Effect of the habitat fragmentation on the persistence of native species against an alien invasion

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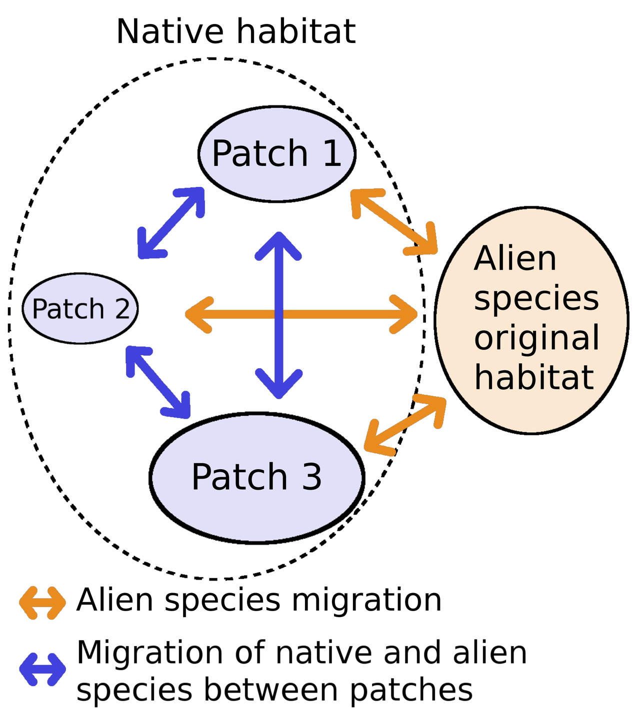
Introduction

Habitat fragmentation could be a threat to biodiversity. Understanding the ecological dynamics in a fragmented habitat is crucial, for example, for the conservation of a species inhabiting there. We consider here the influence of a habitat fragmentation on a competition population dynamics. We show some results on a specific model in which the habitat is divided into a number of equivalent patches according to the resource for the reproduction in each patch.

Assumptions

- The habitat fragmentation alters the availability of a resource limiting the reproduction in each patch.
- An invading alien species competes with a native species for a common resource limiting their reproductions.
- The resource follows its intrinsic renewal dynamics affected by the habitat fragmentation.
- The intrinsic renewal dynamics of the resource is much faster than the population dynamics in the habitat.
- A higher resource availability in a patch induces a higher immigration rate into the patch.



Equilibrium of native species extinction

If one of the following conditions is satisfied, then the equilibrium $(0, A_1^*, 0, A_2^*, \dots, 0, A_n^*)$ is locally asymptotically stable:

- $R_N^c > \max_{0 \le i \le n} R_i^*$; • $R_N^c > R_A^c + \frac{m_0}{\alpha_A}$;
- $\frac{\beta_A}{\gamma} M_0 A_0 \ge (\alpha_A R_A^c + m_0) \sum_{i=1}^{n} R_i^*$.

On the other hand, if

$$\begin{aligned} R_N^c + \frac{m_N}{\alpha_N} &< R_A^c + \frac{m_0}{\alpha_A}, \quad \text{and} \\ \frac{\beta_A}{\gamma} M_0 A_0 &< \left(\sum_{i=1}^{n} R_i^* - \left(R_N^c + \frac{m_N}{\alpha_N} \right) \right) \\ &\quad \times \left(\alpha_A R_A^c + m_0 - \alpha_A \left(R_N^c + \frac{m_N}{\alpha_N} \right) \right) \end{aligned}$$

then there exists a $\tilde{R} > R_N^c + \dfrac{m_N}{\alpha_N}$ such that

$$\max_{0 \le i \le n} R_i^* > \tilde{R} \implies (0, A_1^*, 0, A_2^*, \dots, 0, A_n^*) \text{ is unstable.}$$

Habitat fragmentation with an equivalent patch division

For a system with n patches equivalent in their resource distribution: $\forall i, k,\ p_i^* = p_k^*$, the Jacobian matrix for the equilibrium $(0, A_1^*, 0, A_2^*, \dots, 0, A_n^*)$ has a positive eigenvalue if and only if

$$\begin{aligned} R_N^c &< R_A^c + \frac{m_0}{\alpha_A} \quad \text{and} \\ R_i^* &> R_N^c + \frac{1}{n} \frac{M_0 A_0 \beta_A / \gamma}{R_N^c (\alpha_A (R_A^c - R_N^c) + m_0)}. \end{aligned}$$

Conclusion

The existence of a patch with sufficiently high resource availability is relevant for the persistence of the native species. A habitat fragmentation may be beneficial for the persistence of the native species by moderating the competition with an alien species in each patch with a change in the resource availability.

Generic model of resource-consumer dynamics

$$\begin{aligned} \frac{dR_i}{dt} &= D_i(R_i(t)) - \beta_N N_i R_i - \beta_A A_i R_i \quad \text{with } D_i(R_i) = p_i \lambda R_i - \gamma R_i^2 \\ \frac{dN_i}{dt} &= \alpha_N \left(R_i(t) - R_N^c \right) N_i(t) - m_N N_i(t) + \frac{p_i}{P_n} m_N \sum_j N_j(t) \\ \frac{dA_i}{dt} &= \alpha_A \left(R_i(t) - R_A^c \right) A_i(t) - m_A A_i(t) + \frac{p_i}{P_n} m_A \sum_j A_j(t) - m_0 A_i(t) + \frac{p_i}{P_n} M_0 A_0 \end{aligned}$$

R_i: Resource density in patch i.

N_i: Population size of native species in patch i.

A_i: Population size of alien species in patch i.

p_i: Coefficient of the resource availability at patch i.

$P_n = \sum_{j=1}^{n} p_j$ with the total number of patches n.

β_N, β_A: Coefficients of the resource consumption by the native and alien species.

α_N, α_A: Conversion coefficients of the resource consumption to the reproduction.

λ: Intrinsic renewal rate of the resource.

γ: Intrinsic decay coefficient of the resource.

R_N^c, R_A^c: Least resource values needed for the reproduction.

m_N, m_A: Migration rates between patches in the native habitat.

$M_0 A_0$: Net invasion rate of alien species in the native habitat.

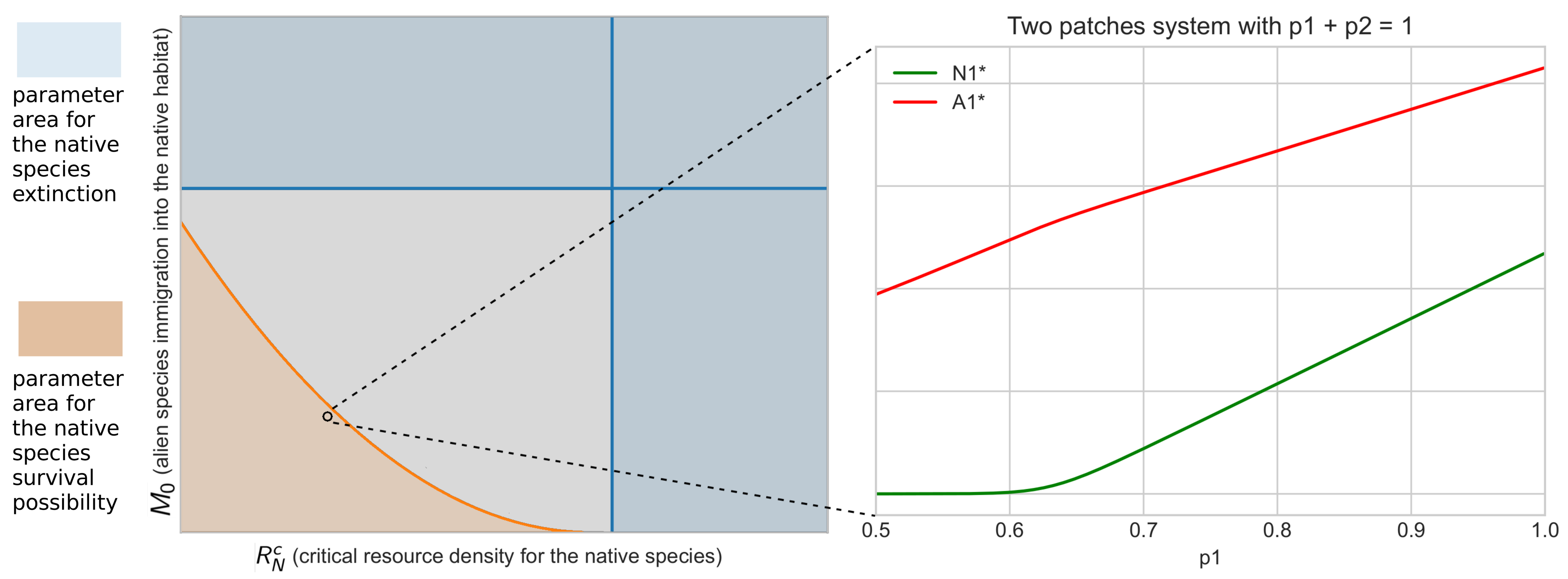
m_0: Return rate of the alien species to its original habitat.

$R_0^* = \lambda/\gamma$: Equilibrium resource density without the habitat fragmentation.

Population dynamics model with QSSA

$$\begin{aligned} \frac{dN_i}{dt} &= \alpha_N \left(-R_N^c + p_i R_0^* - \frac{\beta_N}{\gamma} N_i - \frac{\beta_A}{\gamma} A_i \right) N_i - m_N N_i(t) + \frac{p_i}{P_n} m_N \sum_j N_j(t) \\ \frac{dA_i}{dt} &= \alpha_A \left(-R_A^c + p_i R_0^* - \frac{\beta_N}{\gamma} N_i - \frac{\beta_A}{\gamma} A_i \right) A_i - m_A A_i + \frac{p_i}{P_n} m_A \sum_j A_j(t) - m_0 A_i(t) + \frac{p_i}{P_n} M_0 A_0 \end{aligned}$$

Native species persistence



Native species persistence in a fragmented habitat with the equivalent patch division