Habitat quality and the velocity of spatial population expansion

Conference Models in Population Dynamics and Ecology
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Haond Marjorie, Mailleret Ludovic , Morel-Journel Thibaut, Roques Lionel & Vercken Elodie

IUCN World Conservation Congress Hawai'i 2016

Planet at the crossroads

www.iucnworldconservationcongress.org
1-10 September 2016, Hawai'i

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Photo Martha de Jong-Lantink

Endangered (2008)

Photo Martha de Jong-Lantink

Vulnerable (2016)

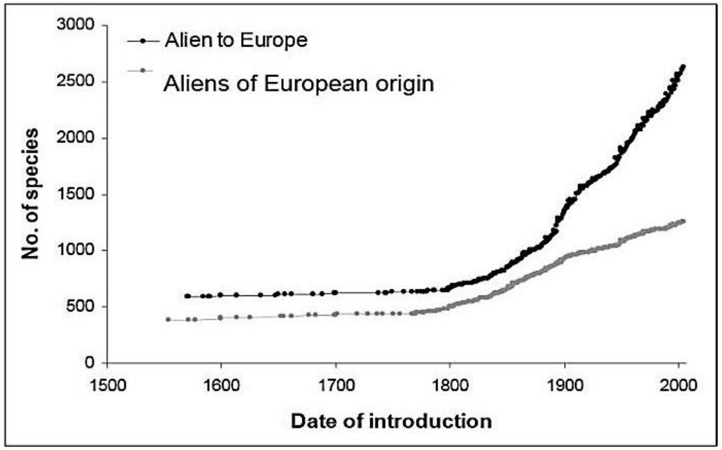
Photo Martha de Jong-Lantink

Vulnerable (2016)

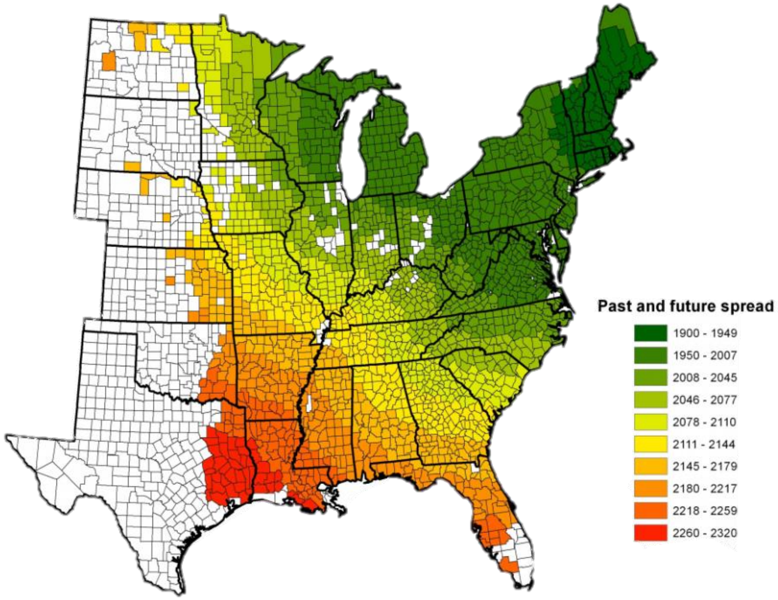
Extinct (2016)

Biological invasion

- 2nd cause of biodiversity loss (IUCN)
- 12 billions Euros per year in Europe (Kettunen et al., 2009)



Source: DAISIE project



Past and predicted future spread of the gypsy moth
Epanchin-Niell &Liebhold 2015

Habitat quality and the velocity of spatial population expansion

- How the quality of the landscape can affect the spreading velocity?

  Proxy of habitat quality = Carrying capacity

Carrying capacity (K) : Maximum number of individuals an area can support

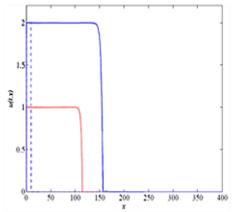
Studied Mechanisms

(1) **Classic model (Fisher-KPP)**

(2) **Positive density dependent dispersal (DD dispersal)**

(3) **Positive density dependent growth** (strong **Allee effect**)

-> Reaction-Diffusion Models



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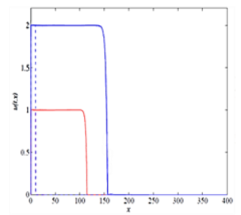
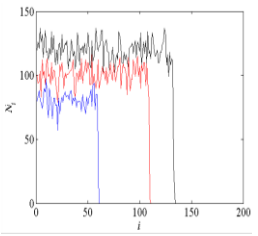


(4) **Stochasticity** {**Fisher-KPP**, **DD dispersal**, **Allee effect**}

-> Individual Based Model



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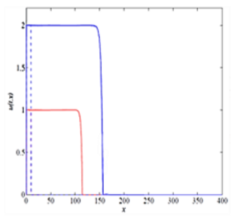

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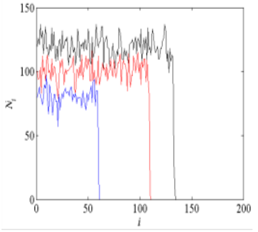


Laboratory experiment **(DD dispersal)**

1. Reaction-diffusion models

(1) Classic model (Fisher-KPP)

Equation :

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2} + ru(1-u)$$

Velocity Formulae :

$$v = 2\sqrt{rD}$$

Fisher 1937 ; Kolmogorov et al.1937, Skellam 1951

1. Reaction-diffusion models

(1) Classic model (Fisher-KPP)

Equation :

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2} + ru\left(1 - \frac{u}{K}\right)$$

Velocity Formulae :

$$v = 2\sqrt{rD}$$

=> Constant velocity whatever K

Fisher 1937 ; Kolmogorov et al.1937, Skellam 1951

1. Reaction-diffusion models

(2) Positive density dependent dispersal **(DD dispersal)**

Equation :

$$\frac{\partial u}{\partial t} = \frac{\partial^2 (D(u)u)}{\partial x^2} + ru(1-u)$$

$$D(u) = u^a$$

with $a > 0$

Newman 1980; Langlais & Phillips 1985; Murray 2002

1. Reaction-diffusion models

(2) Positive density dependent dispersal **(DD dispersal)**

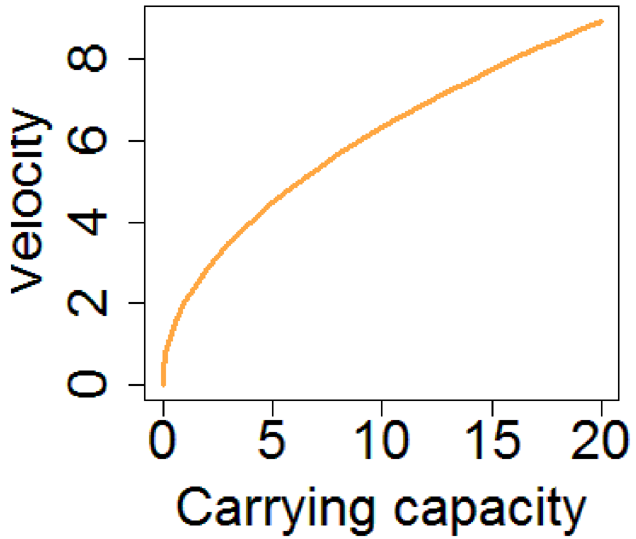
Equation :

$$\frac{\partial u}{\partial t} = \frac{\partial^2 (D(u)u)}{\partial x^2} + ru\left(1 - \frac{u}{K}\right)$$

Velocity Formulae :

$$v = \sqrt{rDK}$$

=> Increasing velocity with K



1. Reaction-diffusion models

(3) Positive density dependent growth (Allee effect)

Equation :

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2} + ru(1-u)(u-\rho)$$

ρ = Allee threshold

Aronson and Weinberger 1975; Hadeler and Rothe 1975; Fife and McLeod 1977; Lewis & Kareiva 1993; Turchin 1998

1. Reaction-diffusion models

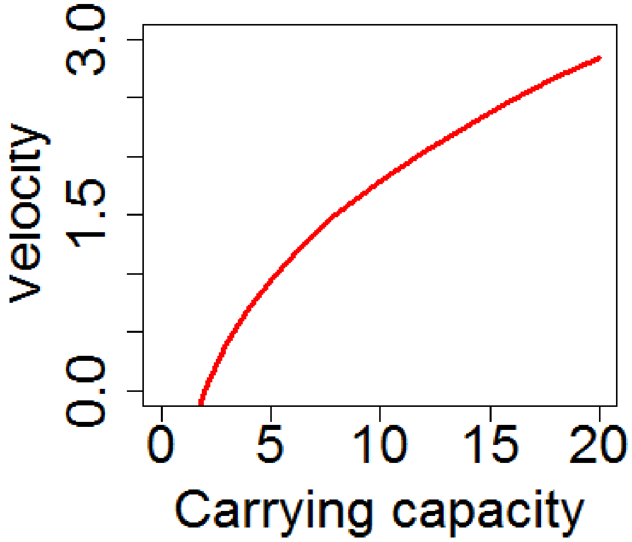
(3) Positive density dependent growth (Allee effect)

Equation :

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2} + ru\left(1 - \frac{u}{K}\right)(u-\rho)$$

Velocity Formulae :

$$v = \sqrt{\frac{2rD}{K}\left(\frac{K}{2} - \rho\right)}$$

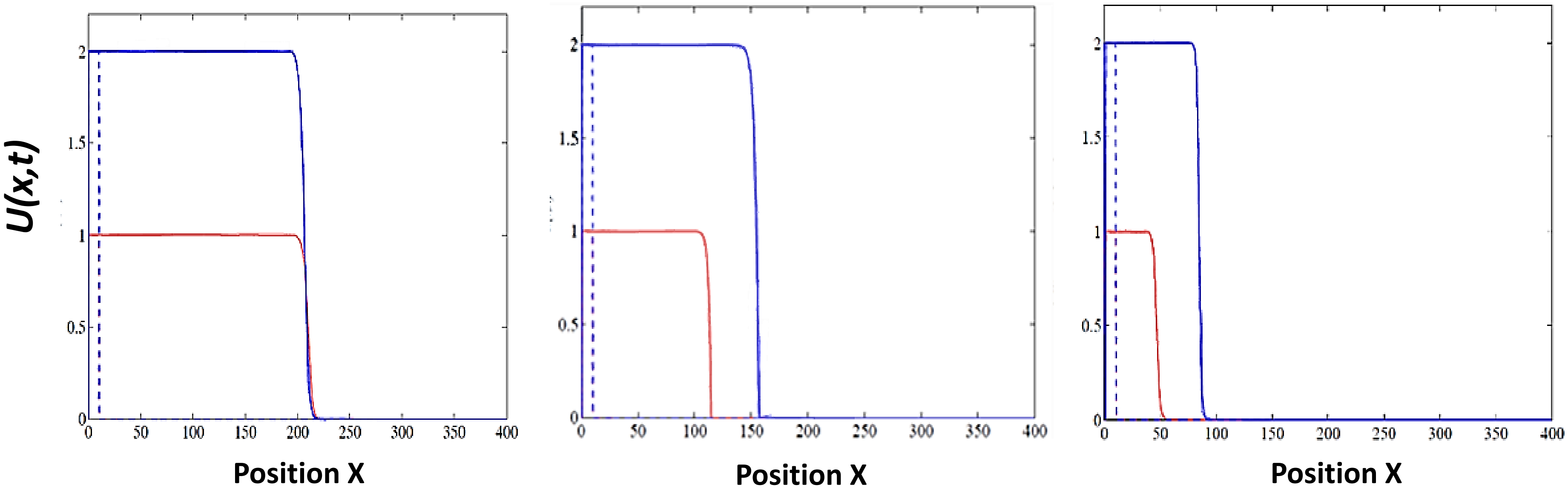


=> Increasing velocity

1. Reaction-diffusion models

- Travelling waves for
  - K=1 (red)
  - K=2 (blue)

T = 100

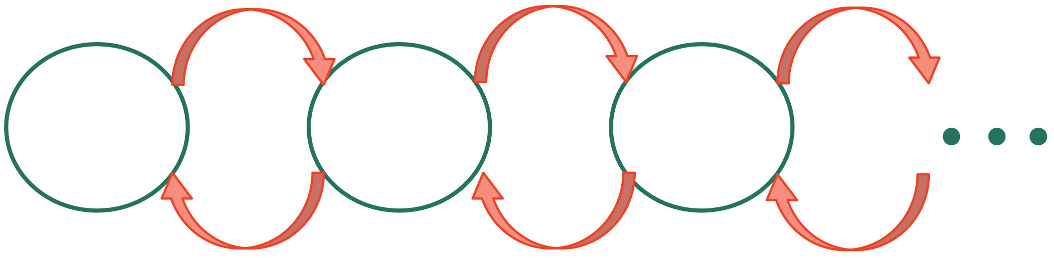


Fisher-KPP (1)

DD dispersal (2)

Allee Effet (3)

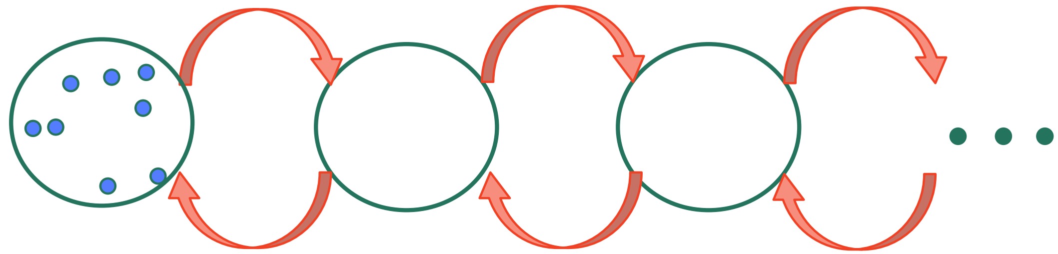
2.Individual based models



- Discrete space: stepping stone landscape

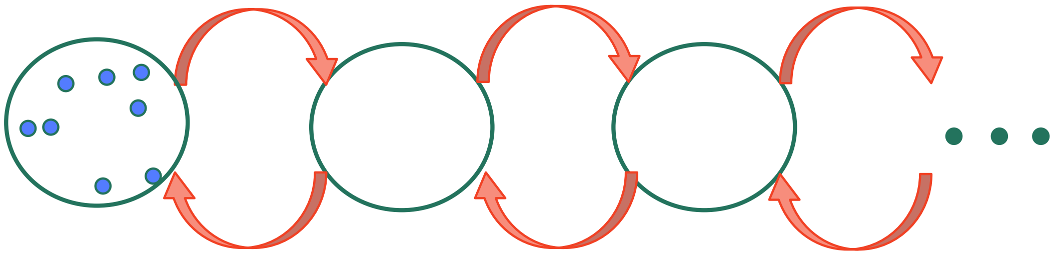
2.Individual based models

Initial number of individuals = *K*



- Discrete space: stepping stone landscape
- Discrete state: population size in number of individuals

2.Individual based models



- Discrete space: stepping stone landscape
- Discrete state: population size in number of individuals
- Discrete time: non overlapping generations

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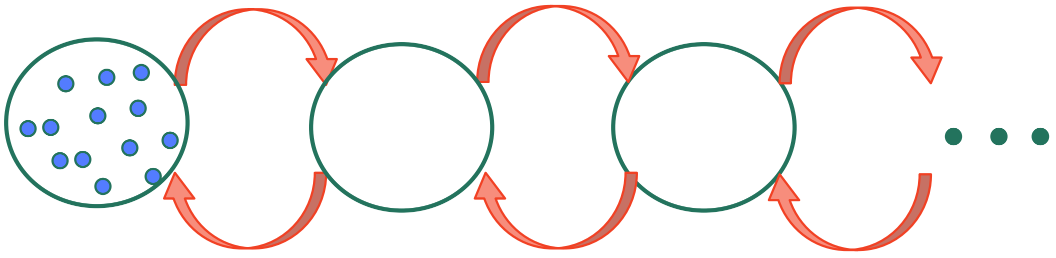

- Discrete space: stepping stone landscape
- Discrete state: population size in number of individuals
- Discrete time: non overlapping generations

Model steps:

- Reproduction (Poisson process)

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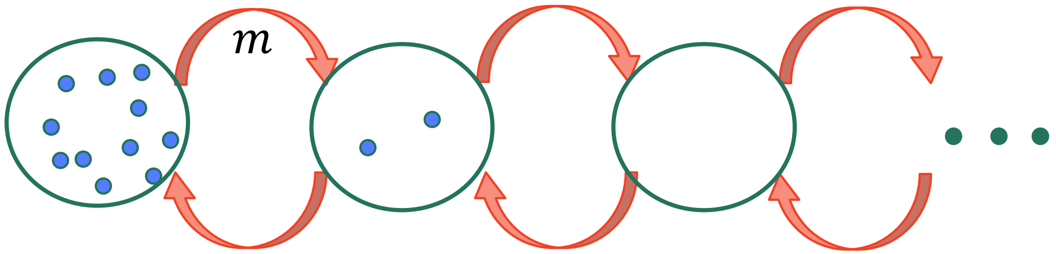
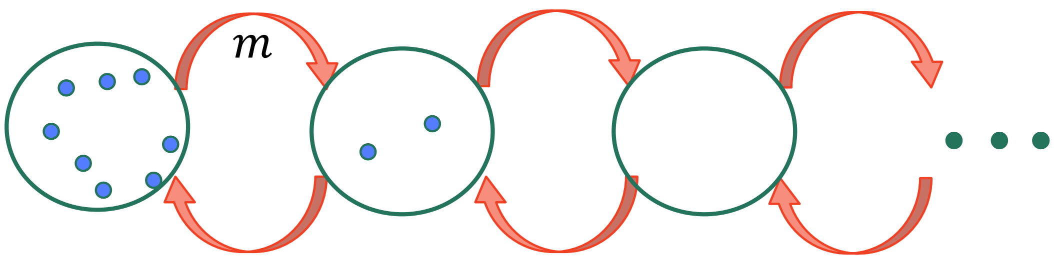


- Discrete space: stepping stone landscape
- Discrete state: population size in number of individuals
- Discrete time: non overlapping generations

Model steps:

- Reproduction (Poisson process)
- Dispersal (m)

2.Individual based models



- Discrete space: stepping stone landscape
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- Dispersal (m)
- Competition (stochastic cut off at K)

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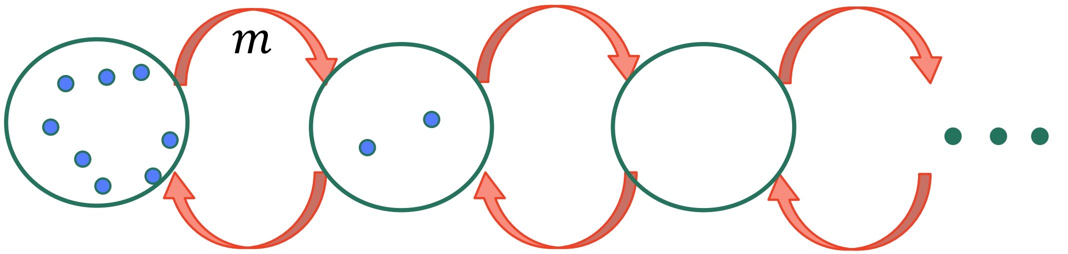

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- Discrete state: population size in number of individuals
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Model steps:

- Reproduction (Poisson process)
- Dispersal (m)
- Competition (stochastic cut off at K)

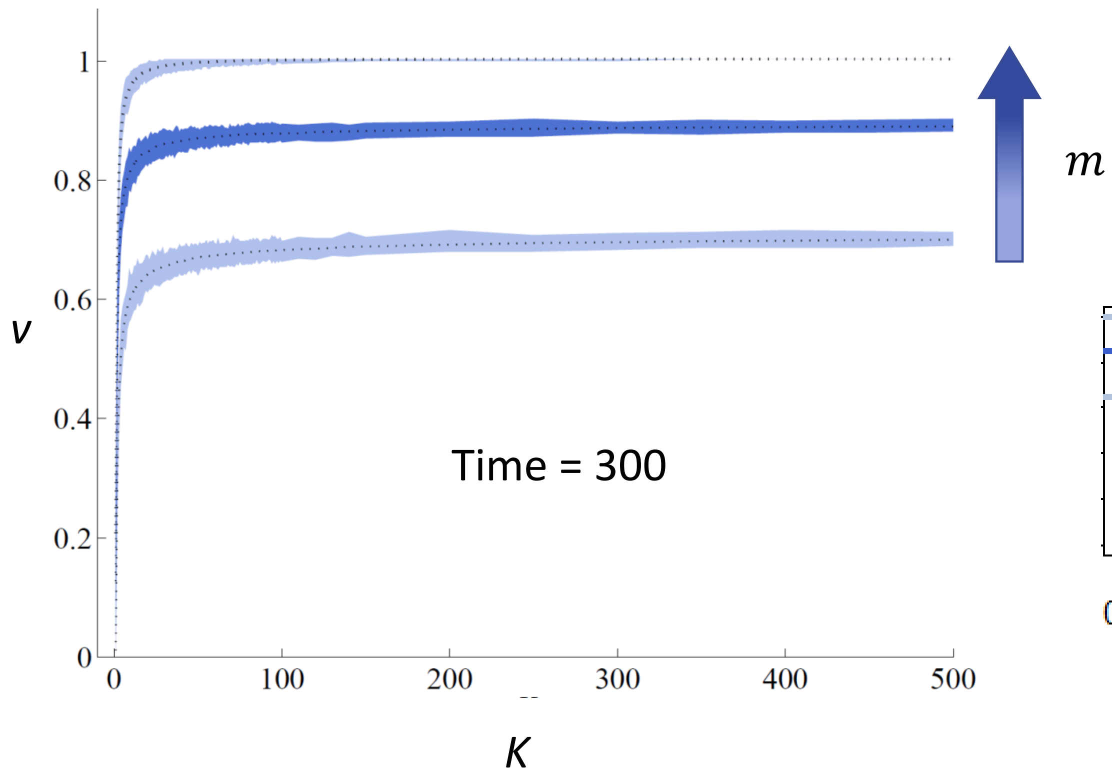
3 scenarios: **Fisher-KPP**, **DD dispersal**, **Allee effect**

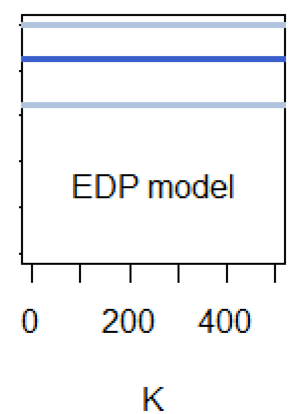
2.Individual based models

v for K ϵ [1:500], 200 replicated simulations. 99% conf. int.

Probability to disperse: $m = \{0.25, 0.5, 0.75\}$

(1)
Fisher-KPP





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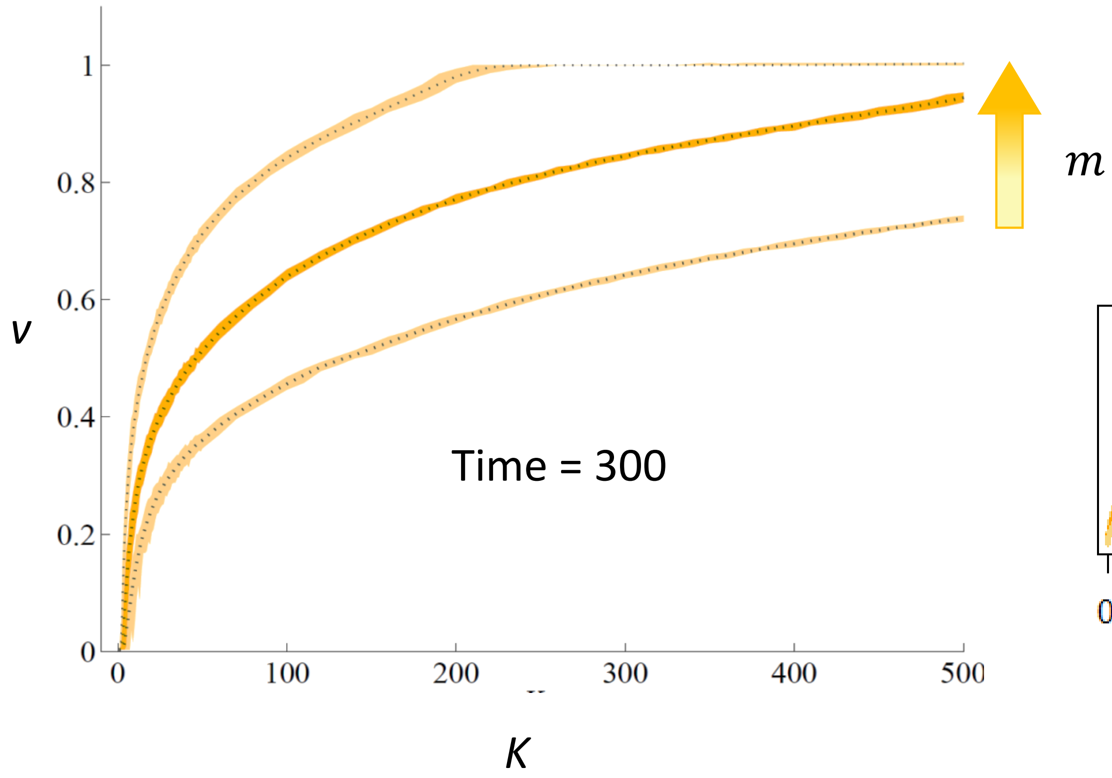
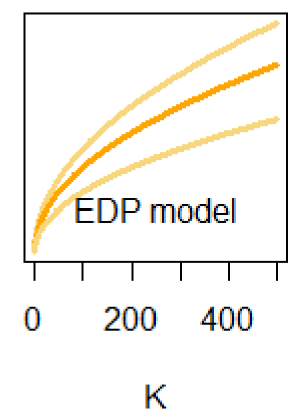
(2)
DD dispersal





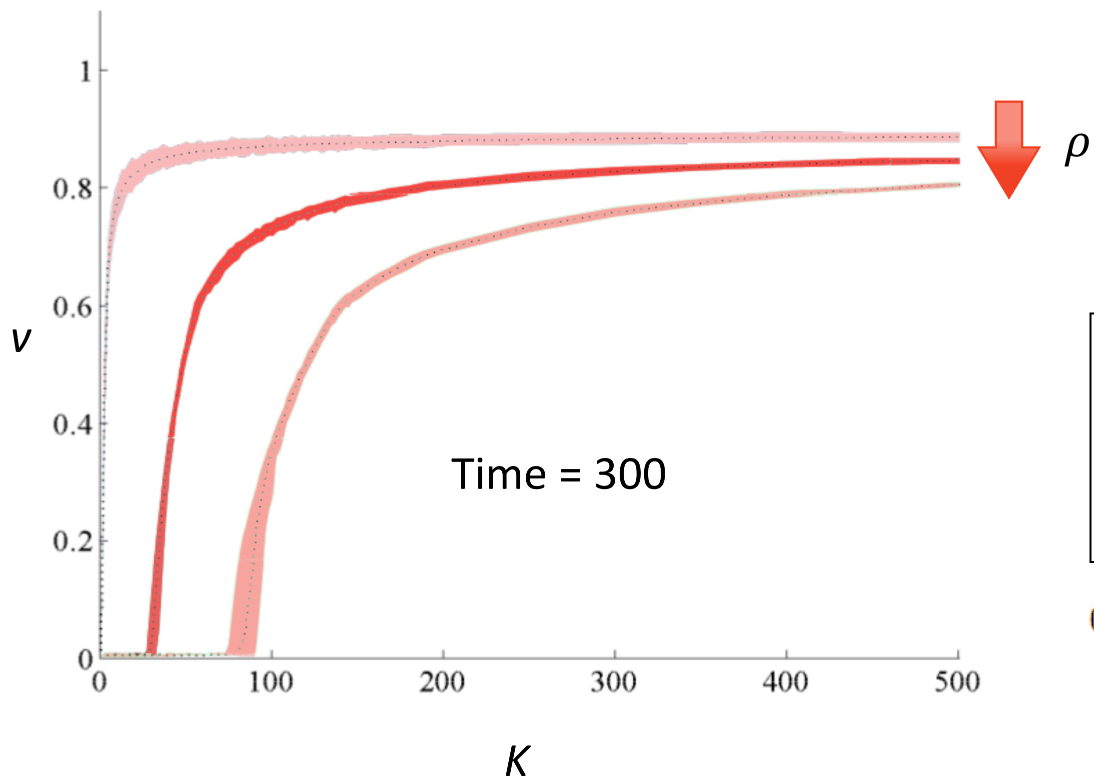
2.Individual based models

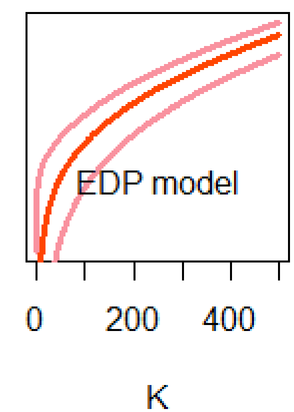
v for K ϵ [1:500], 200 replicated simulations. 99% conf. int.

Probability to disperse : $m = 0.5$
Allee threshold: $\rho = \{1, 20, 50\}$

(3)

Allee effects





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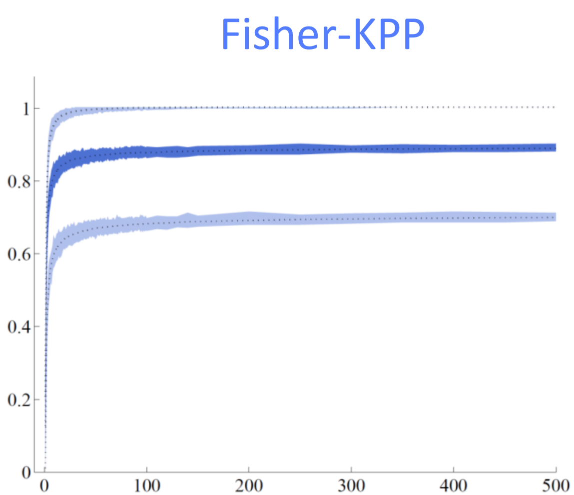
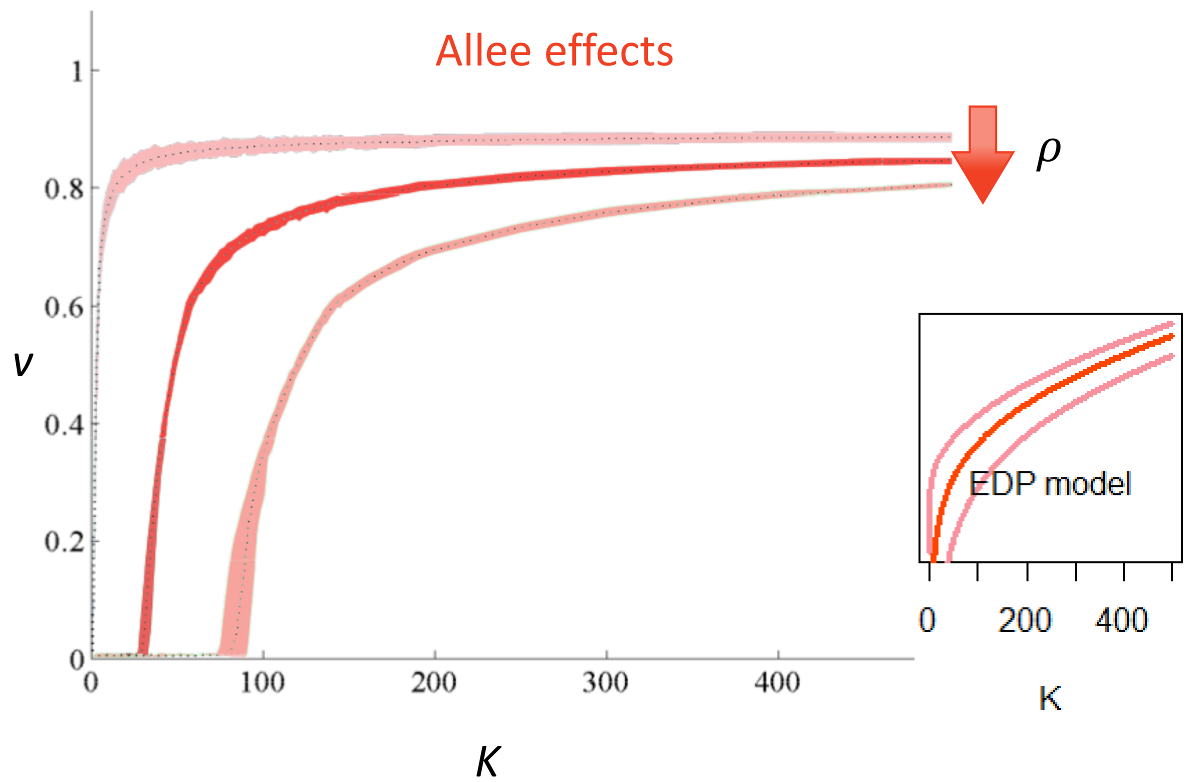
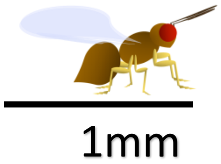


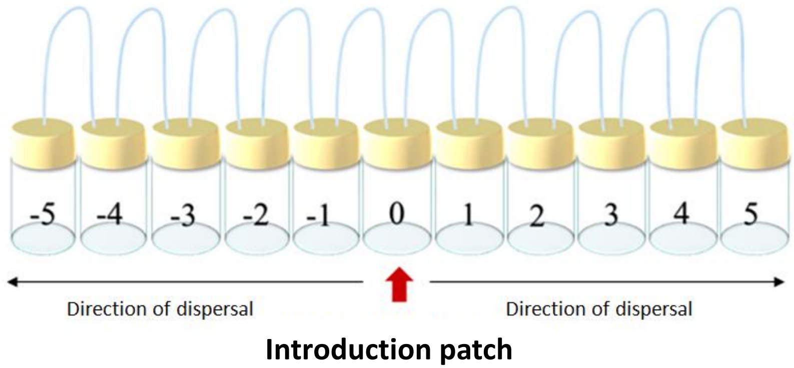


3.Microcosm experiments

- Biological model: minute wasp, *Trichogramma chilonis*
  - small size, short generation time
  - tendency to positive DD dispersal (scenario 3)



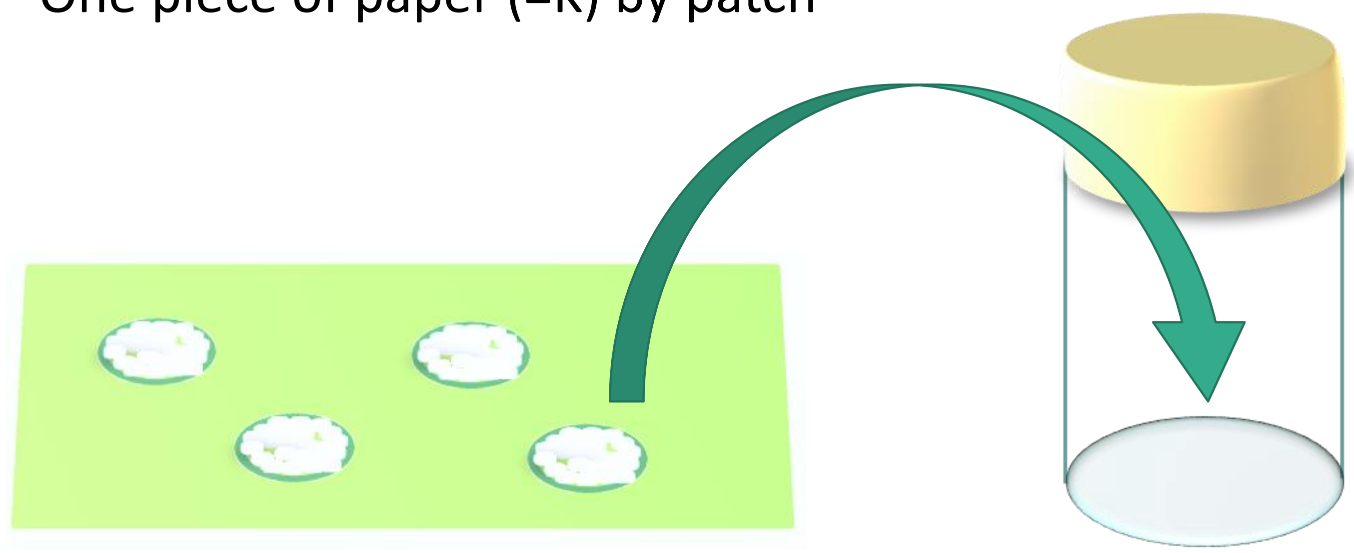
- Environment: Linear landscape in stepping stone



Protocol: Morel Journel et al., 2016, Oikos

3.Microcosm experiments

- Biological model:
  - Parasitoid
  - Artificial host Ephestia kuehniella, Mediterranean flour moth
  - One piece of paper (=K) by patch

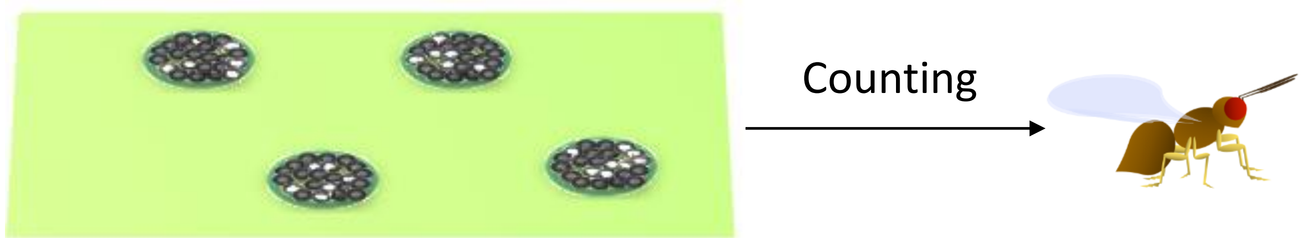


3.Microcosm experiments

- Biological model:
  - Parasitoid
  - Artificial host Ephestia kuehniella, Mediterranean flour moth
  - One piece of paper (=K) by patch
  - Parasitized eggs turn dark

3.Microcosm experiments

- Biological model: *Trichogramma chilonis*



- 2 modalities of carrying capacity:

  Small: ~ 150-200 host eggs x20 Replicats

  Large: ~400-450 host eggs x20 Replicats

- 10 generations = 99 days

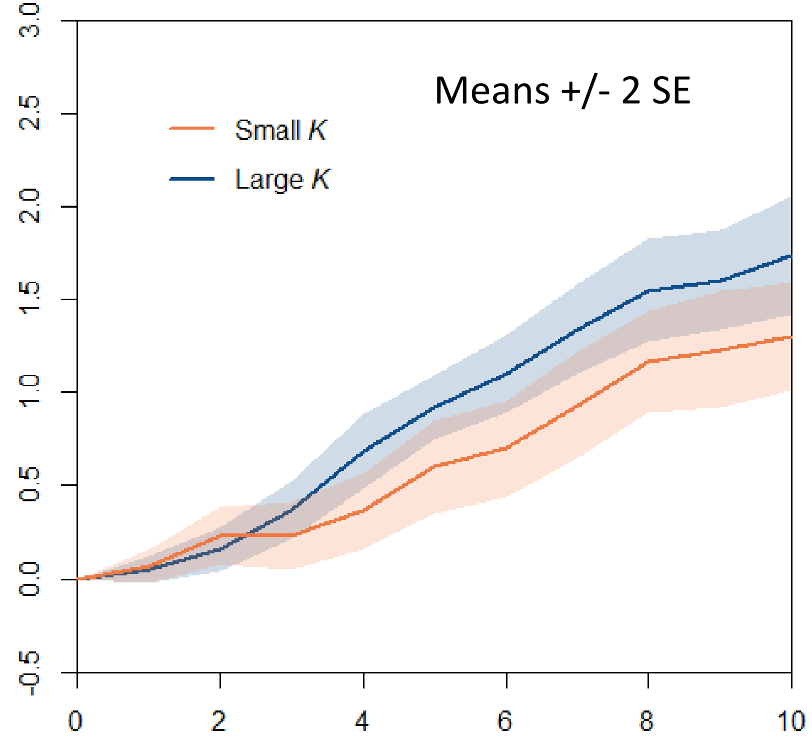
3.Microcosm experiments

Statistical analysis

General Linear Mixed Model :

Is there any difference in the mean number of colonized patches between the two modalities of carrying capacity?

Mean number of colonized patches



Generation

3.Microcosm experiments

Statistical analysis

General Linear Mixed Model :

Is there any difference in the mean number of colonized patches between the two modalities of carrying capacity?

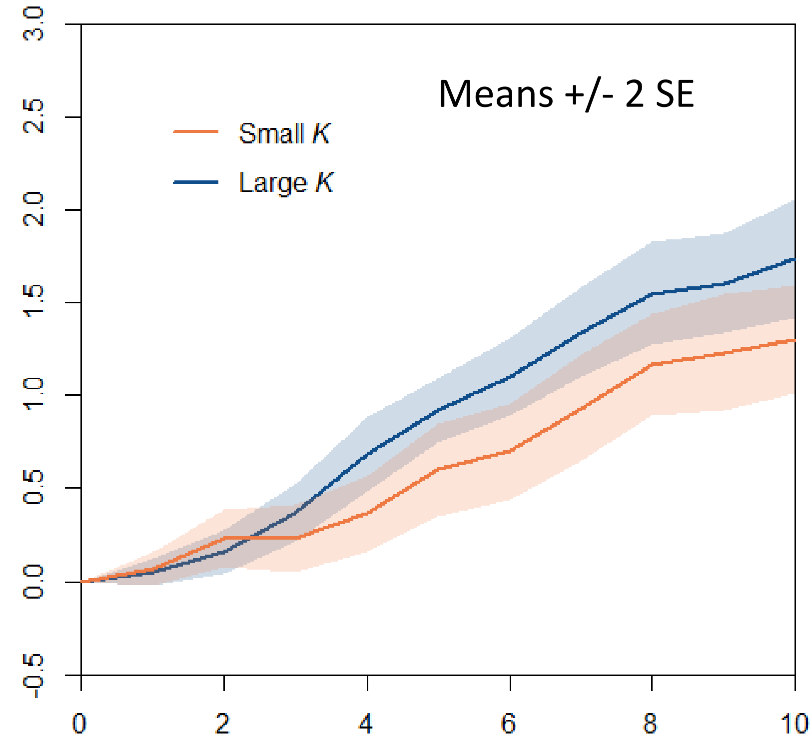
Z-value = 2.008

p_value = 0.0447

Small K: + 0.13 patch per generation

Large K: + 0.17 patch per generation

Mean number of colonized patches



Generation

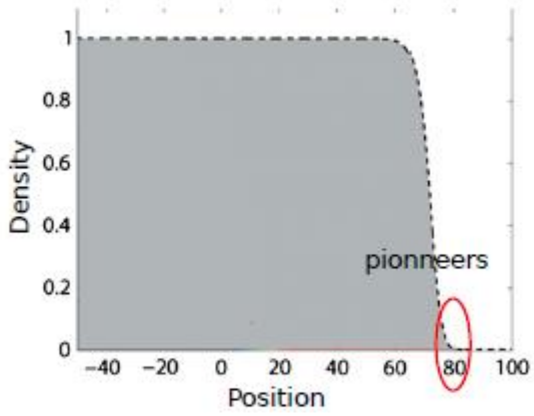
What's to keep in mind

- carrying capacity impact on spreading speed was overlooked
- Different mechanisms may lead populations to have a spreading speed positively influenced by habitat quality:
    - positive density dependent migration
    - positive density dependent growth (Allee Effect)
    - stochasticity (small populations)
- Marginal influence of *K* decreases with *K* (may vanish for large *K*)
- Large scale may hide *K/v* relation
- Relationship *K/v* -> indicator of pushed waves?

What's to keep in mind

Relationship K/v -> indicator of pulled/pushed nature
of the expanding front ?

- Propagation speed depends on the growth function for small population densities in the edge -> Fisher-KPP (pulled wave)

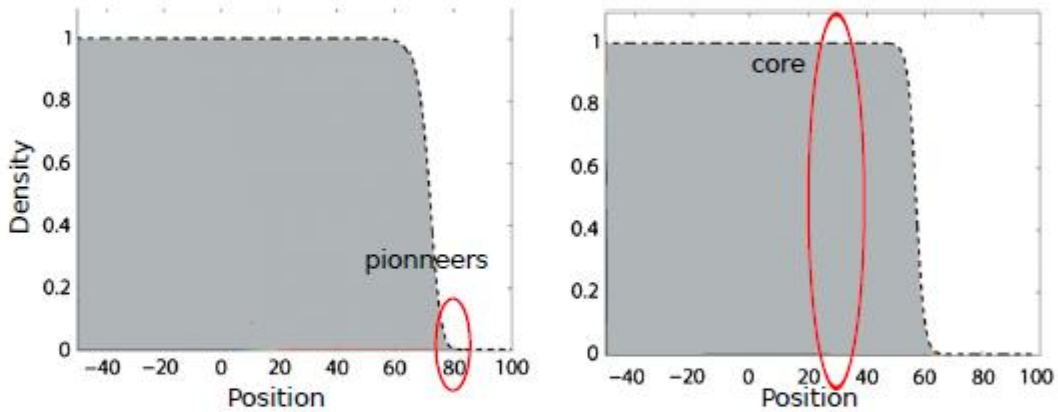


What's to keep in mind

Relationship K/v -> indicator of pulled/pushed nature
of the expanding front ?

- Propagation speed depends on the growth function for small population densities in the edge -> Fisher-KPP (pulled wave)

- Propagation speed depends on the growth function of the core population -> Allee effect (Pushed wave)

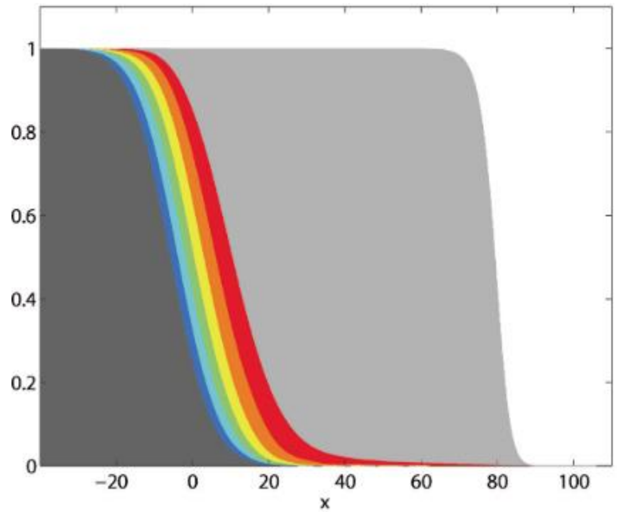


What's to keep in mind

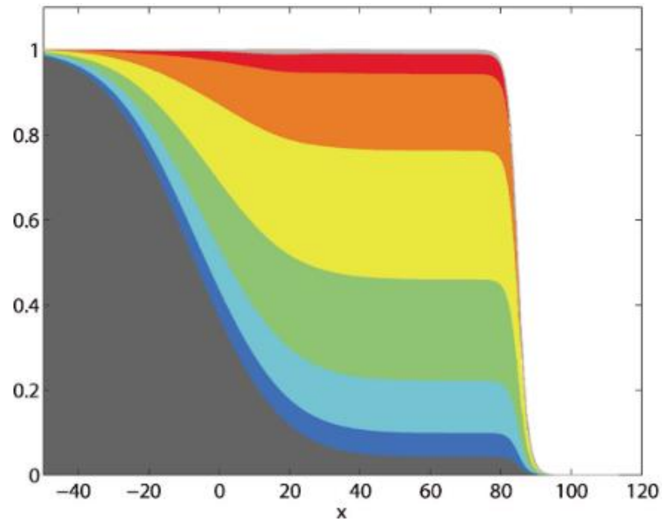
Relationship K/v -> indicator of pulled/pushed nature of the expanding front ?

Roques & al. 2012: Allee effect promotes diversity in traveling waves of colonization

Pulled



Pushed



Thank you for listening!

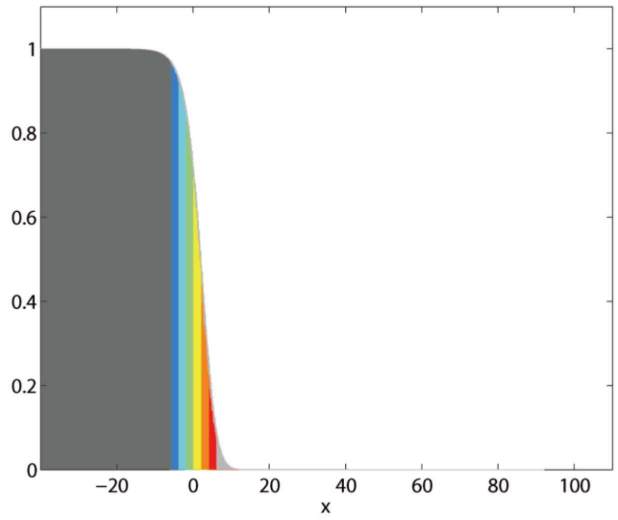
Trichogramma having fun with waves

What’s to keep in mind

A link between *K*-speed and the
pulled/pushed nature of the expanding front ?

Roques & al. 2012: Allee effect promotes diversity in traveling waves of colonization

Pulled



Pushed