Species-Area Relationships in Changing Environments

Integrating Habitat Loss and Resource Competition into SAR

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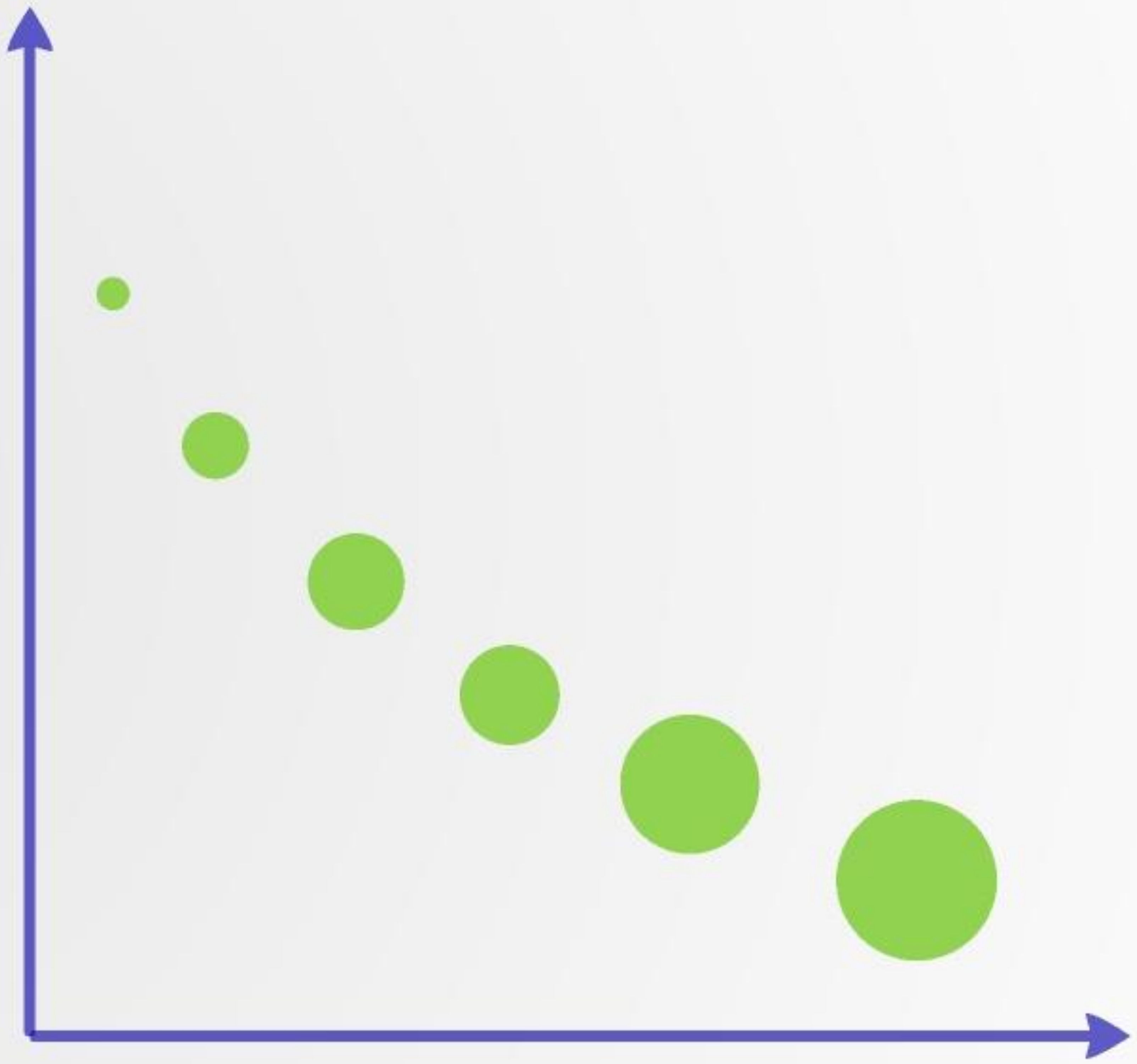


The SAR

Species-Area Relationship definition

A species–area relationship is the observation that the **number of biological species** found in a region is a positive function of the **area** of that region, e.g. a **power-law**:

$$S = cA^z$$

Why is the SAR important?

Understanding the spatial distribution of species provides insights into: (1) **extinction** risk from habitat loss, (2) optimal **reserve** design for biodiversity conservation, and (3) fundamental ecological processes such as **competition** and species coexistence.

Test whether SAR exhibits power-law behavior and assess its **robustness** under environmental perturbations and ecological dynamics.

1. When and why does the SAR follow a power-law?

- Species individuals exhibit clustering
- Abundance follows a lognormal distribution

Ref.: H. García Martín & N. Goldenfeld (2006)

2. How do population thresholds alter extinction predictions from SAR and EAR models?

- Incorrect predictions of species extinction
- Extinction-Area Relationship (EAR) provides different insights

Ref.: J. Kitzes & J. Hart (2014)

3. Will power-law persist when competitiveness is introduced?

- Extend on the findings of the baseline paper.
- Explore interspecies dynamics.

Self-Similar Distribution of Individuals

To create the pool of species we use a **Bisecting Tree Algorithm**:

For each species:

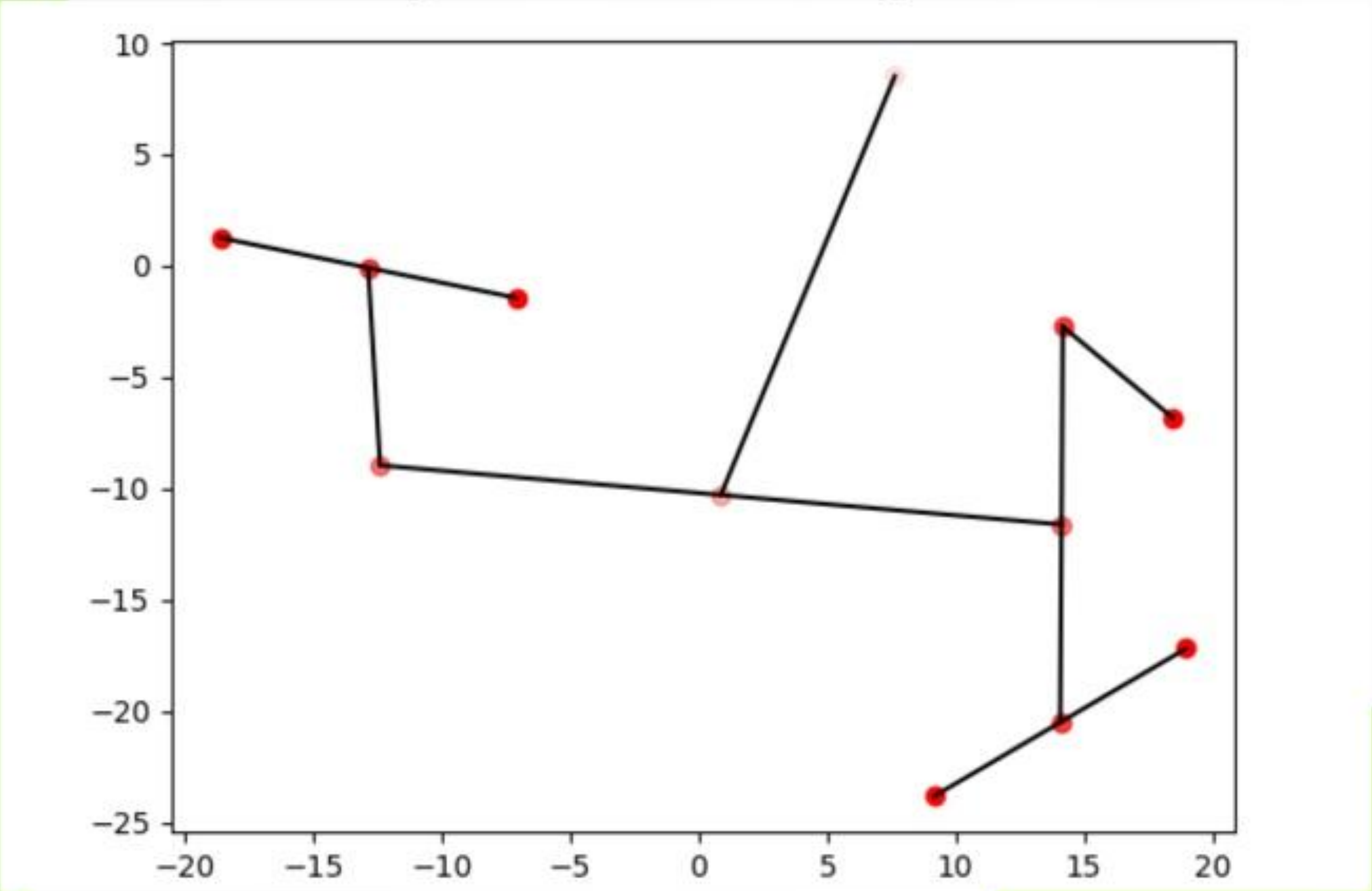
1. generate a root within a radius d from the origin
2. draw a line through the root with a random angle ϴ
3. determine left, right, or both branch based on **probability α**
4. place new points at a distance l_0
5. at each time step n for each new point (M = 14):
   - draw a new line through this point at:
   angle of parent + 90 degrees + random angle between +-δ^{max}
   - determine left, right, or both branch based on α
   - place the new points at a distance $l_0 * 1.5^{-n}$

$$\delta^{max} = \delta_0 (\Delta\delta)^{2int(n/2)m}$$

- δ_0 = base angle
- $\Delta\delta$ = range for possible angles
- n = current branch
- m = total amount of branches

*

Example of branching tree



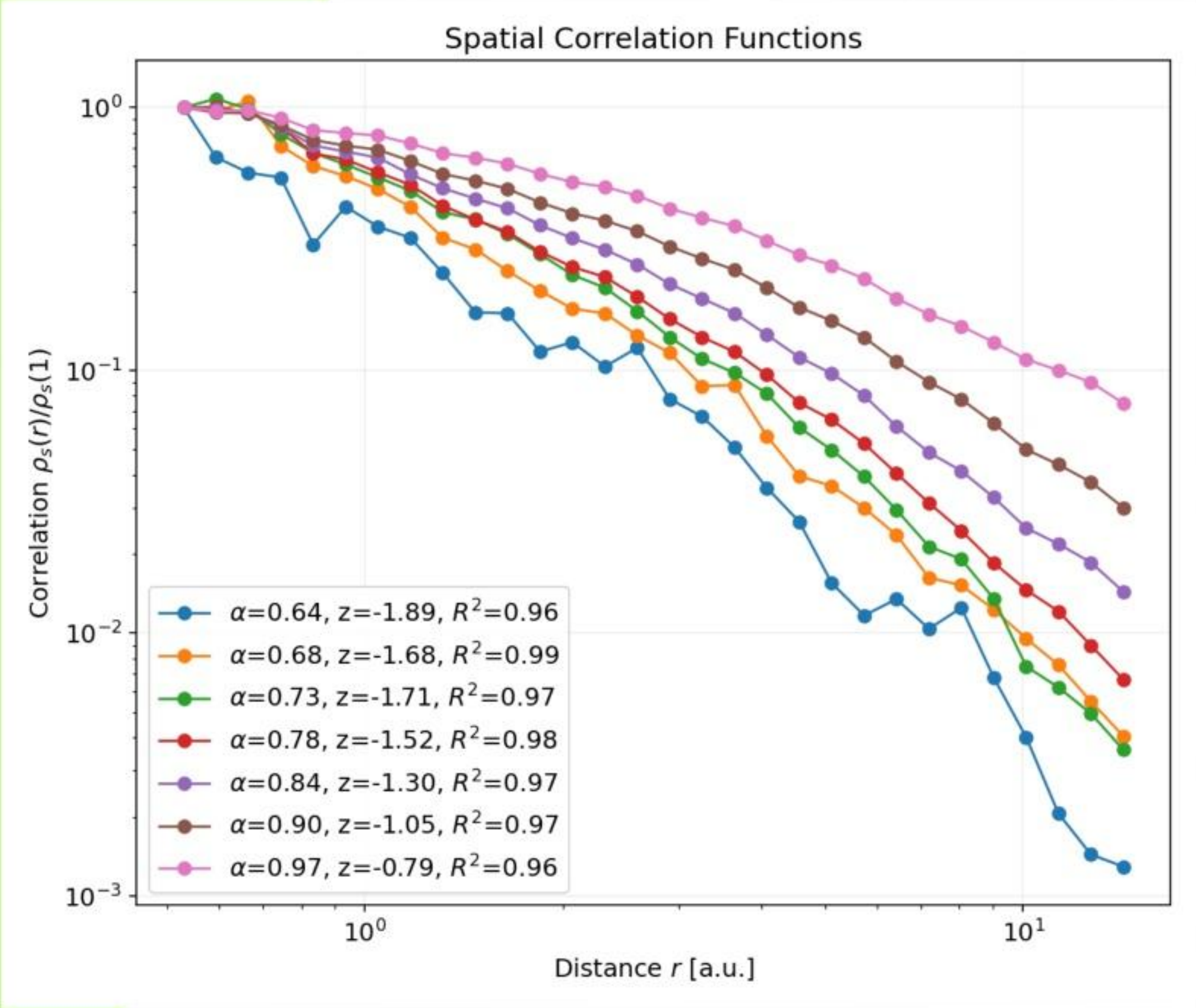
* different from H. García Martín & N. Goldenfeld (2006) paper

Self-Similar Distribution of Individuals

To create the pool of species we use a **Bisecting Tree Algorithm**:

- Self-similar **clusters** that exhibit a **power-law correlation function**.

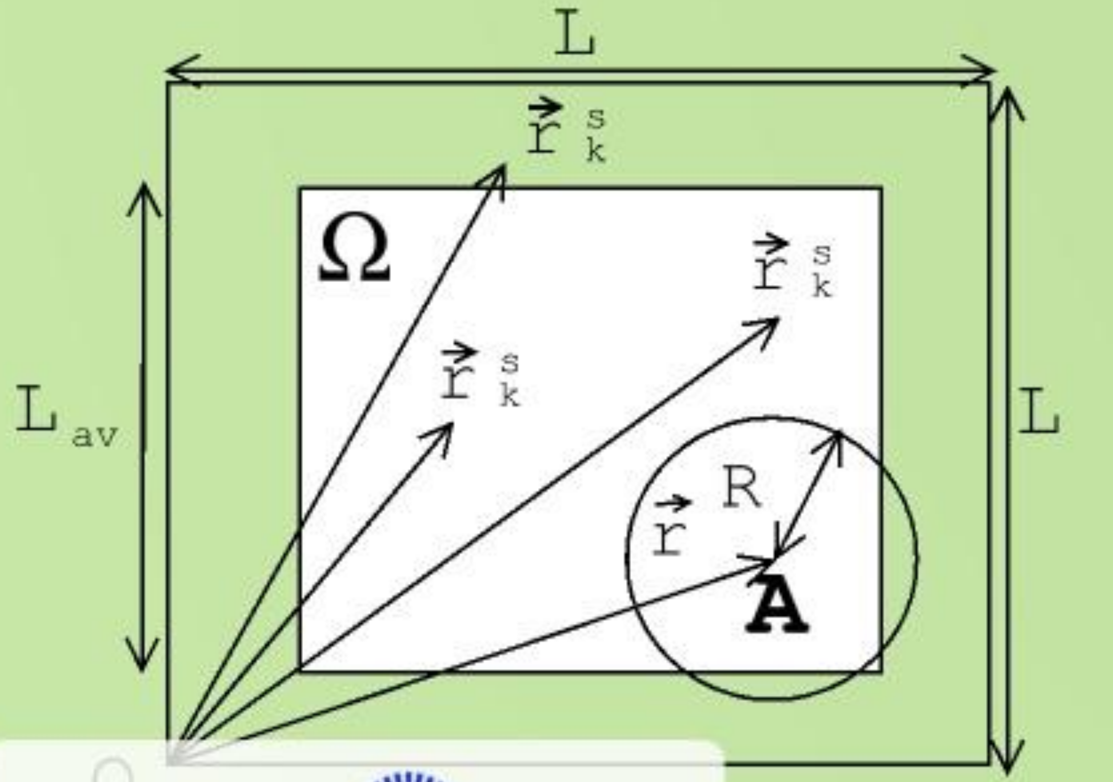
$\rho_{s(r)}$: probability that two individuals of species s are at a distance r from each other.



Towards a Power-Law SAR

Species richness S(A) emerges from **extreme value statistics**: species are counted based on **proximity to their nearest individual.**

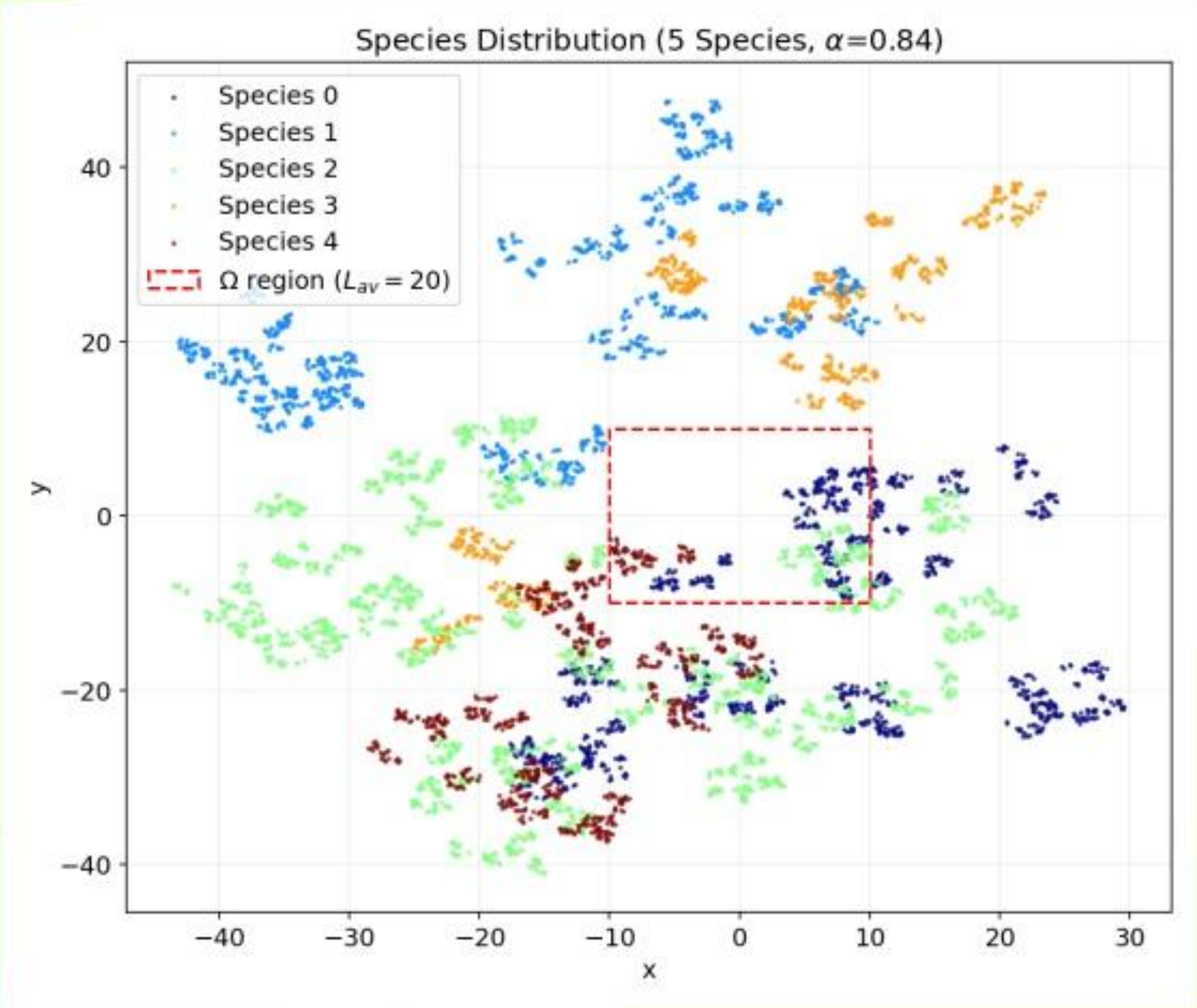
Assume that there are S species with n_s individuals in landscape Ω.
To count the number of species:
1. Sample random points r in Ω
2. Around each point, consider circle of radius R (area A = πR²)
3. Species s is PRESENT if: **distance to nearest individual of s < R**
4. Average species count over all sample points



from H. García-Martín & N. Goldenfeld (2006)

$$S_c(R) = \sum_s F_s(R) = \int_0^{C_{max}} h(R,c)p(c)dc$$

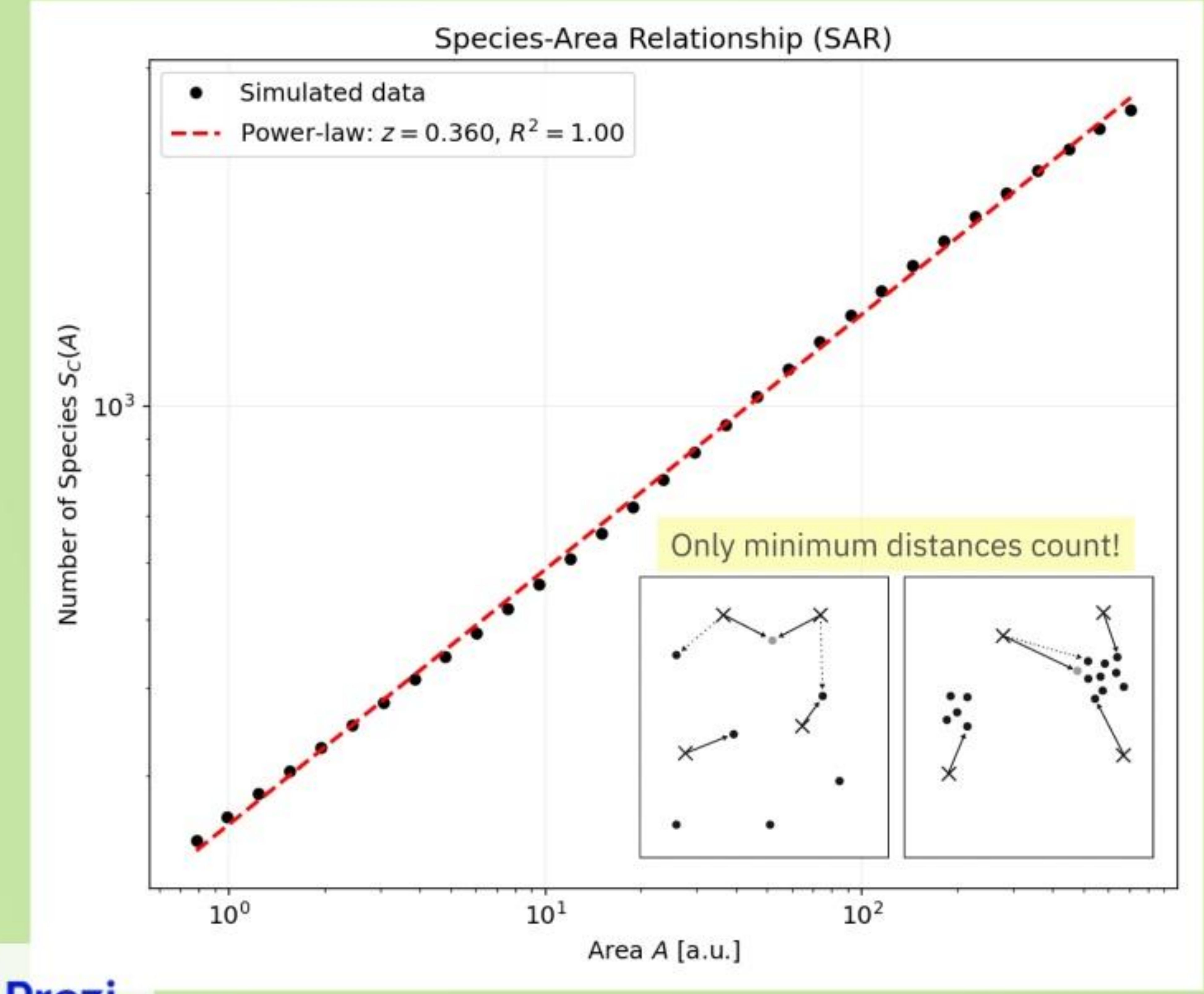
- Fs(R) = probability species s is within R (proximity f.)
- h(R,c) = prob. of finding species with abundance c inside radius R
- p(c) = abundance distribution (lognormal)
- c = abundance, # of individuals of a specie

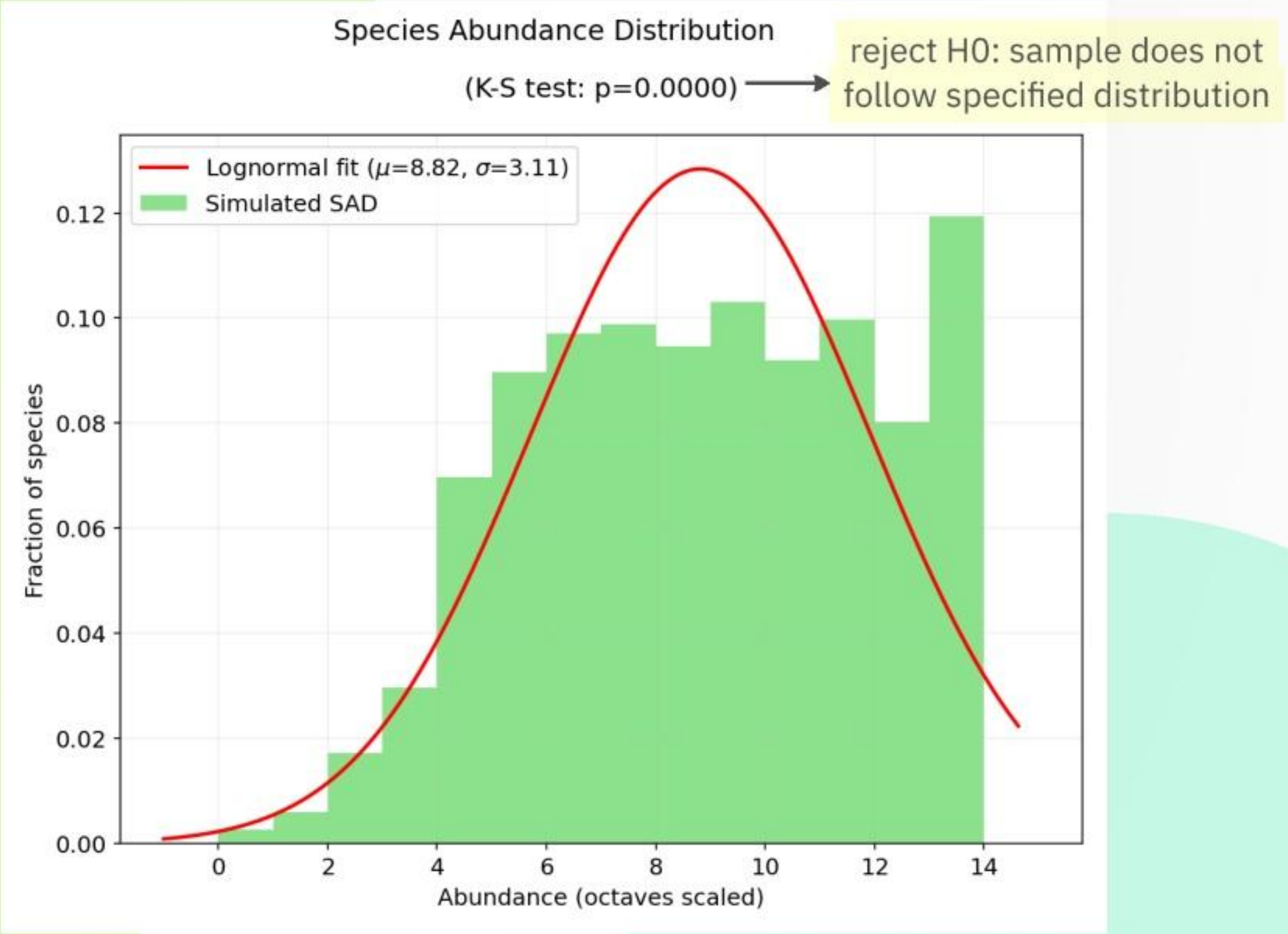


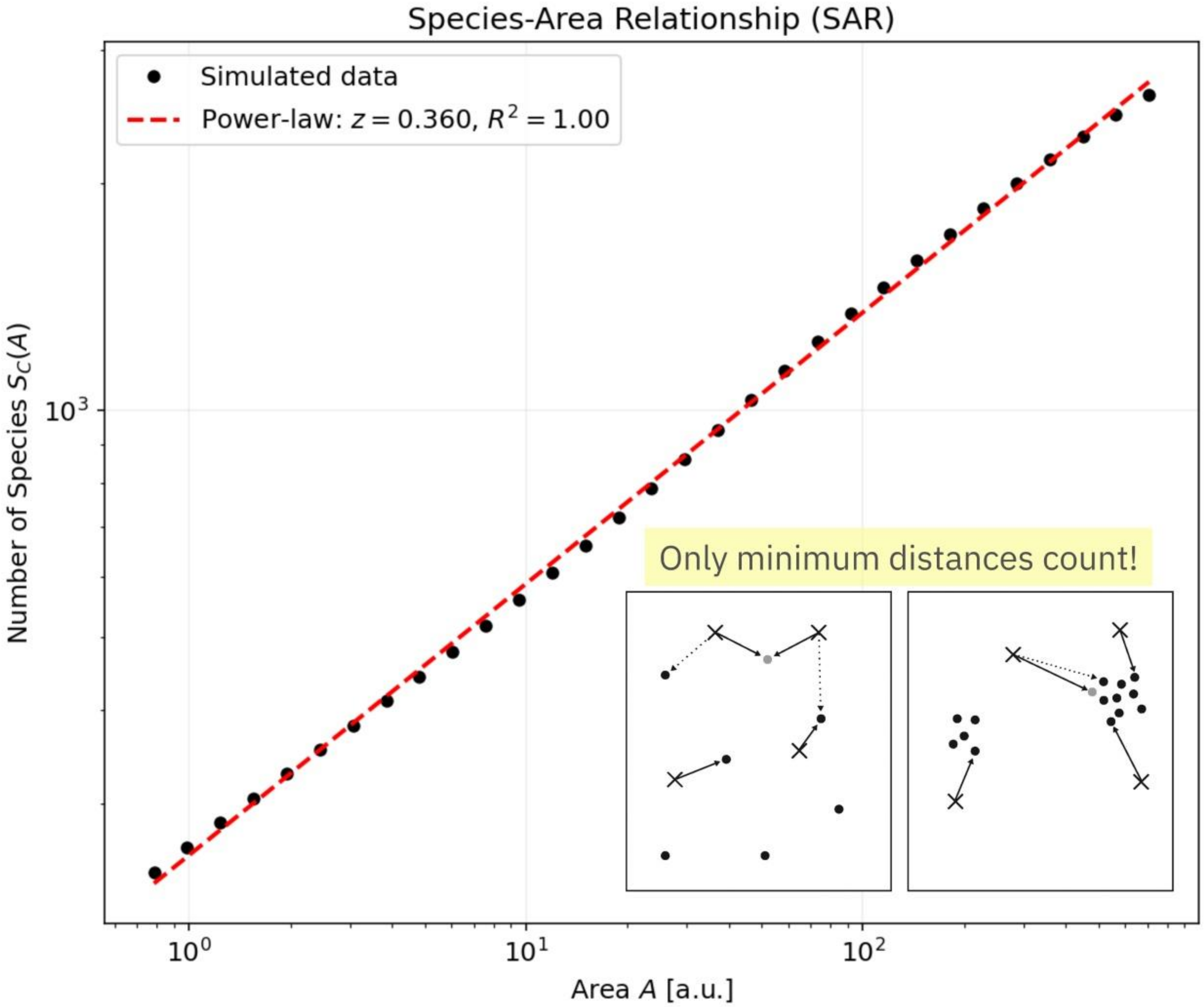
Example of branching process for 5 species out of the 500 generated for α = 0.84 (3500, in total)

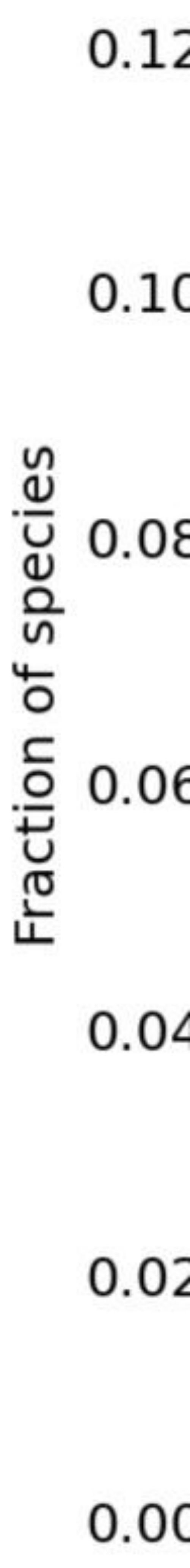
Towards a Power-Law SAR

With **clustering** (and *lognormal* abundance) **species-area relationship** exhibits **power-law**. The coefficient z = 0.36 is within the biologically expected range [0.2, 0.4].






Species-Area Relationship (SAR)
Simulated data
Power-law: $z = 0.360$, $R^2 = 1.00$
Number of Species $S_C(A)$
10^3
10^0
10^1
10^2
Area A [a.u.]
Only minimum distances count!


Fraction of species
0.12
0.10
0.08
0.06
0.04
0.02
0.00

Introducing the Extinction-Area Relationship

? Can SAR predict extinction due to habitat loss?

Species-Area Relationship (SAR)

1. An estimate is given of the number of species expected to go extinct
2. Extinction is predicted across all species
3. A species is considered protected if a single individual is present

Extinction-Area Relationship (EAR)

from Kitzes et al.

→ Probability of extinction

→ Look at individual species

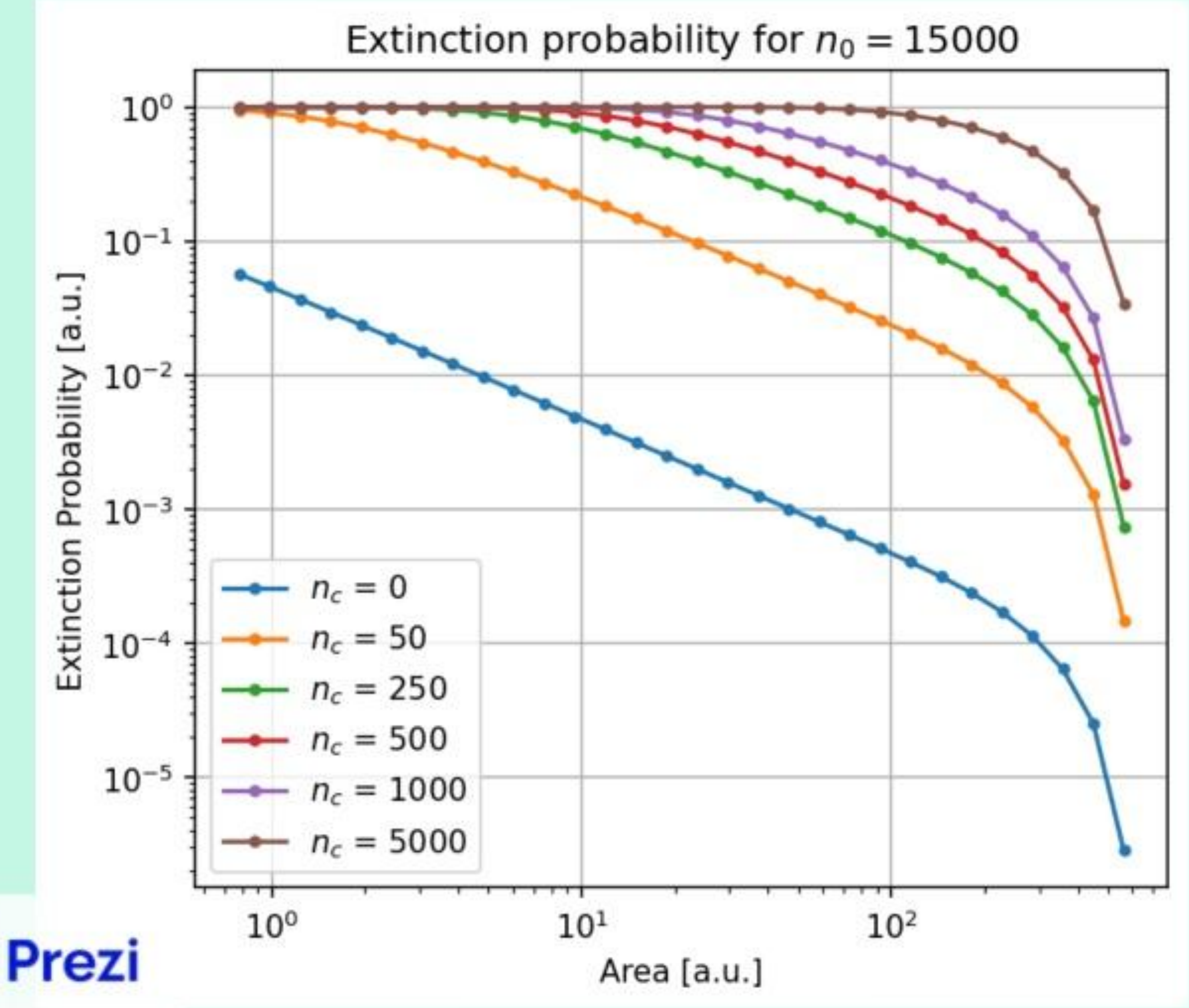
→ Critical abundance: how many individuals necessary for species to survive

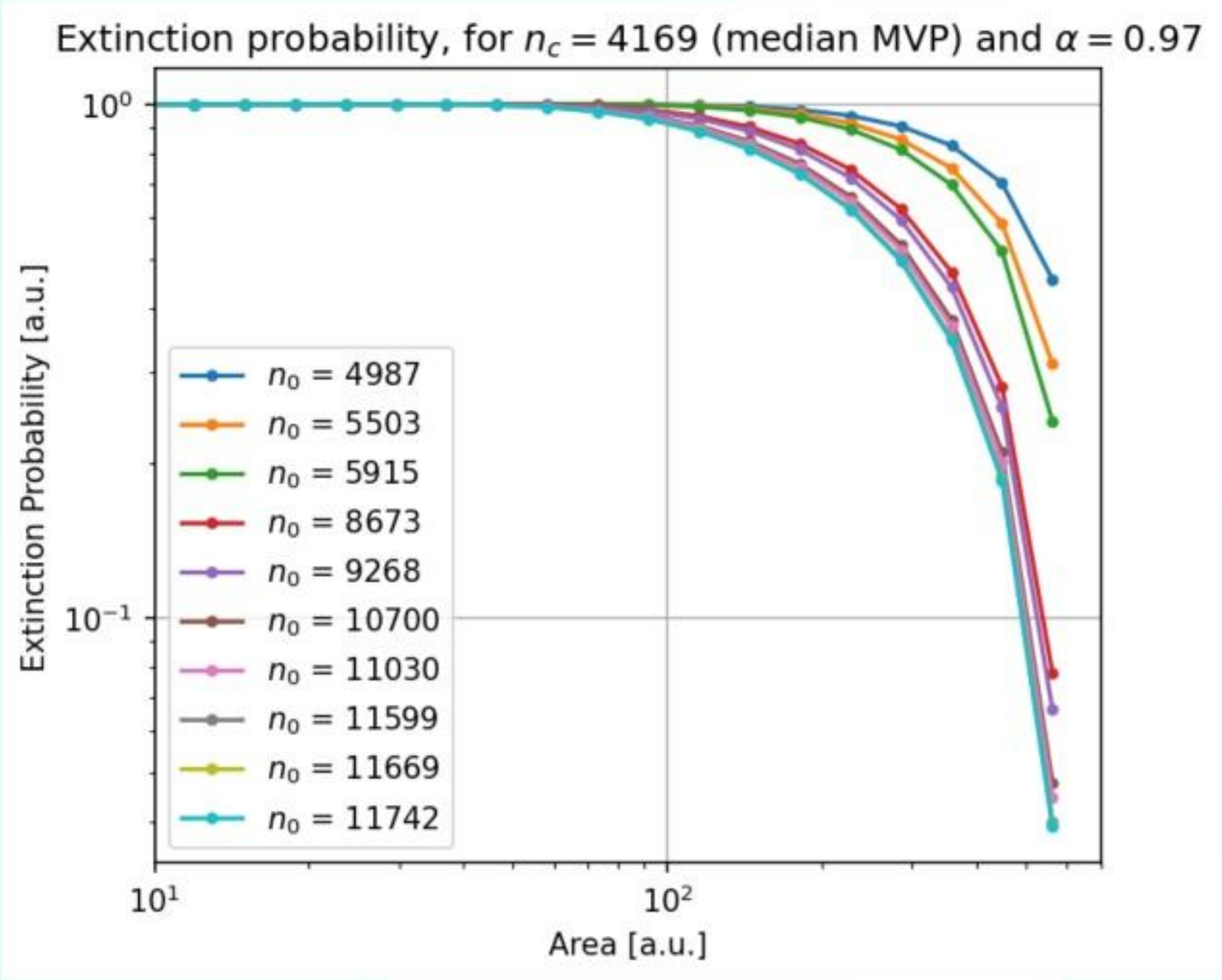
The Extinction-Area Relationship

$$a n_0 = \frac{q}{1-q} - \frac{(n_0+1)q^{n_0+1}}{1-q^{n_0+1}}$$

$$\mathrm{EAR} = \frac{q^{n_c+1}-1}{q^{n_0+1}-1}$$

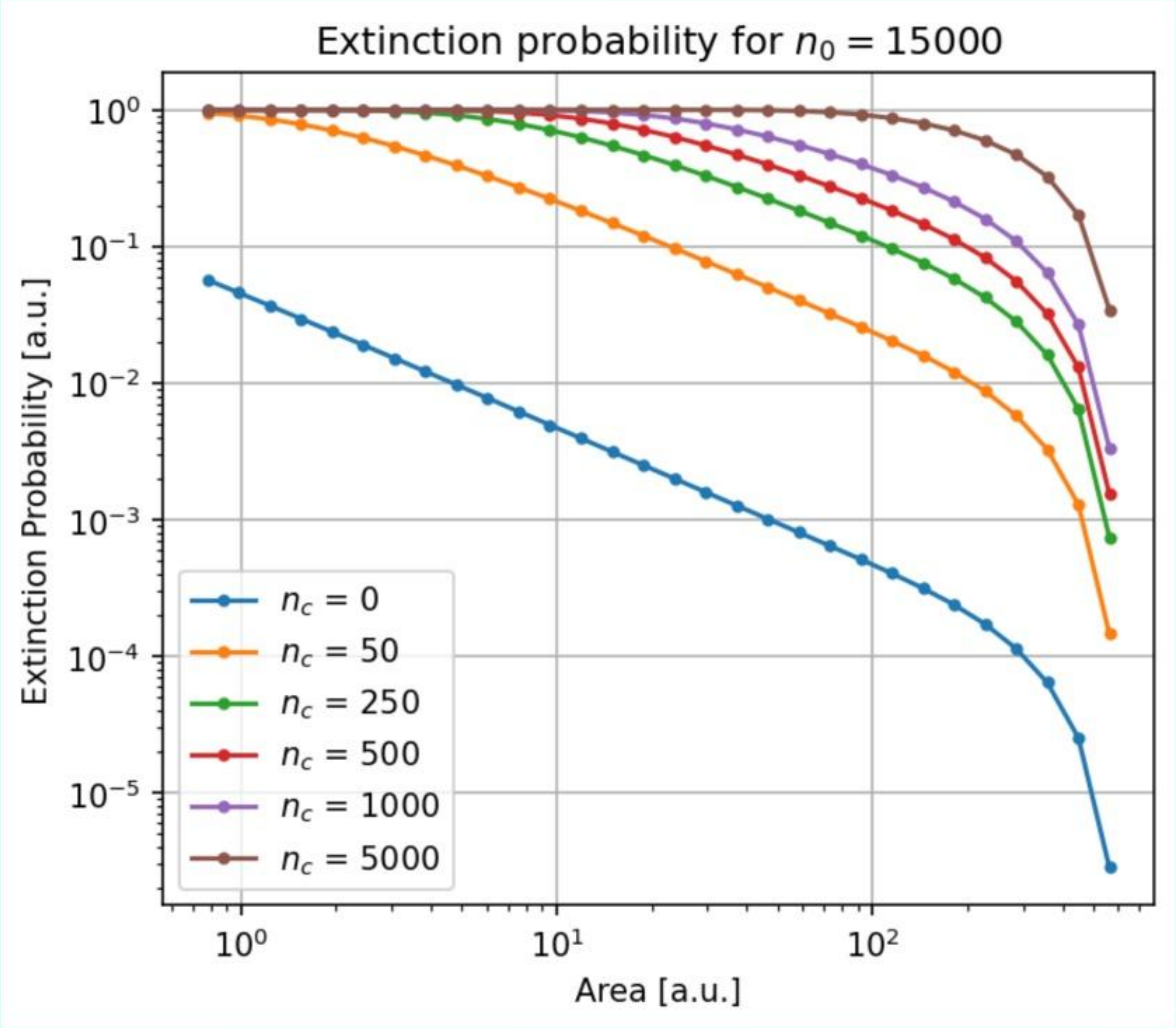
- Dependent on **fractional area loss (*a*), initial abundance (*n0*)** and **critical abundance (*n_c*)**
- Determine constant *q = [0,1]* through numerical root finding
- Get *n_c* through minimum viable population size (*Traill et al.*)

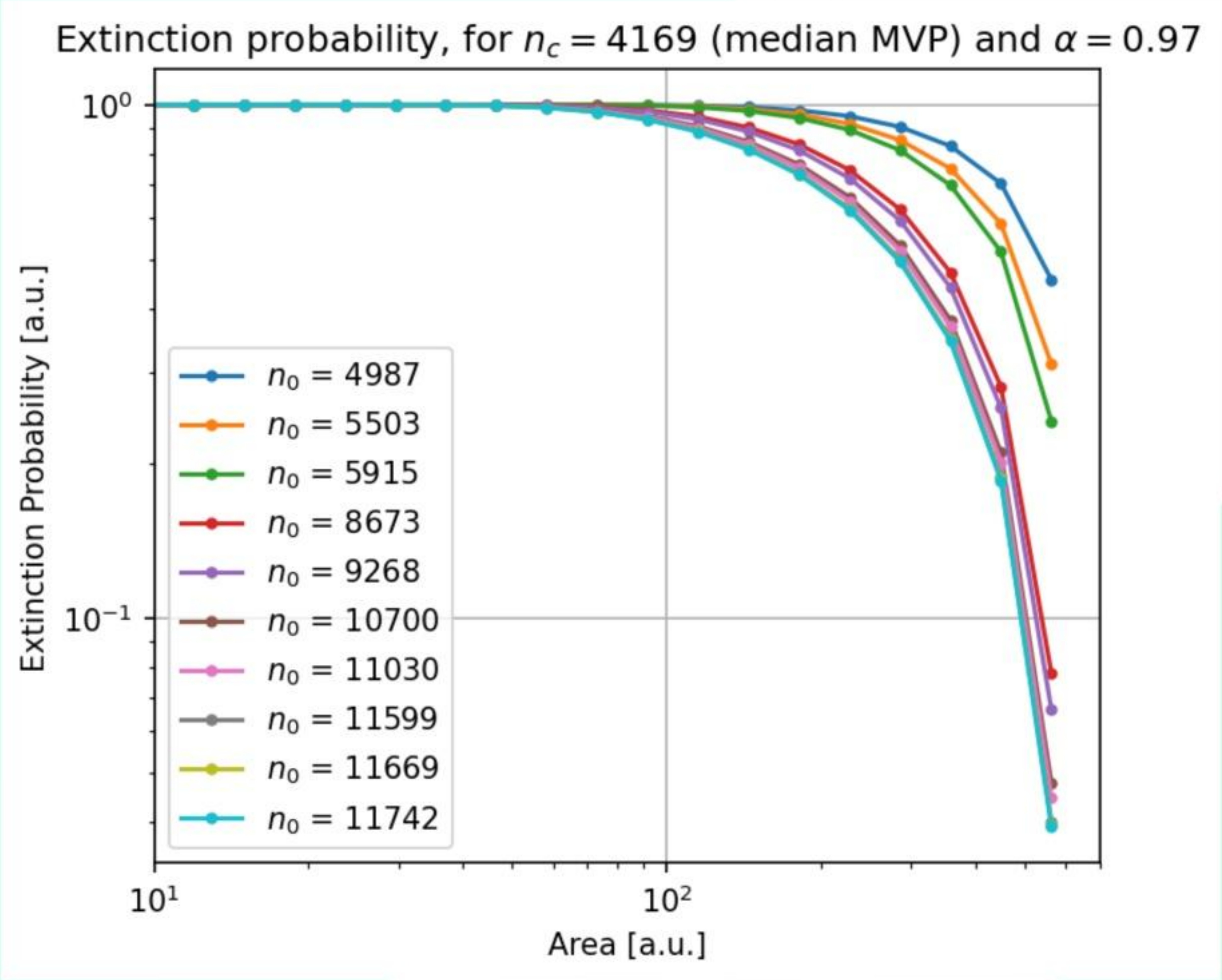




Determine constant $q = [0,1]$ through numerical root finding

et n_c through minimum viable population size (*Traill et al.*)





Limitations to EAR

→ Interspecies interactions are not taken into account

→ Extinction is dependent on more than just area loss

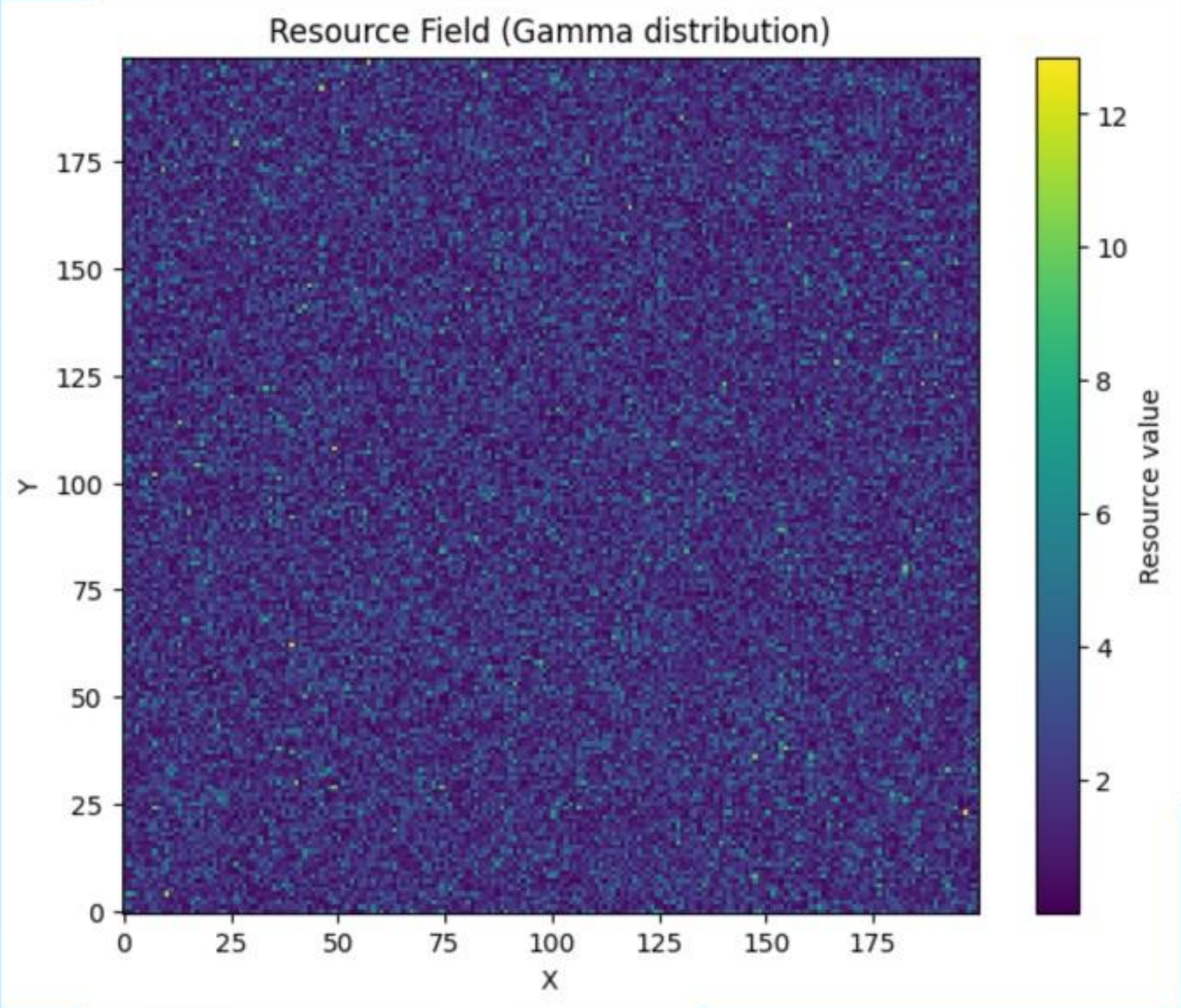
→ Resource competition and depletion

Adding Resource Competitiveness

? Is the SAR power-law affected when competition for resources is introduced?

As an extension to the baseline paper Martìn et al.:

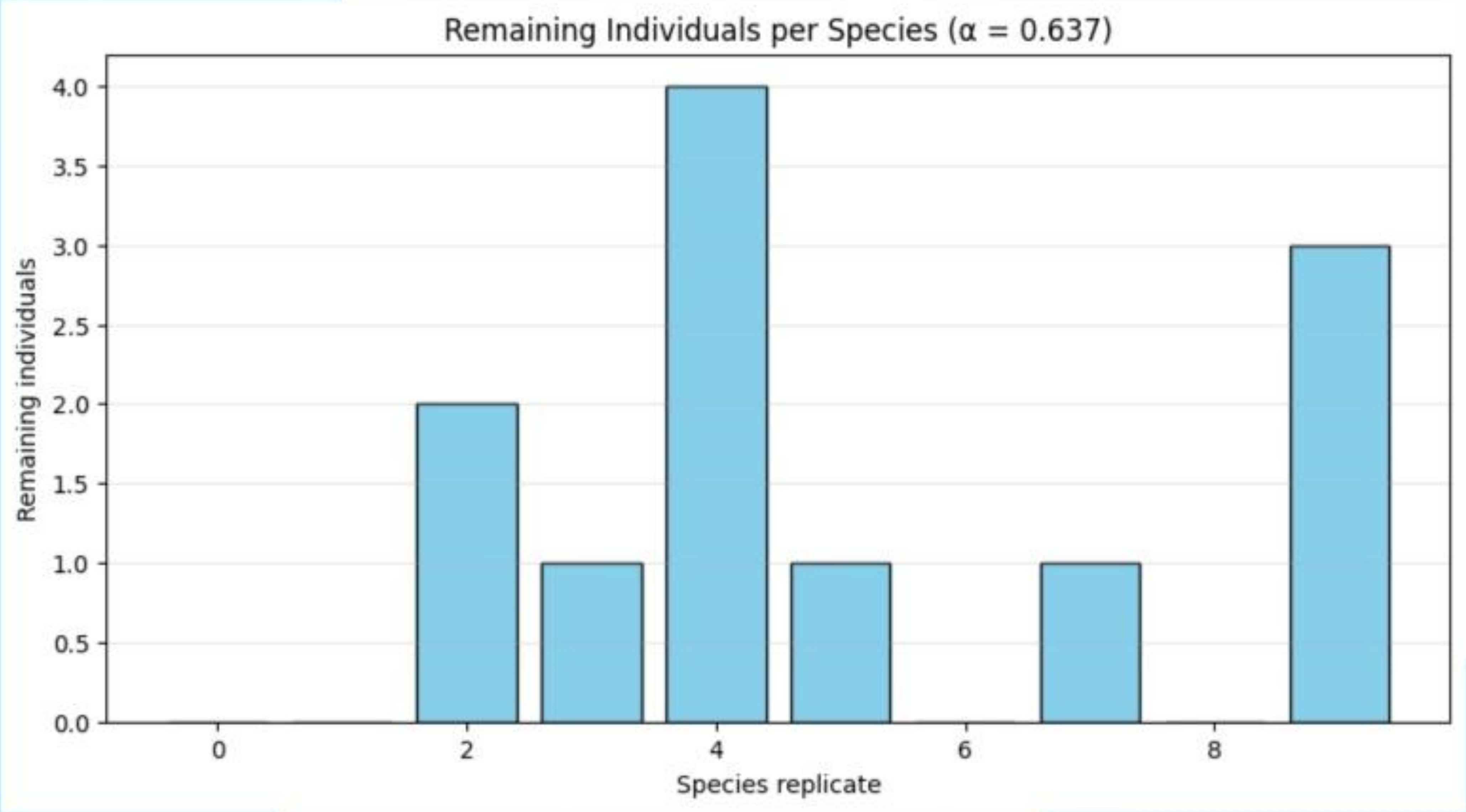
- To explore competition we introduce two new parameters; a **resource** and a **species specific competition value.**
- Resources are allocated according to a Gamma distribution applied to a grid.
- This ensures each species is allocated a positive resource while ensuring a realistic distribution.



Setting Up the Competition

→ To explore competition between species we define a competition parameter of varying strengths.

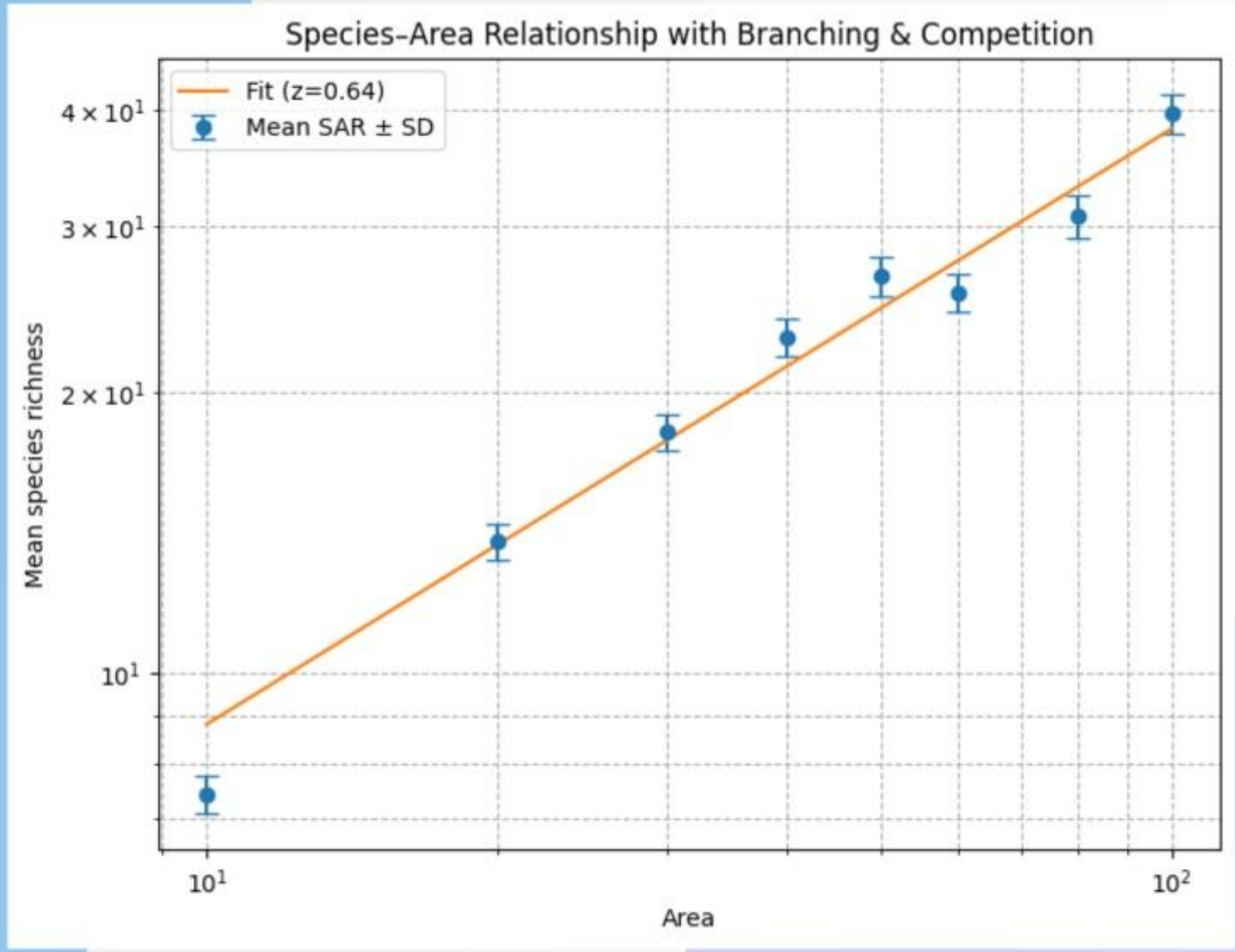
- We define a radius of competition where **all species within this radius compete with one another.**
- Next, a **threshold of resources** is defined
- If an individual has less then the threshold, they die.
- We can then compute the **surviving population** for each species.



Power-Law with Competition

→ Using the resource grid and the competition values, we can determine whether resource competition effects the power law property.

- We consider **several grid sizes and compute SAR** running the competition grid 50 times, producing a mean value at each grid size.
- A power law is then fitted to the results to compute the z-value.
- We observe **z = 0.64**, indicating that introducing resource competition results in strong spatial clustering and high species turnover.



Conclusions

✅ **Baseline validation**: clustering is what matters to obtain a **power-law SAR**

But...

1. External factors for **Habitat loss** disrupts power-law behavior
   → EAR improves probability of extinction measures

2. **Resource competition** modifies equilibria
   → Species interactions affect spatial patterns

Multiple factors beyond geometry matter!

References

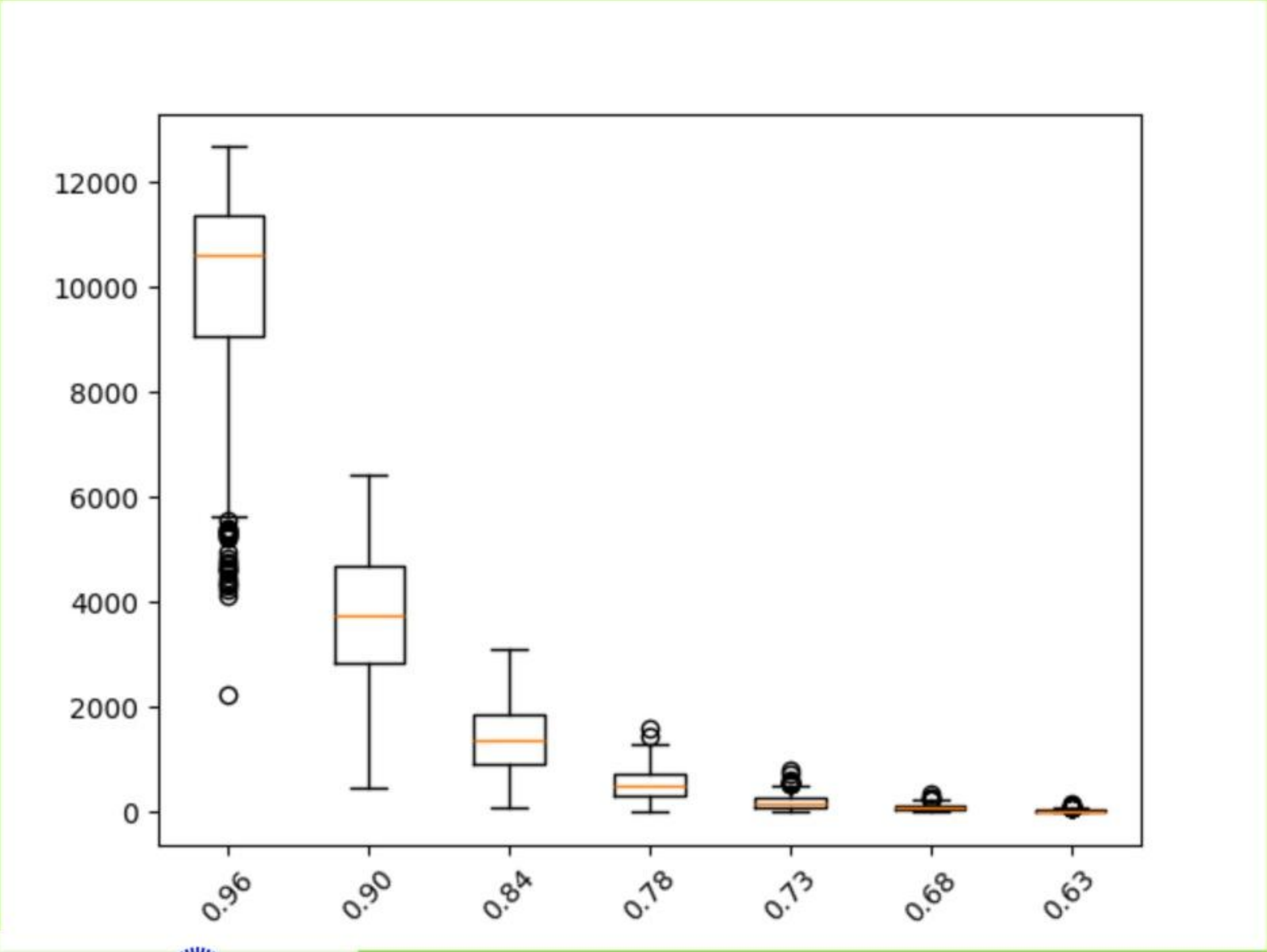
- *H García Martín and Nigel Goldenfeld*. “On the origin and robustness of power-law species-area relationships in ecology”. In: Proceedings of the National Academy of Sciences (2006). DOI: https://doi.org/10.1073/pnas.0510605103

- *Justin Kitzes and John Harte*. “Beyond the species–area relationship: improving macroecological extinction estimates”. In: Methods in Ecology and Evolution 5.1 (2014), pp. 1–8. DOI: https://doi.org/10.1111/2041-210X.12130

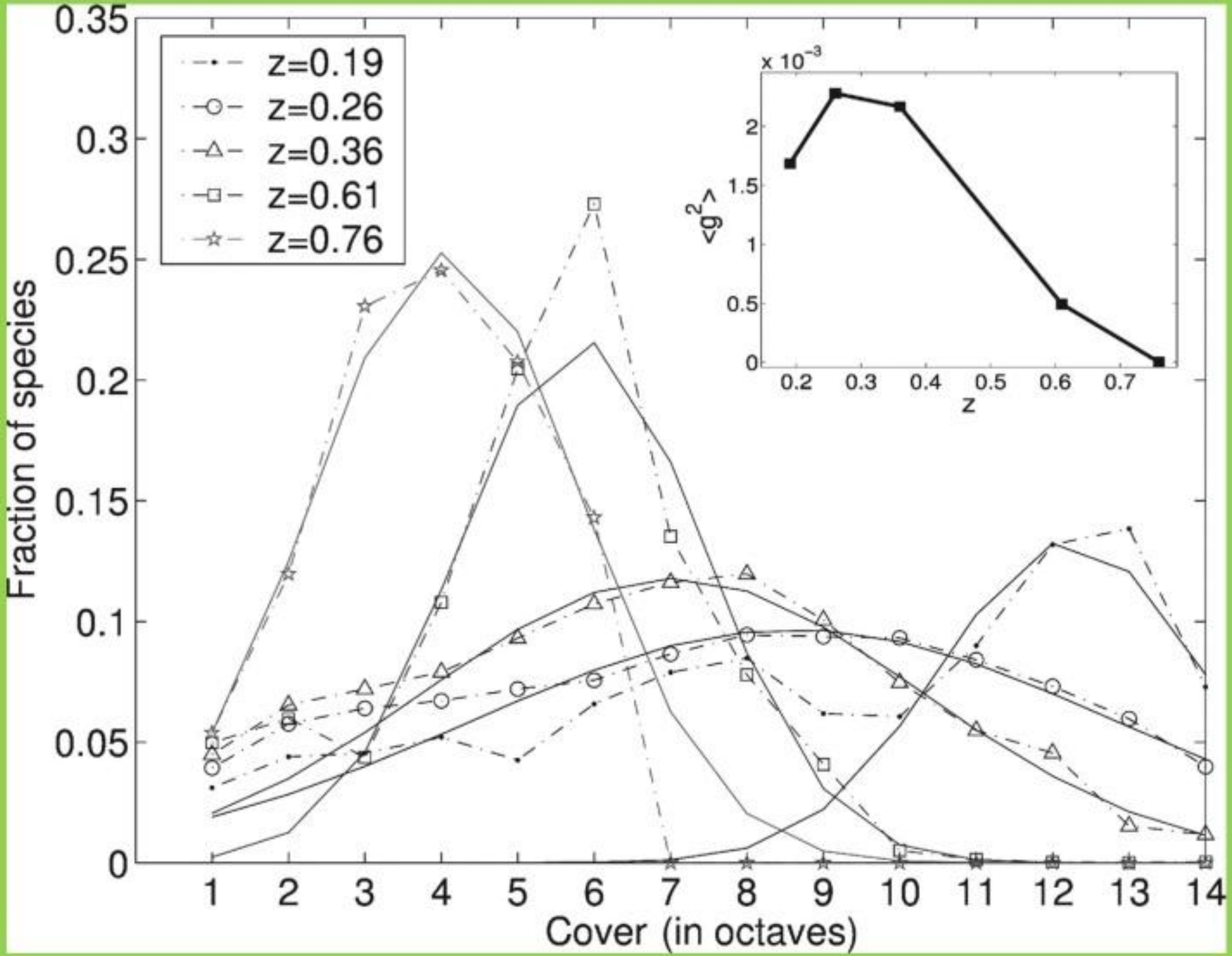
- *Lochran W. Traill, Corey J.A. Bradshaw, and Barry W. Brook*. “Minimum viable population size: A meta-analysis of 30 years of published estimates”. In: Biological Conservation 139.1 (2007), pp. 159–166. issn: 0006-3207. DOI: https://doi-org.vu-nl.idm.oclc.org/10.1016/j.biocon.2007.06.011

Appendix

- Number of individuals generated per alpha



- **Results from the paper**
  - why does z belongs to the 0.2 and 0.4 interval?



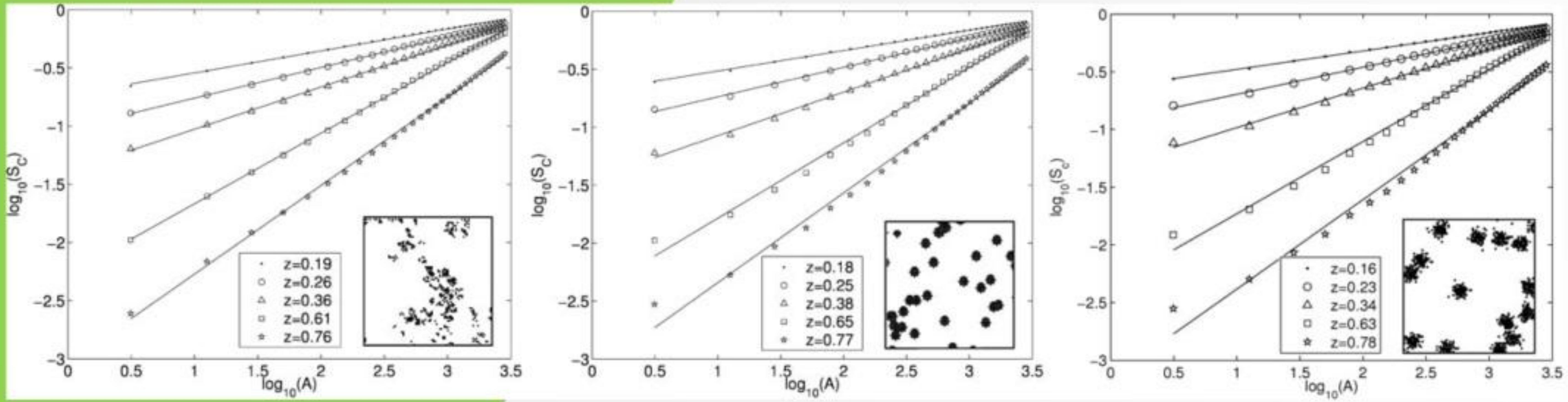
Degeneracy:
range of abundance distributions that could create specific power law, as z change

$$
\begin{aligned}
S_C(R) &= \sum_s F\left(\frac{R-\langle R\rangle^s}{\sigma_s}\right) \\
&= \int_0^{R_m}\int_0^{C_{max}} g(r,c)p(c)F\left(\frac{R-r}{\sigma(r)}\right) dr\,dc \\
&= \int_0^{C_{max}}\int_0^{R_m} g(r,c)F\left(\frac{R-r}{\sigma(r)}\right) p(c)\,dr\,dc \\
&= \int_0^{C_{max}} h(R,c)p(c)\,dc \qquad [18]
\end{aligned}
$$

Discretizating...

$$\hat{S}_{Ci} = \sum_j H_{i,j} P_j \qquad [20]$$

- Self-similar (left), compact cluster (center), and Gaussian cluster distributions (right) of individuals



- Self-similar (left), compact cluster (center), and Gaussian cluster distributions (right) of individuals

Prezi

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