Confirming the insurance effect of rare species in ecological communities using an agent-based model

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1 Insurance Hypothesis

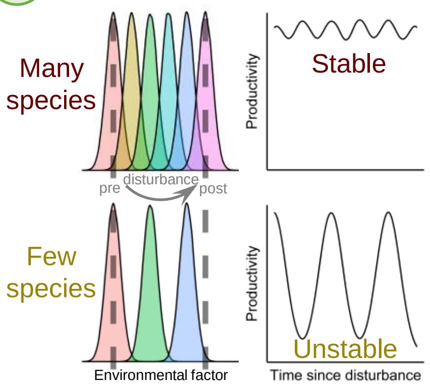


Fig. 1. When environmental conditions fluctuate and become unsuitable for dominant species, other species may take over resource retention and ensure stability

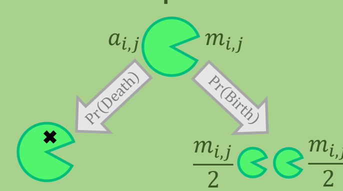
- Biodiversity → insurance effect
- Insurance effect hypothesis [*1*]: in a moment or location only a few species are in their ecological optimum, while other (rare) species are in their zones of intolerance
- Rare species may turn valuable when conditions change and other species move away from their optimum (Fig. 1)
- Buffer for disturbances, ensures ecosystem stability [*2*]
- Although widely implied, limited experimental works [*3*]

2 Model Flowchart

- The agent-based model is written in R [*4*] implementing tidyverse [*5*]
- The **world** has resource starting at a set level ($R_0 = 10{,}000$)
- Constant increase each time step ($R_i = R_{i-1} + 100$)
- All **individuals** have: species (s_j), body mass (m_j), age (a_j), and species-specific resource consumption coefficient (c_s) as a function of current level of environmental factor ε, $c_{i,s} = f(\varepsilon_i)\ \forall\ s$
- Critical $m_{\text{crit}} = 5$, $a_{\text{crit}} = 10$, and carrying capacity $R_{\text{crit}} = 20{,}000$ are constant among species and throughout the simulation
- 500 time steps per simulation; 10,000 simulation runs

Initialize world with simulation length I, initial resource level R_0 and carrying capacity R_{crit}, initial and final environmental factor levels $(\varepsilon_0, \varepsilon_I) \rightarrow \varepsilon_i = \varepsilon_0 + i(\varepsilon_I - \varepsilon_0)/I$, and species richness S

Individuals **reproduce or die**



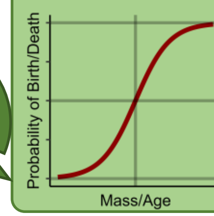
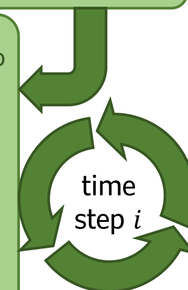


Fig. 3. Logistic function where $m_{i,j} = m_{\text{crit}} \rightarrow \Pr(\text{Birth}) = 0.5$; $a_{i,j} = a_{\text{crit}} \rightarrow \Pr(\text{Death}) = 0.5$

Update species' resource consumption rate $c_{s,i} = f(\varepsilon_i)$ to match the current ε_i



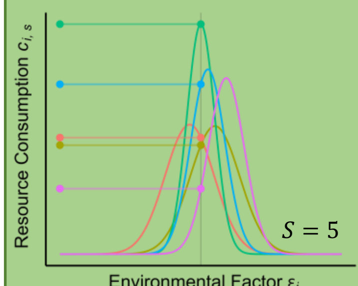
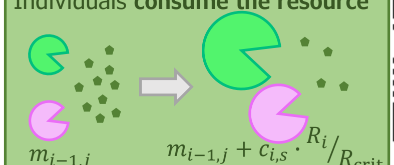


Fig. 2. $c_{i,s} = f(\varepsilon_i)$ is modelled as normal distribution with random μ and σ^2 for each s [*6*]

Individuals **consume the resource**



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3 Results & Discussion

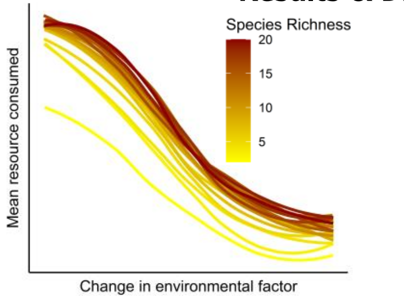

Fig. 4. Mean resource consumption throughout a simulation is higher in species-rich communities

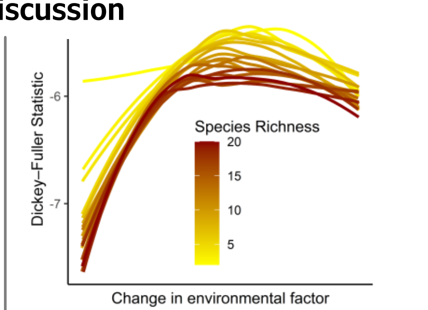

Fig. 5. Dickey-Fuller statistic is lower for stationary processes, i.e., resource consumption by a community is a stationary time series when there are more species and less environmental variability

- Insurance effect of species richness explained by niche complementarity [*7*]
- Rare species become abundant when environmental conditions shift
- Rare species are important for maintaining ecosystem stability under unstable circumstances (Fig. 4, 5)
- Validation required – experiments with biological systems (e.g., bacteria)

References: [*1*] Yachi & Loreau (1999) *PNAS* 96: 1463–1468; [2] Loreau et al. (2003) *PNAS* 100: 12765-12770; [3] Balvanera et al. (2006) *Ecol Lett* 9: 1146-1156; [4] R Core Team (2023); [5] Wickham et al. (2019) *J Open Source Softw* 4: 1686; [6] McGill & Collins (2003) *Evol Ecol Research* 5: 469-492; [7] Cardinale et al. (2007) *Nature* 104: 18123-18128.

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