Modeling the Evolution of Interacting Species

The Confluence of Biology, Mathematics, and Computer Science

Gregg Hartvigsen
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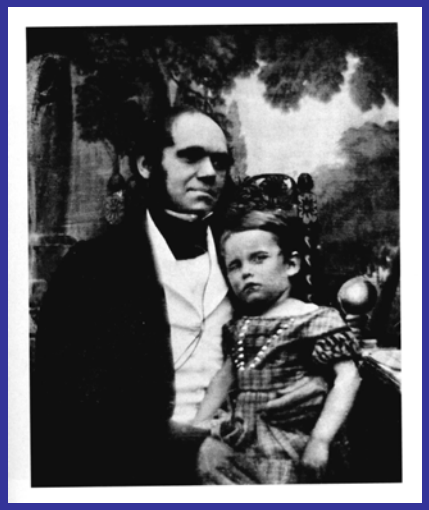
The basic question

The model

Evolution and space interact to affect population and community dynamics

The dynamics of species

Conclusions



Question:

Evolution

Space

Populations

Communities

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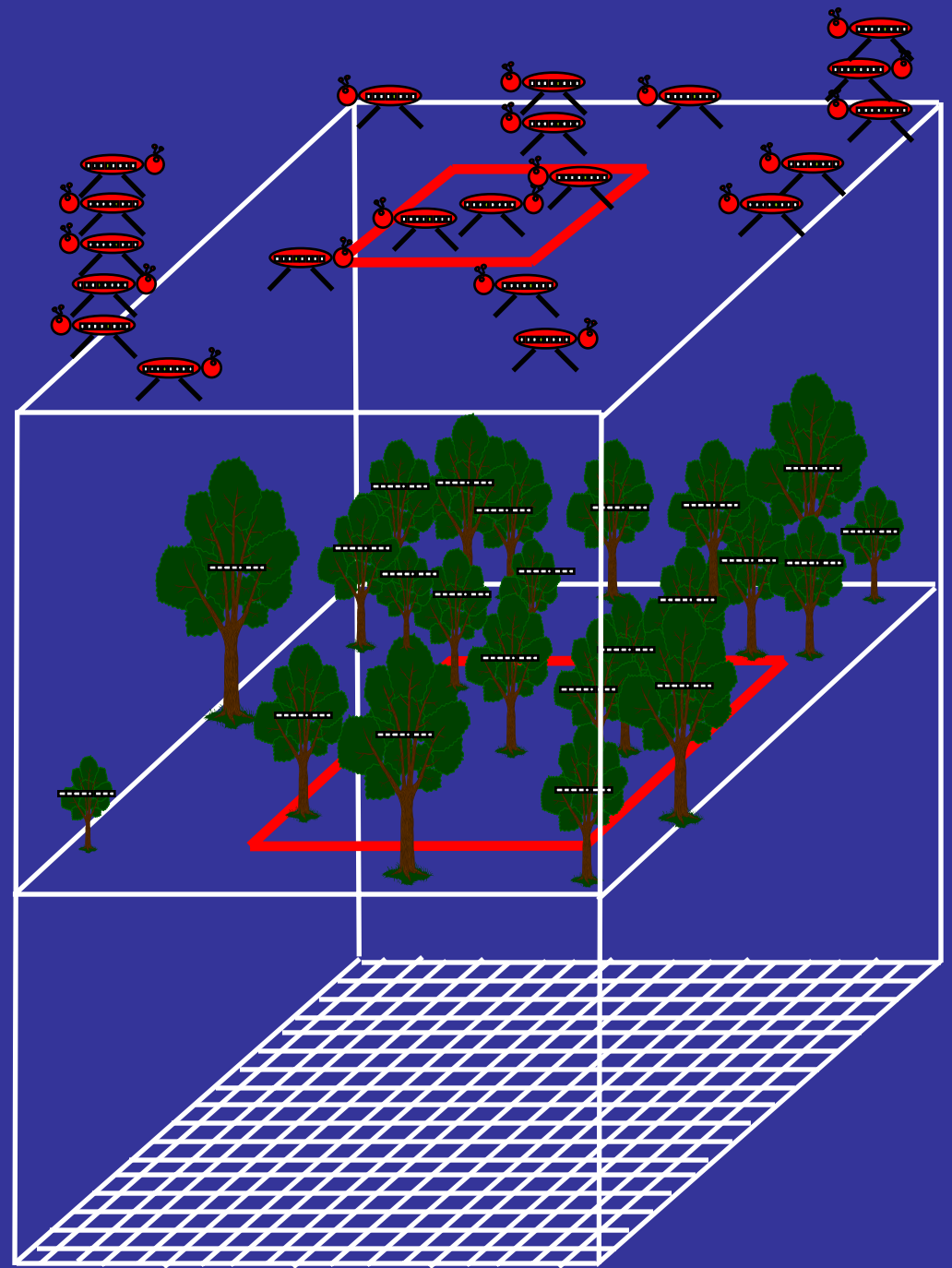
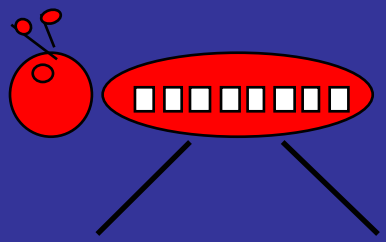
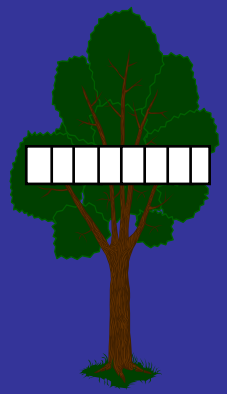






Diversity of individuals
Local interactions
Selection

$$P_{i,\text{end}} = P_{i,\text{start}} - \sum_{j=1}^{m} (C_{ij} P_i)$$

Plants

$$H_{k,\text{end}} = H_{k,\text{start}} + \epsilon \sum_{l=1}^{n} (C_{kl} P_l)$$

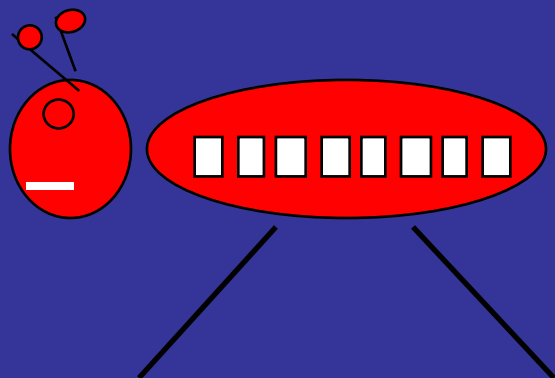
Herbivores

Mating

	Interaction Chromosome
Mate 1	
Mate 2	
Recombinant	
Mutation	x
Offspring	

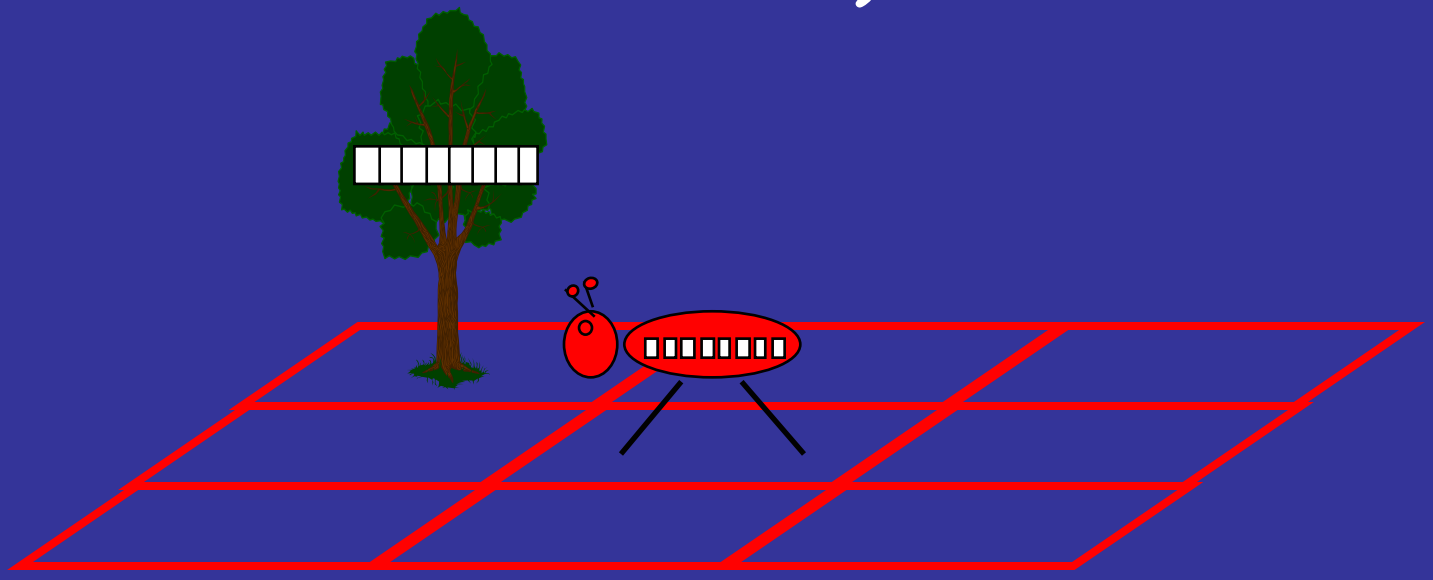
Feeding

	Interaction Chromosome	Concordance (*C*)
Herbivore Plant		1.0
Herbivore Plant		1.0
Herbivore Plant		0.0
Herbivore Plant		0.5



Movement:

Random walk
Five steps (randomly chosen individuals)



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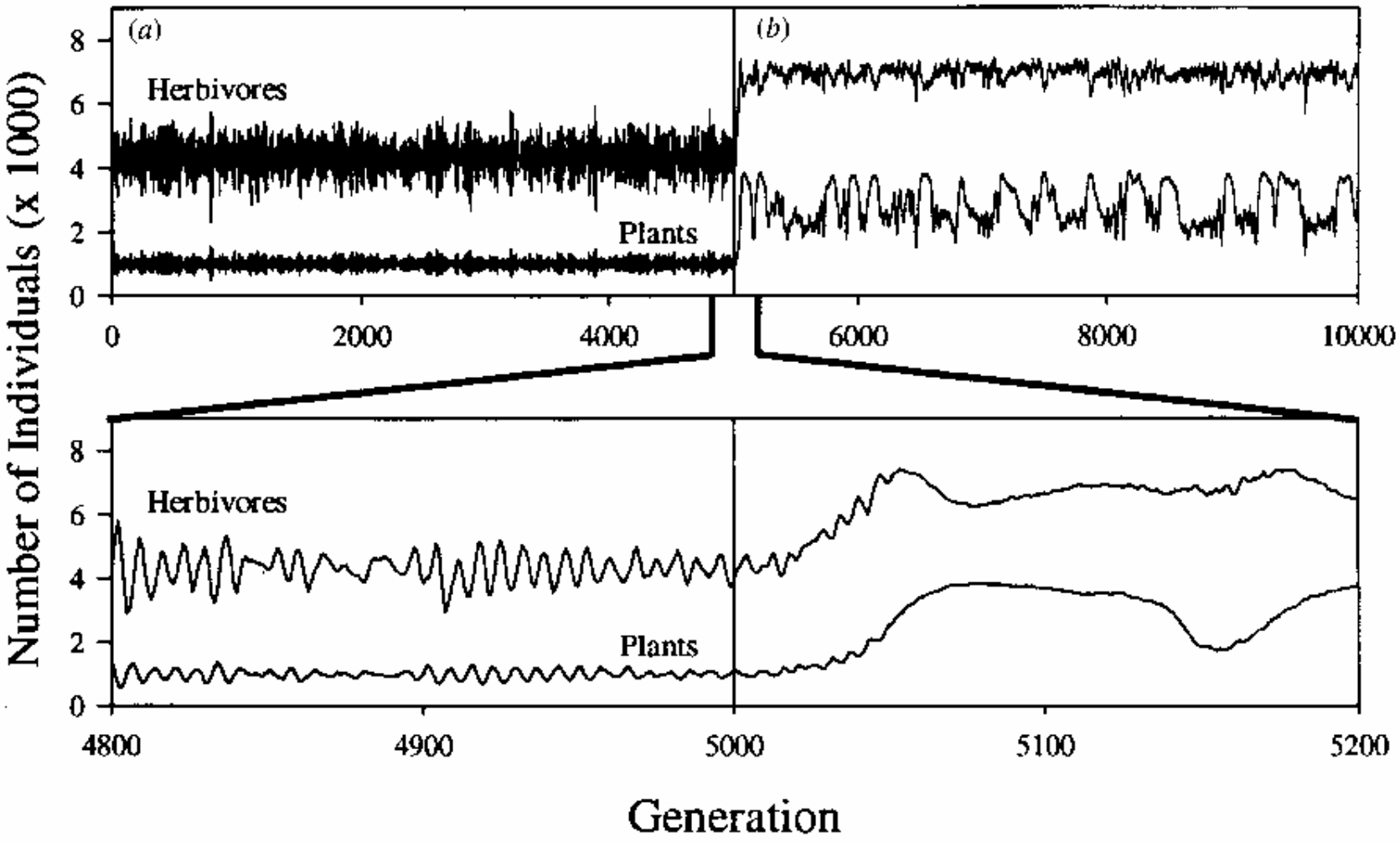
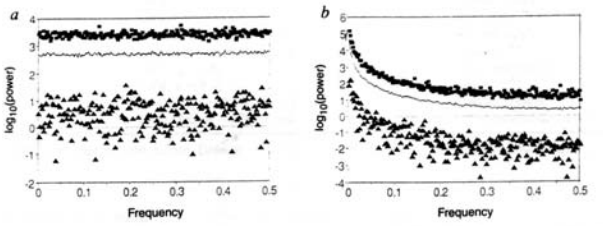
No Evolution Evolution



Hartvigsen, G., & S. Levin. 1997. Evolution and spatial structure interactto influence plant-herbivore population and community dynamics. Proc. R. Soc. Lond. B 264: 1677-1685.

FIG. 1 Power spectral densities (spectra) of discrete-time random sequences: *a*, white noise $X_t = \varepsilon_t$, and *b*, red noise (or random walk or brown noise) $X_{t+1} = X_t + \varepsilon_t$. In both cases, ε_t is a sequence of independent and identically distributed normal random variates with mean 0 and variance 1. Sequences of length 512 were generated starting from $X_0 = 0$ and standardized to have overall mean 0 and variance 1. The fast Fourier transform and spectrum were then computed as described in the text. The continuous lines represent the average spectrum from 100 simulations; the rectangles represent the maximum spectrum; and the triangles represent the minimum spectrum. The horizontal coordinate *x* is frequency; the corresponding period is 1/*x*. For example, the abscissa 0.4 corresponds to 0.4 cycles per time unit or a period of 1/0.4 = 2.5 time units.



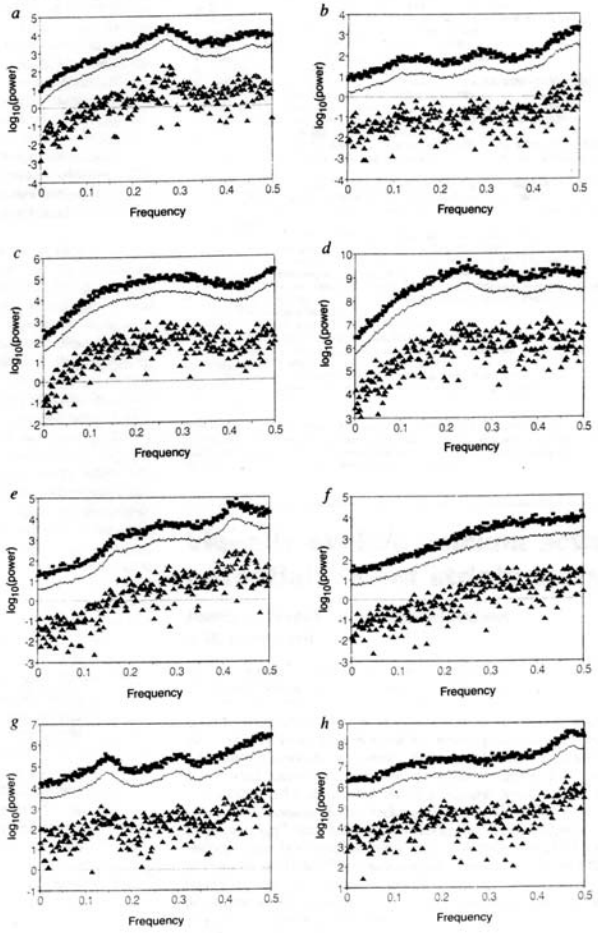
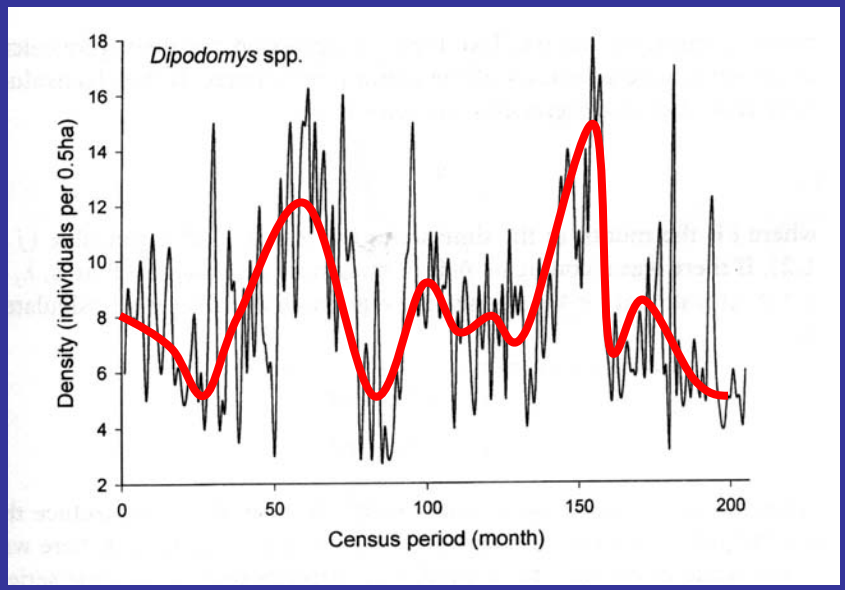


FIG. 2 Power spectral densities of eight discrete-time nonlinear population models: *a*, Moran–Ricker[12,25,26]; *b*, Verhulst[12]; *c*, Pennycuick[12,27]; *d*, Hassell[12,28]; *e*, Maynard Smith[12,29]; *f*, Varley[12,30]; *g*, Austin–Brewer[14]; and *h*, Malthus–Condorcet–Mill[15]. Table 1 gives the equations and parameter values. Symbols and units are as in Fig. 1. By contrast with the white or reddened spectra commonly observed in environmental and ecological time series, these spectra are blue, with greater power at higher frequencies.

Cohen, JE. 1995. Unexpected dominance of high frequencies in chaotic nonlinear population models. Nature 378: 610-612.



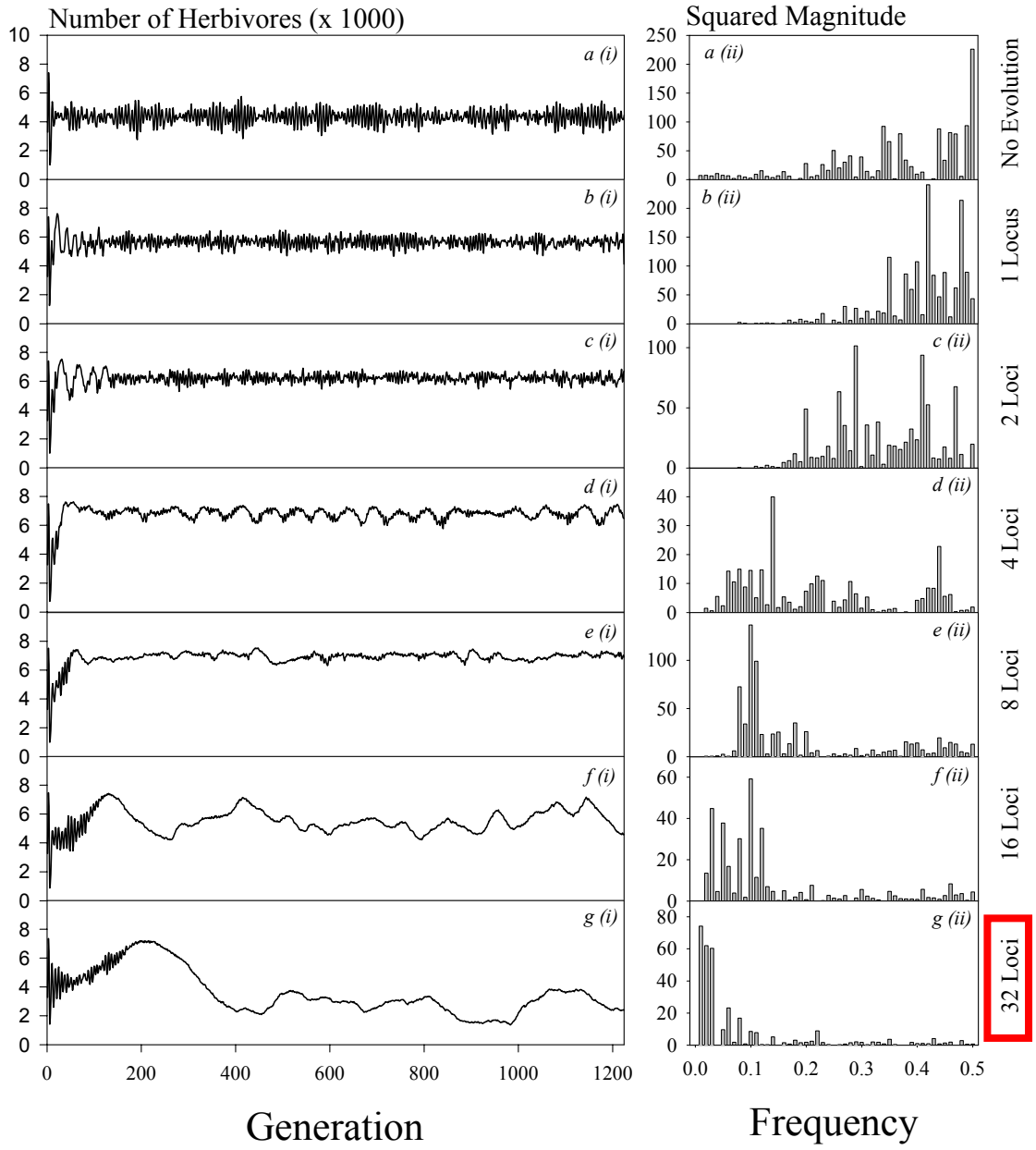
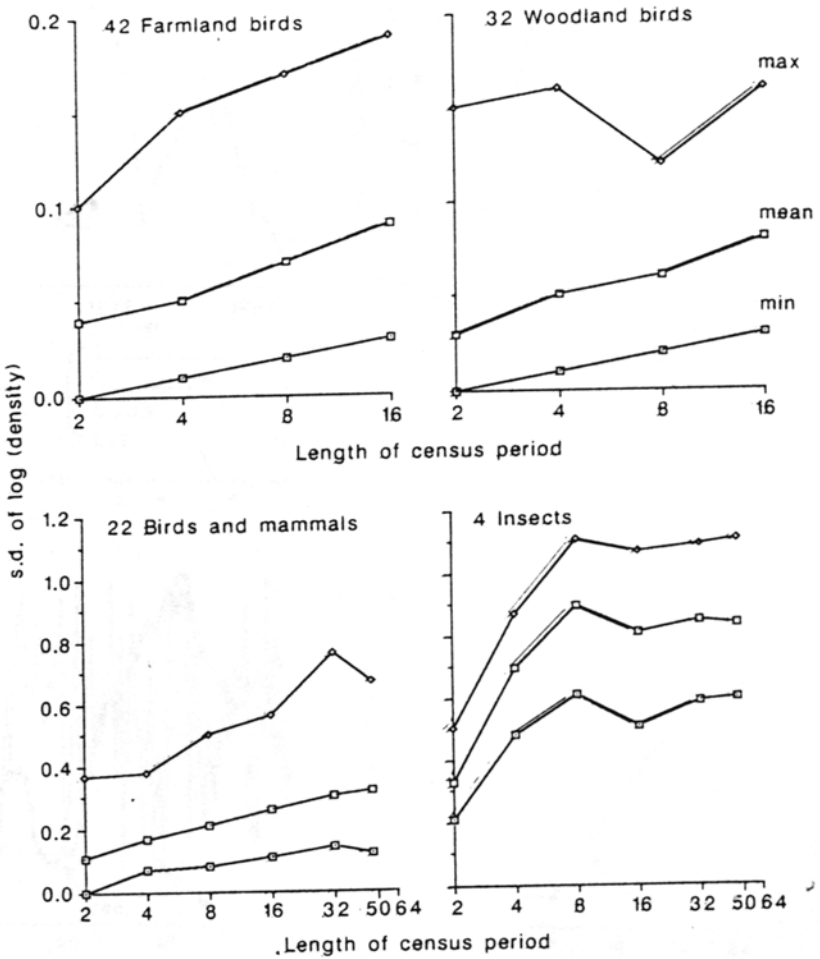
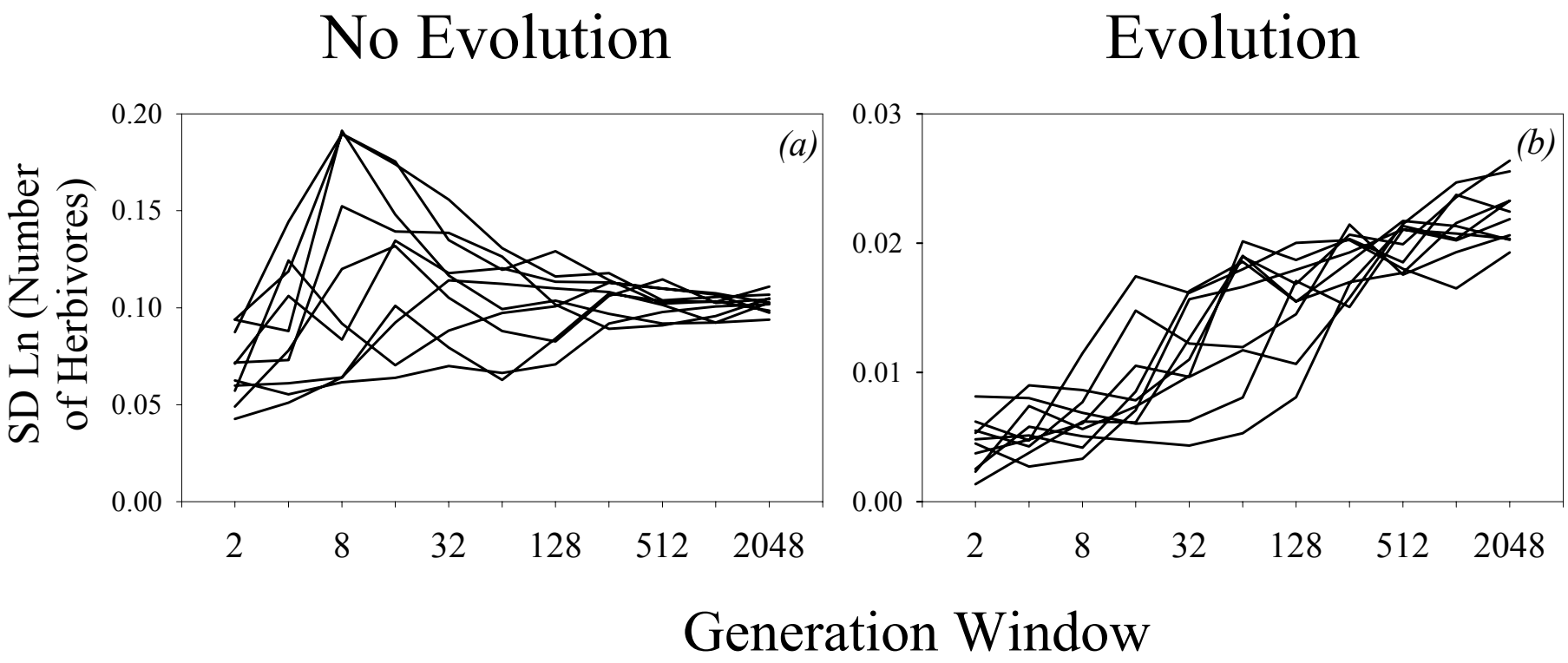

Number of Herbivores (x 1000)
Squared Magnitude
a (i)
b (i)
c (i)
d (i)
e (i)
f (i)
g (i)
a (ii)
b (ii)
c (ii)
d (ii)
e (ii)
f (ii)
g (ii)
No Evolution
1 Locus
2 Loci
4 Loci
8 Loci
16 Loci
32 Loci
Generation
Frequency

Fig. 2 Population variabilities versus the number of years over which those variabilities were calculated. Only standard deviations of the logarithms of densities (SDL) are shown: the other measures of variability show a similar pattern. On each graph, the middle line joins the means among the different species; the top and bottom lines join the maximum and minimum values respectively. For the nested analyses (shown), regressions of SDL versus the length of census period are significant at $P < 0.0001$ for the farmland birds, for the woodland birds, and for the 22 miscellaneous birds and mammals; the analysis for the four insect species is significant at $P = 0.008$. For the non-nested analyses (not shown), regressions are significant at $P = 0.0001$ and $P = 0.0003$ for the farmland and woodland birds respectively. The percentages of these species that show increases between the different numbers of years that go into the calculation are shown in Table 1.



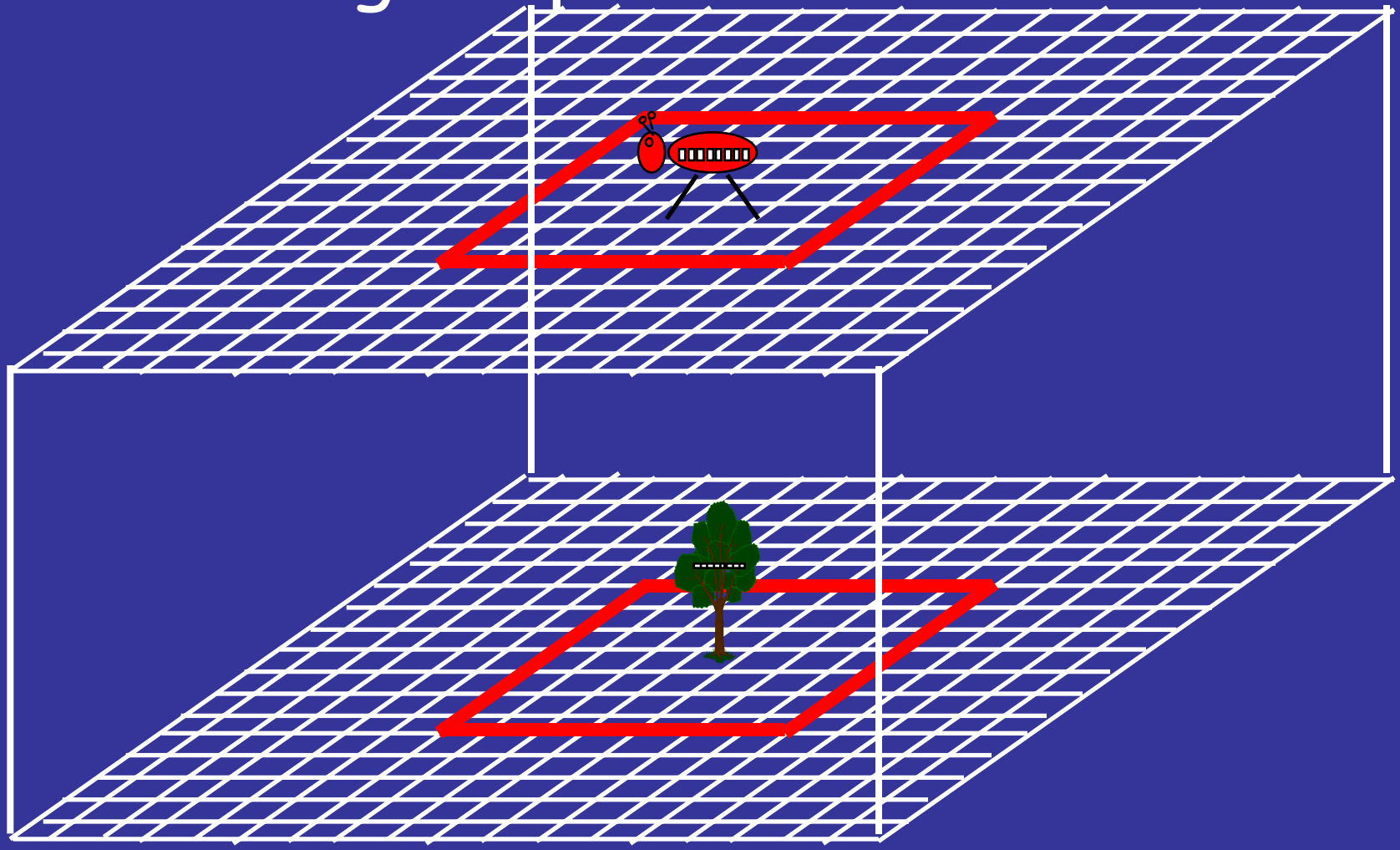
Pimm, SL and A Redfearn. 1988. The variability of population densities. Nature 334: 613-614.

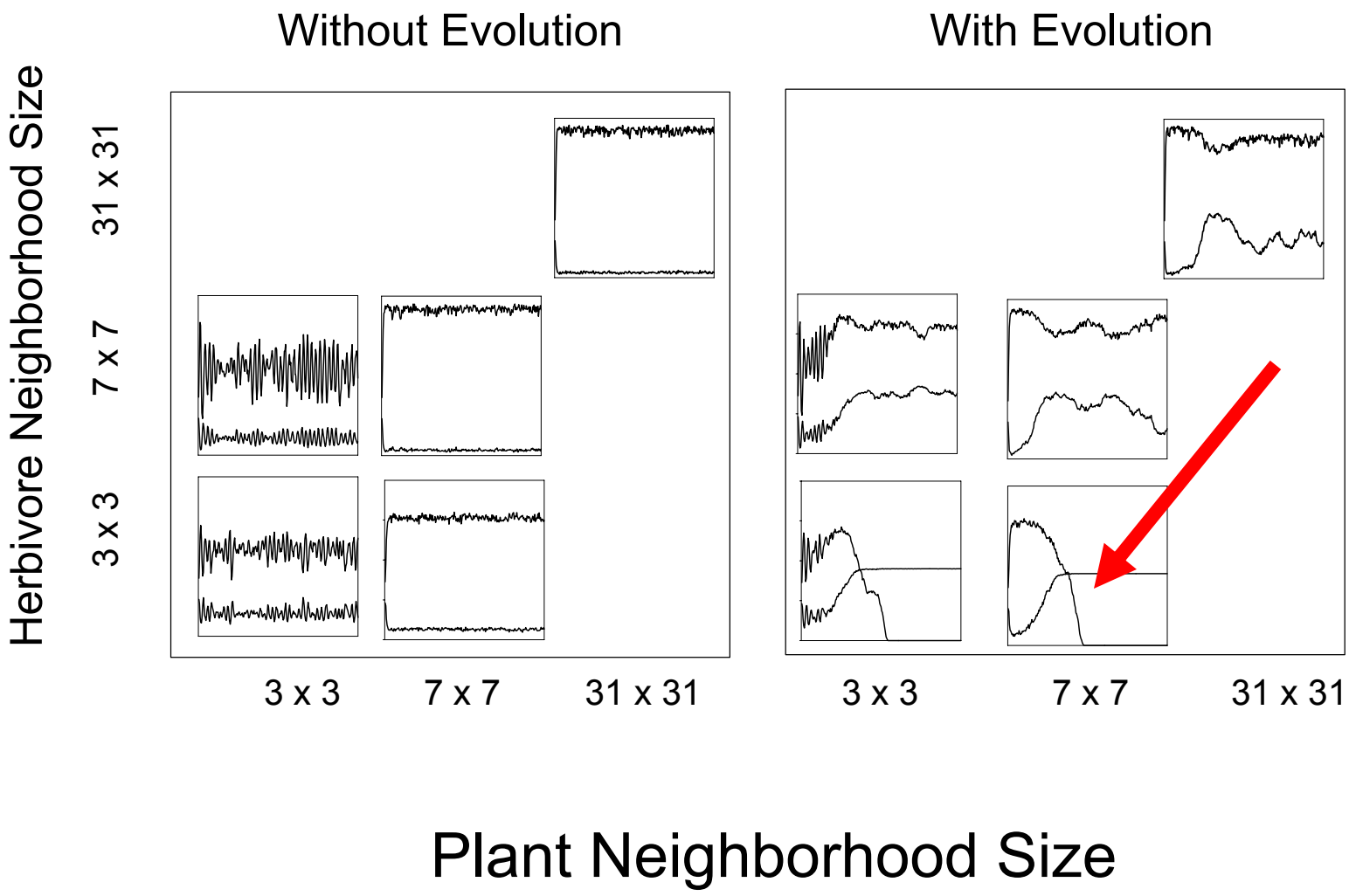

No Evolution
Evolution
SD Ln (Number of Herbivores)
0.20
0.15
0.10
0.05
0.00
0.03
0.02
0.01
0.00
(a)
(b)
2
8
32
128
512
2048
Generation Window

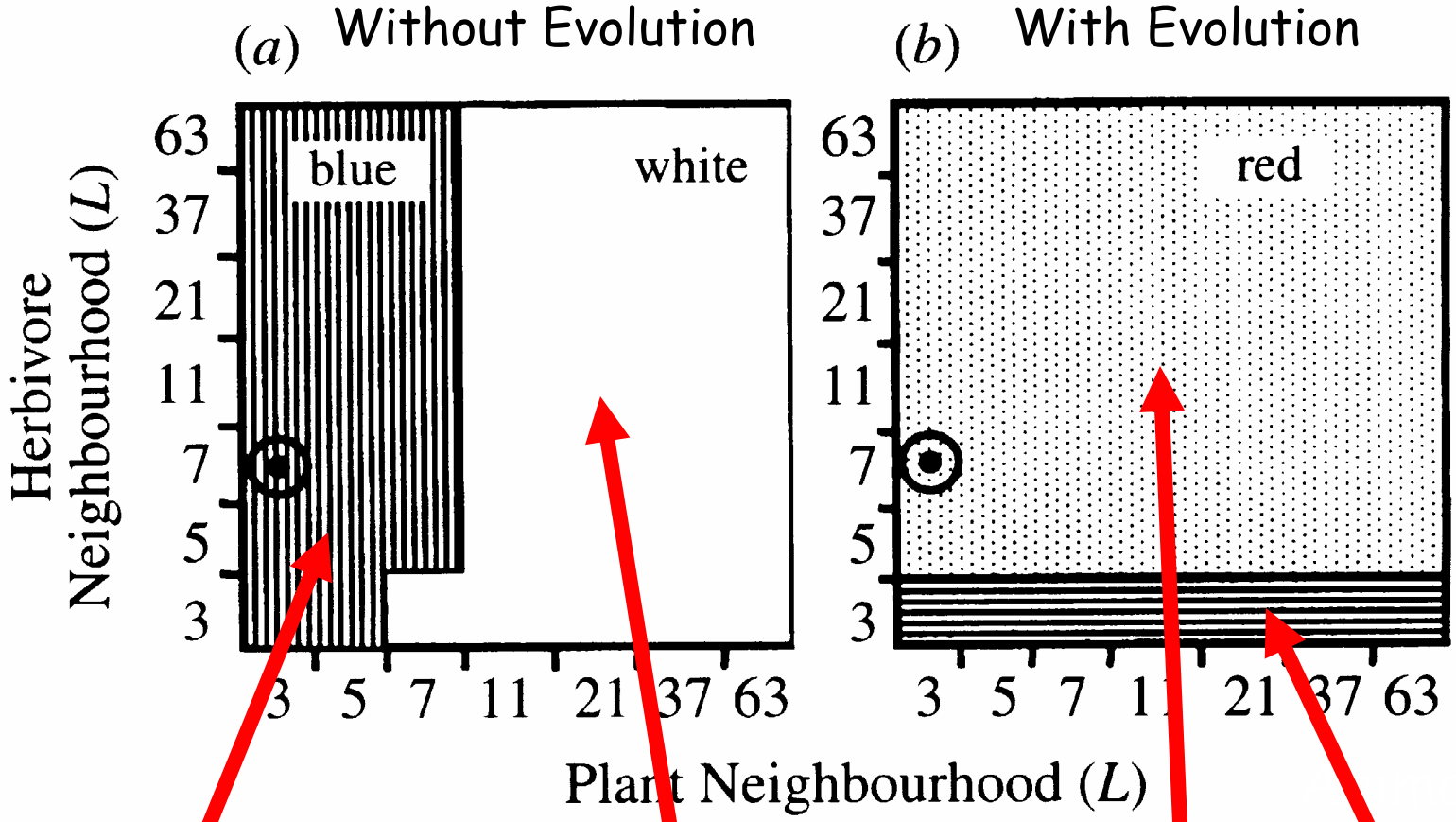
Space -

herbivores feed

mating/dispersal




Without Evolution
With Evolution
Herbivore Neighborhood Size
31 x 31
7 x 7
3 x 3
3 x 3
7 x 7
31 x 31
3 x 3
7 x 7
31 x 31
Plant Neighborhood Size



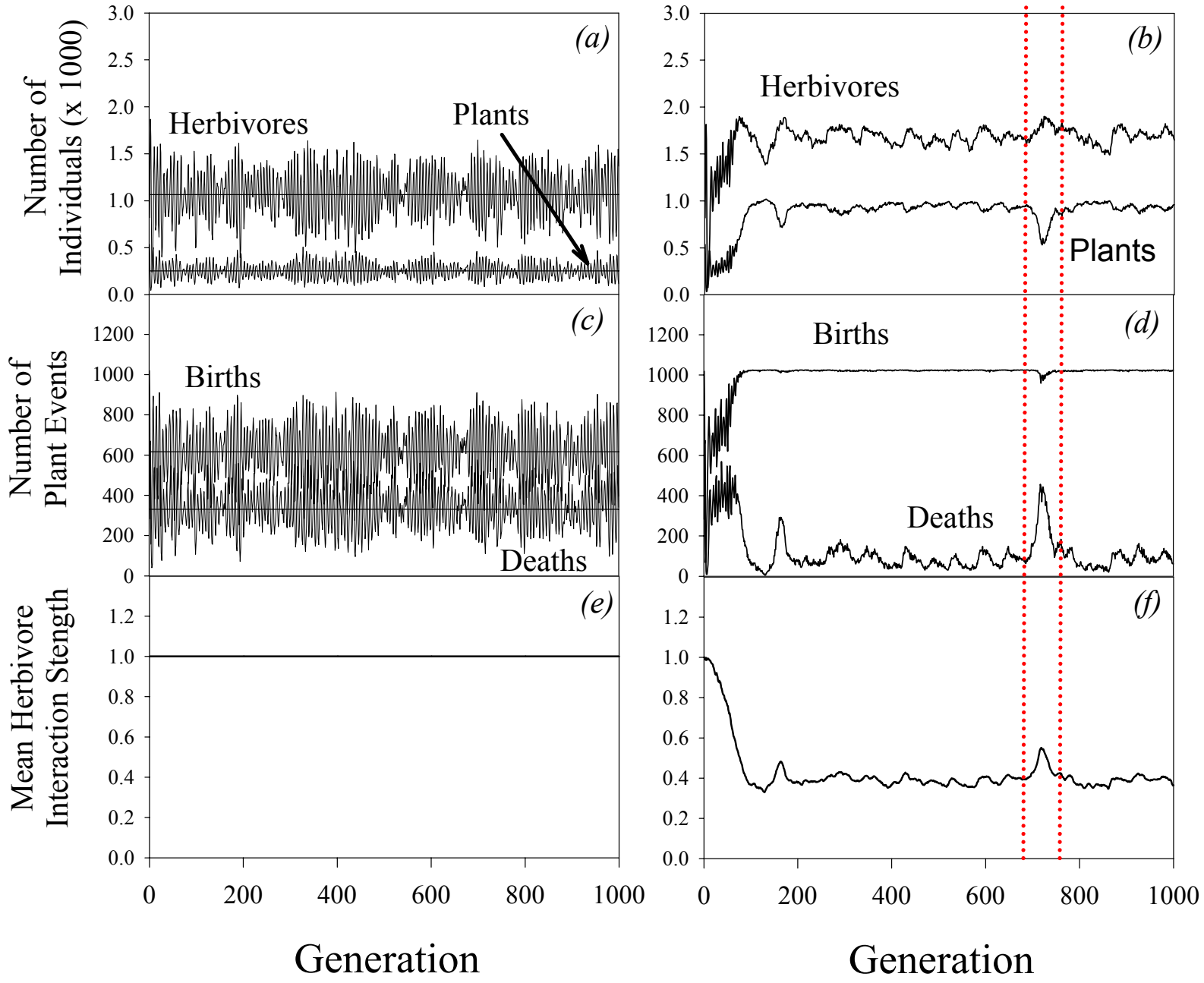
High Frequency Oscillations

Random Fluctuations

Low Frequency Dynamics

Animal Death

Mechanism?


No Evolution
Evolution
Number of Individuals (x 1000)
Herbivores
Plants
(a)
(b)
Number of Plant Events
Births
Deaths
(c)
(d)
Mean Herbivore Interaction Stength
(e)
(f)
Generation
Generation

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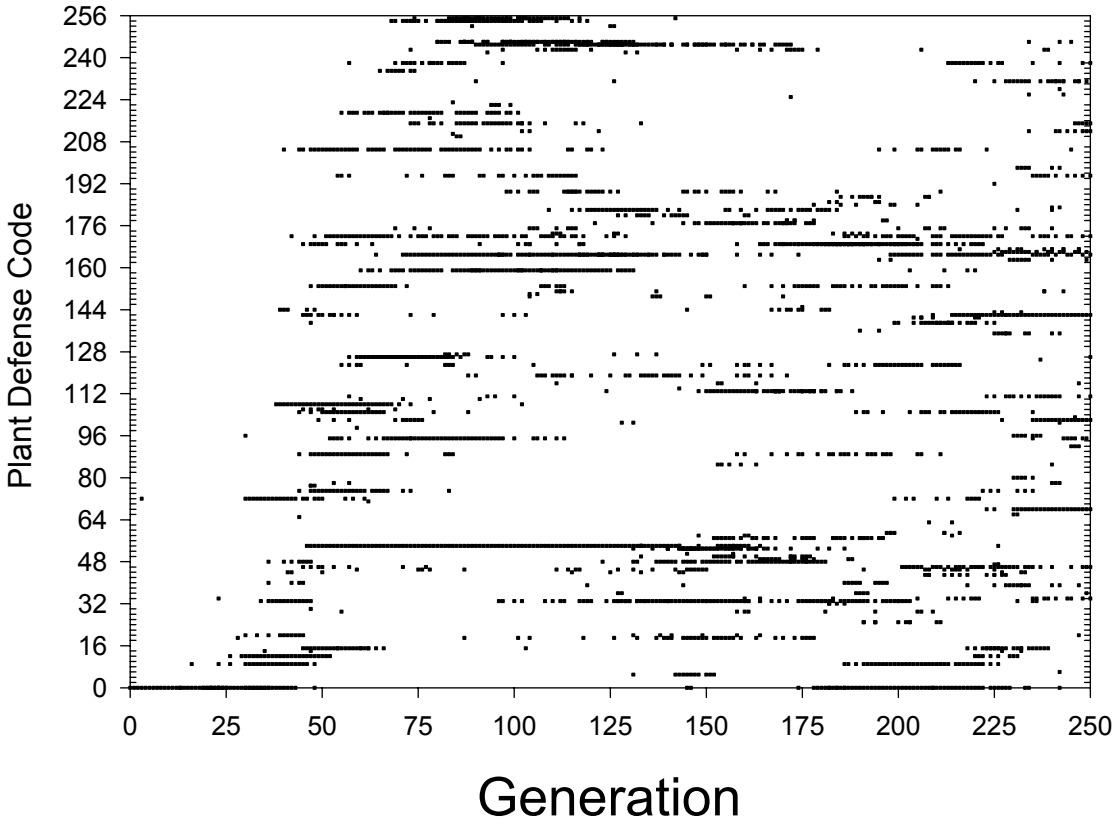
Diversity of Plant Defense Codes on 32 x 32 Lattice, 2500 Generations



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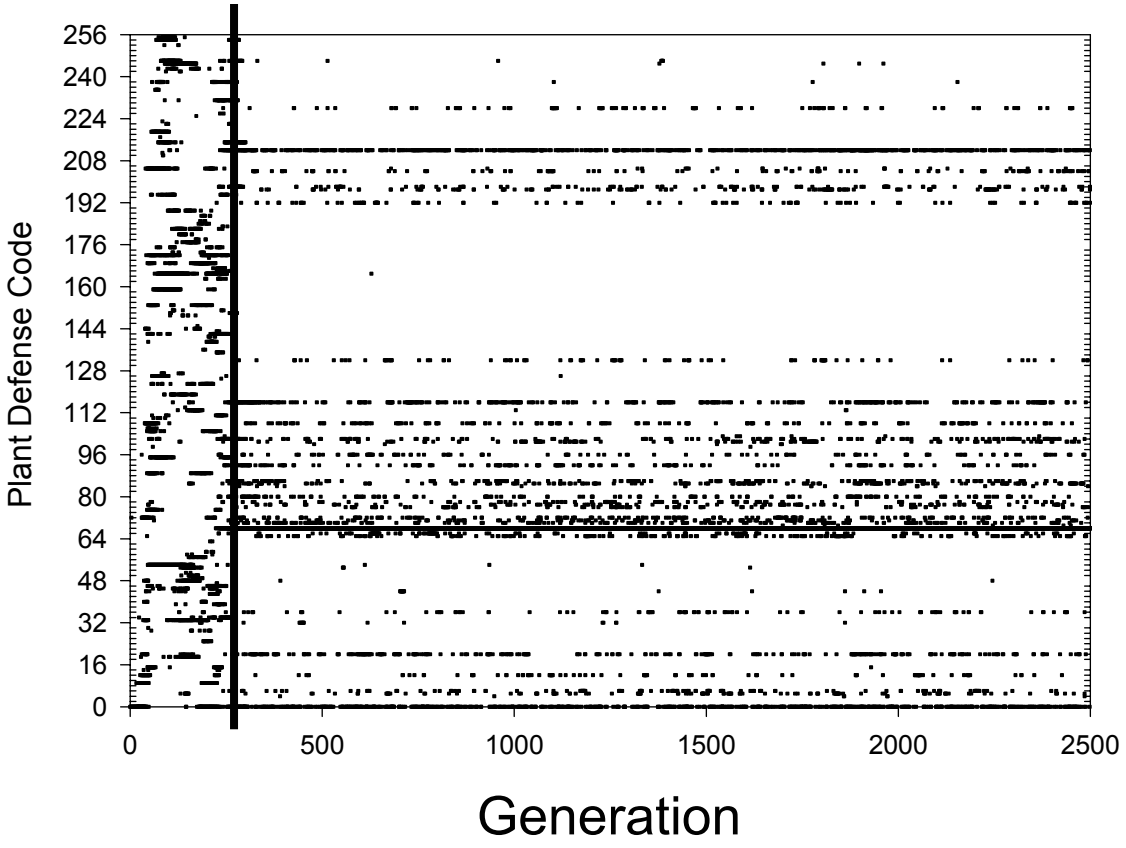
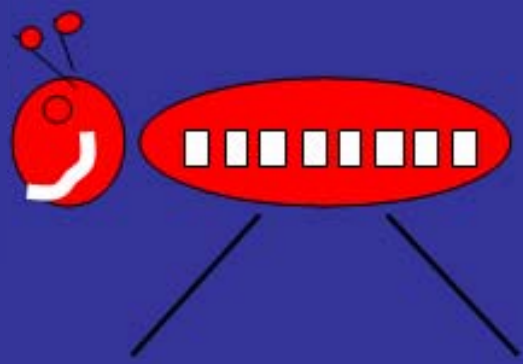


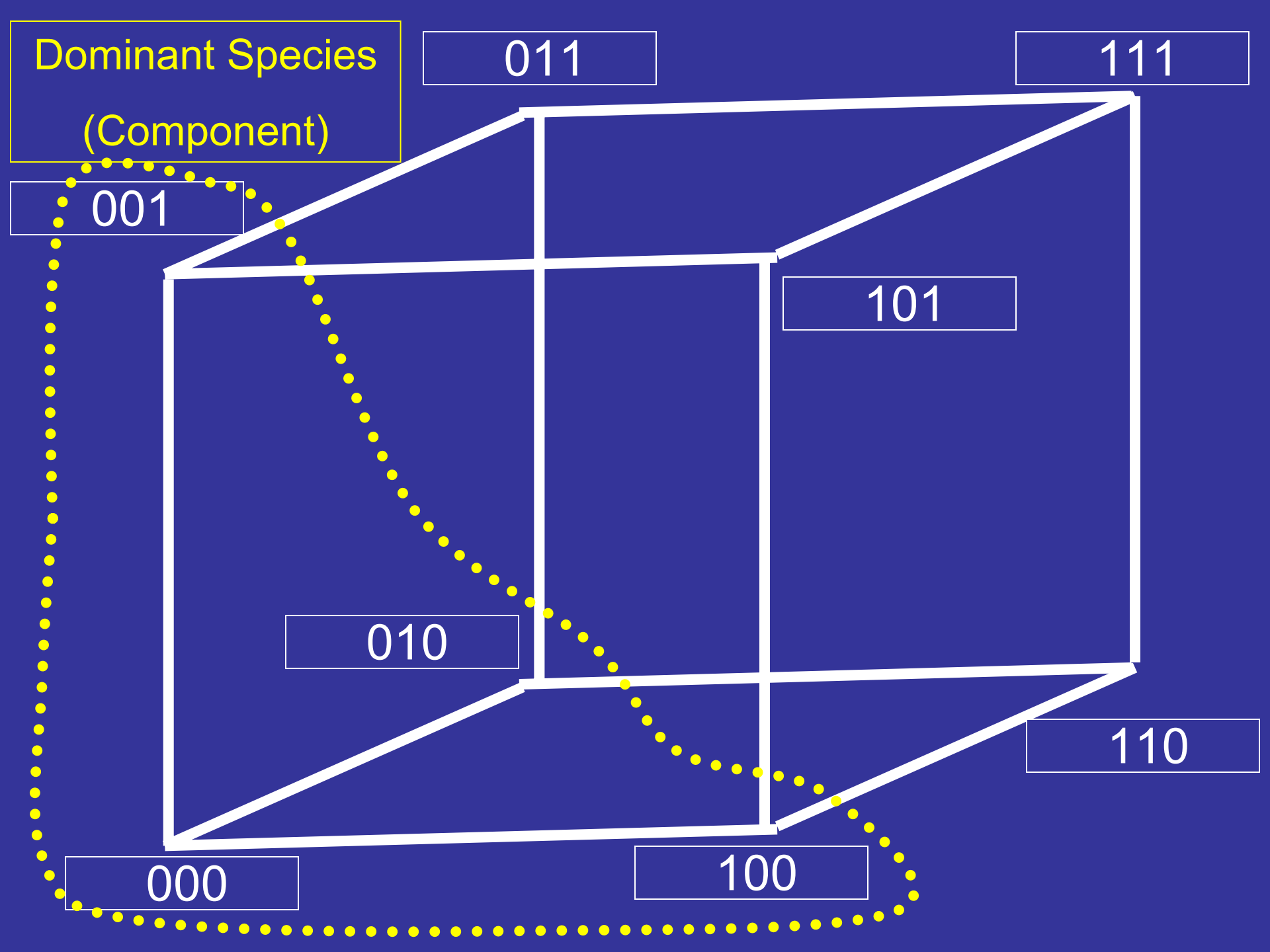
Defining "species"

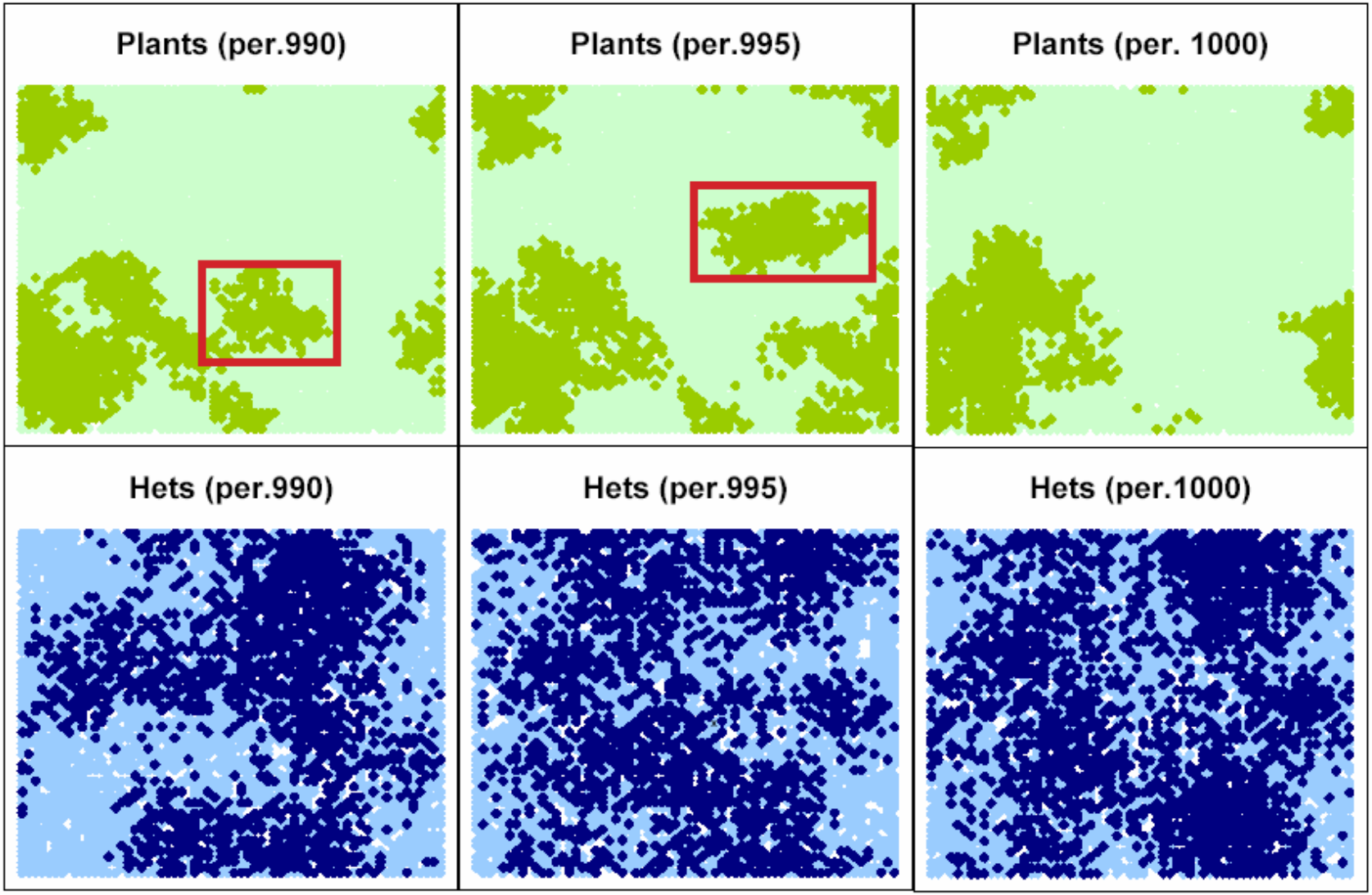
The collection of all organisms that can potentially interbreed.

Mating

	Interaction Chromosome
Mate 1	
Mate 2	

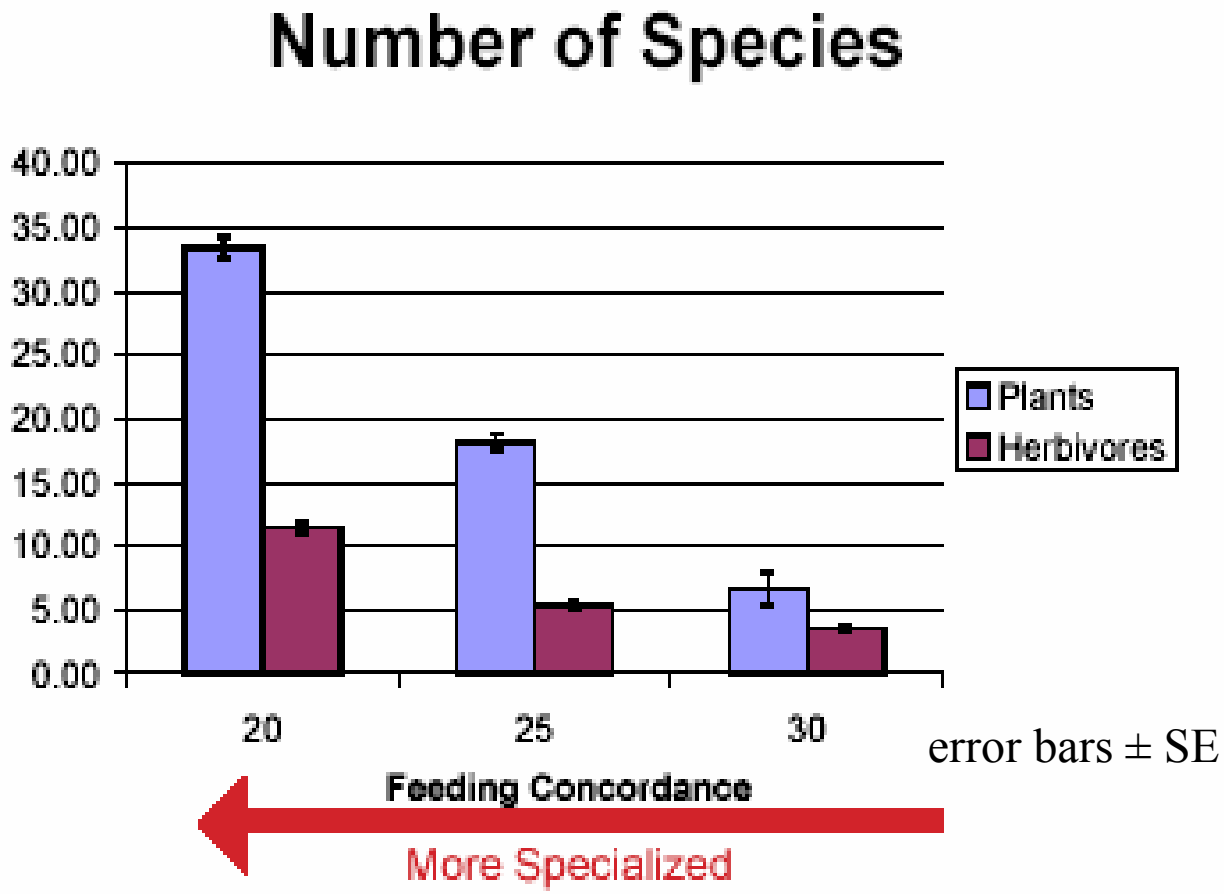



Dominant Species
(Component)
011
111
001
101
010
110
000
100



Plants (green) and Herbivore (blue) on a 64 x 64 toroidal grid. Thus, for each map, the top edge is connected to the bottom and the left edge is connected to the right.

Maximum number of matches such that herbivore still gains energy



error bars ± SE

Analysis of Variance for Number of Species

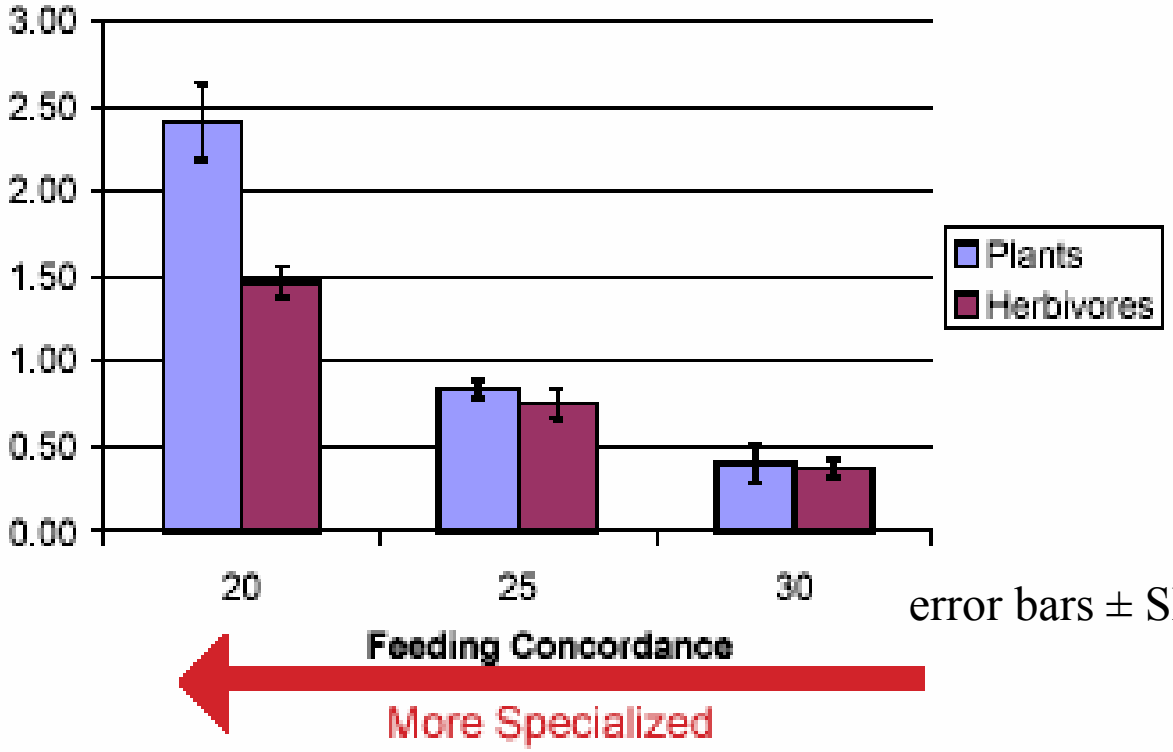
Source	DF	Seq SS	Adj SS	Adj MS	F	P
FC[1]	2	3071.4	3071.4	1535.7	315.10	0.000
Trophic Level	1	2407.9	2407.9	2407.9	494.06	0.000
FC×Trophic Level	2	896.9	896.9	448.4	92.01	0.000
Error	54	263.2	263.2	4.9		
Total	59	6639.3				

FC[1] = Feeding Concordance

S = 2.20764 R-Sq = 96.04% R-Sq(adj) = 95.67%

Maximum number of matches such that herbivore still gains energy

Rate of Evolution



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Analysis of Variance for Rate of Evolution

Source	DF	Seq SS	Adj SS	Adj MS	F	P
FC	2	26.0572	26.0572	13.0286	93.32	0.000
Trophic Level	1	1.8866	1.8866	1.8866	13.51	0.001
FC×Trophic Level	2	2.6152	2.6152	1.3076	9.37	0.000
Error	54	7.5391	7.5391	0.1396		
Total	59	38.0981				

S = 0.373648 R-Sq = 80.21% R-Sq(adj) = 78.38%

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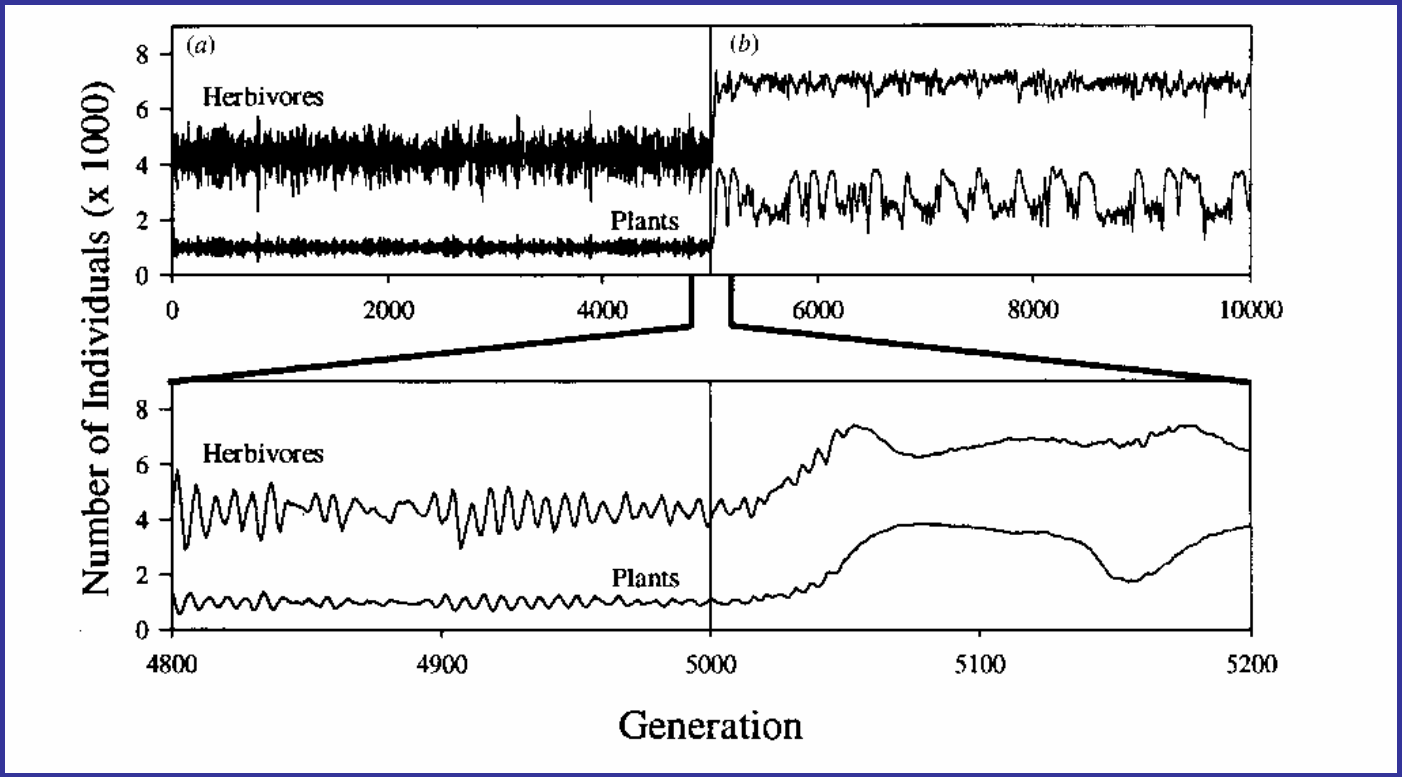
Conclusions (1 of 3)

In this model evolution leads to changes in

a. population dynamics
b. relative abundances of species



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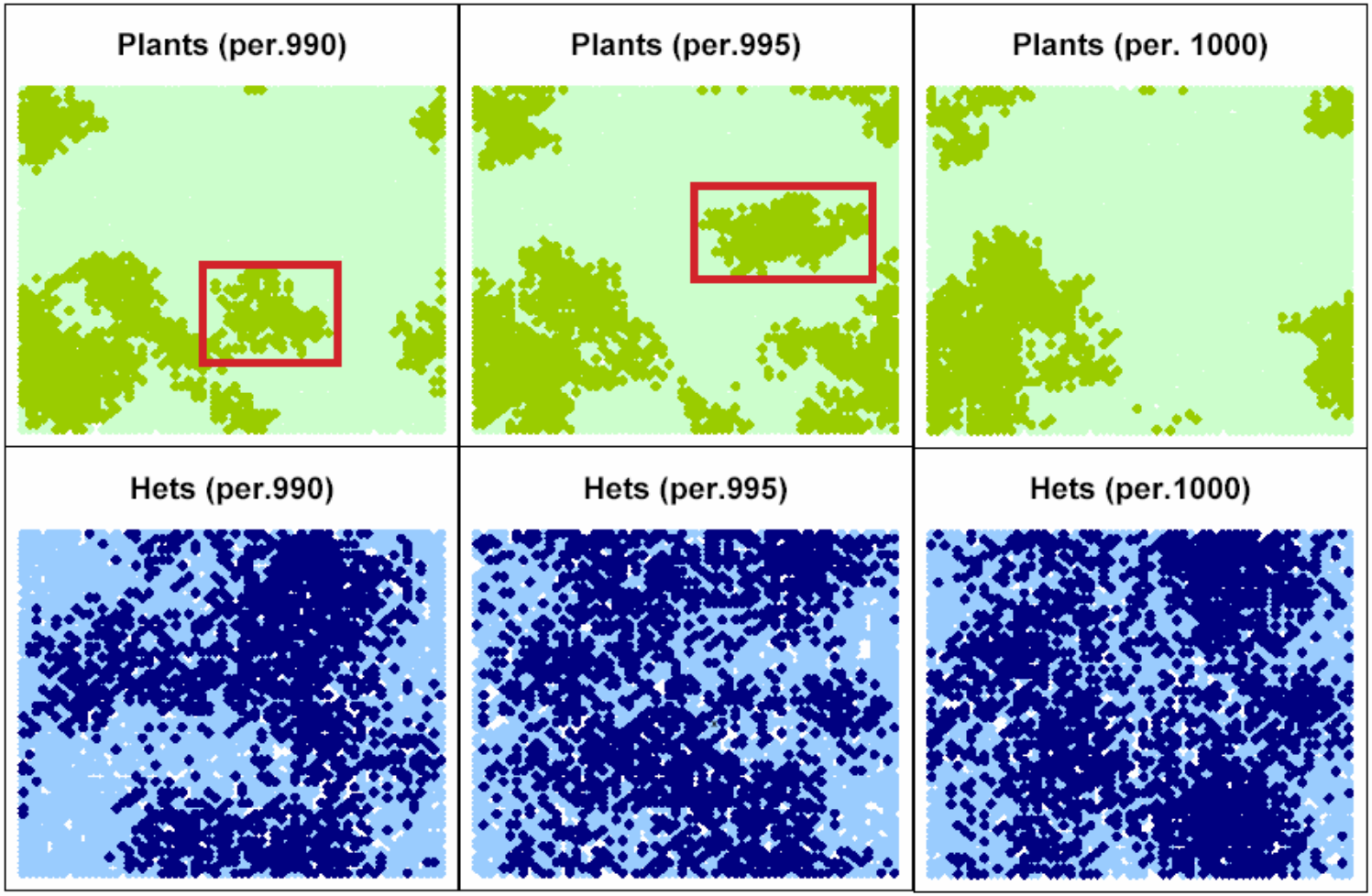
Conclusions (2 of 3)



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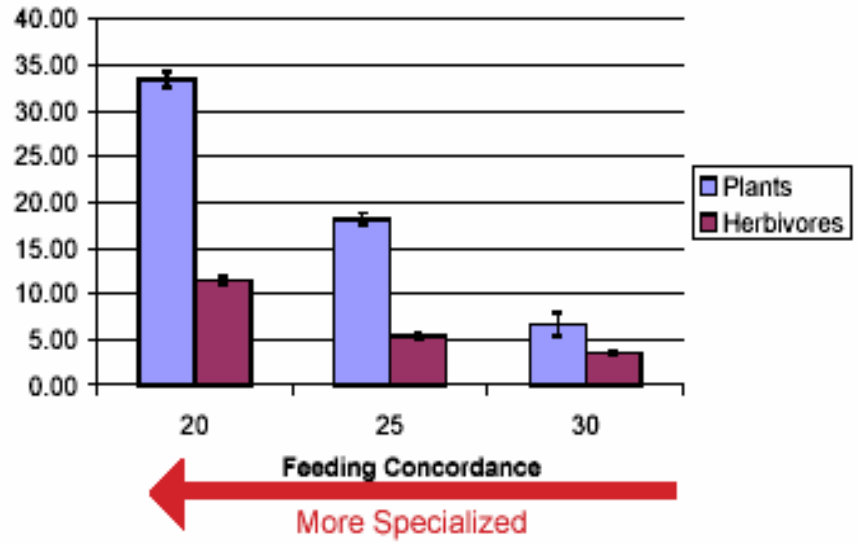
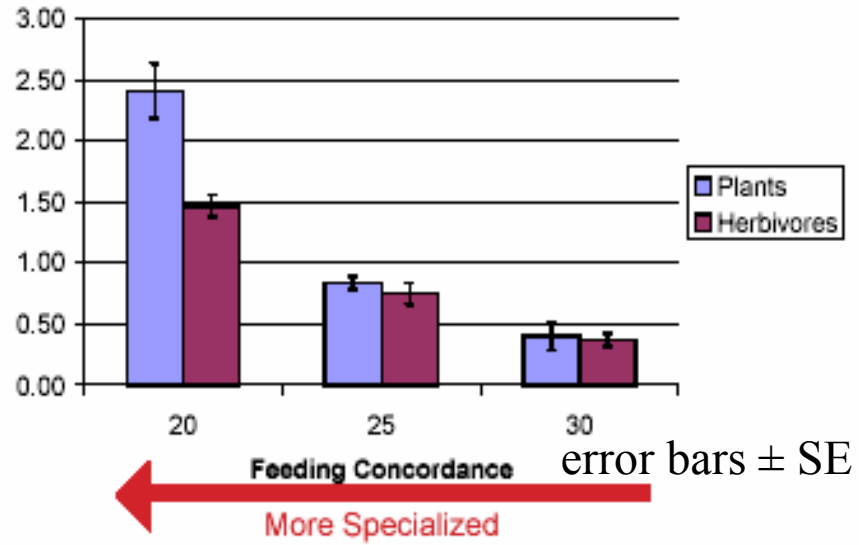
Conclusions (3 of 3)





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Acknowledgements

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