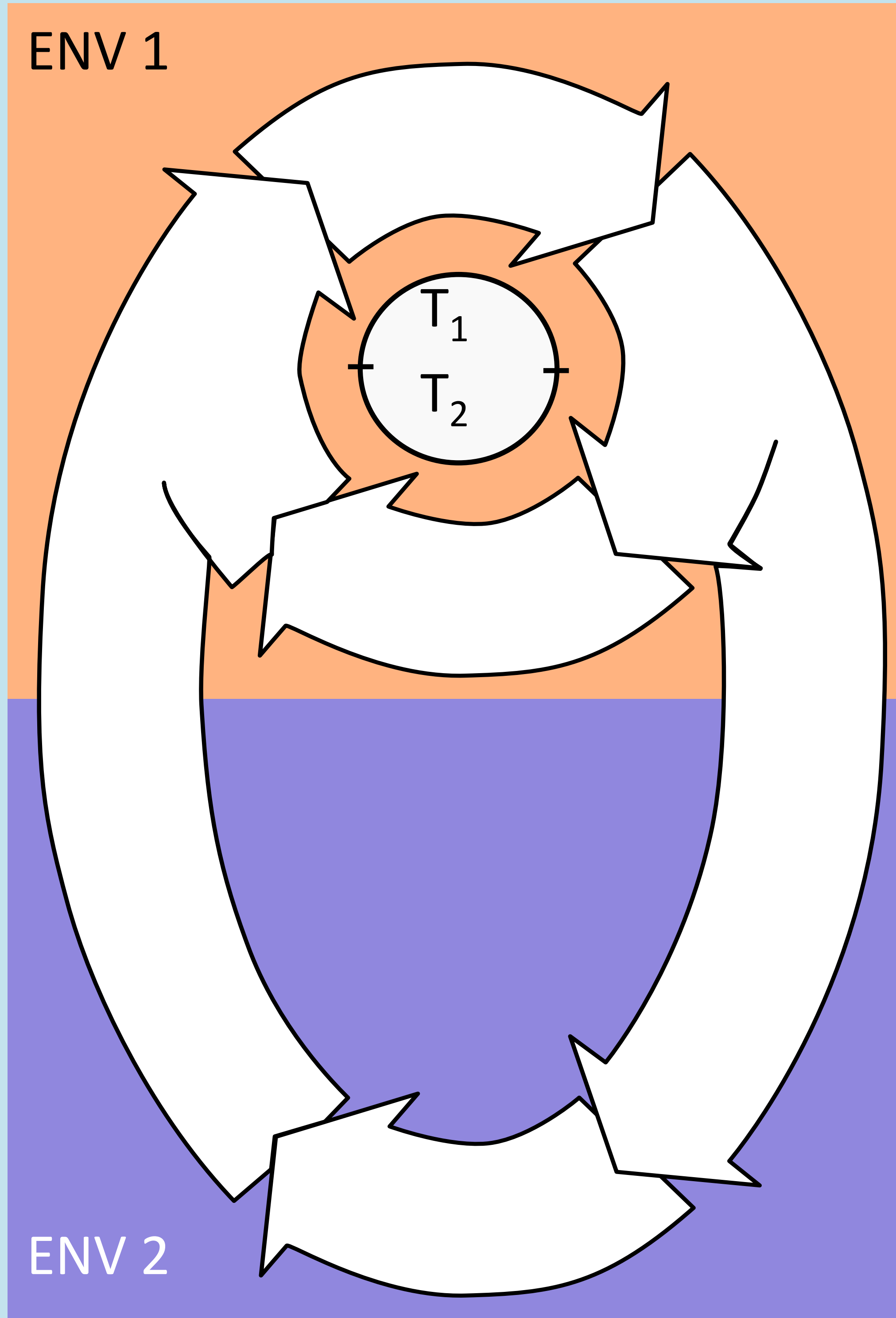
(Möller 1978)

Alpine newts (*Mesotriton alpestris*) migrate overland between ponds. Newts infected with *Batrachochytrium dendrobatidis* recovered faster on land than in water

(Daversa et al. in review)

When can recovery from infection be a sufficient selective pressure to favor migration by the host species?

Model framework



Model dynamics (T_1)

Infection

$$\frac{dS}{dt} = -\beta S \qquad \frac{dI}{dt} = \beta S$$

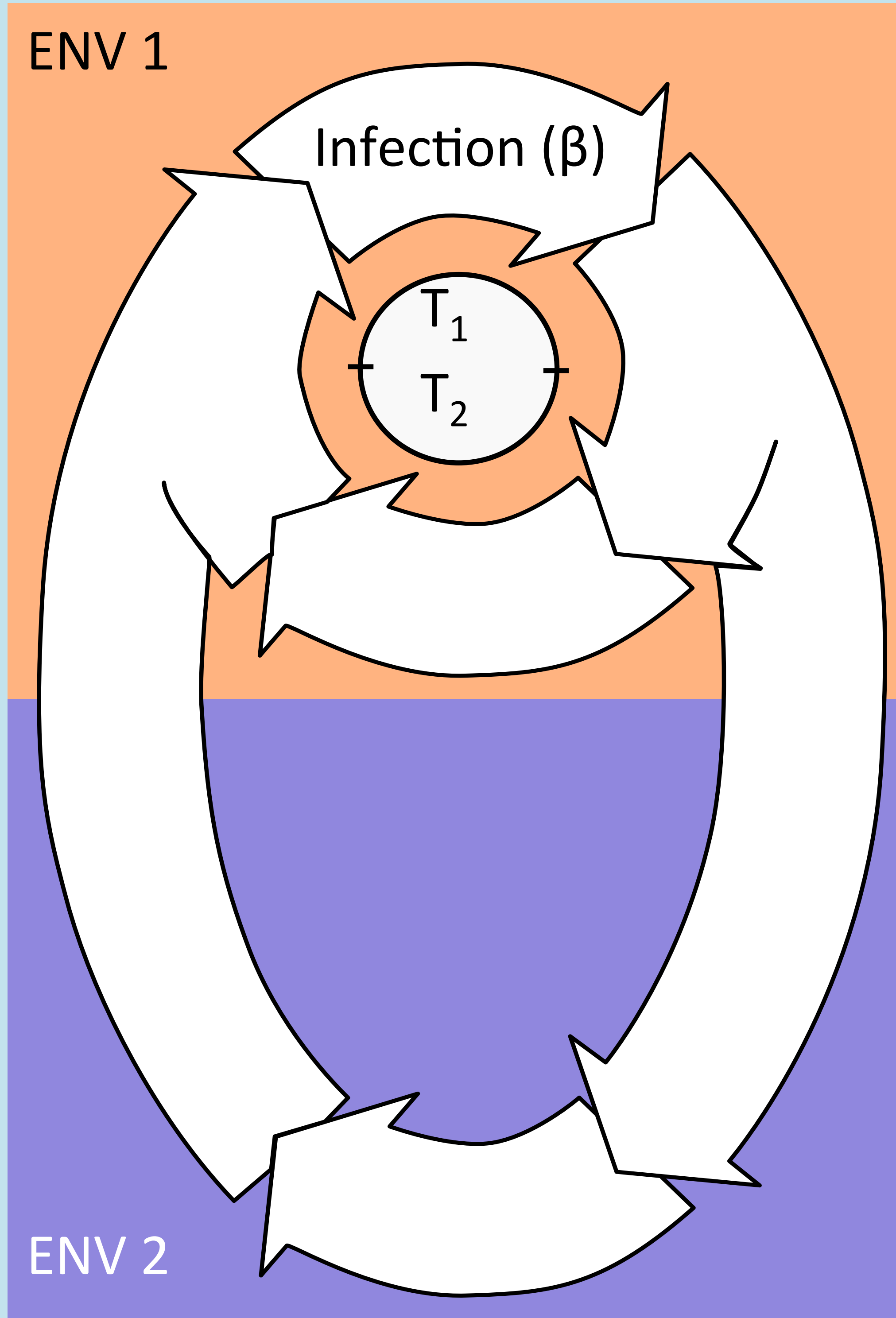
S = susceptible individuals

I = infected individuals

β = rate of infection

$$S(T_1) = S_0 e^{-\beta T_1}$$

$$I(T_1) = I_0 + S_0 \left(1 - e^{-\beta T_1}\right)$$



Model dynamics (T_2 – residents)

Infection

$$\frac{dS}{dt} = -\beta S \qquad \frac{dI}{dt} = \beta S$$

S = susceptible individuals

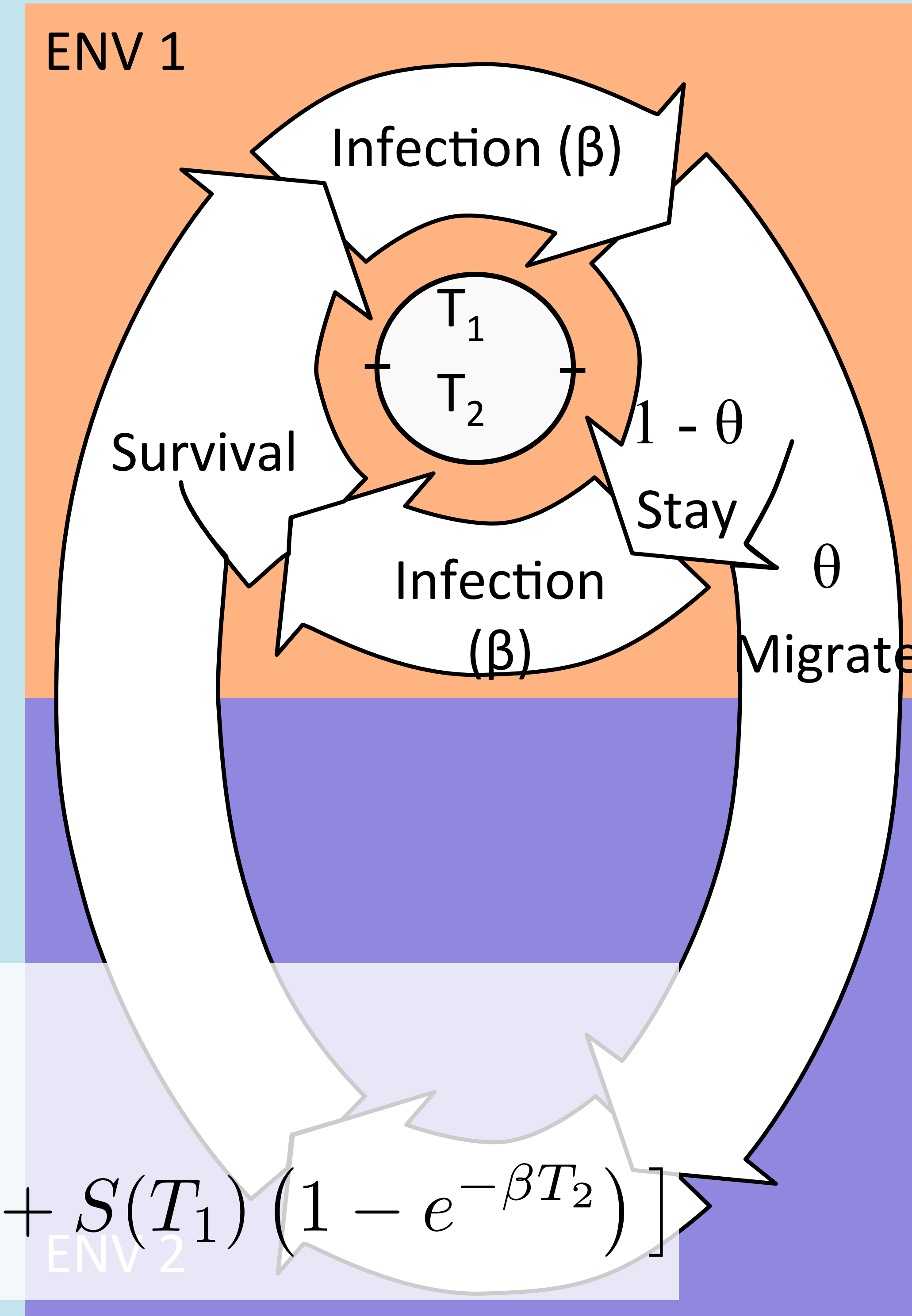
I = infected individuals

β = rate of infection

θ = migration probability

σ = suscep. resident survival

c_I = infection survival cost



$$S_R = (1-\theta)\sigma\left[S(T_1)e^{-\beta T_2}\right]$$

$$I_R = (1-\theta)(1-c_I)\sigma\left[I(T_1) + S(T_1)\left(1-e^{-\beta T_2}\right)\right]$$

Model dynamics (T_2 – migrants)

Recovery

$$\frac{dS}{dt} = \gamma S \qquad \frac{dI}{dt} = -\gamma S$$

θ = migration probability

γ = rate of recovery

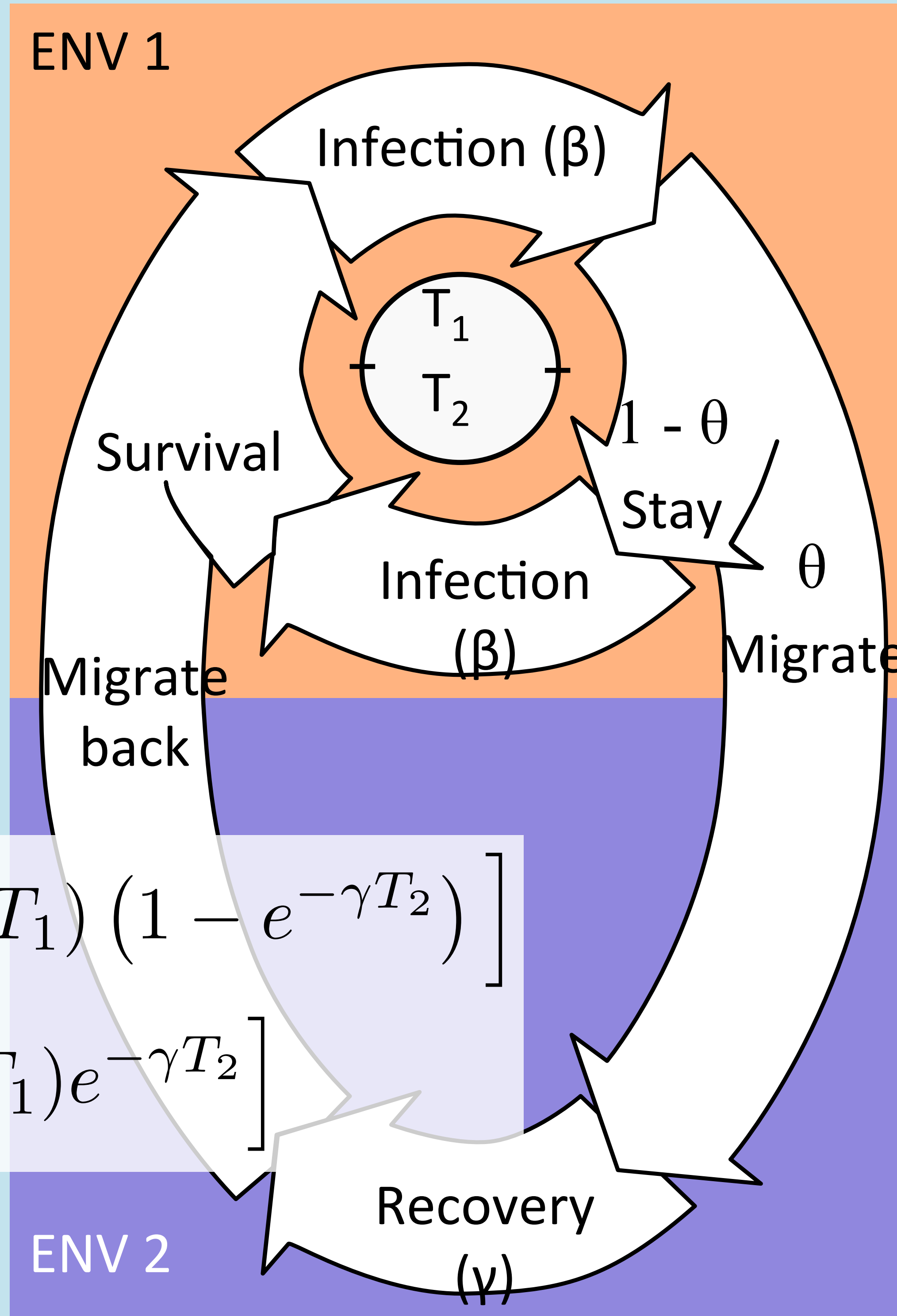
σ = suscep. resident survival

c_I = infection survival cost

c_M = migration survival cost

$$S_M = \theta(1 - c_M)\sigma\left[S(T_1) + I(T_1)\left(1 - e^{-\gamma T_2}\right)\right]$$

$$I_M = \theta(1 - c_M)(1 - c_I)\sigma\left[I(T_1)e^{-\gamma T_2}\right]$$



Model dynamics (reproduction)

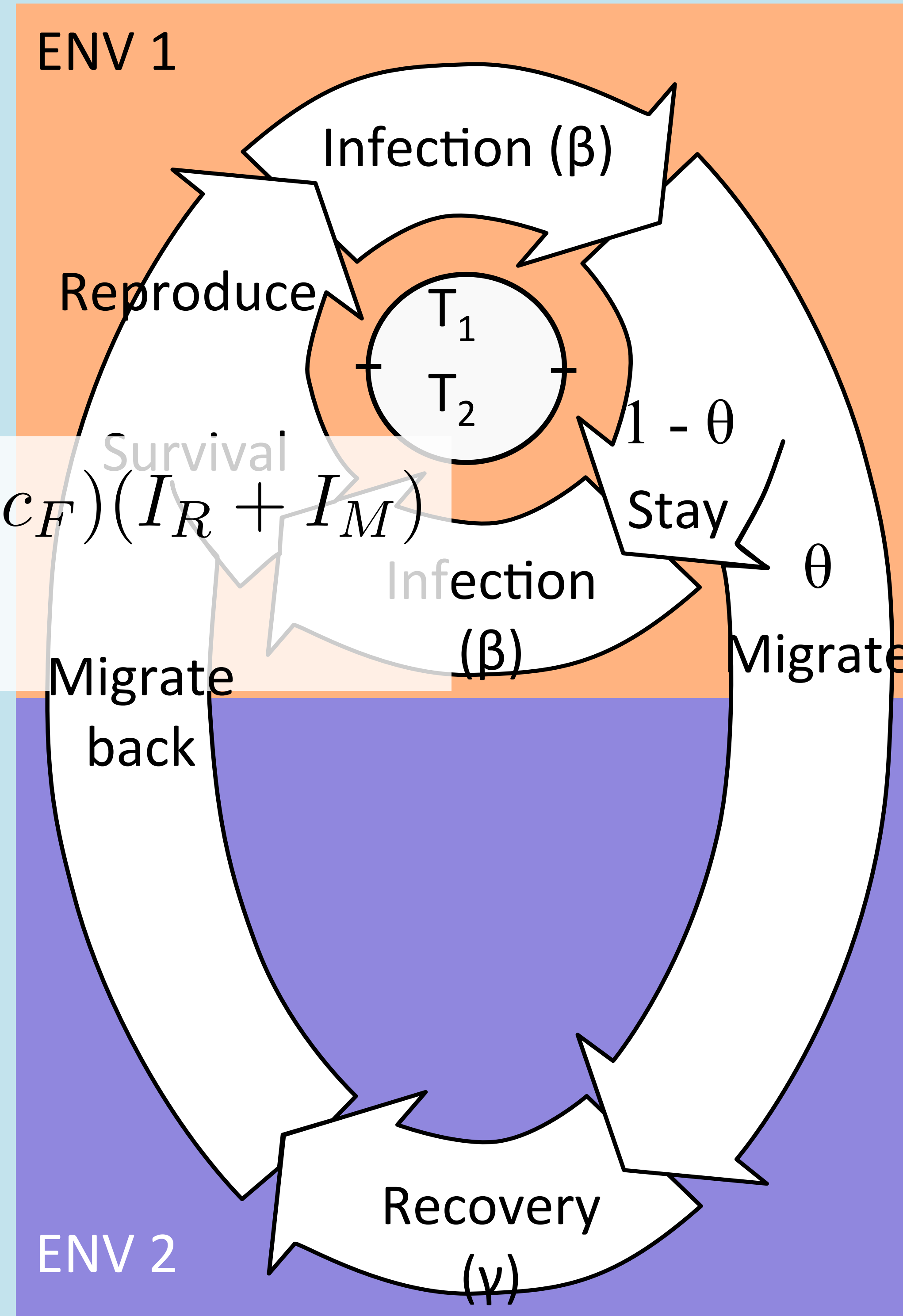
Reproduction

ϕ = susceptible fecundity

c_F = infection fecundity cost

$$b_{max} = \phi(S_R + S_M) + \phi(1 - c_F)(I_R + I_M)$$
$$b = b_{max} DD$$

$$DD(S = 0, I = 0) = 1$$
$$\frac{\partial DD}{\partial S} < 0$$
$$\frac{\partial DD}{\partial I} < 0$$
$$DD \geq 0$$



Full model

$$\begin{bmatrix} S \\ \\ I \end{bmatrix}_{\tau+1} = \begin{bmatrix} A\theta + B(1-\theta) & C\theta \\ +DD\left[J\theta + K(1-\theta)\right] & +DD\left[L\theta + M(1-\theta)\right] \\ E\theta + F(1-\theta) & G\theta + H(1-\theta) \end{bmatrix} \begin{bmatrix} S \\ \\ I \end{bmatrix}_{\tau}$$

θ = migration probability

with coefficients:

$$A = \sigma_{SM}\left[e^{-\beta T_1} + \left(1 - e^{-\beta T_1}\right)\left(1 - e^{-\gamma T_2}\right)\right]$$

$$B = \sigma_{SR} e^{-\beta(T_1+T_2)}$$

$$C = \sigma_{SM}\left(1 - e^{-\gamma T_2}\right)$$

$$E = \sigma_{IM} e^{-\gamma T_2}\left(1 - e^{-\beta T_1}\right)$$

$$F = \sigma_{IR}\left[\left(1 - e^{-\beta T_1}\right) + \left(1 - e^{-\beta T_2}\right) e^{-\beta T_1}\right]$$

$$G = \sigma_{IM} e^{-\gamma T_2}$$

$$H = \sigma_{IR}$$

$$J = \phi_S A + \phi_I E$$

$$K = \phi_S B + \phi_I F$$

$$L = \phi_S C + \phi_I G$$

$$M = \phi_I H$$

Methods 1: Ecological equilibrium

Step 1: find ecological equilibrium

Given our model, what population size do we expect to see?

- I.e. the stable population size: $S(\tau+1) = S(\tau) = S^*$

$$I(\tau+1) = I(\tau) = I^*$$

$$DD^* = \frac{\Big[1 - A\theta - B(1-\theta)\Big]\Big[1 - G\theta - H(1-\theta)\Big] - C\theta\Big[E\theta + F(1-\theta)\Big]}{\Big[J\theta + K(1-\theta)\Big]\Big[1 - G\theta - H(1-\theta)\Big] + \Big[L\theta + M(1-\theta)\Big]\Big[E\theta + F(1-\theta)\Big]}$$

$$I^* = S^*\left[\frac{E\theta + F(1-\theta)}{1 - G\theta - H(1-\theta)}\right]$$

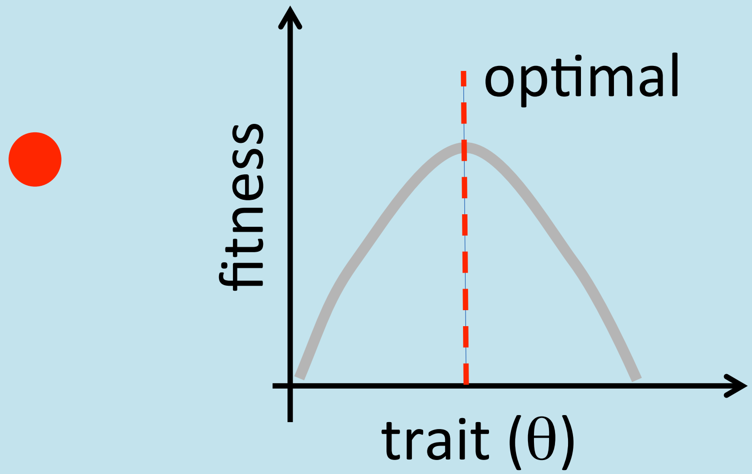
Methods 2: Evolutionary equilibrium

Step 2: find evolutionary equilibrium (ESS)

Given our model, what migration strategy (θ) do we expect?

- I.e. the migration probability that if adopted by a population cannot be invaded by a mutant with a different migration probability

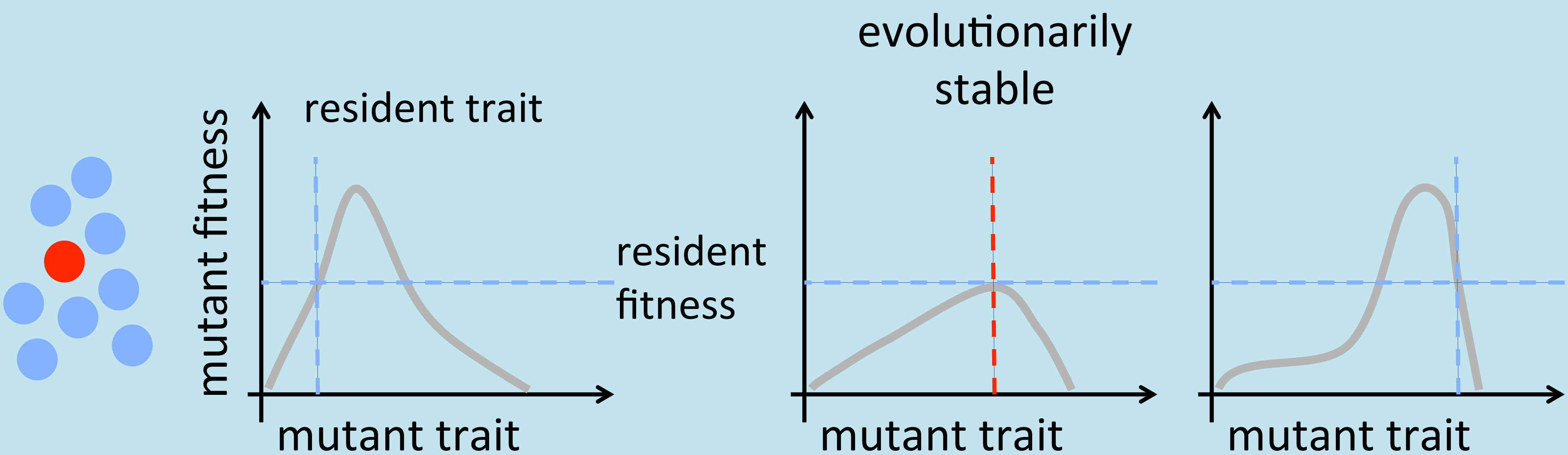
ASIDE: Optimal vs Evolutionarily Stable



Evolutionarily Stable Strategy (ESS):

$$G(\theta_R, \theta_R) > G(\theta_M, \theta_R)$$

$$G(\theta_R, \theta_R) = G(\theta_M, \theta_R) \text{ and } G(\theta_R, \theta_M) > G(\theta_M, \theta_M)$$



Methods 2: Evolutionary equilibrium

Step 2: find evolutionary equilibrium (ESS)

Given our model, what migration strategy (θ) do we expect?

- I.e. the migration probability that if adopted by a population cannot be invaded by a mutant with a different migration probability

- Growth of mutant (θ') in a resident ($\bar{\theta}$) population:

$$\begin{bmatrix} S' \\ \\ I' \end{bmatrix}_{\tau+1} = \begin{bmatrix} \begin{array}{c} A\theta' + B(1-\theta') \\ +\overline{DD}\left[J\theta' + K(1-\theta')\right] \end{array} & \begin{array}{c} C\theta' \\ +\overline{DD}\left[L\theta' + M(1-\theta')\right] \end{array} \\ \\ E\theta' + F(1-\theta') & G\theta' + H(1-\theta') \end{bmatrix} \begin{bmatrix} S' \\ \\ I' \end{bmatrix}_{\tau}$$

Methods 2: Evolutionary equilibrium

Step 2: find evolutionary equilibrium (ESS)

$$\theta_{ESS} = \begin{cases} -y/(2x) & \text{if} \quad 0 < y < -2x \\ \text{either } 0 \text{ or } 1 & \text{if} \quad -2x < y < 0 \\ 1 & \text{if} \quad 0 < y, -2x < y \\ 0 & \text{if} \quad y < 0, y < -2x \end{cases}$$

where

$$x = \Big[C(E-F) - (A-B)(G-H)\Big]\Big[1 + \overline{DD}\phi_S\Big]$$

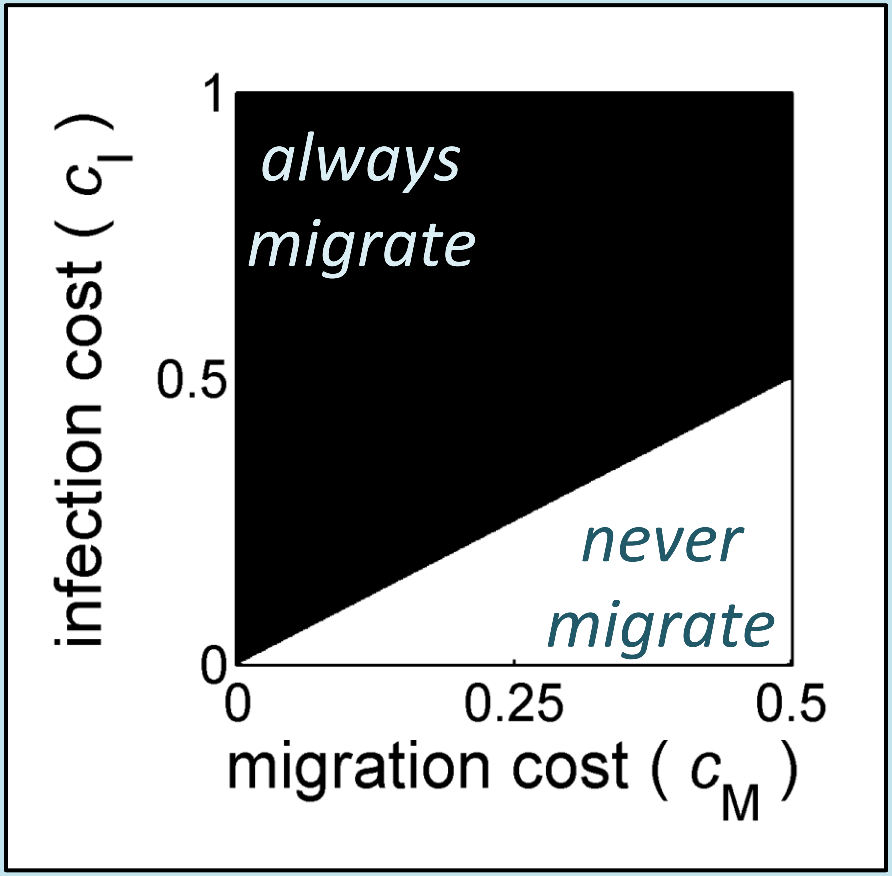
$$y = \Big[(A-B)(1-H) - B(G-H) + CF\Big]\Big[1 + \overline{DD}\phi_S\Big] + (G-H) + \overline{DD}\phi_I(E-F)$$

θ = migration probability

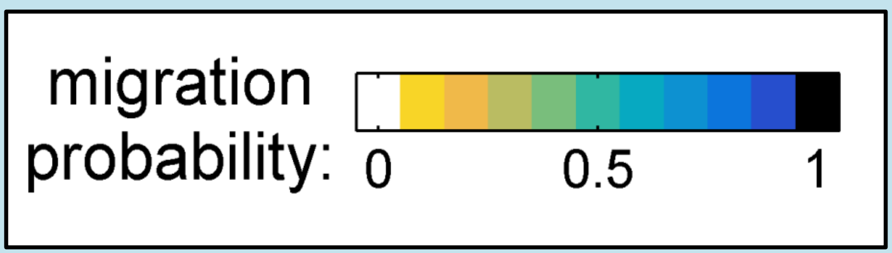
Result 1: choose the less costly/risky option

Fast infection in env. 1
& Fast recovery in env. 2

$$e^{-\beta T}, e^{-\gamma T} \to 0$$



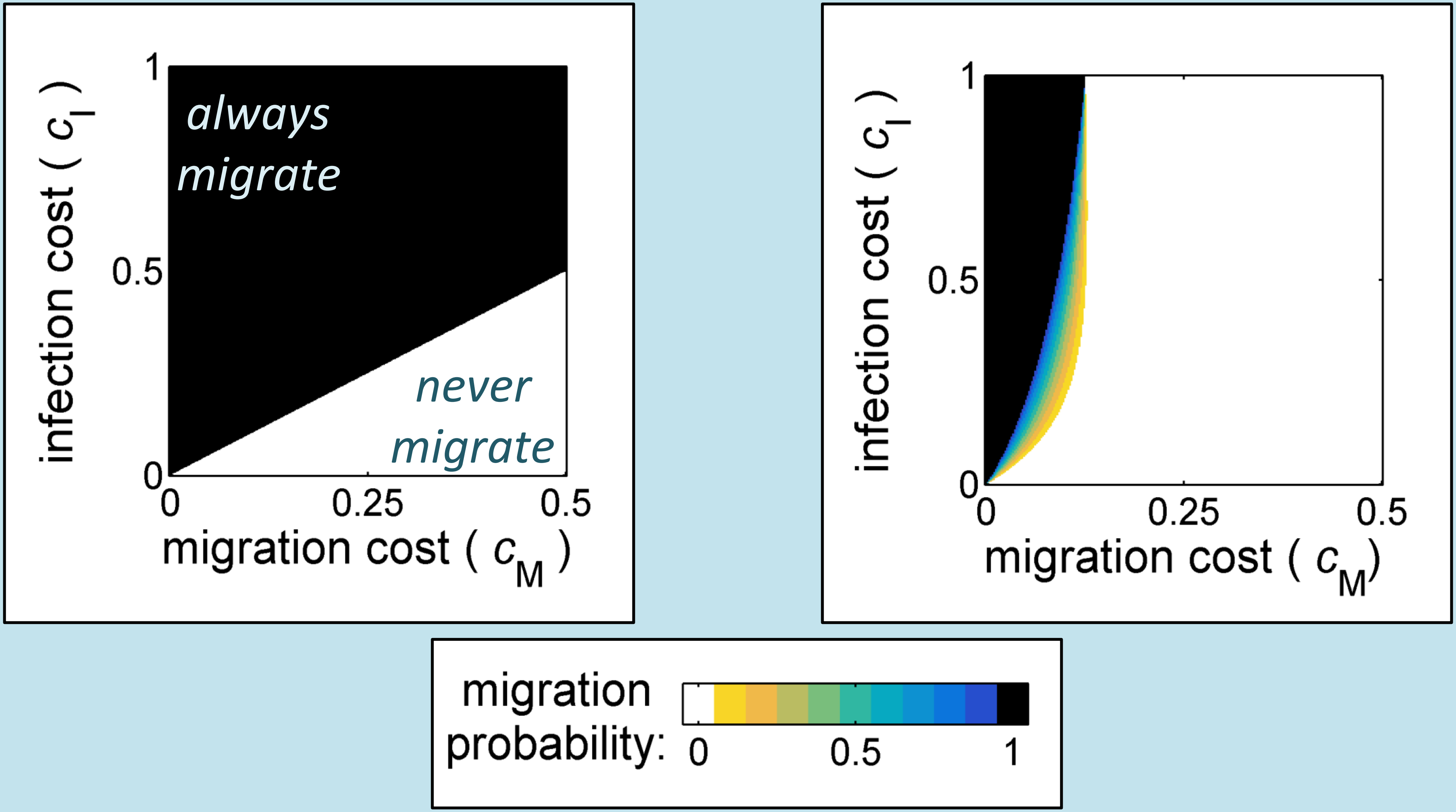
$$\theta_{ESS} = \begin{cases} 0 & \frac{\sigma(1-c_M)\phi}{1-\sigma(1-c_M)} < \frac{\sigma(1-c_I)\phi(1-c_F)}{1-\sigma(1-c_I)} \\ 1 & \frac{\sigma(1-c_M)\phi}{1-\sigma(1-c_M)} > \frac{\sigma(1-c_I)\phi(1-c_F)}{1-\sigma(1-c_I)} \end{cases}$$



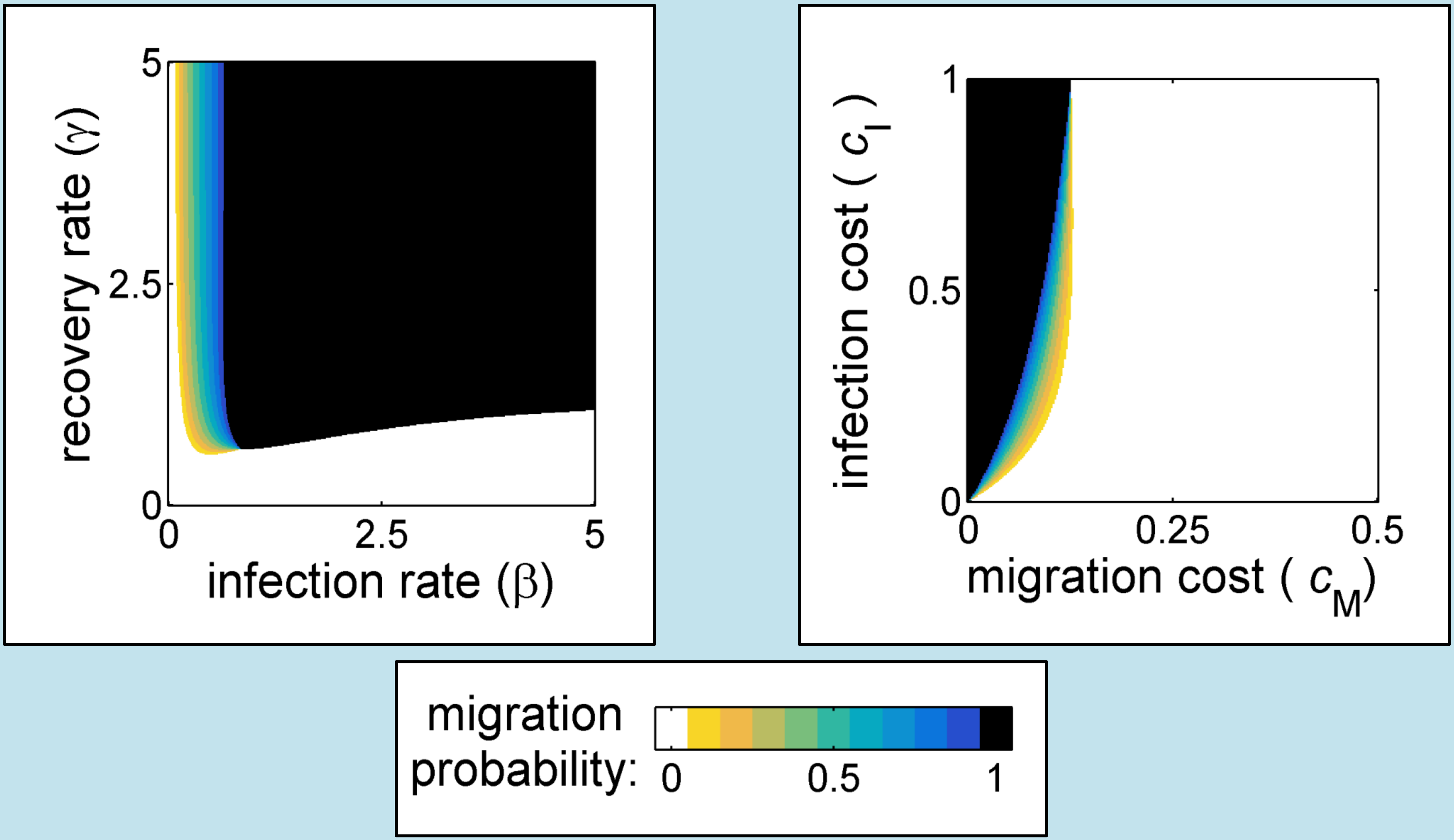
Result 1: choose the less costly/risky option

Fast infection in env. 1 & Fast recovery in env. 2

Slow infection in env. 1 & Slow recovery in env. 2



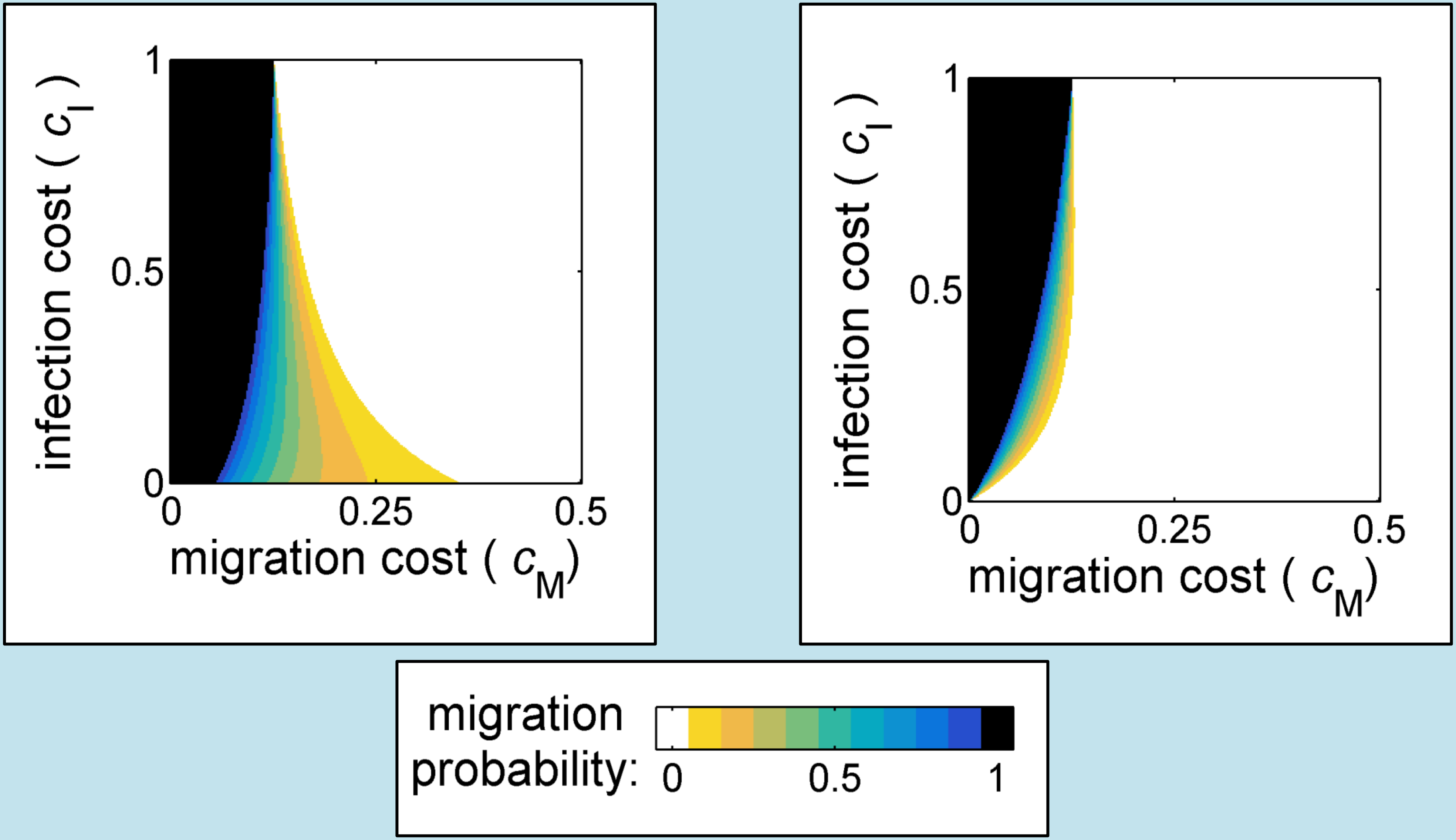
Result 2: play a mixed strategy



Result 3: multiple costs generate surprising results

Infection has both survival and fecundity costs

Infection has only survival cost



Empirical comparisons

In Threespine sticklebacks, *S. solidus* causes:

- 47% mortality (vs. 20%) under food stress
- 15% reduction in body condition

(Pascoe and Mattey 1977; Tierney et al. 1996)

Batrachochytrium dendrobatidis can cause 100% mortality in some amphibians

(Skerratt et al. 2007)

In Mourning doves, Ischnocera lice can cause:

- 2.4% body and 19% feather weight loss
- reduced survival in high infestations

(Clayton et al. 1999)

Where to from here?

Different transmission dynamics

Indirect

$$\frac{dS}{dt} = -\beta S$$

Density-dependent

$$\frac{dS}{dt} = -\beta SI$$

Frequency-dependent

$$\frac{dS}{dt} = -\frac{\beta SI}{S + I}$$

- No longer get closed-form ESS, need to simulate

S = susceptible individuals

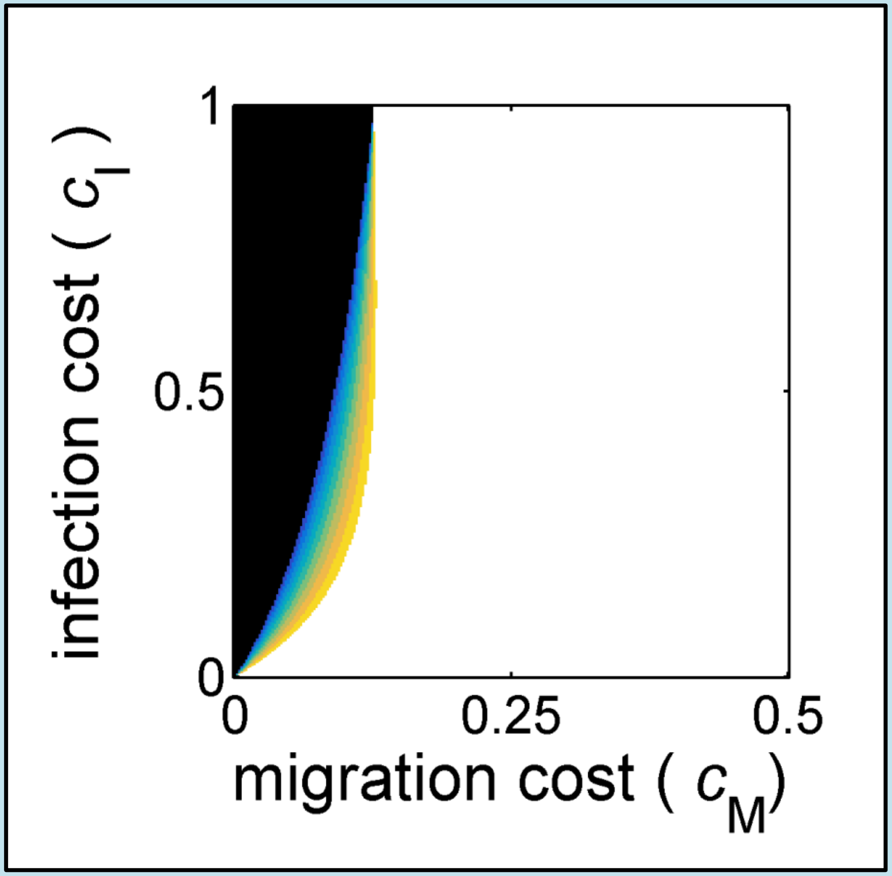
I = infected individuals

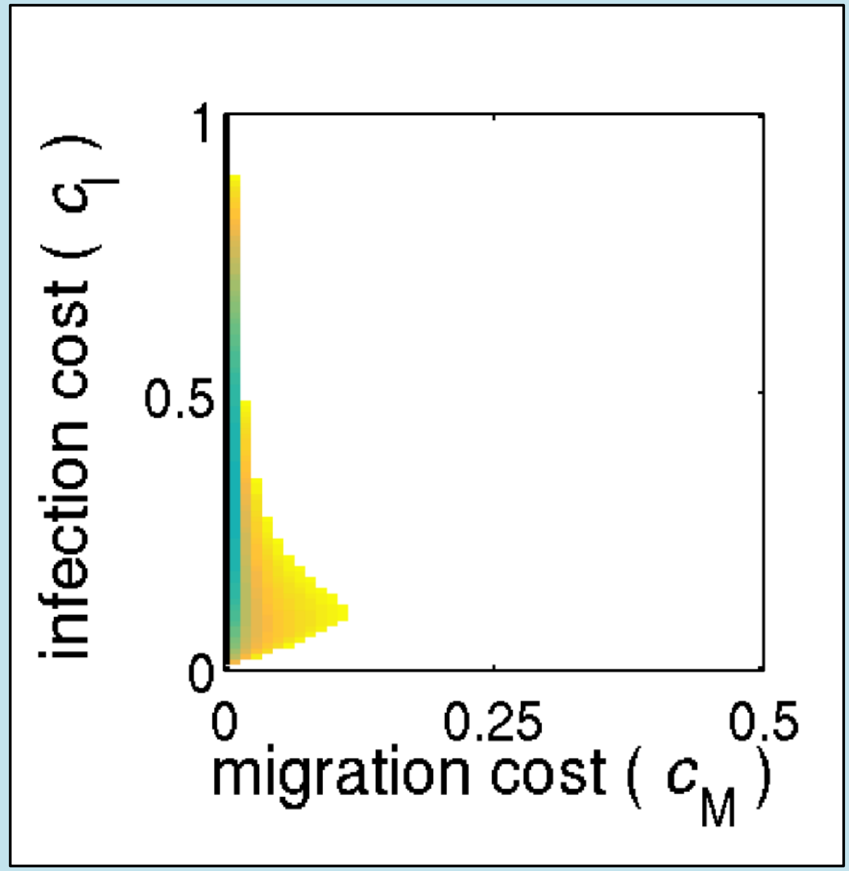
β = rate of infection

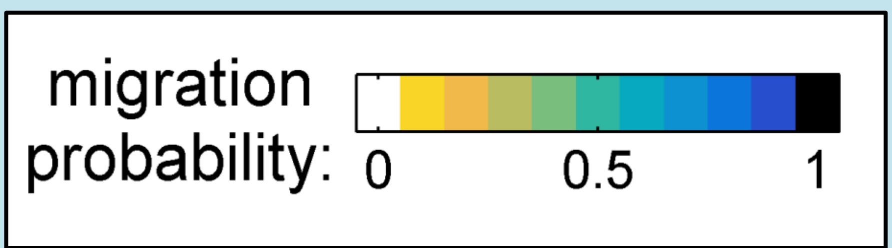
Where to from here?

Different transmission dynamics

$$\frac{dS}{dt} = -\beta S \qquad\qquad \frac{dS}{dt} = -\frac{\beta S I}{S + I}$$





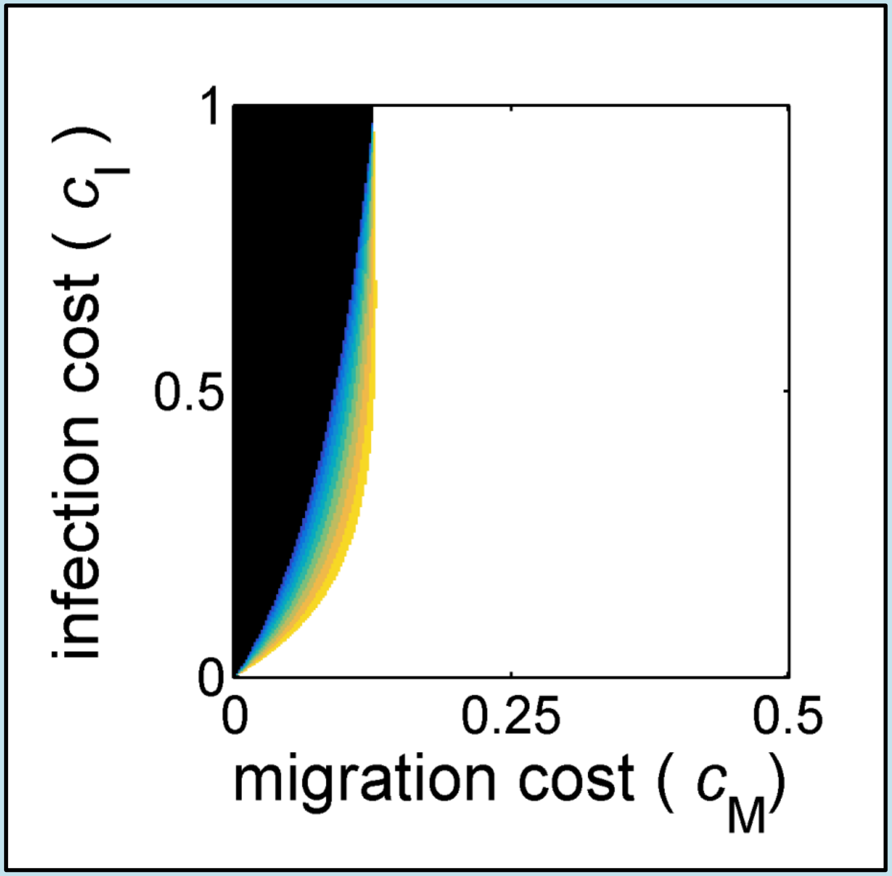


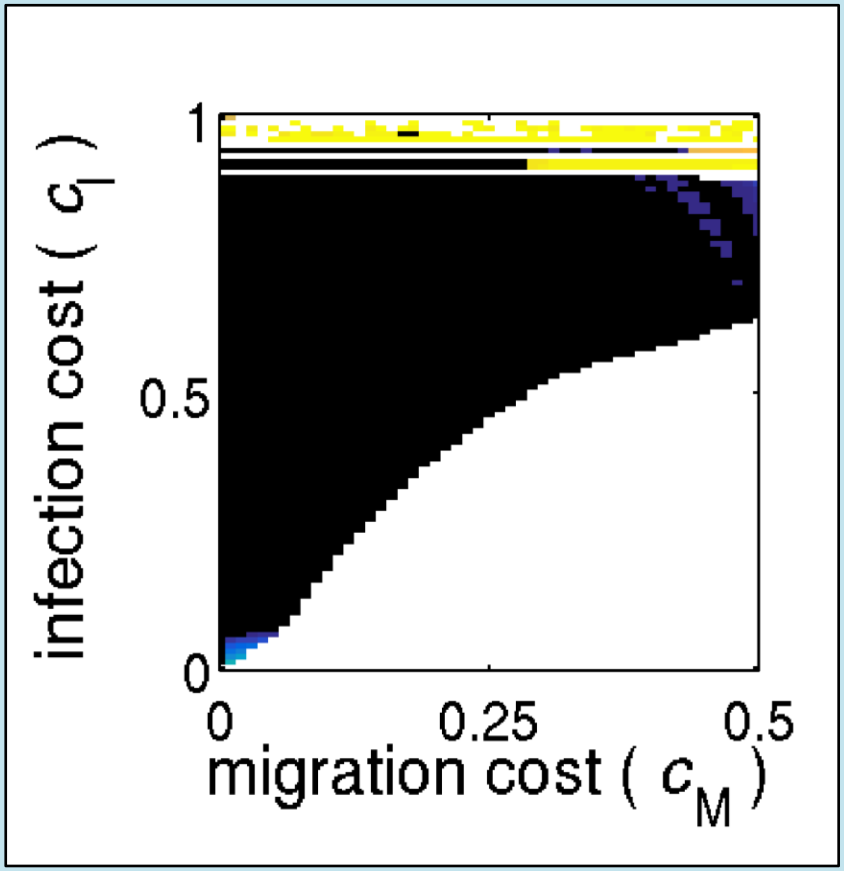
Where to from here?

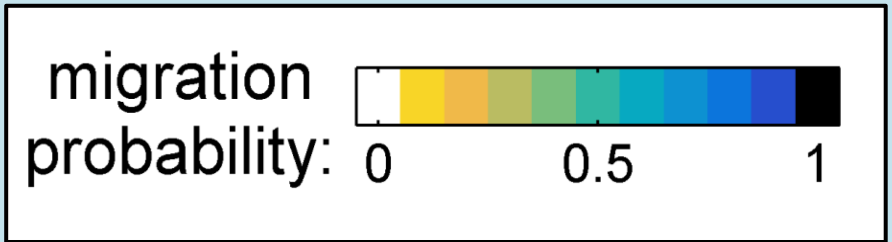
Different transmission dynamics

$$\frac{dS}{dt} = -\beta S$$

$$\frac{dS}{dt} = -\beta SI$$







Where to from here?

Natural Systems in Changing Climates
www.sciencemag.org/special/climate2013

REVIEW

Climate Change and Infectious Diseases: From Evidence to a Predictive Framework

Sonia Altizer,[1]* Richard S. Ostfeld,[2] Pieter T. J. Johnson,[3] Susan Kutz,[4] C. Drew Harvell[5]

Vol. 7: 87–99, 2009
doi: 10.3354/esr00095

ENDANGERED SPECIES RESEARCH
Endang Species Res

Printed May 2009
Published online June 17, 2008

Contribution to the Theme Section 'Incorporating climate change into endangered species conservation'

REVIEW

OPEN ACCESS

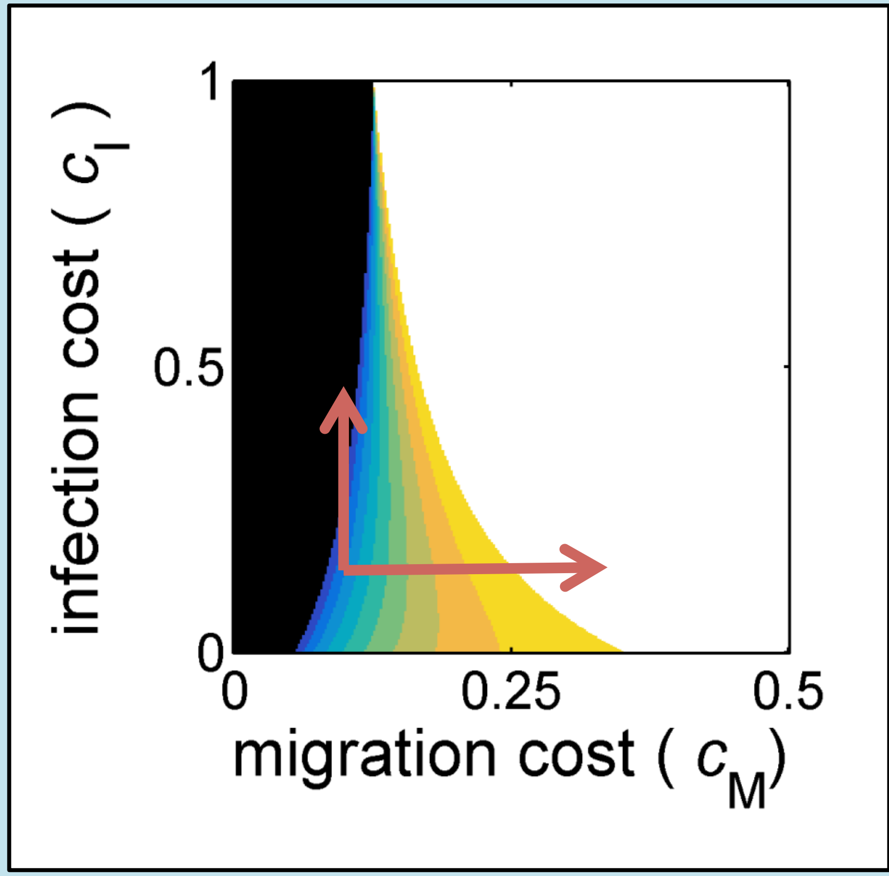
Travelling through a warming world: climate change and migratory species

Robert A. Robinson[1,*], Humphrey Q. P. Crick[1], Jennifer A. Learmonth[2],

Where to from here?

How does climate change affect migration?

- Move across parameter space (e.g. increased mortality)
- Assumes that evolution keeps up with change
- Ignores tradeoffs



What are alternative approaches?

Acknowledgements

Coauthor:

Sandra Binning

Institute of Biology

University of Neuchâtel

Switzerland

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