

Life is not a long quiet river: consequences of migration pulsedness for adaptation and divergence

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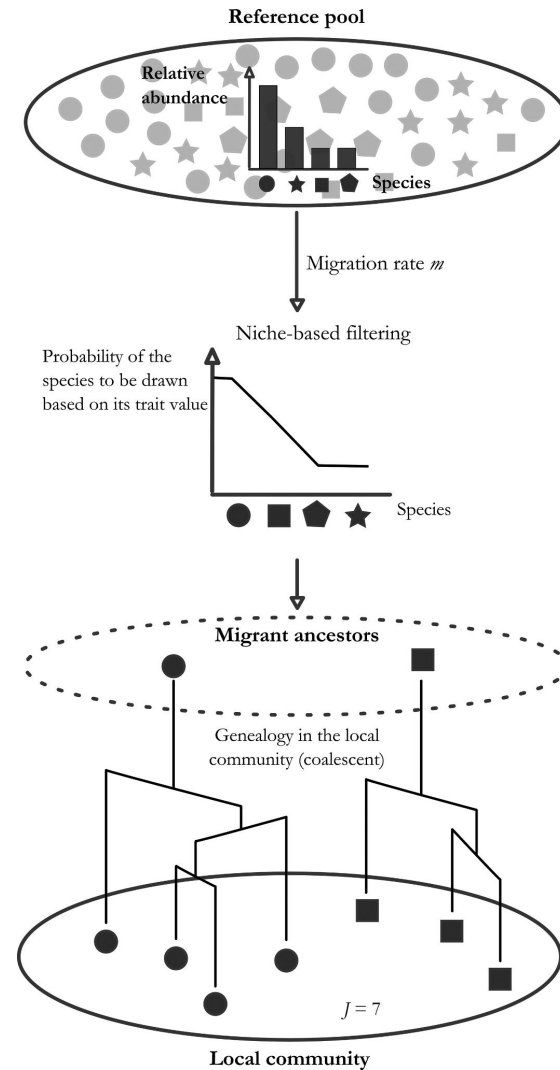
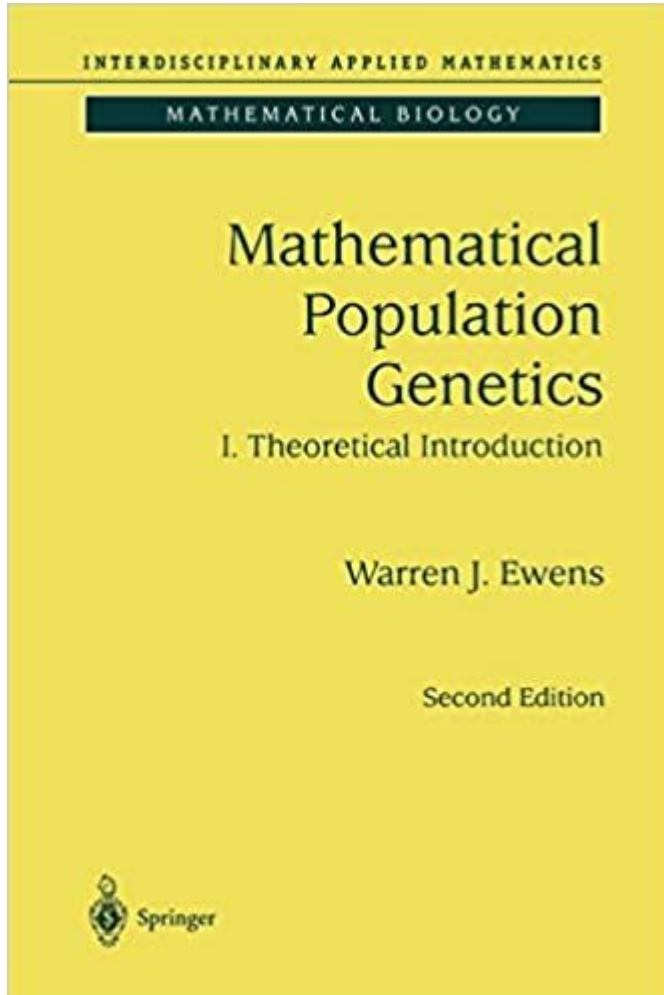
Defended one year ago
Now working at Cereg

Aubree et al. (2022)

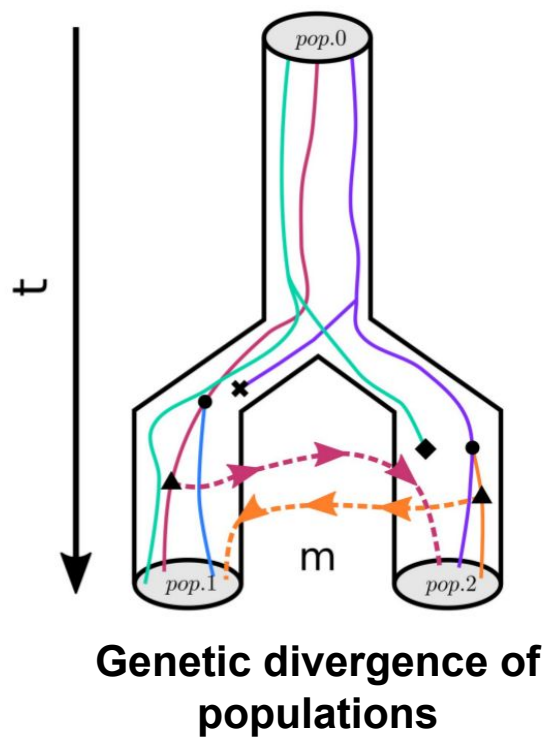
<https://doi.org/10.1101/2021.06.24.449762>

Evolution (in press)

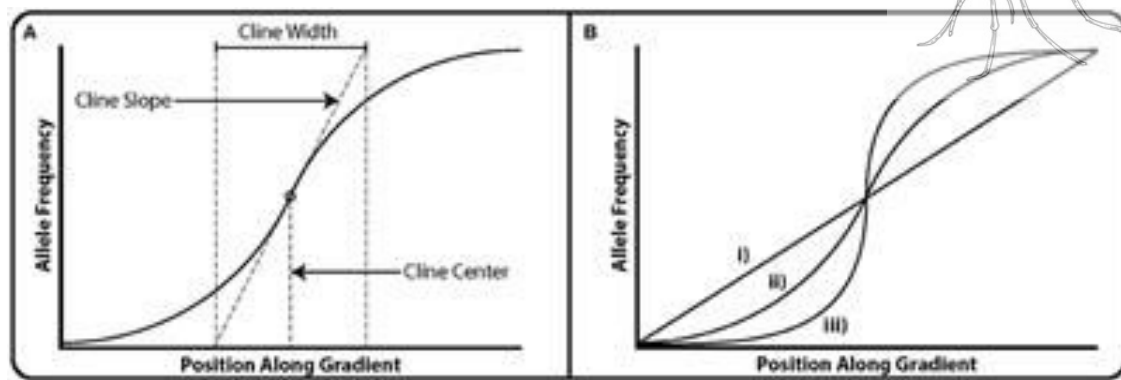
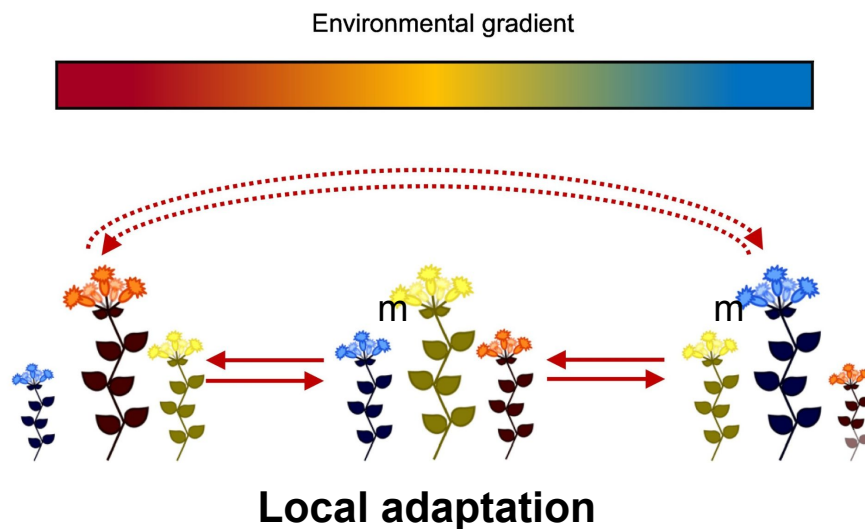
Migration of individuals/genes between populations: a major evolutionary force (geneflow)



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(A)



Clines / genetic introgression

Most theory assumes a steady (constant) rate of migration...

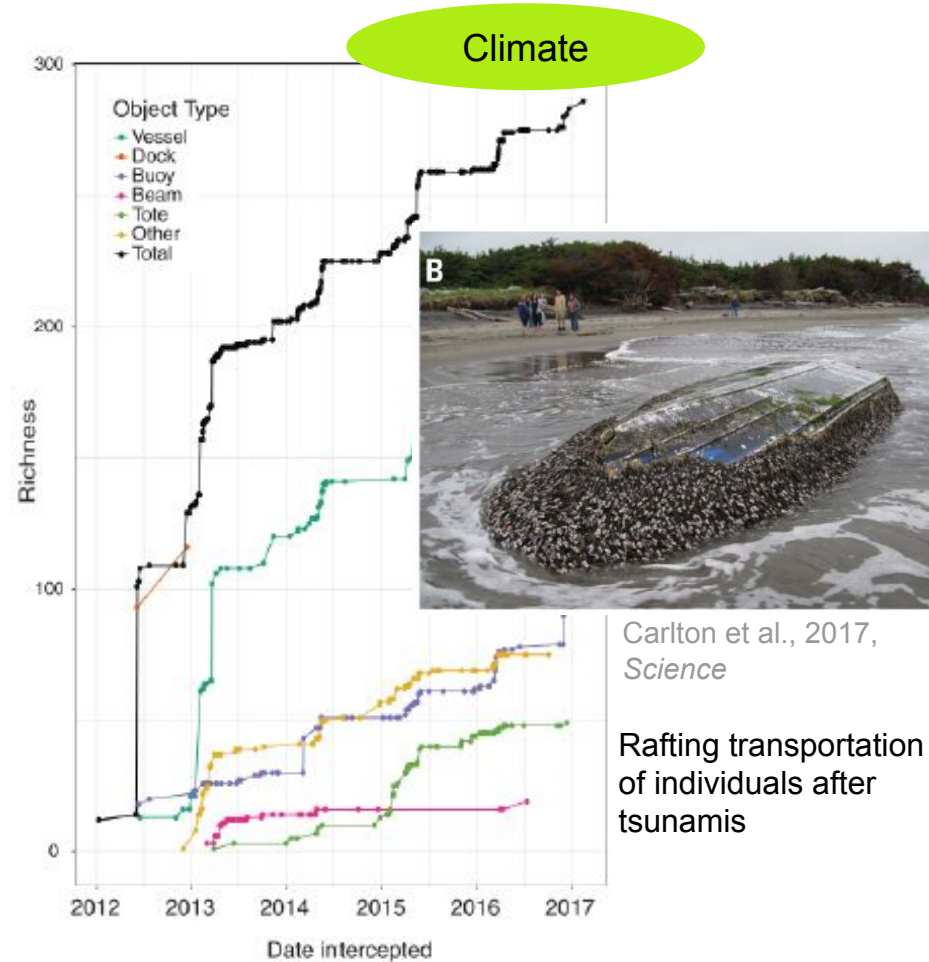


Most theory assumes a steady (constant) rate of migration...



...but in reality the flow of individuals would often be more agitated.

Migration: not a steady gene flow

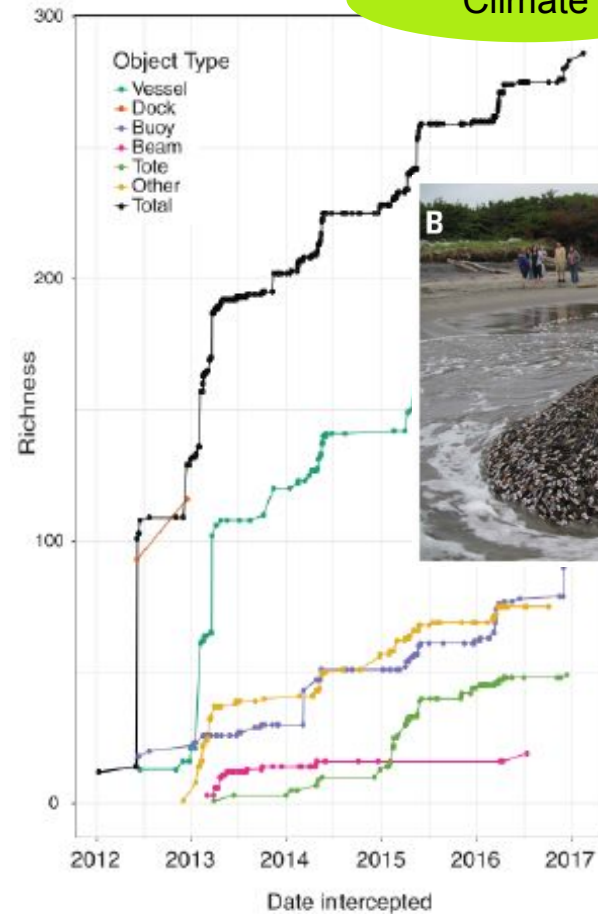


Migration: not a steady gene flow

Behavior



Ballooning dispersal
© Barnett



Carlton et al., 2017,
Science

Rafting transportation
of individuals after
tsunamis

Migration: not a steady gene flow

Behavior



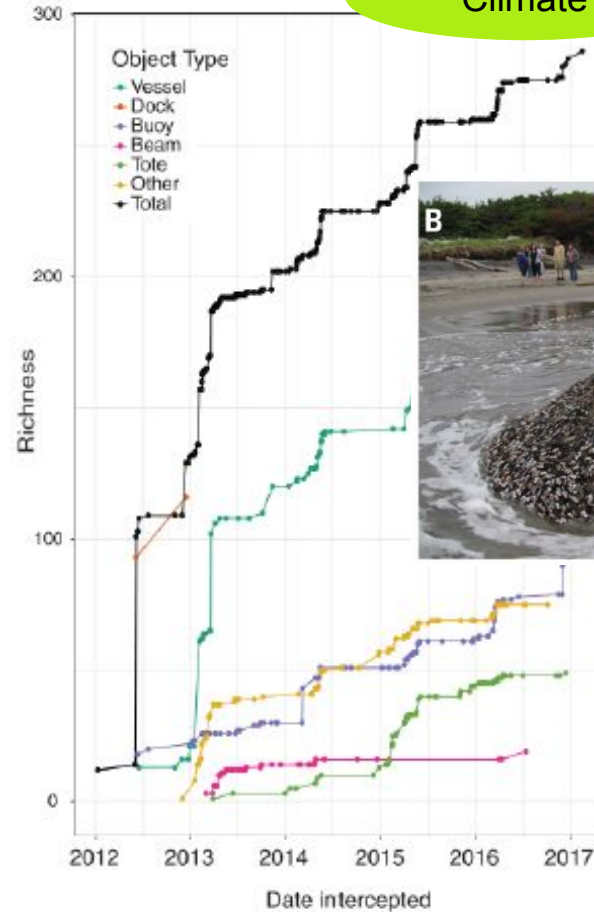
Ballooning dispersal
© Barnett

Human activities



Ballast waters © W.Carter

Climate



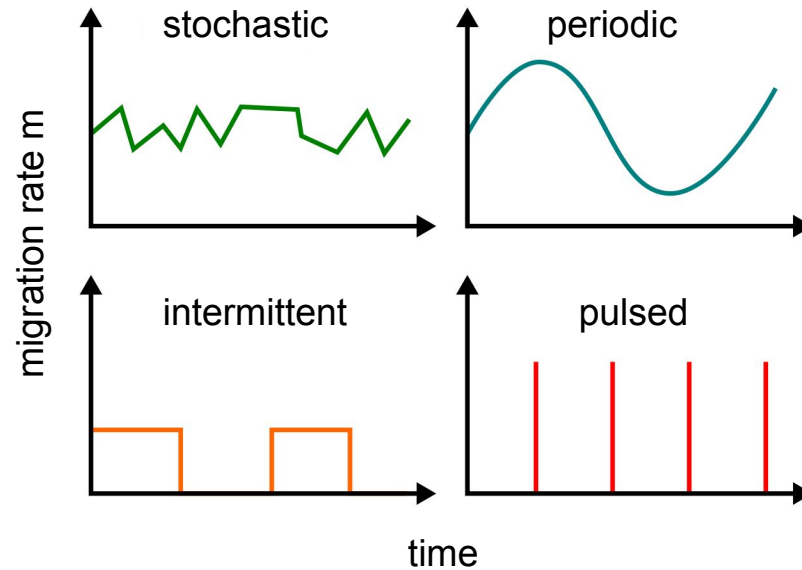
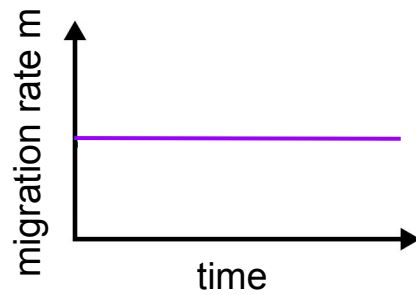
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Rafting transportation of individuals after tsunamis



Variable migration

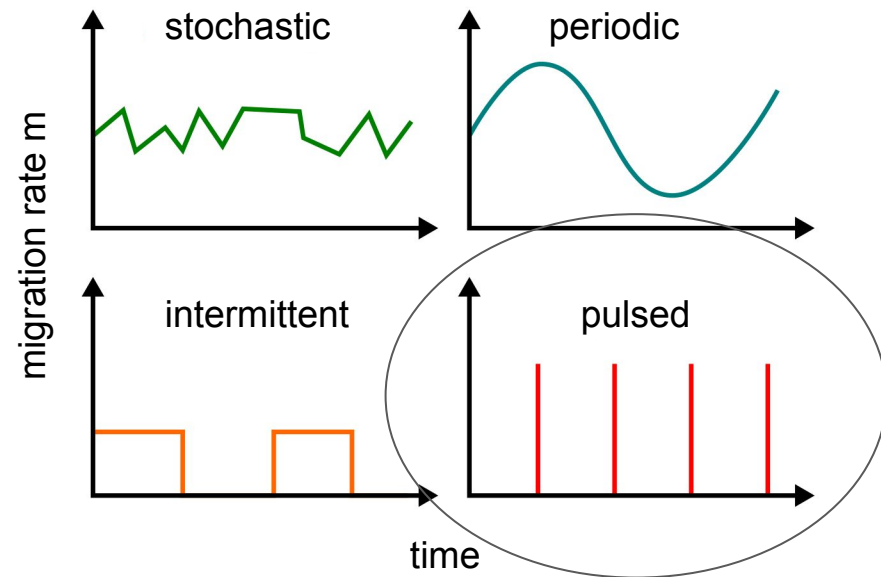
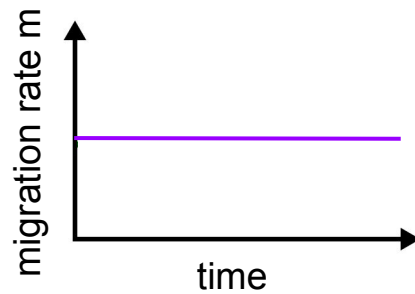
Constant migration





Variable migration

Constant migration



What are the consequences of pulsed migration patterns for:


- **genetic divergence at neutral markers?**
- **local adaptation, average fitness and migration load?**

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- genetic divergence at neutral markers?
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The few existing theoretical studies suggest that increasing temporal variability of migration rate **should decrease the effective migration rate** (i.e. promote genetic divergence)

Mainland-island model



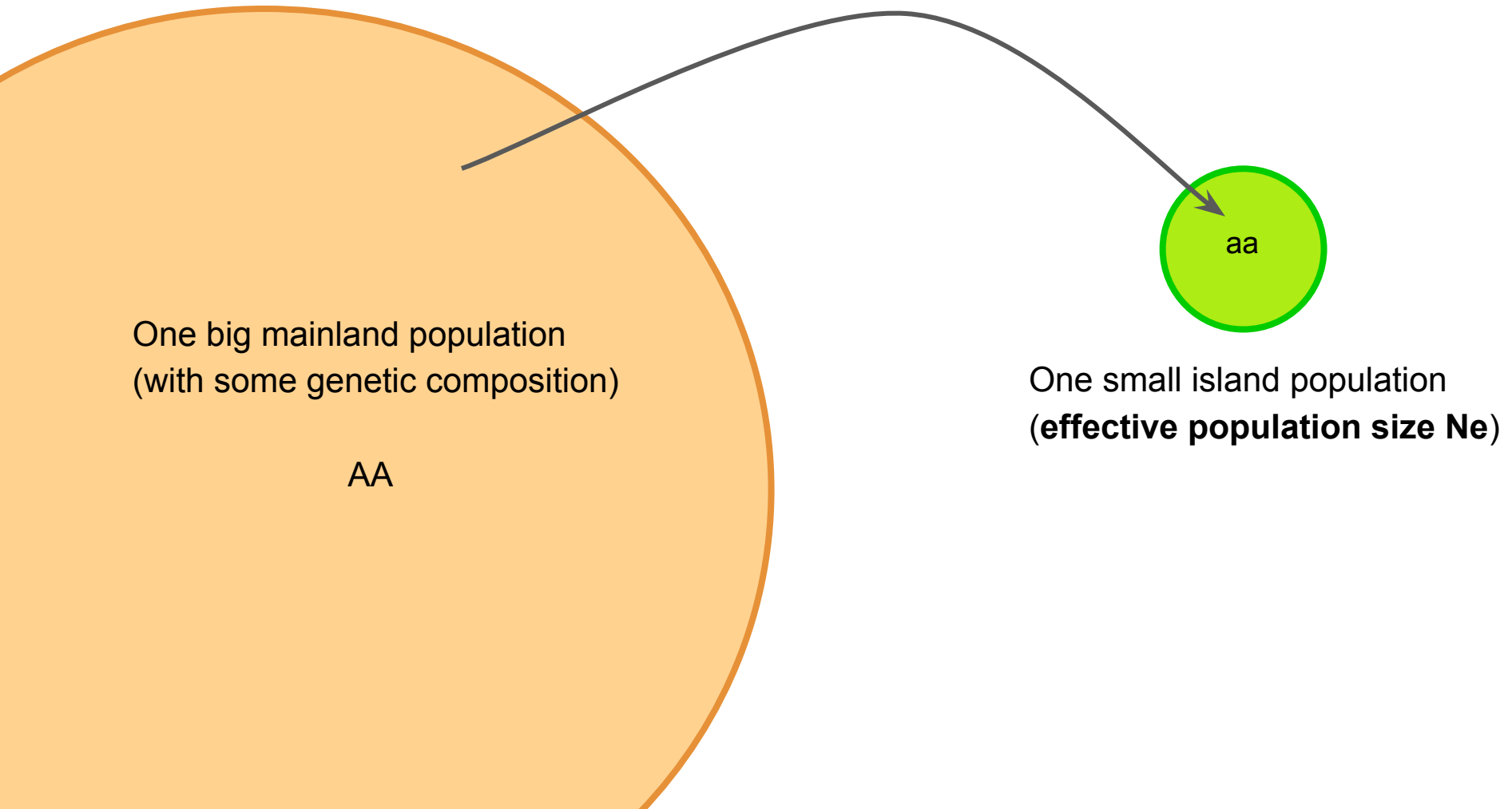
One big mainland population
(with some genetic composition)

AA

aa

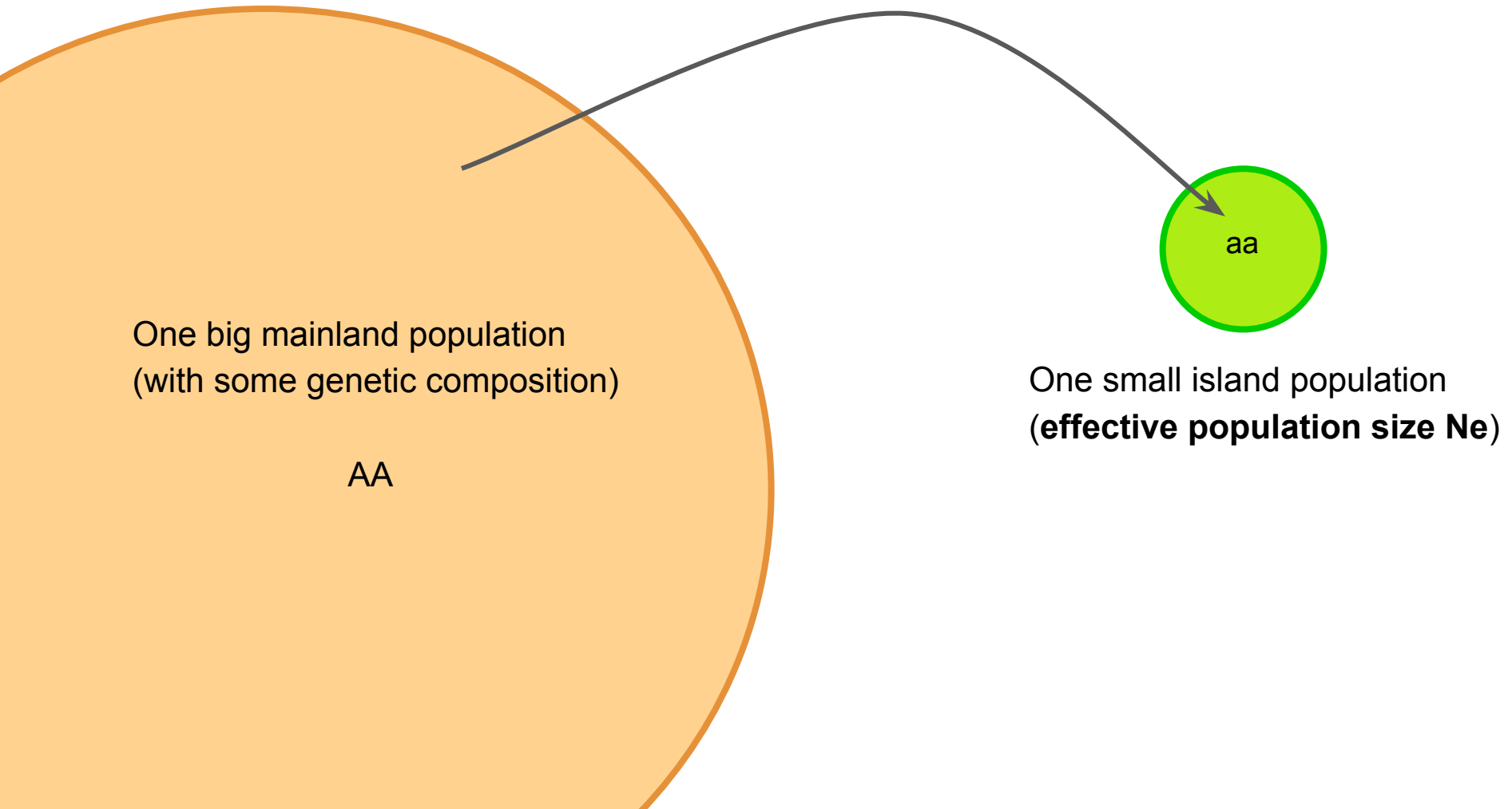
One small island population
(**effective population size N_e**)

Mainland-island model



Mainland-island model

Individuals migrate from mainland into the island at some **rate m** (mean number of migrants per generation)



One big mainland population
(with some genetic composition)

AA

aa

One small island population
(effective population size N_e)

1. Modelling of pulsed migration

Bursts of migration (migration events): n migrants per migration event

Mean number of migrants per unit time (m) is kept constant

→ The occurrence rate of migration events = m/n

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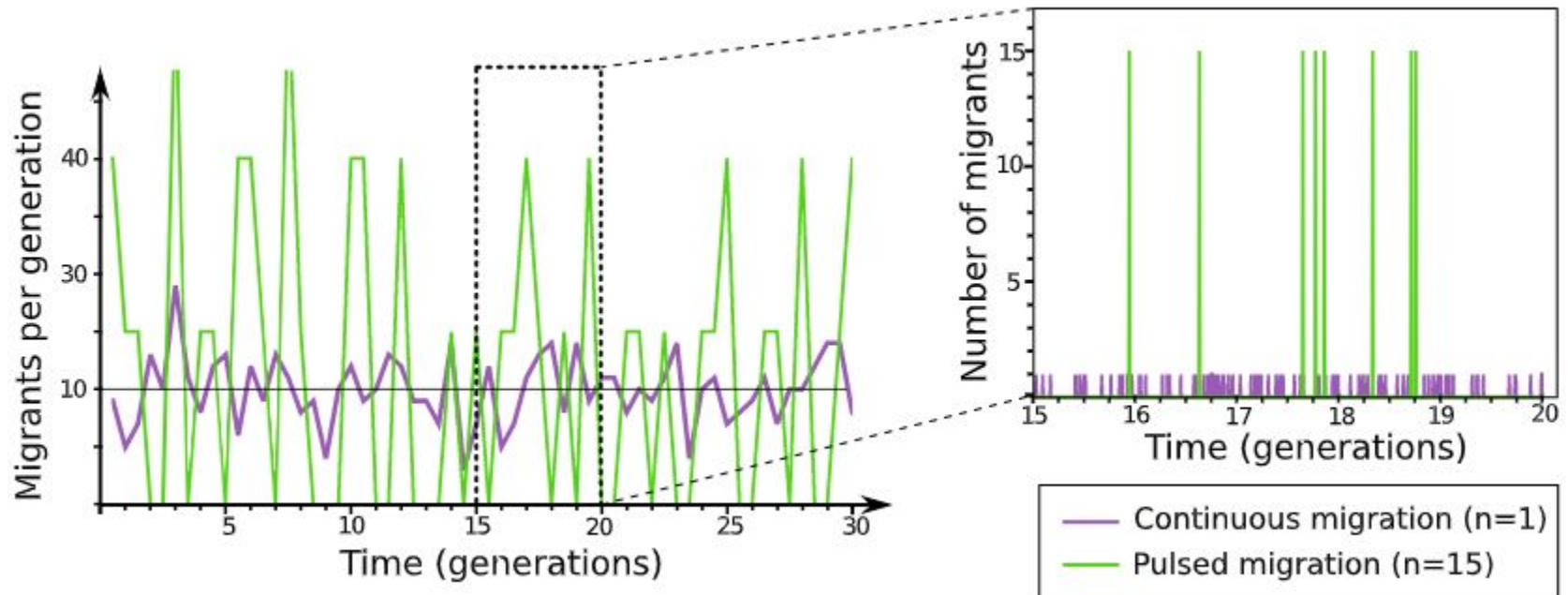
Bursts of migration (migration events): n migrants per migration event

Mean number of migrants per unit time (m) is kept constant

→ The occurrence rate of migration events = m/n



Pulses occur randomly in time at rate m/n



Variance in number of migrants per generation = $mT_g n$

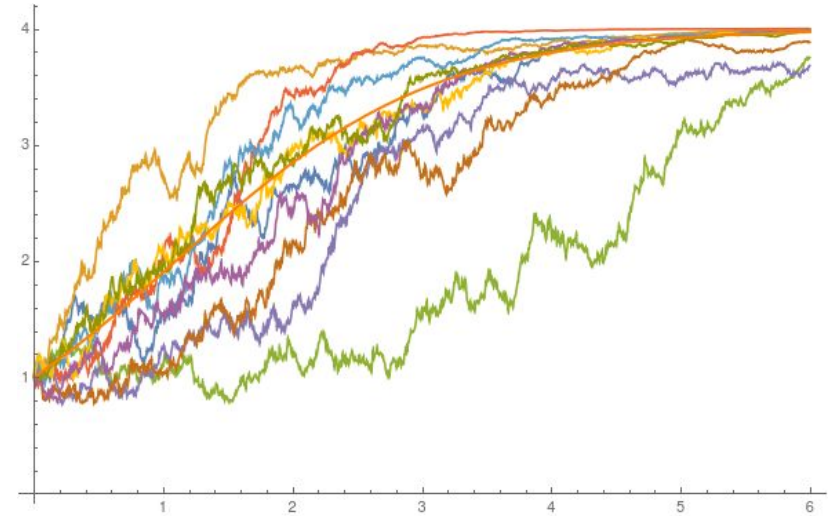
→ parameter n is the **overdispersion in the number of migrants per generation**

2. Dynamics on island population

Continuous time stochastic logistic demography

Carrying capacity $K = N_e$

Density-dependence on death

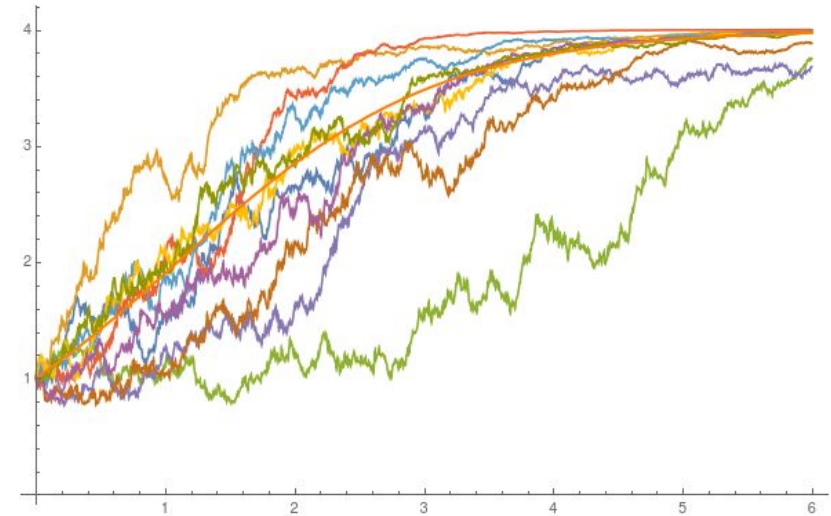


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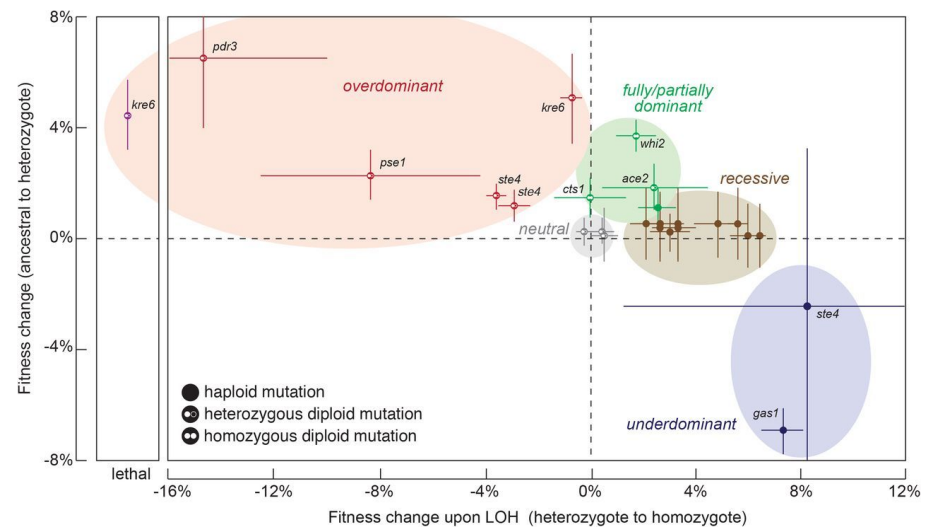
Density-dependence on death



Diploid individuals, panmixia

Three genotypes **AA, Aa** and **aa**

Reproductive fitness: $(1+s)$ $(1+hs)$ 1



3. Metrics of interest

We compute the **effective migration rate** m_e

Alleles from the mainland population will eventually overtake the island population.

→ How long does it take (time to fixation)?

→ Frequency of mainland alleles at some time t ?

The effective migration rate is, for some level of migration pulsedness level n , the value of migration rate that **would produce the same dynamics with constant migration** ($n=1$).

$m_e > m \Rightarrow$ migration pulsedness **increases** geneflow

$m_e < m \Rightarrow$ migration pulsedness **decreases** geneflow

4. Mathematical predictions

Under a slow-fast limit ($m \ll 1$), and assuming a constant population size N , we obtain that **migration pulsedness increases geneflow iff**

$$u\left(\frac{n}{N+n}\right) > nu\left(\frac{1}{N+1}\right)$$

$$u(f) = \frac{\int_0^f G(x) dx}{\int_0^1 G(x) dx}$$

with $G(x) = \exp[2N_e s((2h-1)x^2 - 2hx)]$ (Kimura, 1962).

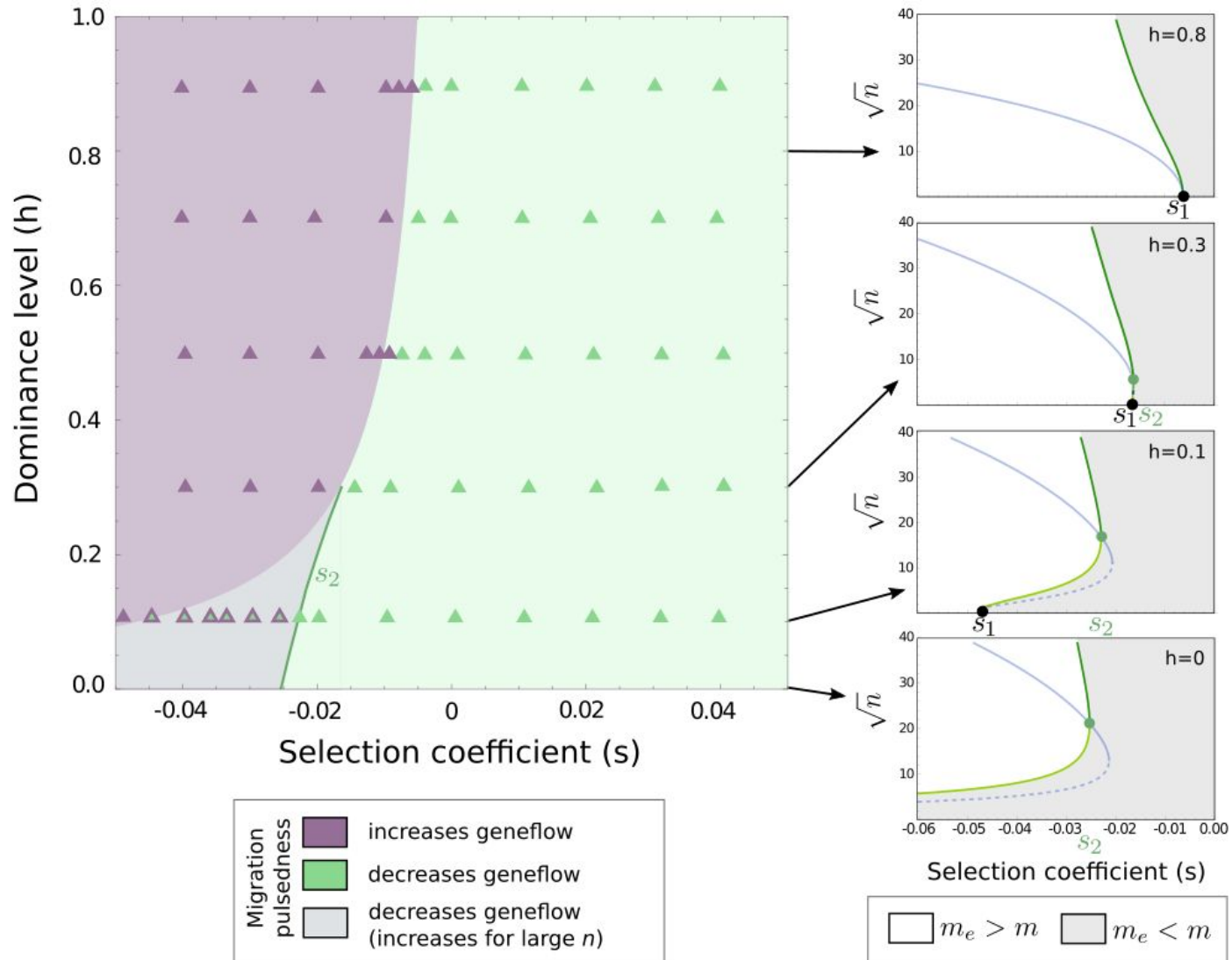
4. Mathematical predictions

With some further analysis, **migration pulsedness increases geneflow if**

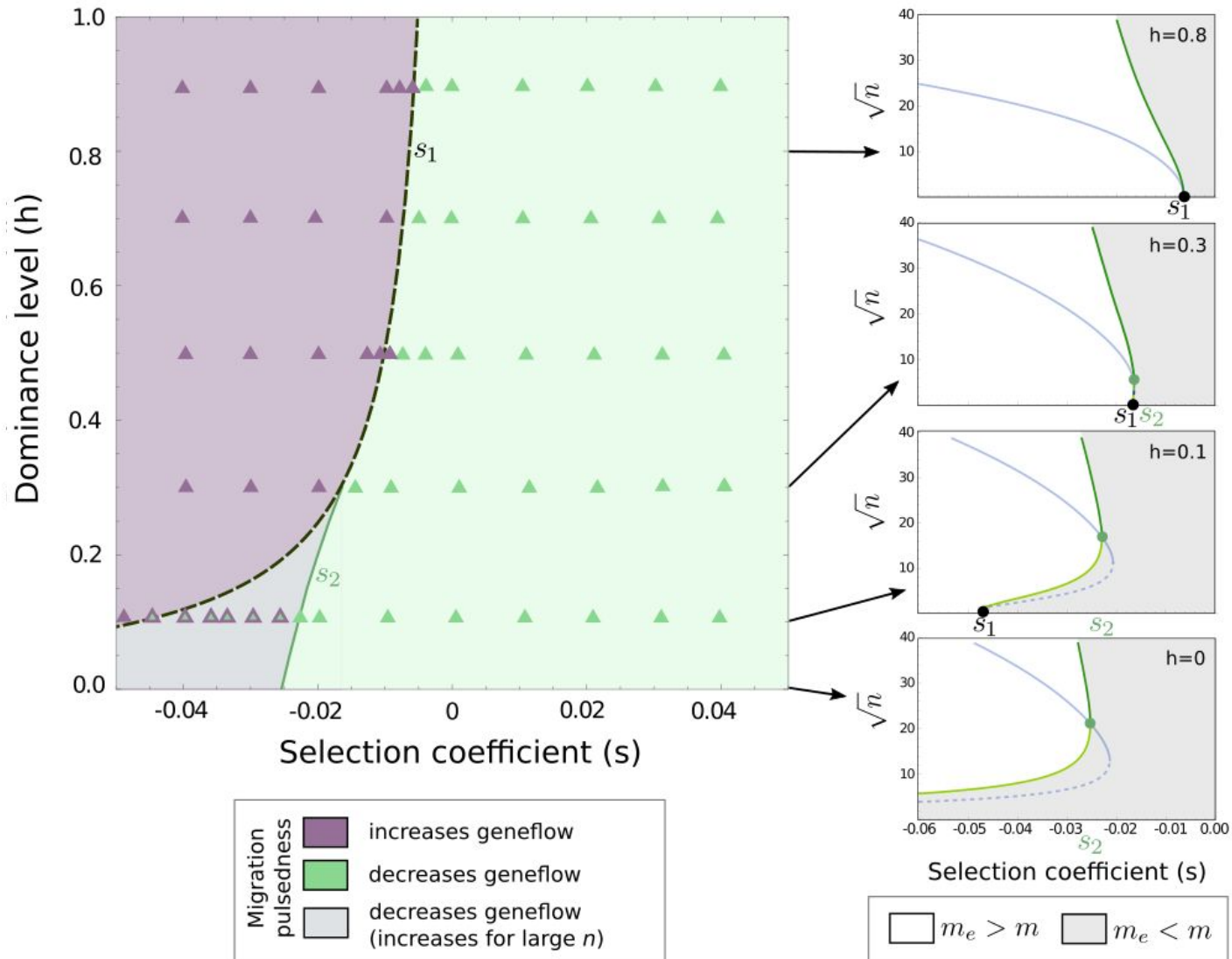
$$s < s_1 = -\frac{(N + 1)^2}{2N_e N(hN + 1 - h)}$$

and decreases geneflow otherwise.

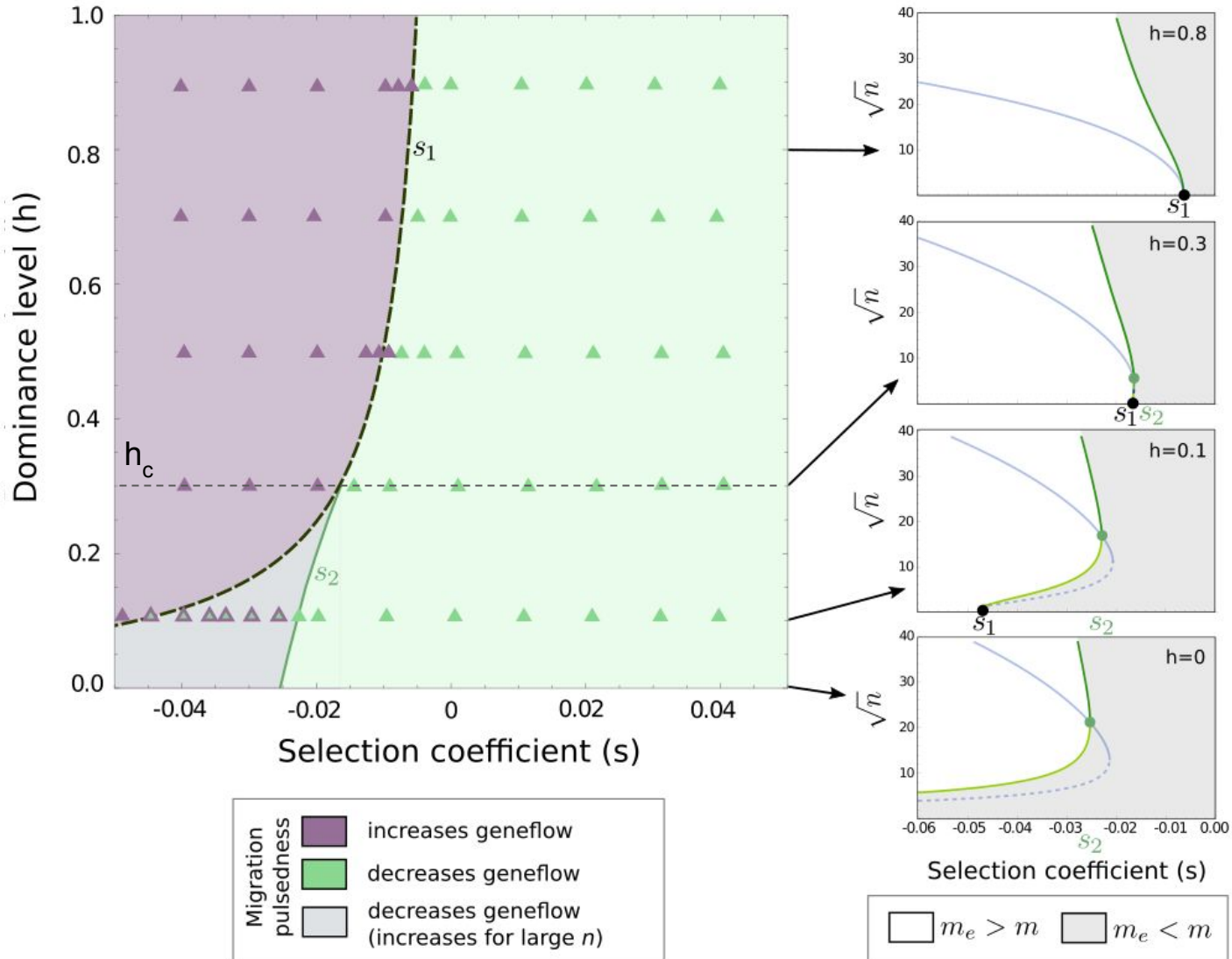
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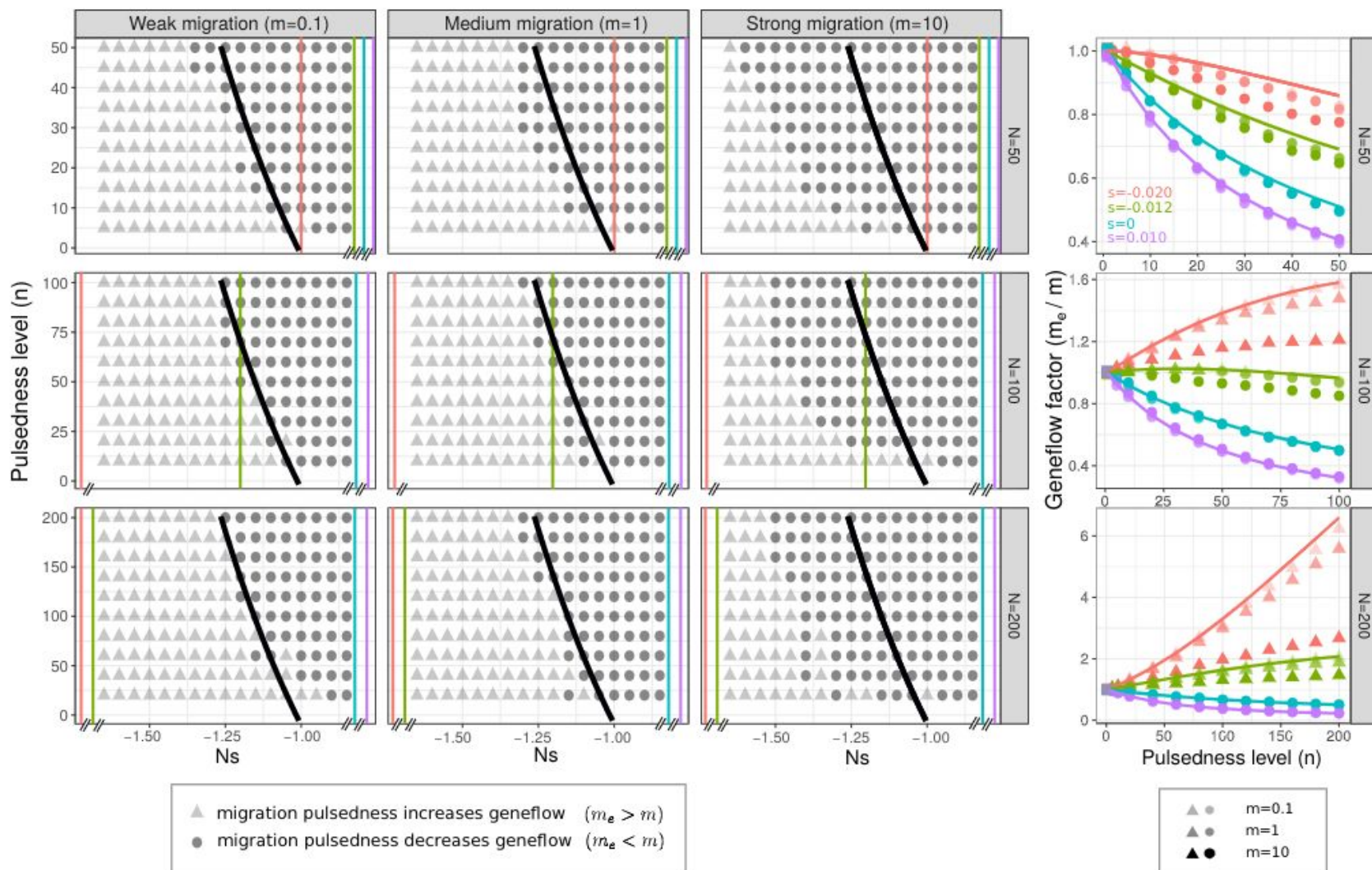
4. Mathematical predictions



4. Mathematical predictions



5. Stochastic simulations with larger migration rates



6. Important message A: the fingerprint of pulsedness

Migration pulsedness **increases** geneflow for deleterious alleles ($s < s_1$)

Migration pulsedness **decreases** geneflow for beneficial alleles

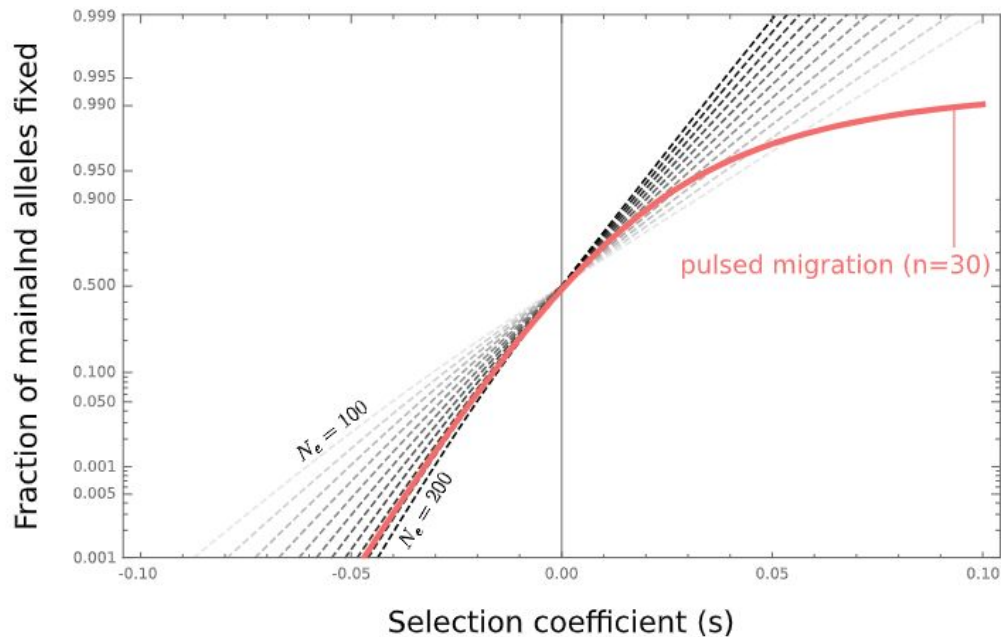
⇒ Migration pulsedness homogenizes fixation rates over genomes

This homogenization effect is not comparable to what would be produced by a reduction in effective population size under continuous migration

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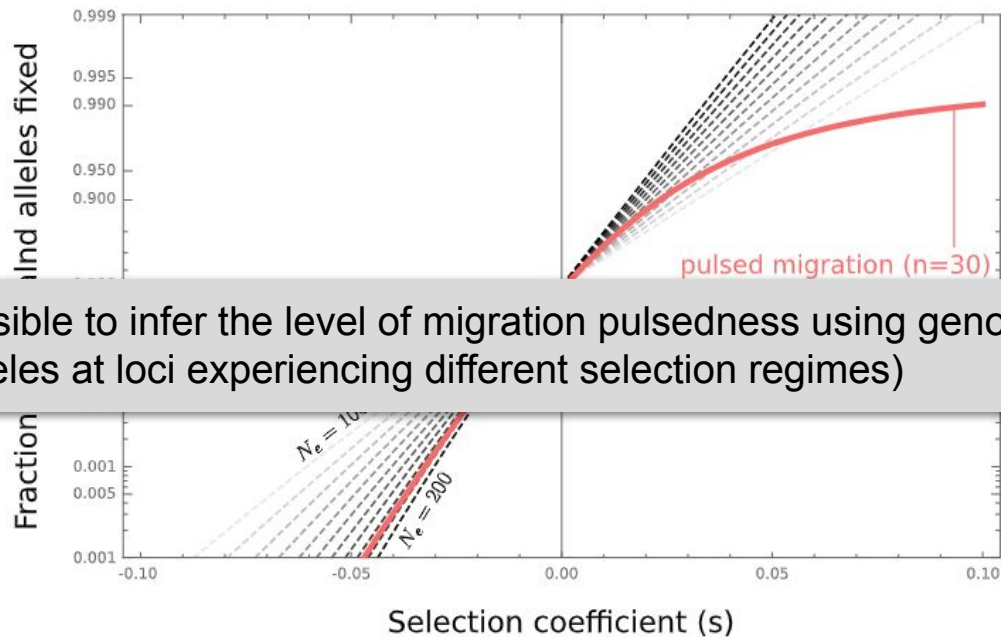
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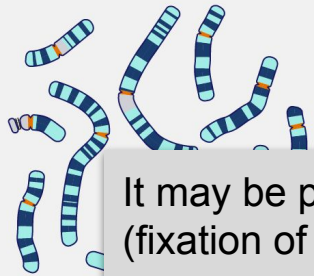
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This homogeneization effect is not comparable to what would be produced by a reduction in effective population size under continuous migration



It may be possible to infer the level of migration pulsedness using genomic data (fixation of alleles at loci experiencing different selection regimes)



7. Important message B: pulsedness reduces local adaptation

Migration pulsedness increases geneflow for deleterious alleles ($s < s_1$)

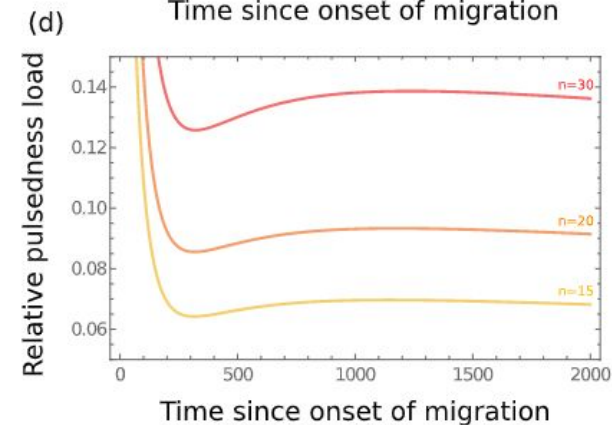
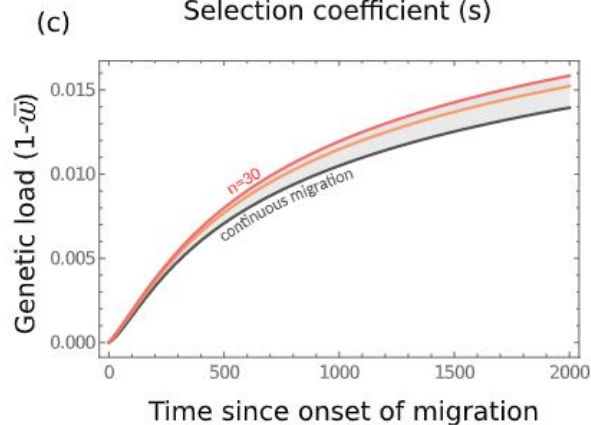
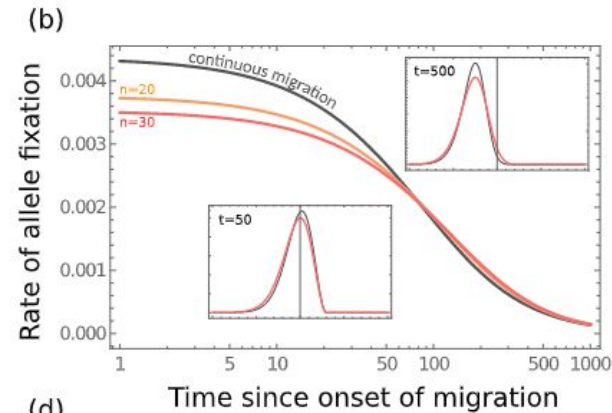
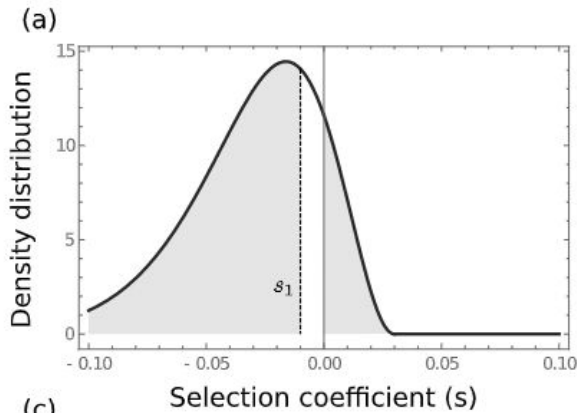
Migration pulsedness decreases geneflow for beneficial alleles

⇒ Migration pulsedness **reduces mean fitness and local adaptation**

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Distribution of
fitness effects
(DFE)
Martin et al. (2015)



Fitness deficit



Conclusion

Migration pulsedness has important consequences:

- It increases the rate of neutral genetic divergence
- It favors maladapted alleles over beneficial alleles

Pulsed migration patterns are less favorable to the adaptation and persistence of small isolated populations (Peniston et al. 2019)

In terms of conservation strategies, it would be better to introduce small many individuals at regular intervals, rather than many individuals on rare occasions.

Extending to ecology:

- Pulsed migration would decrease the effective migration rate of neutral species
- Pulsed migration would promote the invasion of less adapted mainland species on small islands

Thank you!

Flora Aubree, Baptiste Lac, Ludovic Mailleret, Thomas Guillemaud

