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

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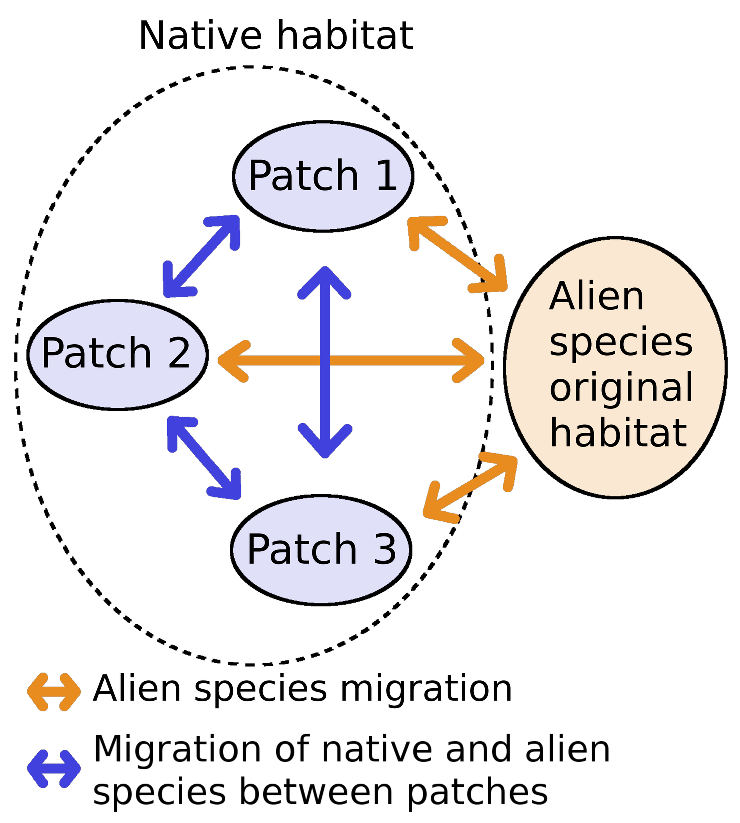
Introduction

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.
- The fragmentation divides the native habitat into a number of patches equivalent according to the resource availability for the reproduction of native and alien species in each patch. (for mathematical simplification)



Persistence condition with no alien invasion

$$n \;<\; P_n \frac{R_0^*}{R_N^c}$$

Persistence condition with an alien invasion

$$\alpha_A(R_A^c - R_N^c) + m_0 \;>\; 0 \quad \text{and}$$

$$n \;<\; \frac{R_0^*}{R_N^c}\left(P_n - \frac{\beta_A}{\lambda}\frac{M_0A_0}{\alpha_A(R_A^c - R_N^c) + m_0}\right)$$

Conclusions

When the habitat fragmentation does not change the resource availability in the habitat of native species, the habitat fragmentation is detrimental to the persistence of the native species. In contrast, when the habitat fragmentation would work to increase the total resource availability, there could be a specific fragmentation for the native species to persist, even though it becomes extinct by the resource competition with an invader species in the habitat without fragmentation. This result is a theoretical implication about the positive effect of habitat fragmentation on the persistence of a species.

Generic model of resource and population dynamics

$$\frac{dR_i}{dt} = D_i(R_i(t)) - \beta_N N_i R_i - \beta_A A_i R_i \qquad \text{with } D_i(R_i) = p_i\lambda R_i - \gamma R_i^2 \text{ in this model}$$

$$\frac{dN_i}{dt} = \alpha_N\big(-R_N^c + R_i(t)\big)N_i - m_N N_i + \frac{1}{n}m_N\sum_j N_j$$

$$\frac{dA_i}{dt} = \alpha_A\big(-R_A^c + R_i(t)\big)A_i - m_A A_i + \frac{1}{n}m_A\sum_j A_j - m_0 A_i + \frac{1}{n}M_0A_0$$

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.

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

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. They are assumed to be proportional to β_N and β_A respectively.

λ: Intrinsic renewal rate of the resource.

γ: Intrinsic decay rate of the resource.

M_0A_0: Net invasion rate of alien species in the habitat of native species.

m_0: Return rate of alien individual to its original habitat.

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

$R_0^* = \lambda/\gamma$: Equilibrium value of the resource in the non-fragmented habitat.

Population dynamics model with QSSA

$$\frac{dN_i}{dt} = \alpha_N\left(-R_N^c + p_i\frac{\lambda}{\gamma} - \frac{\beta_N}{\gamma}N_i - \frac{\beta_A}{\gamma}A_i\right)N_i - m_N N_i + \frac{1}{n}m_N\sum_j N_j$$

$$\frac{dA_i}{dt} = \alpha_A\left(-R_A^c + p_i\frac{\lambda}{\gamma} - \frac{\beta_N}{\gamma}N_i - \frac{\beta_A}{\gamma}A_i\right)A_i - m_A A_i + \frac{1}{n}m_A\sum_j A_j - m_0 A_i + \frac{1}{n}M_0A_0$$

Dependence of the persistence on the number of patches n