Clustering and Phase Transitions on a *Neutral* Landscape

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Context & Motivation

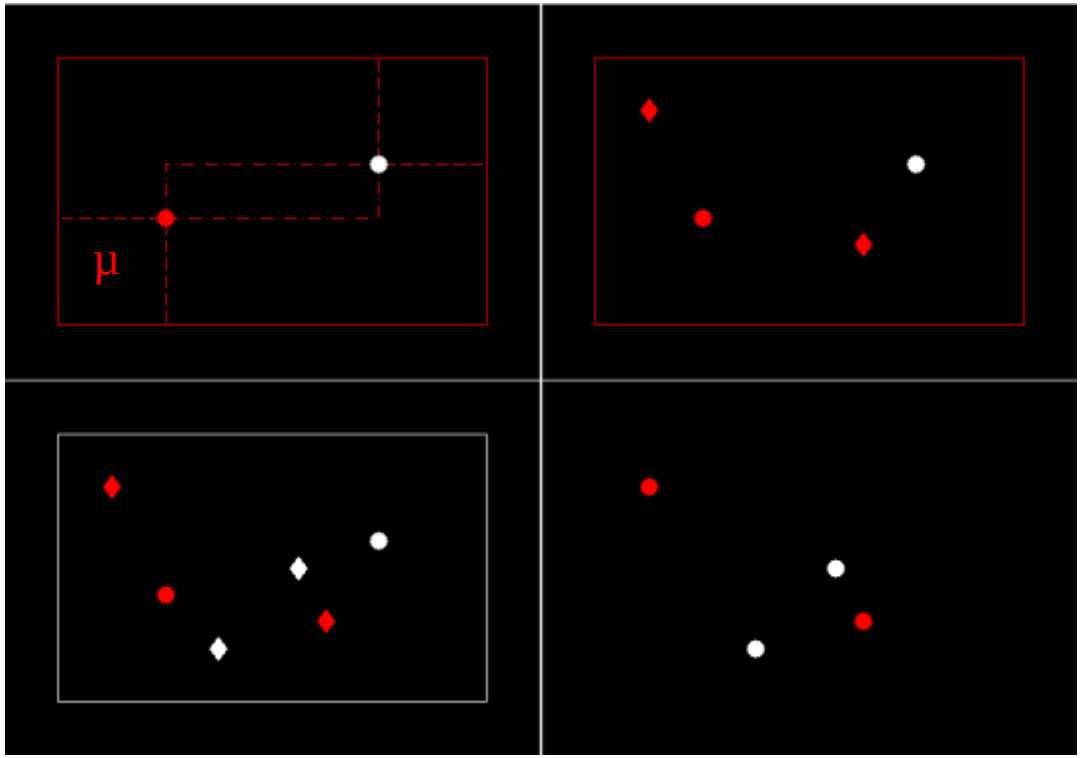
- Phenotype space with *sympatric* speciation
  - Possibility vs. prevalence
- Applicability
  - Example: microbes in hot springs in Kamchatka, Russia (study by Whitaker @ University of Illinois)
- Percolation
- Branching & Annihilating Random Walks
- Role of mutation parameters as drivers of speciation
  - Evolution = f(evolvability)

Model: Landscape

- Phenotype space (morphospace)
  - Planar: two independent, arbitrary, and continuous phenotypes
  - Non-periodic boundary conditions
- Neutral fitness
  - Hubbell
  - 2 offspring generated per organism

Model: Mutation Parameter

- Mutation parameter -> mutability
  - Ability to mutate about parent(s)
  - Maximum mutation size
  - All organisms have the same mutability
  - Offspring uniformly generated



Example of assortative mating

Model: Reproduction Schemes

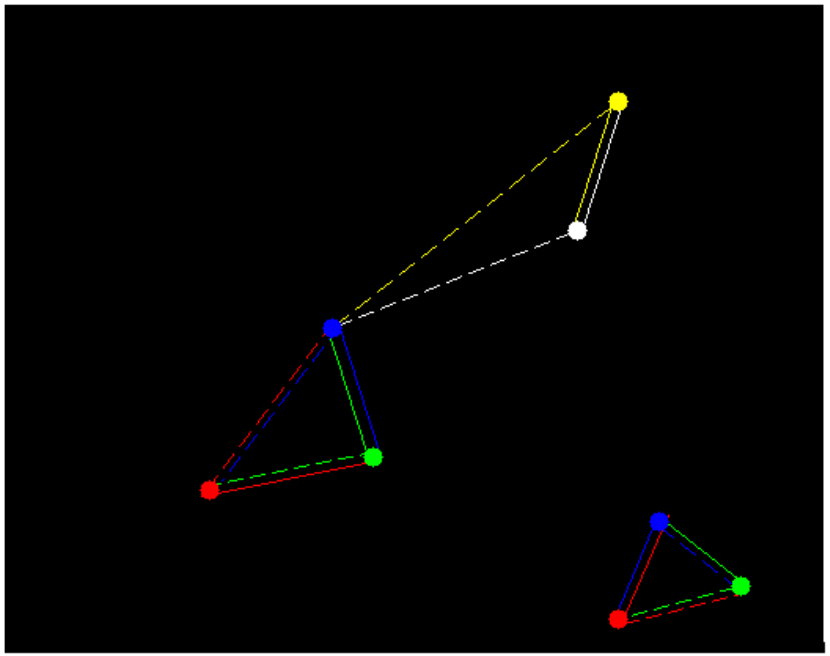
- Assortative Mating
  - Nearest neighbor is mate
- Asexual Fission
  - Offspring generation area is 2μ*2μ with parent at center
- Random Mating
  - Randomly assigned mates

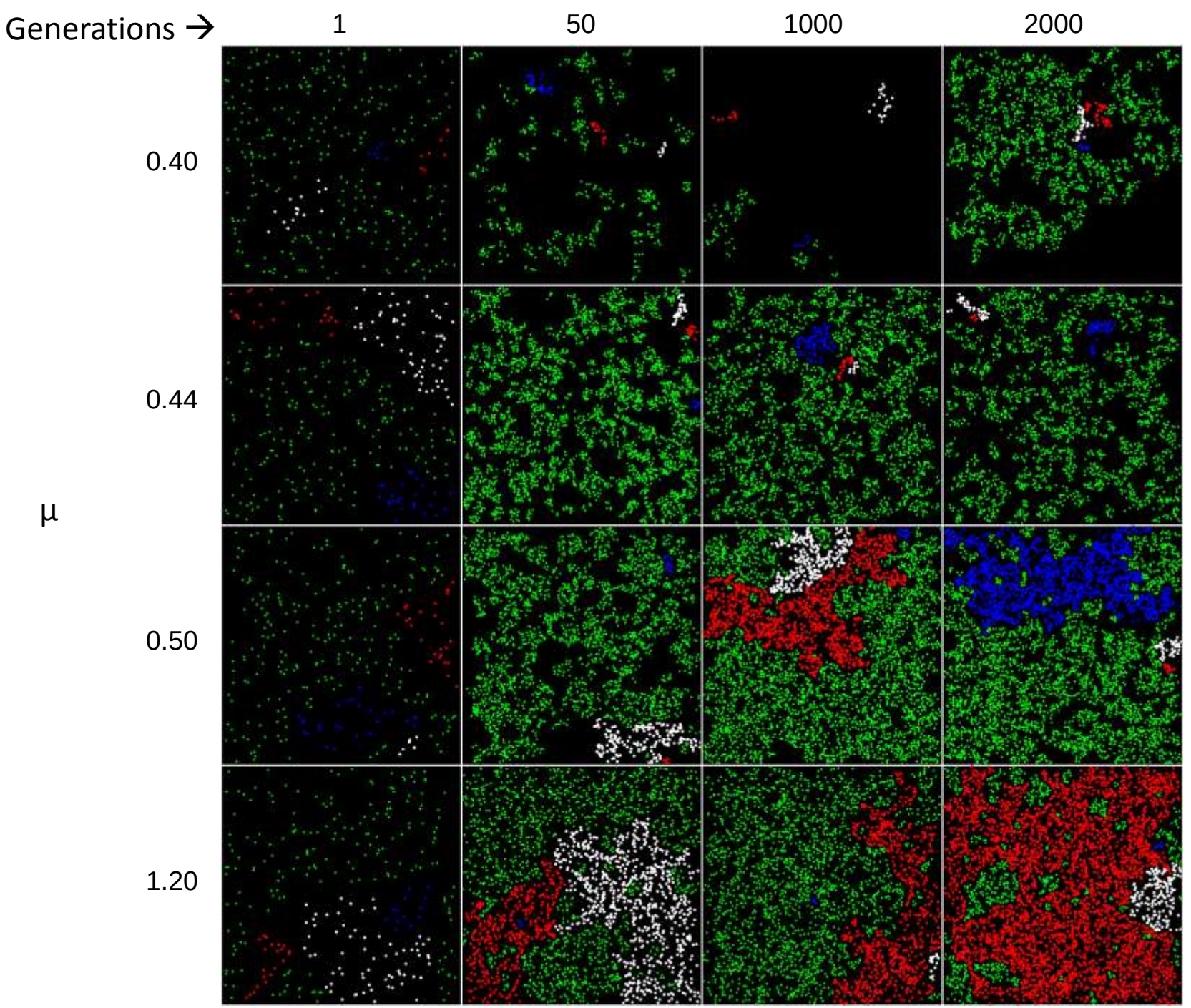
Model: Death

- “Overpopulation”
  - Offspring generated too close to each other
- Random
  - Random proportion of population (up to 70%)
  - “Lottery”
- Boundary
  - Offspring “cliff-jumping”

Model: Clusters

- Clusters seeded by nearest neighbor & second nearest neighbor of a reference organism
  - A closed set of cluster seed relationships make a cluster = species
- Speciation
  - Sympatric



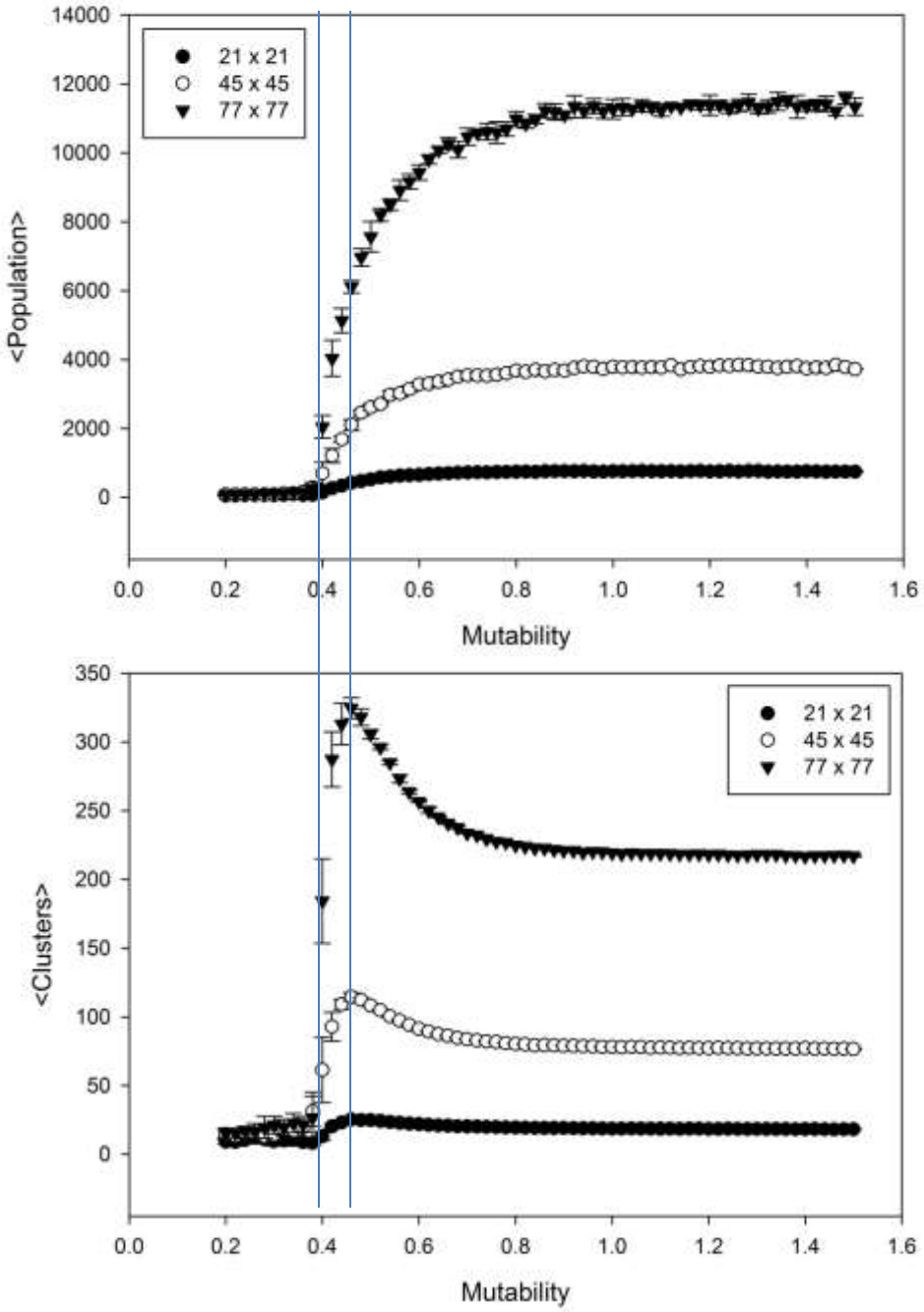

Generations →
1
50
1000
2000
0.40
0.44
μ
0.50
1.20

Assortative Mating

- Potential phase transition
  - Extinction to Survival
  - Non-equilibrium
    - Extinction regime = absorbing phase
  - Critical range of mutability
    - Large fluctuations
    - Power-law species abundances
  - Directed percolation universality class?

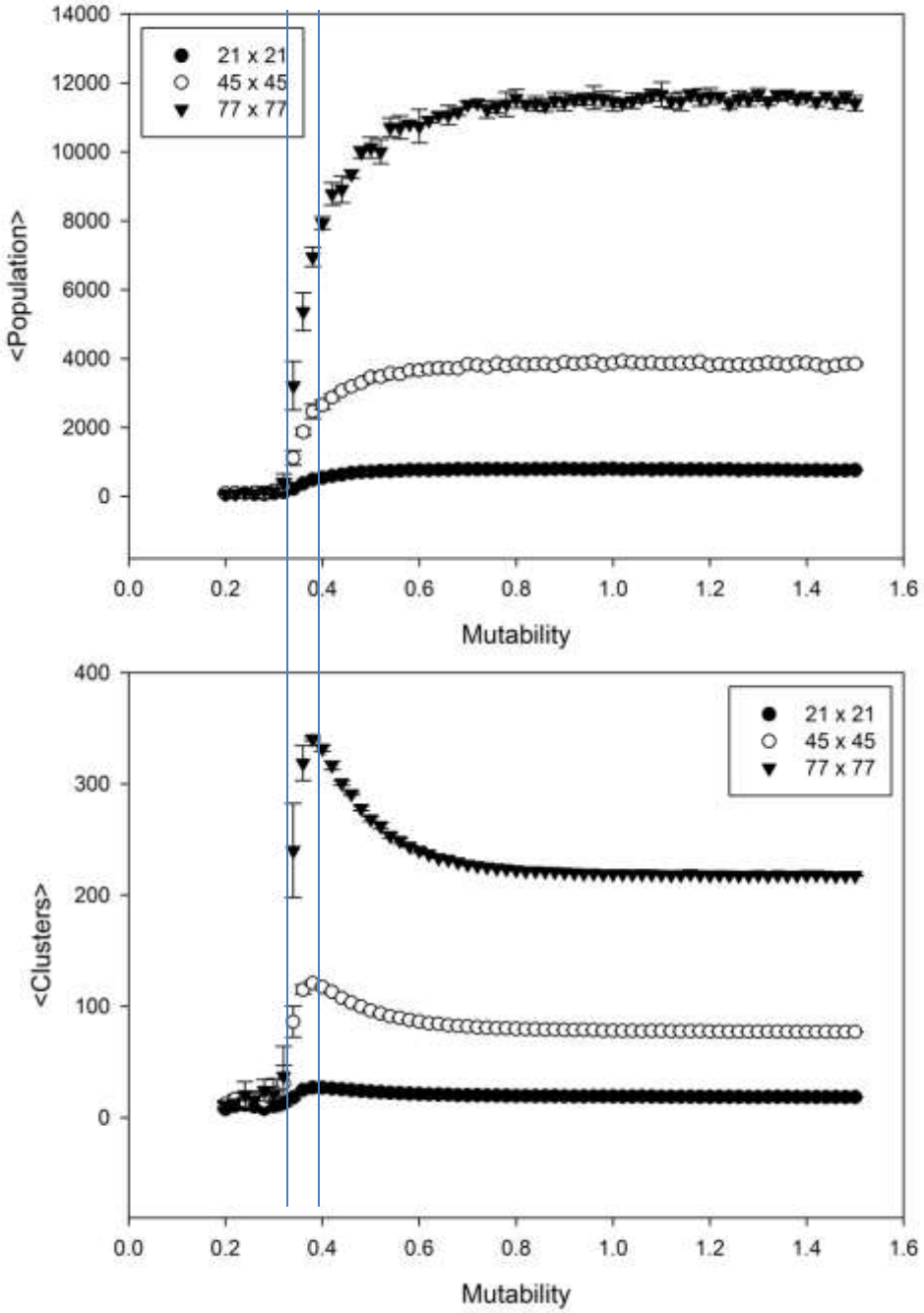
- Peak in clusters → Quality

(Values averaged over surviving generations, then averaged over 5 runs)

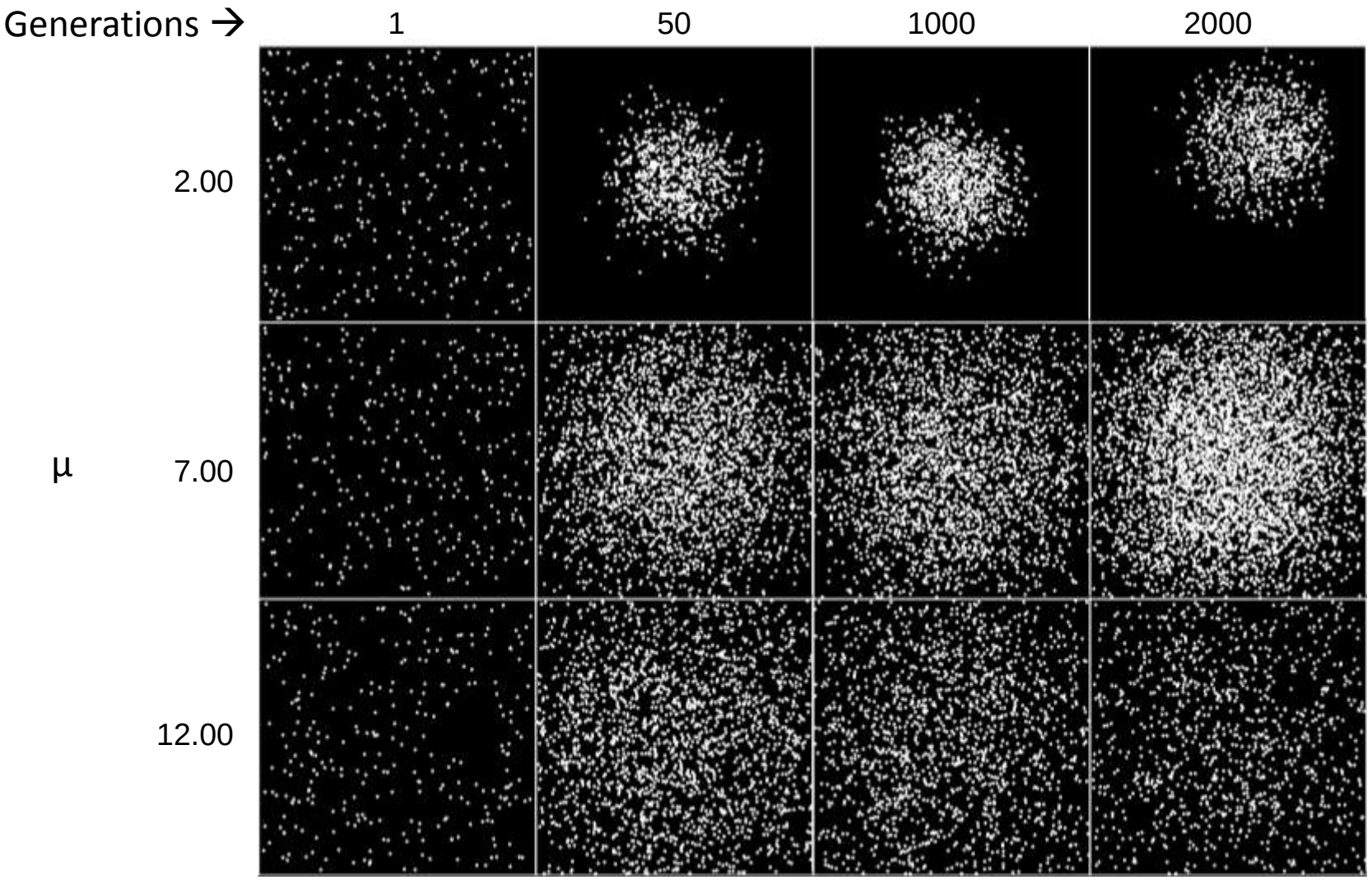


Asexual Fission

- Slightly smaller critical mutability
- Same phase transition indicators
- Same peak in clusters
- Similar results for rugged landscape with Assortative Mating



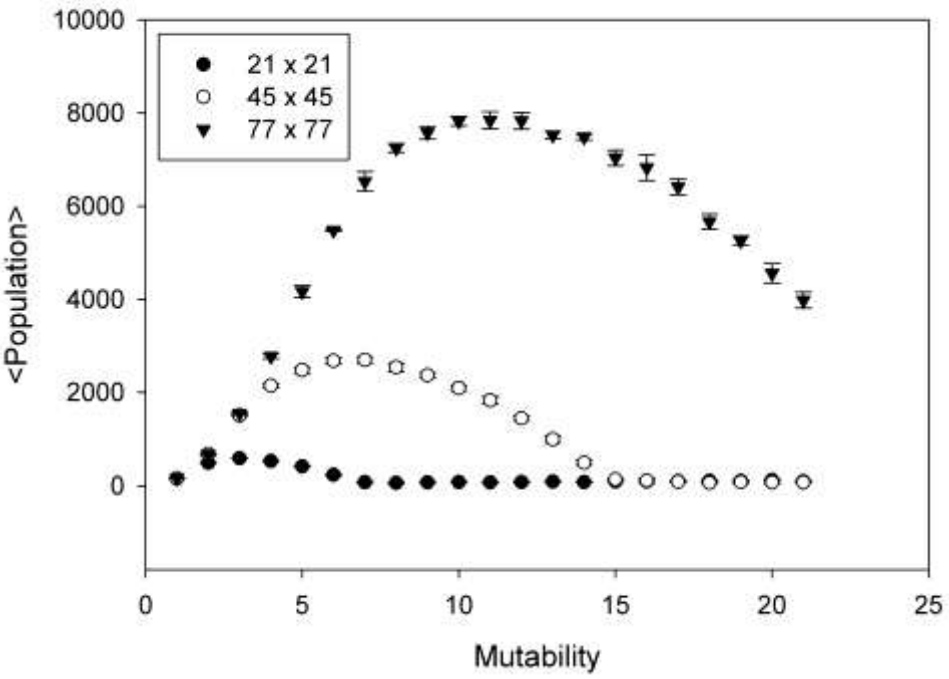
Control case: Random mating

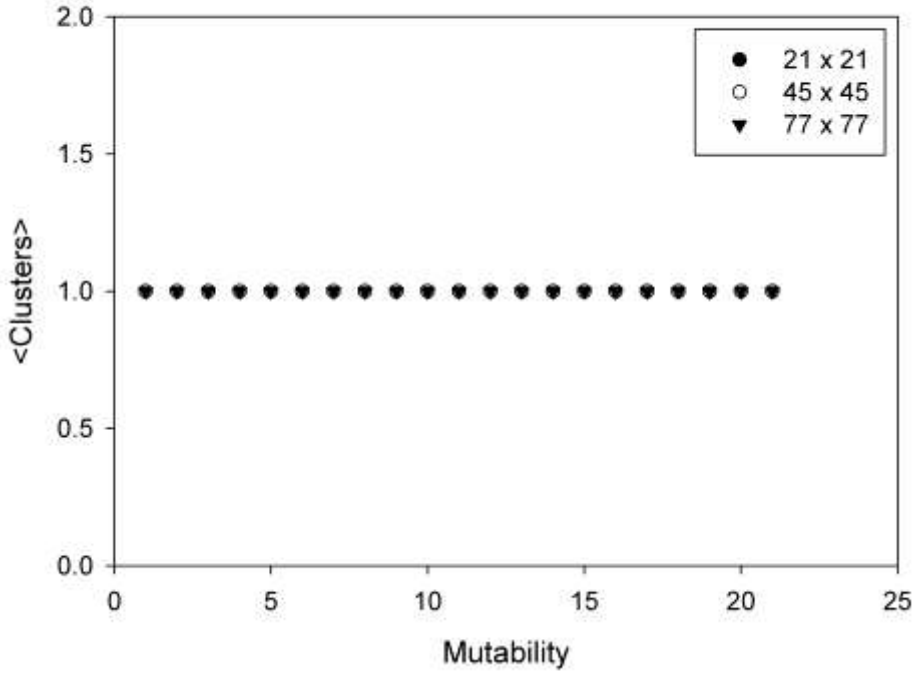


Random Mating

- Population peak driven by mutability & landscape size comparison
- No speciation
- Almost always one giant component

- *Local birth not guaranteed!*





Conclusions

- In our model:
  - Mutability -> control parameter
    - Population & clusters as order parameters
    - Continuous phase transition
      - extinction = absorbing phase
    - Directed percolation universality class?
  - Speciation requirements
    - Local birth/ global death (Young, et al.)
    - Only phenotype space (compare de Aguiar, et al.)
    - For both assortative mating and asexual fission

Related Sources

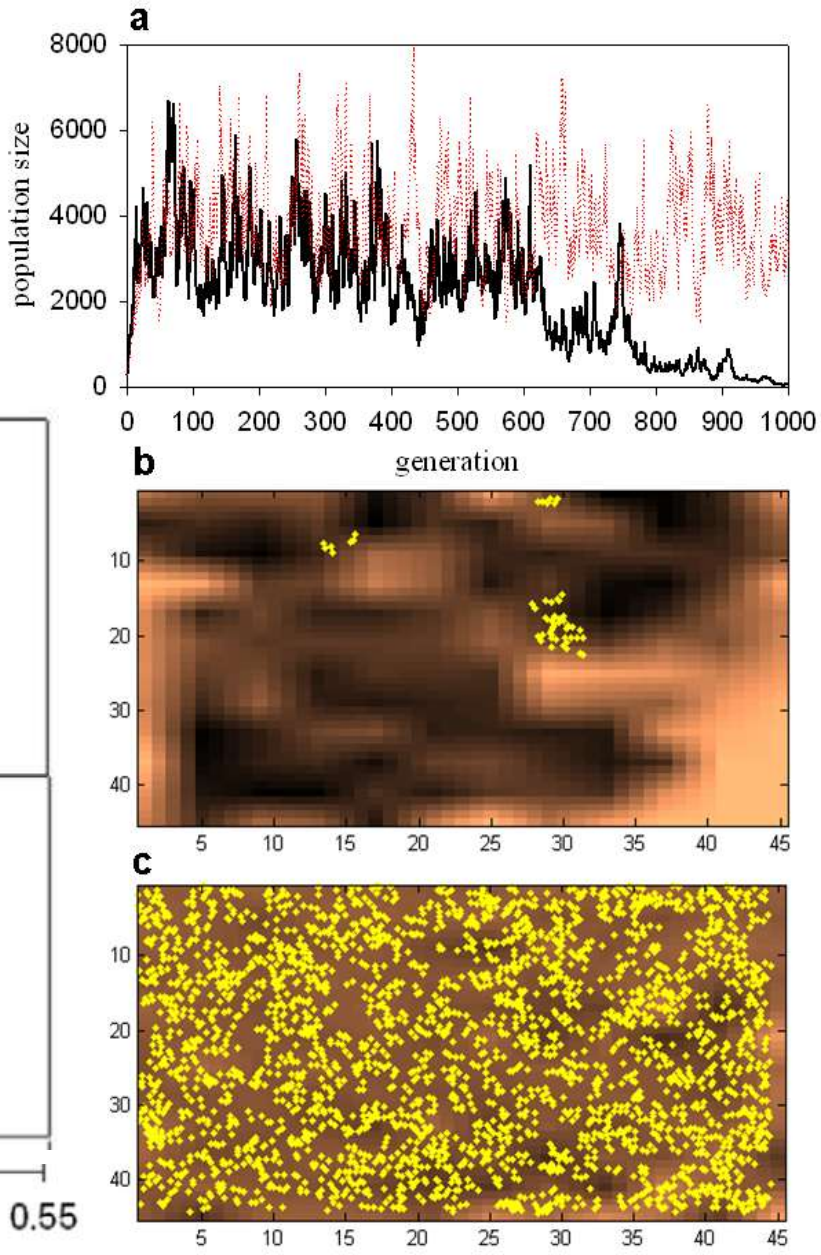
- Dees, N.D., Bahar, S. **Noise-optimized speciation in an evolutionary model**. *PLoS ONE* **5**(8): e11952, 2010.

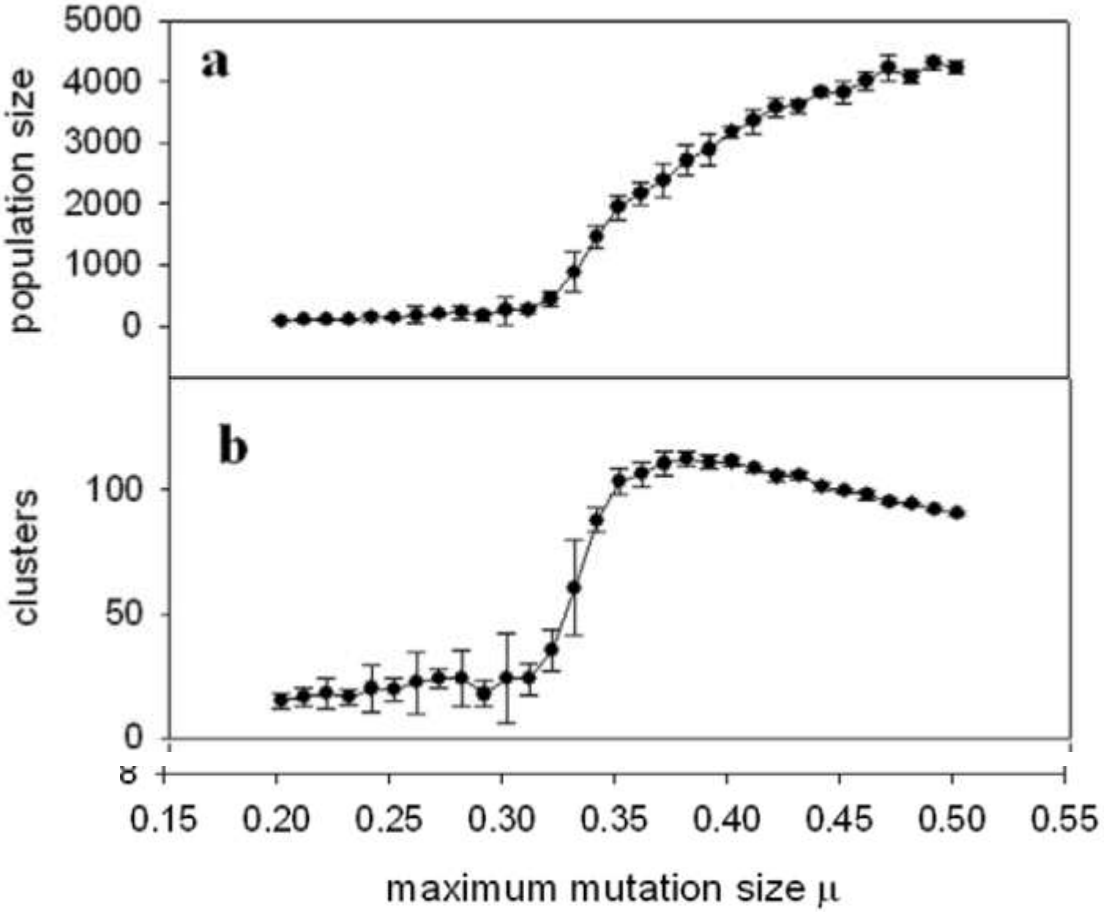
- de Aguiar, M.A.M., Baranger, M., Baptestini, E.M., Kaufman, L., Bar-Yam, Y. **Global patterns of speciation and diversity**. *Nature* **460**: 384-387, 2009.

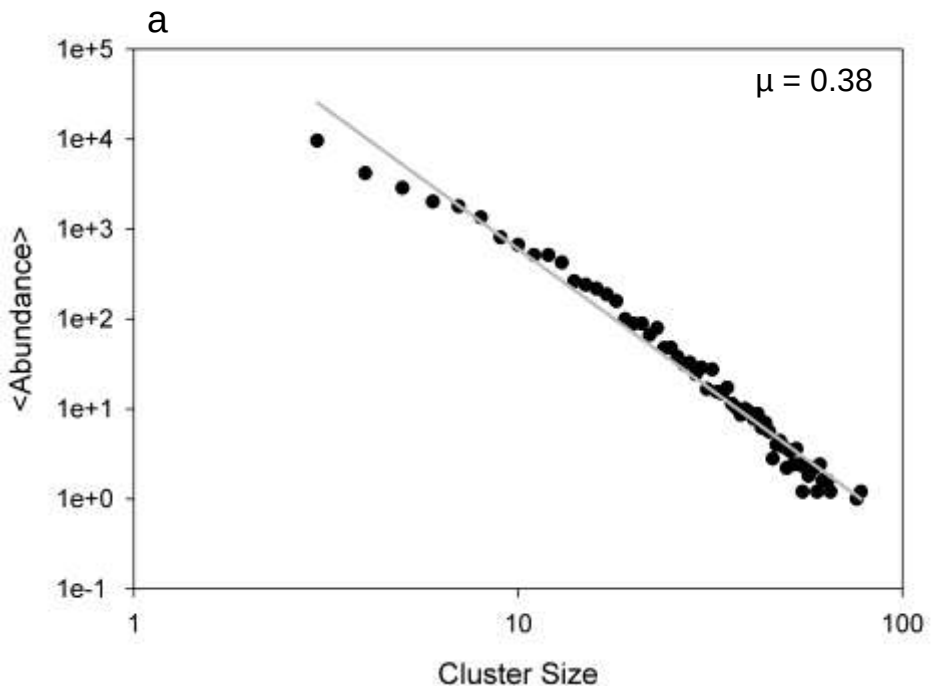
- Young, W.R., Roberts, A.J., Stuhne, G. **Reproductive pair correlations and the clustering of organisms**. *Nature* **412**: 328-331, 2001.

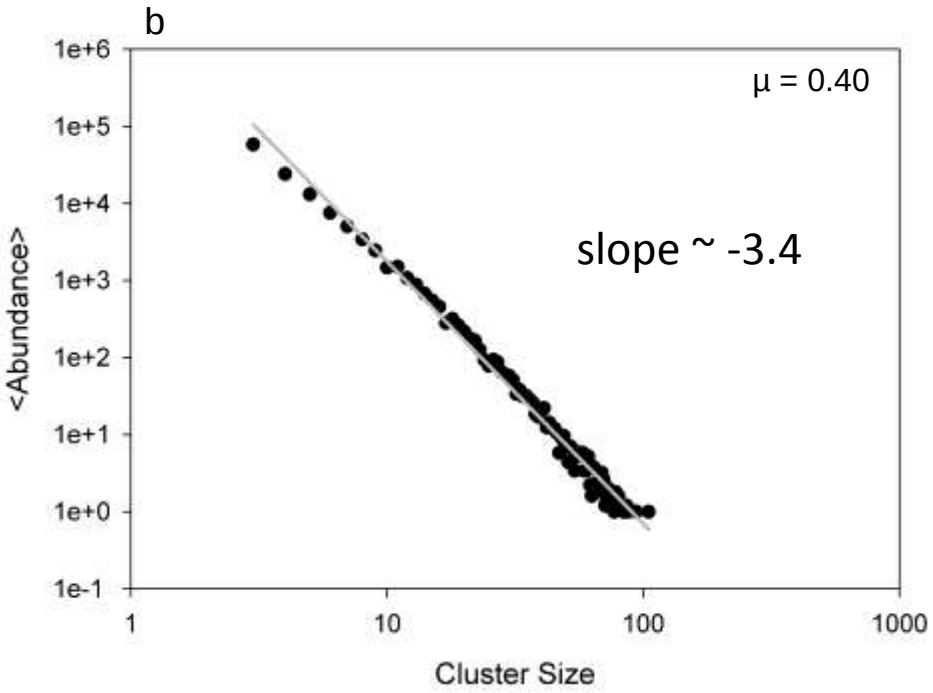
- Hinsby Cadillo-Quiroz, Xavier Didelot, Nicole Held, Aaron Darling, Alfa Herrera, Michael Reno, David Krause and Rachel J. Whitaker. **Sympatric Speciation with Gene Flow in *Sulfolobus islandicus***.. (in press PLoS Biology)

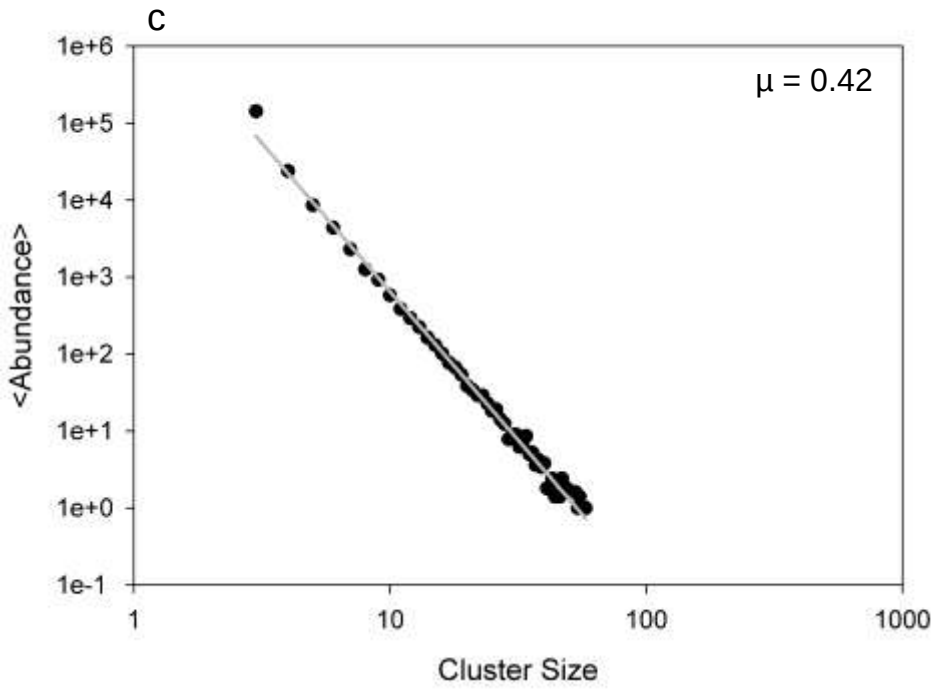
Dees & Bahar (2010)

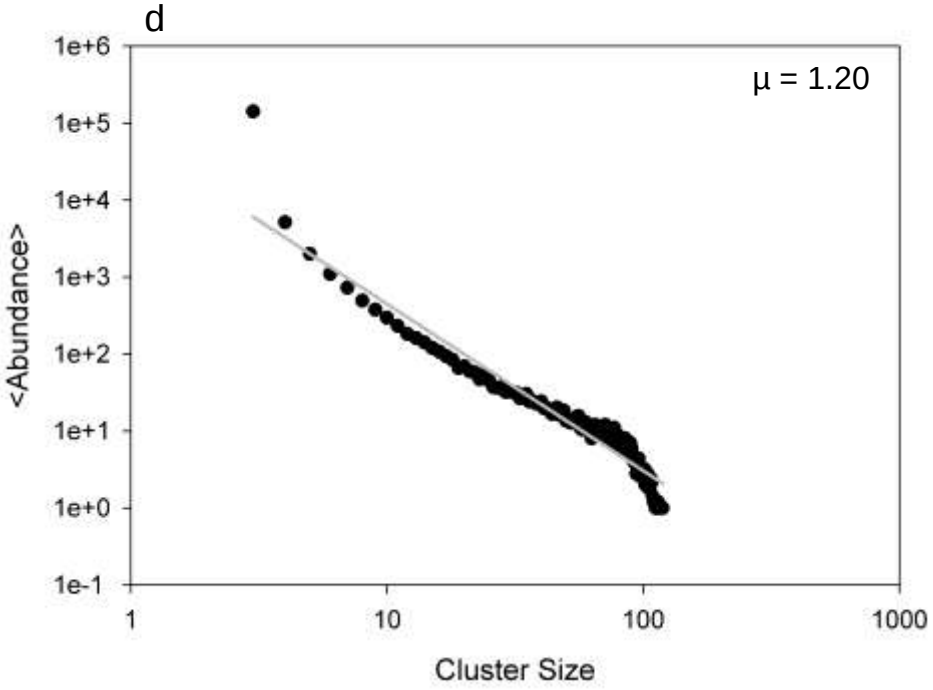





a
μ = 0.38
<Abundance>
Cluster Size
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1
10
100

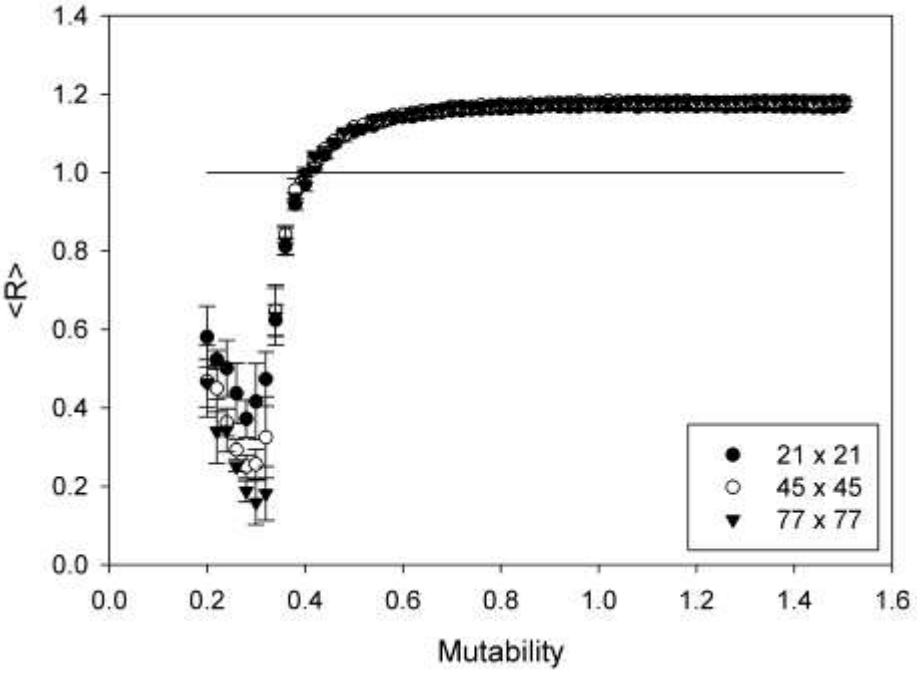

b
μ = 0.40
slope ~ -3.4
<Abundance>
Cluster Size
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1
10
100
1000


c
μ = 0.42
<Abundance>
Cluster Size
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1
10
100
1000


d
μ = 1.20
<Abundance>
Cluster Size
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1
10
100
1000

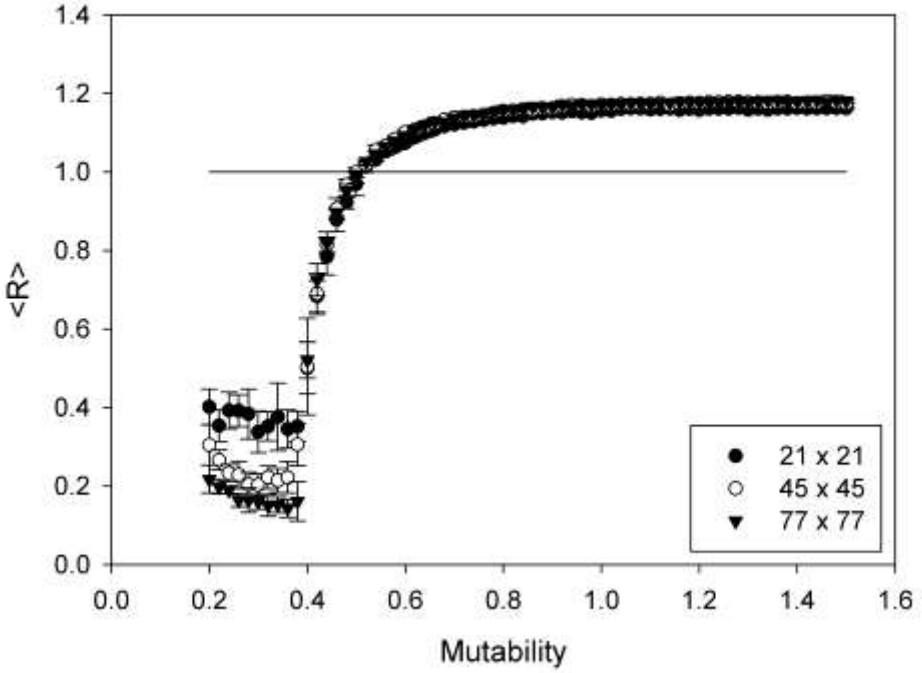
Clark & Evans Nearest Neighbor Test

Asexual Fission

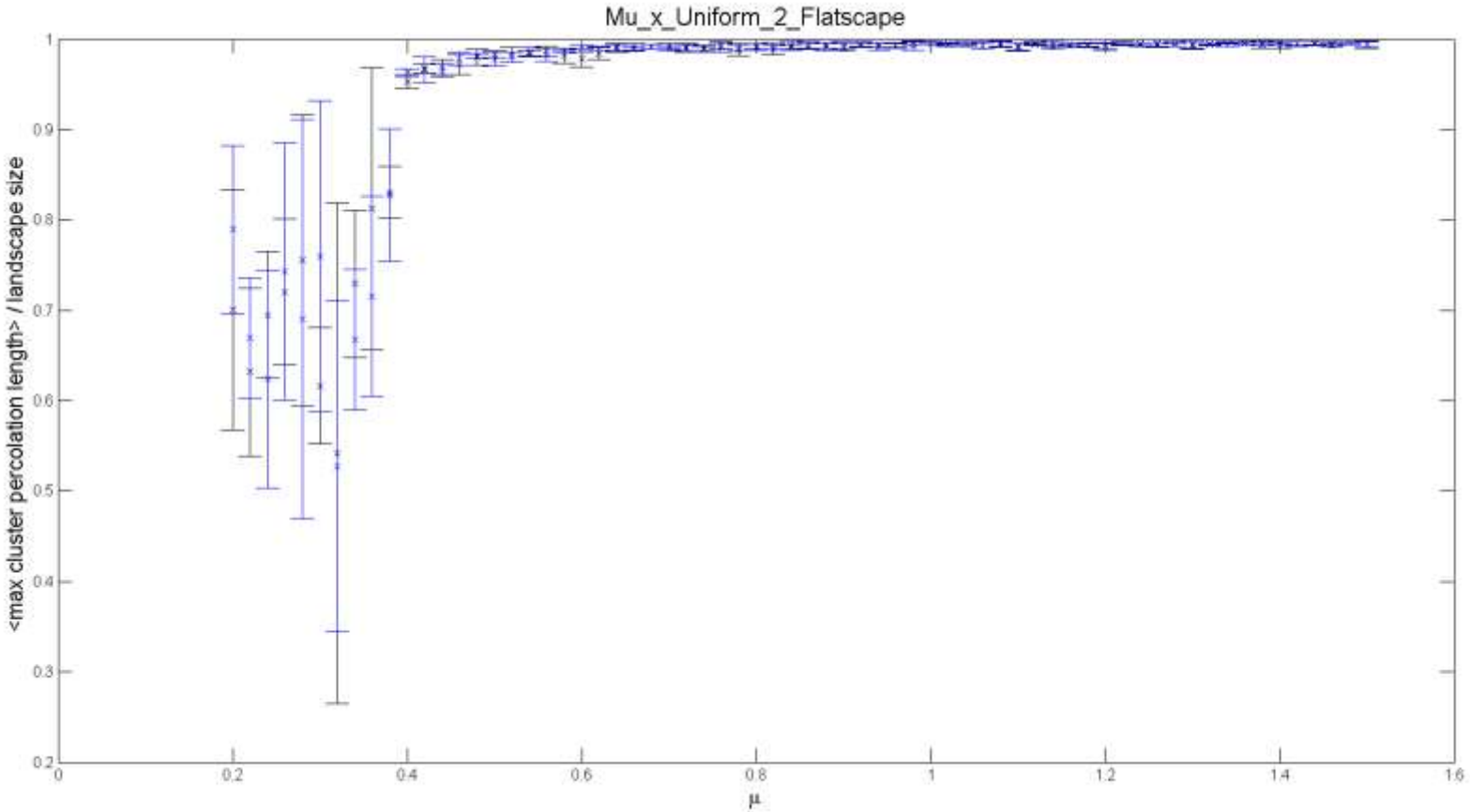


- Clustered <= 0.38
- Dispersed >= 0.44
- Better than 1% significance

Assortative Mating



- Clustered <= 0.46
- Dispersed >= 0.54
- Better than 1% significance


Mu_x_Uniform_2_Flatscape
<max cluster percolation length> / landscape size
μ
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6