Evolutionary rescue and dispersal: the effect of habitat choice on successful adaptation

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in collaboration with
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École de printemps MMB

Aussois, May 2019
Evolutionary rescue?

Carlson et al., 2014, *TRENDS in Ecology & Evolution*
Evolutionary rescue?

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Evolutionary rescue?

Applications: conservation biology, epidemiology

Carlson et al., 2014, *Trends in Ecology & Evolution*
Dispersal?

- Dispersal
- Emigration
- Immigration

- Migrant pool
- Good habitat
- Bad habitat
- Wild type
- (Rescue) mutant

- \( \pi_m \)
- \( \pi_w \)
Dispersal?

Emigration

migrant pool

1

(1) mutant

π

π

wild type

good habitat

bad habitat
Dispersal?

Immigration
Dispersal?

- Emigration
- Immigration

-migrant pool
-good habitat
-bad habitat

-wild type

(rescue) mutant

- \( \pi \)
- \( m \)
- \( \pi_w \)
Dispersal?

- Emigration
- Immigration

- migrant pool
- good habitat
- bad habitat

- wild type
- 1
- (rescue) mutant
- \( \pi_m \)
- \( \pi_w \)
Dispersal?

Random dispersal (RD) - no habitat bias
Dispersal?

Absolute habitat matching (AHM) - all prefer the good habitat
e.g. reptiles, birds, ...

Diagram:

- Two habitats: one with a single individual (left) and another with a migrant pool (right).
- Arrows indicate dispersal and immigration.

Dispersal?

Relative habitat matching (RHM) - all prefer the habitat where they are relatively more fit
e.g. ciliates (specialist vs generalist dispersal)
Dispersal?

Negative density-dependent dispersal (NDD) - all prefer the less crowded habitat

e.g. fish, birds, ...
Dispersal?

Negative density-dependent dispersal (NDD) - all prefer the less crowded habitat e.g. fish, birds, ...

\[ \text{wild type} \]

\[ \begin{array}{c}
1 \\
\pi_w \\
(\text{rescue}) \text{ mutant}
\end{array} \]

\[ \begin{array}{c}
1 \\
\pi_m
\end{array} \]
How does dispersal (and different dispersal schemes) affect the probability of evolutionary rescue?
Model

Life cycle: Dispersal - Reproduction - Regulation

Good habitat dynamics:
Assumption: carrying capacity is always reached
⇒ Wright-Fisher sampling
wild type better adapted than the mutant
mean number of offspring of one mutant: $1 + s$
good

Regulation (competition)
⇒ typically
$s_{\text{good}} < 0$

Bad habitat dynamics:
Assumption: wild type population declines
⇒ carrying capacity is not reached (offspring number $\sim$ Poisson)
mean number of offspring of one wild-type individual: $1 - r$
with $r \in (0, 1]$
mean number of offspring of one mutant: $1 + s$ with $s_{\text{bad}} > 0$
Model
Life cycle: Dispersal - Reproduction - Regulation

**Good habitat dynamics:**
- Assumption: carrying capacity is always reached
  ⇒ Wright-Fisher sampling
- wild type better adapted than the mutant
- mean number of offspring of one mutant: $1 + s_{\text{good}}$
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## Good habitat dynamics:
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## Bad habitat dynamics:
- Assumption: wild type population declines
  ⇒ carrying capacity is not reached (offspring number $\sim$ Poisson)
- Mean number of offspring of one wild-type individual: $1 - r$ with $r \in (0, 1]$
- Mean number of offspring of one mutant: $1 + s_{\text{bad}}$ with $s_{\text{bad}} > 0$
Establishment probability in a heterogeneous environment

Technique: Multi-type branching process theory (weak selection, weak dispersal approximation)

\[
\varphi_{\text{good}} \approx s_{\text{good}} \left( 1 + \frac{(1 - f_{\text{good}} + \pi_m f_{\text{good}})}{\sqrt{C}} (s_{\text{good}} - s_{\text{bad}}) \right) 
\]

\[
+ m \left( \frac{s_{\text{bad}}(1 - f_{\text{good}})}{\sqrt{C}} + \frac{s_{\text{good}} \pi_m f_{\text{good}}}{\sqrt{C}} - \frac{(s_{\text{good}} - s_{\text{bad}})(1 - f_{\text{good}})}{\sqrt{C}} \right)
\]
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local selection + weighted global correction
Establishment probability in a heterogeneous environment

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effect of dispersal: bad patches + good patches − loss to the other patch type
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effect of dispersal: bad patches + good patches – loss to the other patch type

\[ \varphi_{\text{bad}} \approx s_{\text{bad}} \left( 1 + \frac{(1 - f_{\text{good}} + \pi m f_{\text{good}})}{\sqrt{C}} (s_{\text{bad}} - s_{\text{good}}) \right) \]

\[ + m \left( \frac{s_{\text{bad}}(1 - f_{\text{good}})}{\sqrt{C}} + \frac{s_{\text{good}} \pi m f_{\text{good}}}{\sqrt{C}} - \frac{(s_{\text{bad}} - s_{\text{good}}) \pi m f_{\text{good}}}{\sqrt{C}} \right) \]
Establishment probability in a heterogeneous environment
(constant patch configuration – 50% good patches)

Weak selection in the good habitat \((s_{\text{good}} \sim -0.01)\)

![emigration probability and establishment probability graphs with legend and data points for AHM, RHM, NDD, and RD methods, with numerical solution and approximation lines]

Increasing migration rates \(\Rightarrow\) influx to / outflux from bad habitat
Establishment probability in a heterogeneous environment

(constant patch configuration – 50% good patches)

Weak selection in the good habitat ($s_{\text{good}} \sim -0.01$)

Increasing migration rates $\Rightarrow$ influx to / outflux from bad habitat
Establishment probability in a heterogeneous environment

(constant patch configuration – 50% good patches)

Strong selection in the good habitat \((s_{\text{good}} \sim -0.1)\)

![Graph with establishment and emigration probabilities]

- **Emergence in good patch**
- **Emergence in bad patch**

- **RD** • **NDD** ▼ **AHM** ▲ **RHM**

High migration rates ⇒ relaxed competition in good patches
Establishment probability in a heterogeneous environment
(constant patch configuration – 50% good patches)

Strong selection in the good habitat \((s_{good} \sim -0.1)\)

High migration rates \(\Rightarrow\) relaxed competition in good patches

![Graph comparing establishment and emigration probabilities in good and bad patches](image-url)
Probability of evolutionary rescue

\[ t = 0 \]

\[ t = 100 \]

\[ t = 200 \]

\[ t = 600 \]

. . .
Probability of evolutionary rescue

\[ P(t) = \begin{cases} 1 & t = 0 \\ 0 & t = 100 \end{cases} \]

- \( t = 0 \)
- \( t = 100 \)
Probability of evolutionary rescue

\[ P(t) = \begin{cases} 
0 & \text{if } t < 0 \\
100 & \text{if } 0 \leq t < 200 \\
200 & \text{if } 200 \leq t < 600 \\
\vdots & 
\end{cases} \]
Probability of evolutionary rescue

\[
t = 0 \\
t = 100 \\
t = 200 \\
t = 600
\]
Probability of evolutionary rescue
(deterioration of patches one after the other over time)

10 patches in total, 100 generations between deterioration events

- Weak selection
- Strong selection

![Graph showing evolutionary rescue probability for weak and strong selection with different models: AHM, RHM, NDD, and RD. The x-axis represents emigration probability, and the y-axis represents the probability of evolutionary rescue, $P_{\text{rescue}}$. The graphs illustrate the non-monotone probability of evolutionary rescue under stronger selection.](image-url)
Probability of evolutionary rescue
(deterioration of patches one after the other over time)

10 patches in total, 100 generations between deterioration events

Stronger selection ⇒ non-monotone probability
Conclusions

- Weak selection strength $\Rightarrow$ positive effect of dispersal on adaptation and evolutionary rescue
- Strong selection strength $\Rightarrow$ non-monotonic effect of dispersal on adaptation and evolutionary rescue
Conclusions

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- Strong selection strength ⇒ non-monotonic effect of dispersal on adaptation and evolutionary rescue
- Decomposition of the probability of establishment of a single mutant: selection + global correction + dispersal
Conclusions

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- Strong selection strength $\Rightarrow$ non-monotonic effect of dispersal on adaptation and evolutionary rescue
- Decomposition of the probability of establishment of a single mutant: selection + global correction + dispersal
- Random dispersal is not the norm in nature (but it is in theory!)
- Habitat choice hinders adaptation and evolutionary rescue under weak selection
Conclusions

- Weak selection strength $\Rightarrow$ positive effect of dispersal on adaptation and evolutionary rescue
- Strong selection strength $\Rightarrow$ non-monotonic effect of dispersal on adaptation and evolutionary rescue
- Decomposition of the probability of establishment of a single mutant: selection + global correction + dispersal
- Random dispersal is not the norm in nature (but it is in theory!)
- Habitat choice hinders adaptation and evolutionary rescue under weak selection
- **Relative habitat choice** promotes adaptation and evolutionary rescue for strong selection (at least for low to intermediate dispersal rates)
Acknowledgements

Florence Débarre @flodebarre
François Blanquart @FrancoisJB
Hildegard Uecker

Merci de votre attention!

grant “MOLA” (F. Débarre)
Probability of evolutionary rescue

\[ P_{\text{rescue}} \approx 1 - \exp \left( -\tau u \sum_{i=0}^{M-1} \phi_{\text{good}}(f_{\text{good}}(i)) N_{w}^{\text{good}}(i) \right) \]

old habitat contribution

\[ + \phi_{\text{bad}}(f_{\text{good}}(i)) i N_{w}^{\text{bad}}(i) (f_{\text{good}}(i)) \]

new habitat contribution

\[ -u \phi_{\text{bad}}(0) \sum_{i=\tau(M-1)}^{\infty} N_{w}^{\text{bad}}(i) \]

contribution after the last patch has deteriorated