Spatial Ecology

image: http://picea.sel.uaf.edu/

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for CS790R, Professor Doursat

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Major topics

- Coupled map Lattices
  - Solé, Bascompte, Valls 1992
- Habitat fragmentation and extinction thresholds
  - Bascompte & Solé 1996
- Stability and complexity
  - May 1972
- Fractal rainforests
  - Solé & Manrubia 1995

There are some peculiarities of complex ecosystems

- Environmental variables are often relatively uniform, yet . . .
- Numbers of each species type highly nonuniform

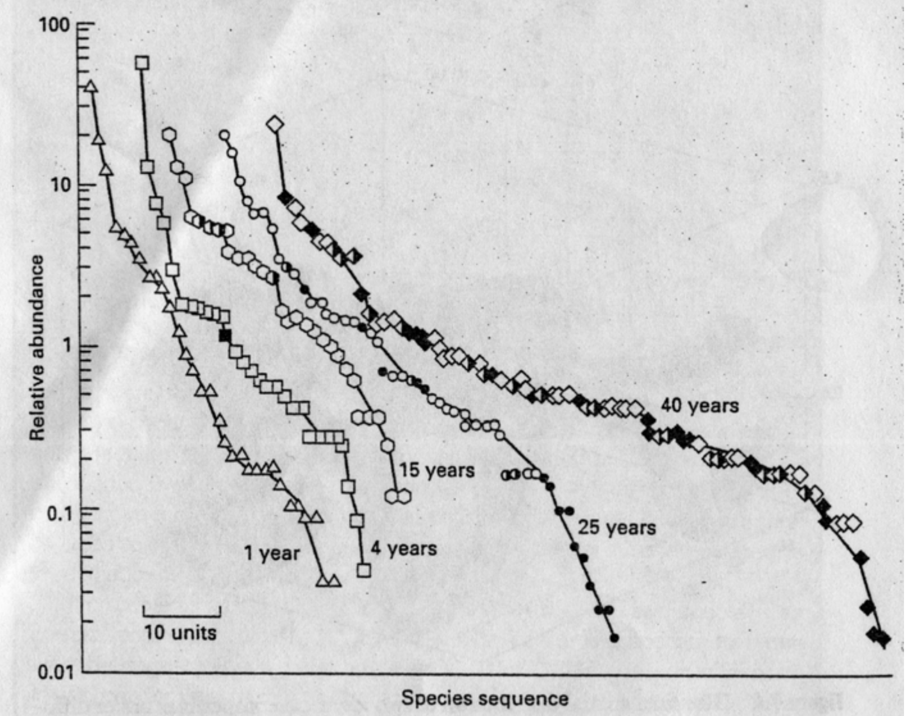


Figure 7.2 Sequence of changes in the rank-abundance vegetation pattern at different times. Here species are ordered from the most abundant to the less frequent, which defines the rank.

- What is “species sequence” “10 units”?

Old theory

- Generally, coexistence of species in niches
- Beyond some critical value of competition, get competitive exclusion
- This is proving to be inadequate to account for observations. Why?
- Laboratory experiments are generally unhelpful in resolving this. Why?

Ecologies make things more complicated!

- Complicated food webs
- Complicated subdependencies
- Complicated dynamics
- Importance of space

Ecologies evolve to homeostatic, complex end distributions with long food chains

- Perturbations change details, but not big picture

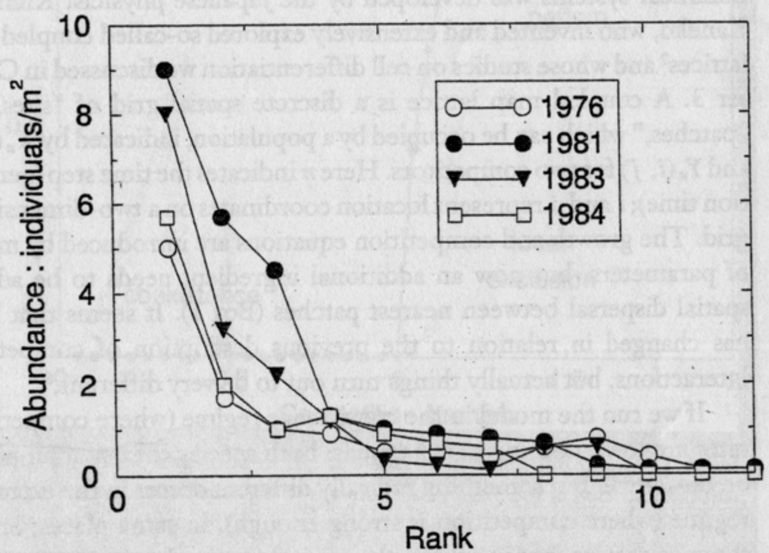


Figure 7.3 Changes in the rank-abundance distribution of species abundances on rocky shore before and after the near extinction of a top predator (see text). The different years are indicated. After a transient change in the distribution, a final state is reached, very close to the original one (data from Brown, 1994).

Topic: Coupled map lattice models

- Systems of differential equations (Lotka 1925, Volterra 1926) can only be taken so far. They do not involve the concept of space. They can often be shown analytically to lead to stable states or extinction of one population or other for certain parameter ranges or initial states.
- Kaneka 1990 began investigating an explicitly *spatial* model (in a nonbiological context)

(more on coupled map lattice models)

Case study: parasitoids

- Question: In laboratory, system is very unstable, resulting in death of both organisms. But system exists in the wild. How?
- Answer: Space
- Simulations show spiral wave population patterns, and local extinction, but global survival of both species (fig. 7.6)

(more on coupled map lattice models)

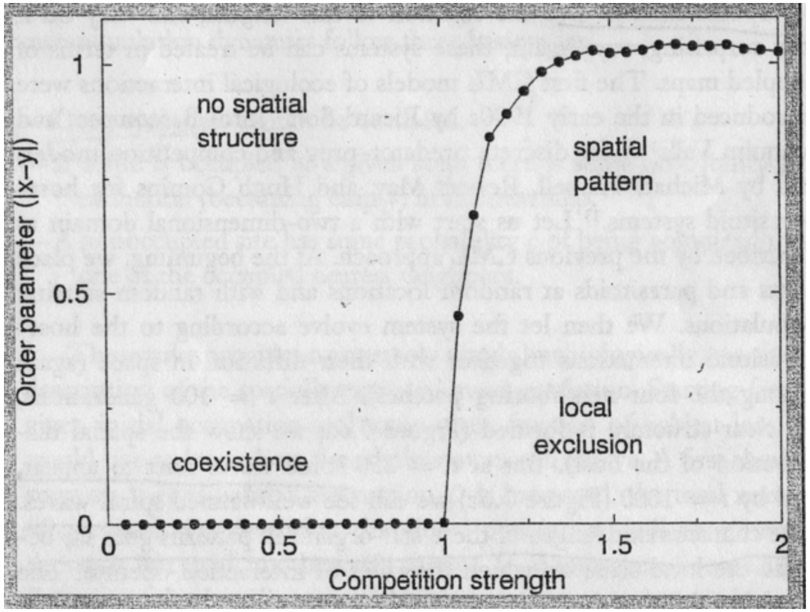
- When competition rates are low, species coexist
- Major change when competition is strong enough: emergence of spatial structure
  - Space matters
  - There is a critical size of space to support two species; if the habitat is too small, one species dominates as before

(more on coupled map lattice models)

Phase transition boundaries

What is an "order parameter"?

"In a nonlinear dynamic system, a variable-acting link, a macrovariable, or combination of variables, that summarizes the individual variables that can affect a system. In a controlled experiment, involving thermal convection, for example, temperature can be a control parameter; in a large complex system, temperature can be an order parameter, because it summarizes the effect of the sun, air pressure, and other atmospheric variables. See: Control parameter."
(www.duke.edu/~charvey/Classes/wpg/bfgloso.htm)



Paper: Solé, Bascompte, Valls 1992

- Coupled lattice model, two species
  - Wide range of dynamical behavior, including chaos
  - Spatial version *shows coexistence even when competition factor is large* and in presence of local exclusion
  - Spatial structures form . . .
  - . . . Even with chaotic time dynamics
  - Local dynamics may be unstable, but global population is quite stable

Topic: Habitat fragmentation

- You might guess that linear habitat destruction would lead to linear population decay
- This is why you are not an ecologist
- In fact, response to habitat reduction is highly nonlinear, “close to criticality”

Paper: Bascompte & Solé 1996

- Investigates effect of habitat destruction on population in a spatially explicit model
- Result: effect is highly nonlinear, with critical thresholds

Paper: Bascompte & Solé 1996

- They spend a little time reviewing a spatially implicit, differential equation model. There is a critical point of site availability beyond which extinction occurs even in the presence of some habitable sites. (Why are all sites not occupied?)

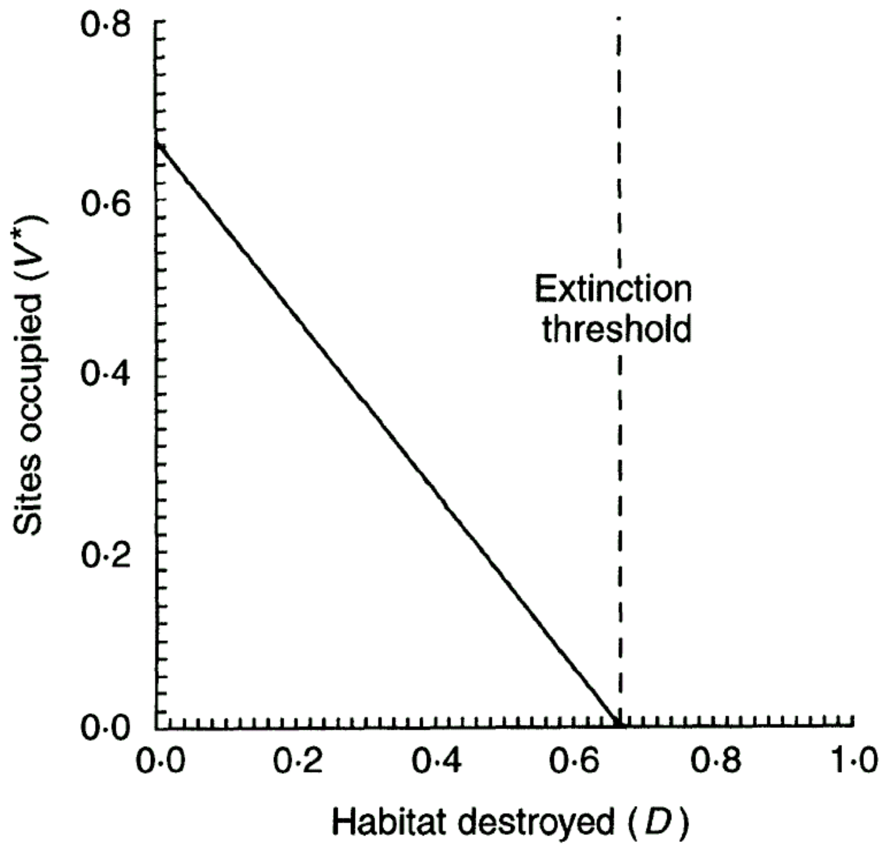
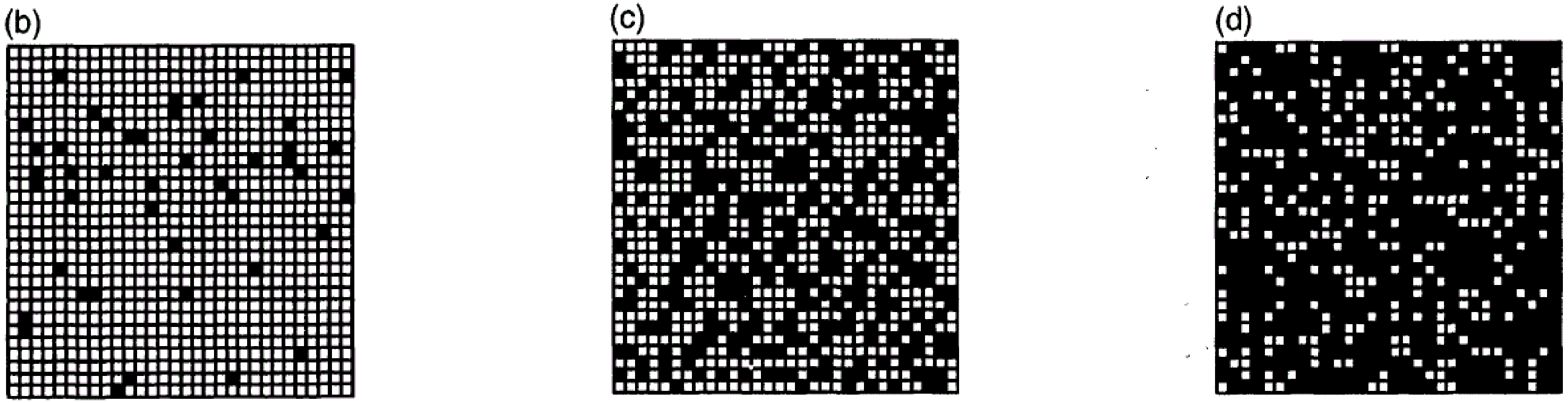
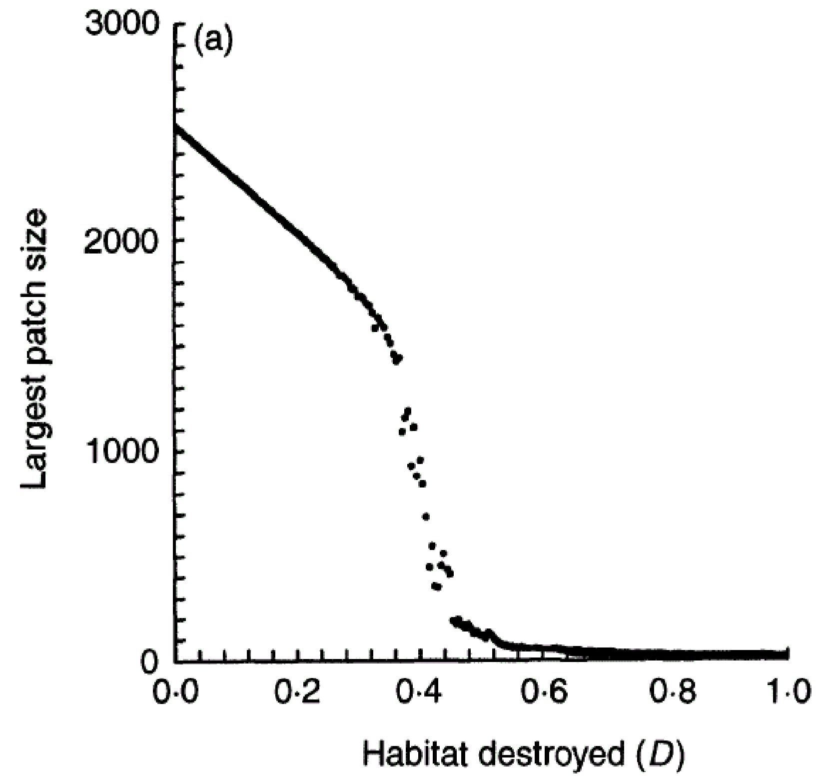


Fig. 1. The equilibrium percentage of occupied sites ($V^* = 1 - D - e/c$) is plotted as a function of the fraction of habitat destroyed (D) according to the metapopulation model (2). Here $e = 0{\cdot}2$ and $c = 0{\cdot}6$. The extinction threshold takes place when the fraction of habitat destroyed is $D_c = 1 - e/c = 0{\cdot}666$.

Paper: Bascompte & Solé 1996

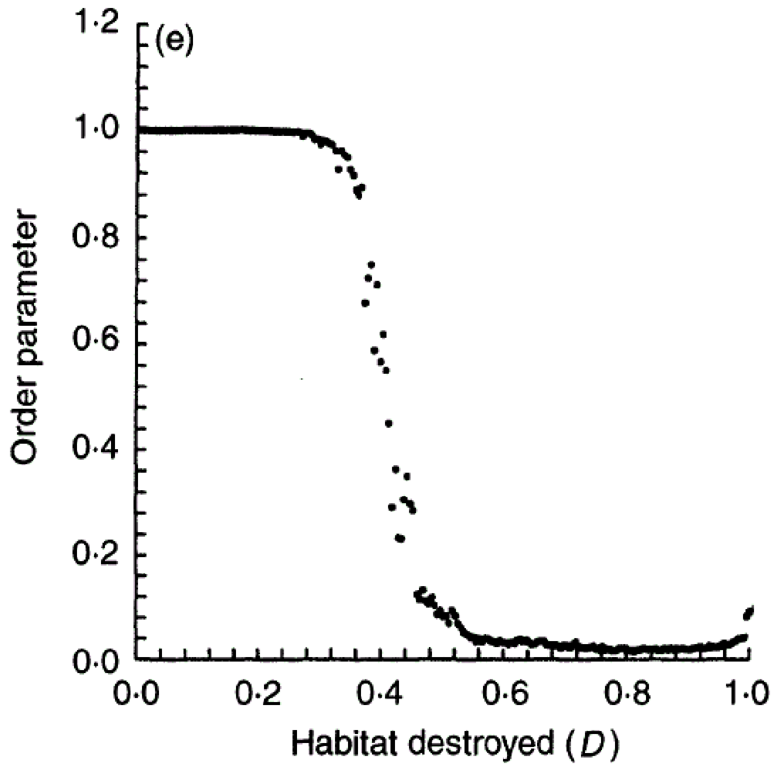


- Two dimensional lattice
- White cell is habitable
- Black cell not habitable
- Progressively destroy more sites and consider the size of the largest habitable patch



Paper: Bascompte & Solé 1996

- But habitat fragmentation (patch size) is not necessarily directly related to habitat loss
- They define an order parameter to study this
- The critical value for survival is where fragmentation starts to occur
- What happens near D=.4?



$$\Omega = \frac{S_{\max}}{\Sigma_i \Sigma_j \Theta(i,j)}$$

Smax is size of largest patch

Paper: Bascompte & Solé 1996

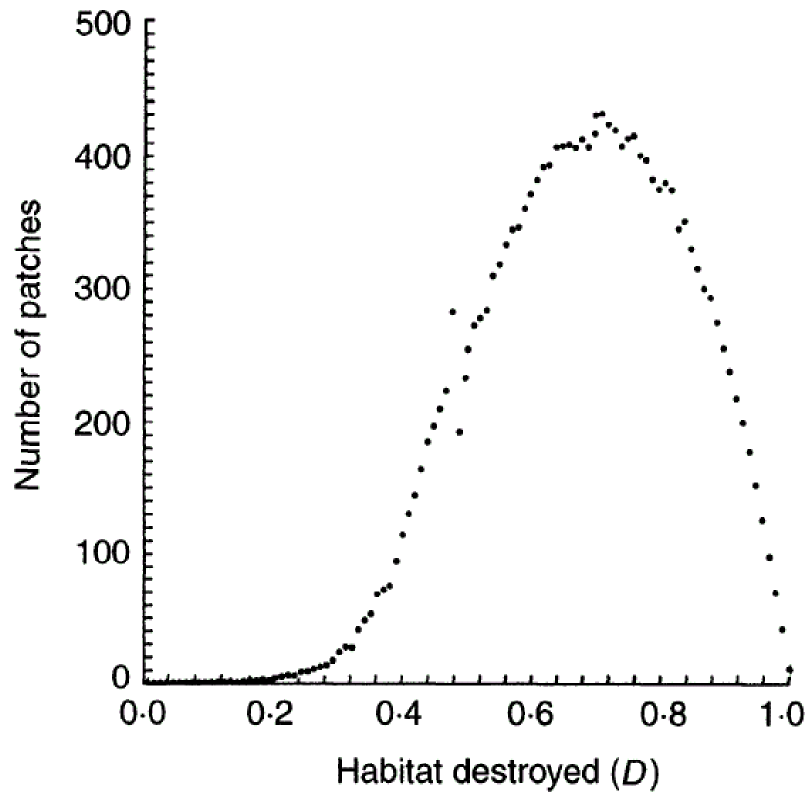


Fig. 4. Number of different patches as the fraction of destroyed sites increases. For very low destruction values all the available sites belong to the same cluster. At higher values, clusters become fragmented. On the other hand, when almost all sites have been destroyed, most of the remaining patches consist of a single site, so further destruction implies a reduction in the number of patches. The maximum number of patches takes place for a fraction of destroyed sites equal to 0·7. Parameters as in Fig. 3.

Paper: Bascompte & Solé 1996

Next step . . . how is this related to population/extinction?

Through probabilistic extinction-colonization rules that depend on number of occupied neighbor sites

Size of habitat matters for viability in a spatially explicit model

Above a certain *D*, very different results for spatially explicit and implicit models

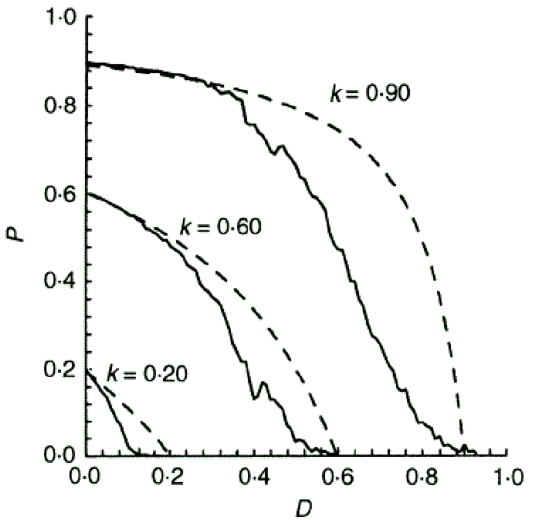


Fig. 6. Similar to Fig. 2. The discontinuous lines plot three examples of model 3, the analytical solution of the fraction of suitable sites occupied (*P*) as a function of the fraction of sites destroyed (*D*). *K* = 0·20, 0·60 and 0·90, respectively. The continuous lines represent the five replicas average of the spatially explicit counterpart. As noted, for low *D*-values both models are coincident, but after a critical *D*-value the spatially explicit model decays faster. This divergence point takes place for larger *D*-values as the demographic potential (*K*) is larger.

Note noise in explicit model for high *D*

Paper: Bascompte & Solé 1996

Extinction happens more easily in spatially explicit model than in spatially implicit model

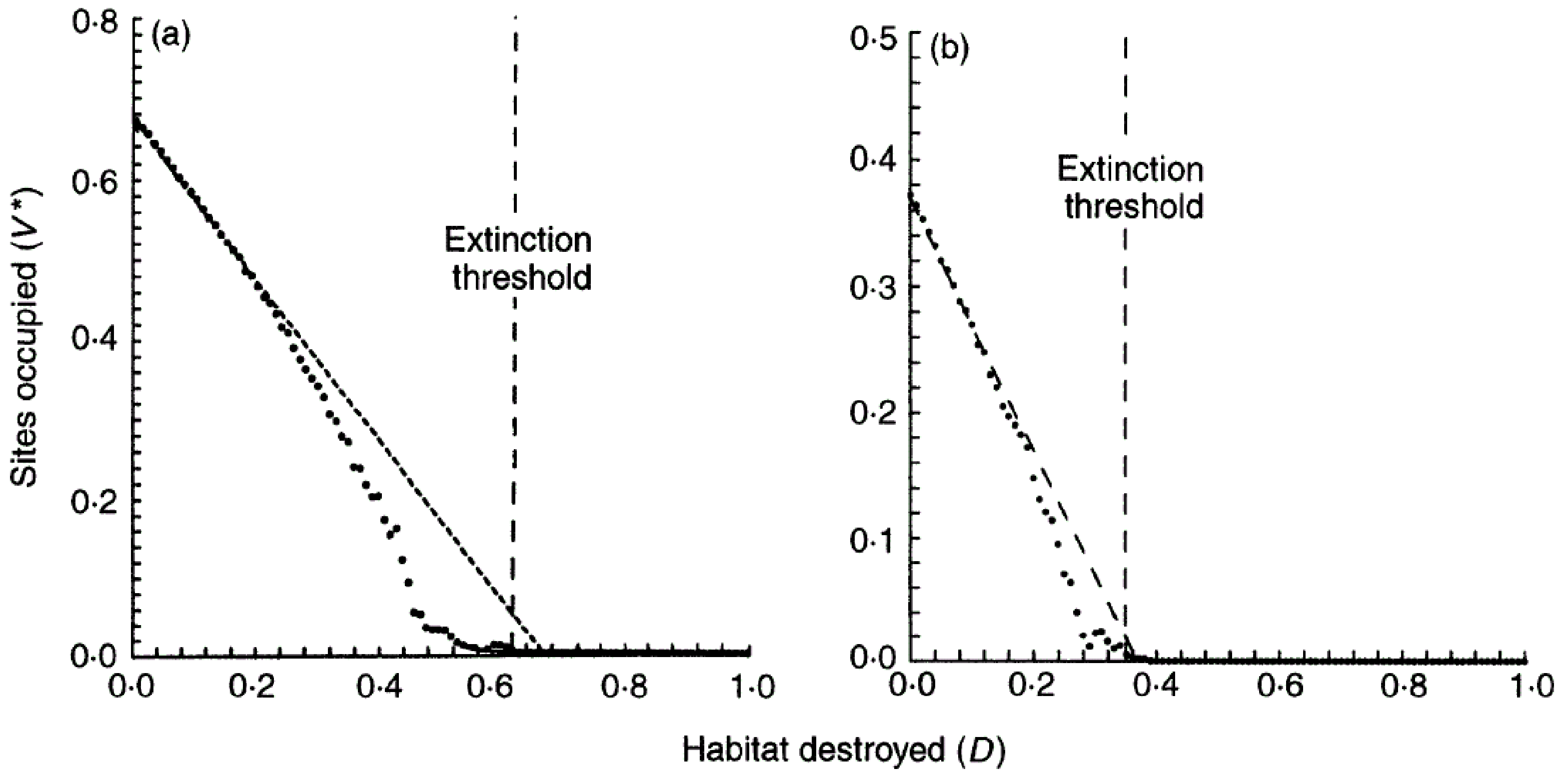


Fig. 5. Occupancy probability (V^*) as a function of destroyed sites (D). Points represent the five replicates average of the spatially explicit model described here. The added discontinuous line shows the spatially implict behaviour (model2) shown in Fig. 1 for comparison purposes. The vertical discontinuous line shows the extinction threshold for the spatially explicit model. As noted, for a given D-value, the fraction of occupied sites is lower in the spatially explicit model. Furthermore, the observed extinction threshold takes place for lower values of habitat destruction compared with the spatially implicit model. Lattice size is 50 × 50 and extinction–colonization probabilities are (a) $p_e = p_c = 0{\cdot}2$ and (b) $p_e = 0{\cdot}6$ and $p_c = 0{\cdot}3$.

Topic: Stability and complexity of ecological webs

- What about more than two species?
- Why do ecosystems with few species show high interconnectedness, and ecosystems with many species show weak interconnectedness?

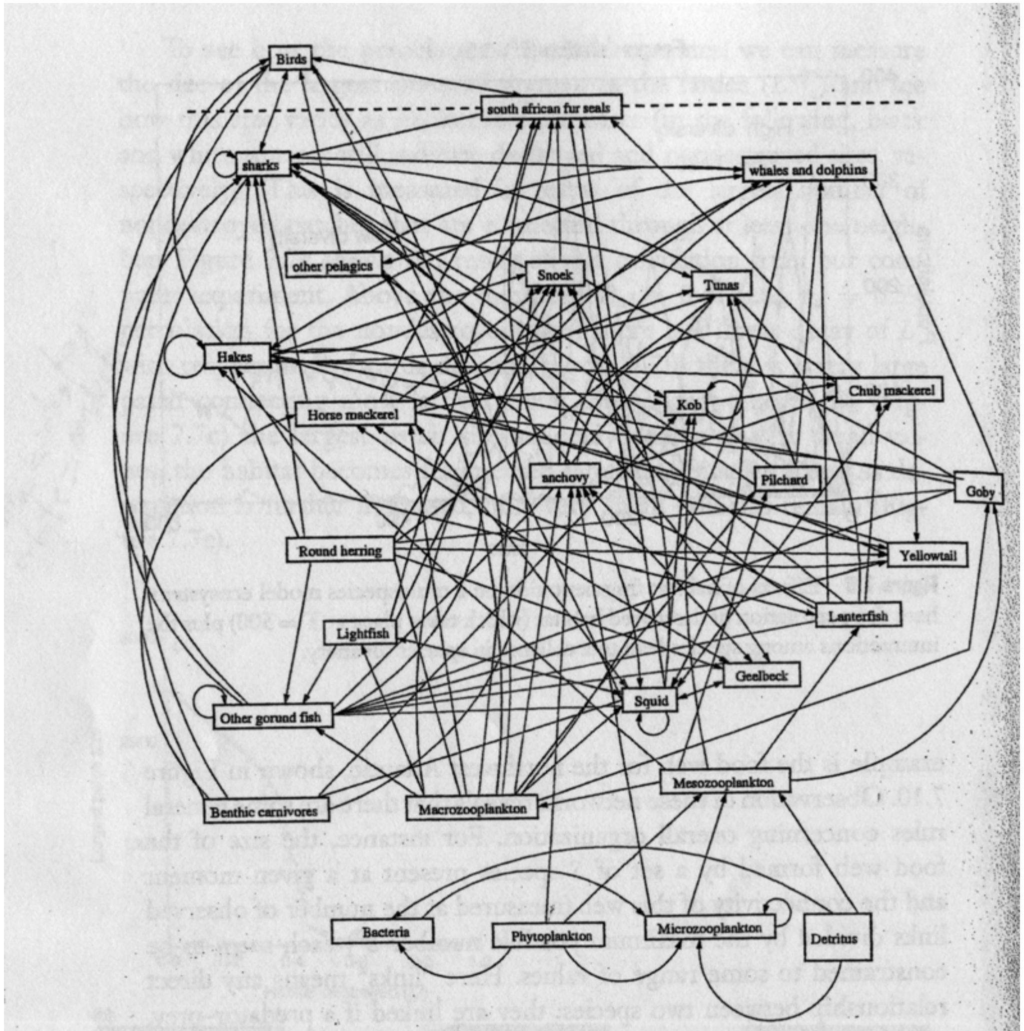


Figure 7.10 A complex food web pattern from a marine ecosystem.

Paper: May 1972

- Too rich a web connectance or too large an average connection strength leads to instability
- For stability, “sub communities” can be richly and strongly connected, but totality should not. Example:
  - 12 species communities with 15% connectance have about 0% chance of stability
  - Three 4x4 communities, 35% probability of stability

Topic: Fractal rainforests

- What is self organization?
- What is criticality?
  - In context of sand piles
  - In context of rainforest canopy

Criticality

"There is order at all length scales, and small perturbations create objects of all sizes"

Paper: Solé and Manrubia, 1995

- Shows how a non-linear dynamic process (gap formation) can lead to fractal structures, through a CA model
- Real-life counterpart: Barro Colorado Island

Paper: Solé and Manrubia, 1995

Barro Colorado Island

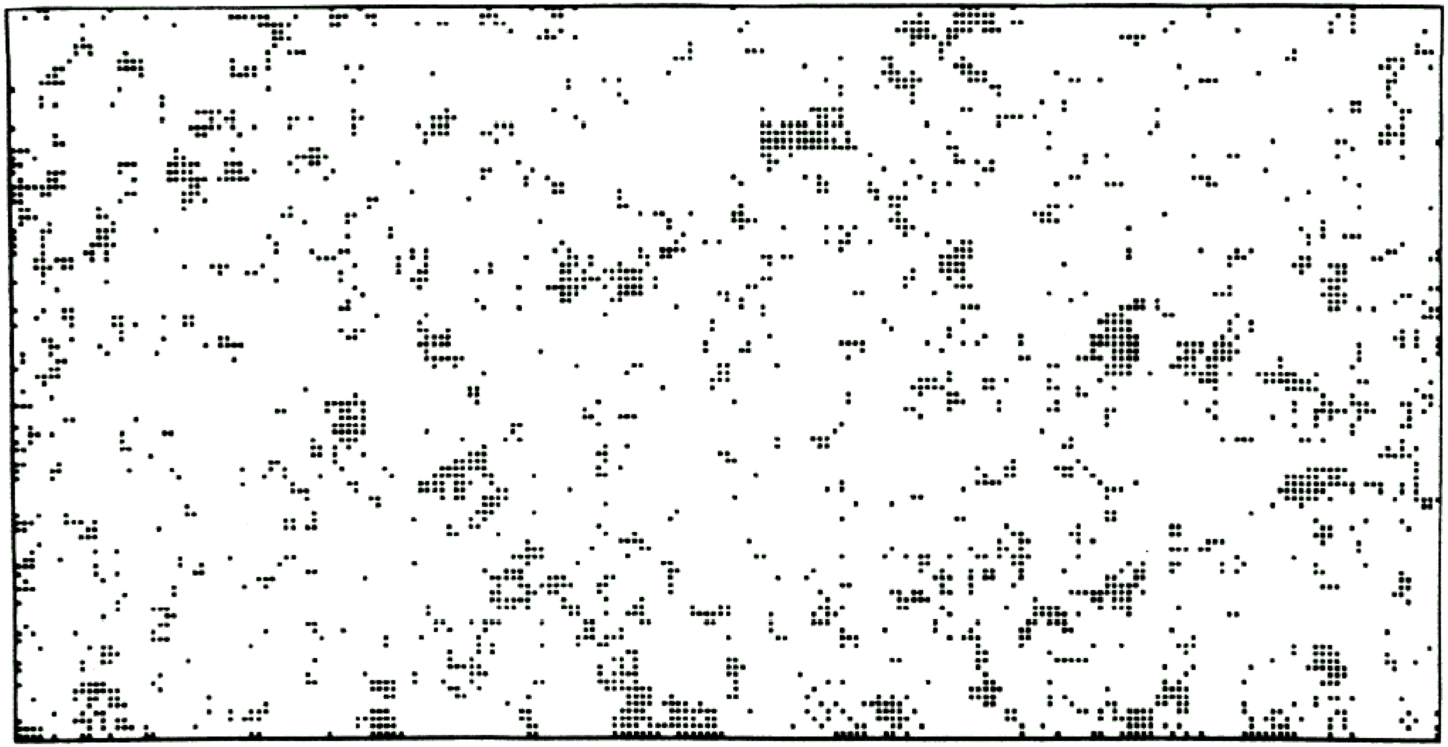


FIG. 1. Map of 50-ha plot on Barro Colorado Island, Panama. Here 2582 low canopy survey points are shown, as block dots. These points indicate that the eight of the canopy was <10 m in 1982, 1983 or in both years.

Paper: Solé and Manrubia, 1995

Yup, it's fractal

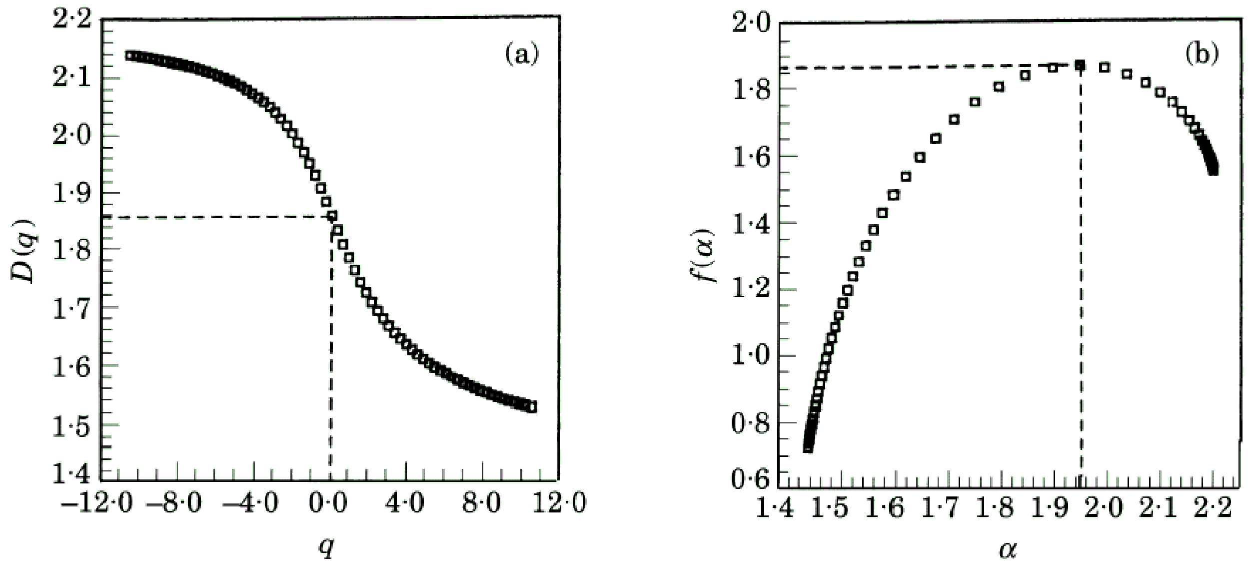


FIG. 3. The BCI of Fig. (1) was covered with a grid of 1250 boxes, in order to obtain the mass measure for the forest. (a) Spectrum of correlation dimensions, $D(q)$. (b) Spectrum of fractal dimensions, $f(\alpha)$. $f(0) = D_0 \approx 1.86$, the fractal dimension of BCI.

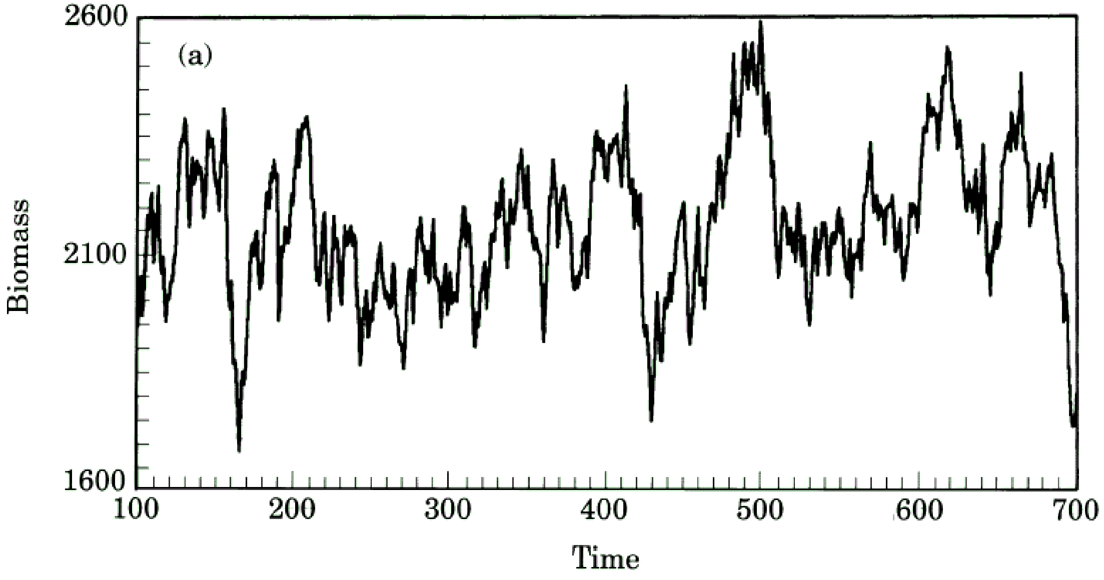
Paper: Solé and Manrubia, 1995

The Forest Game

- CA on LxL grid
- Trees grow and compete for resources
    - too many tall neighbors means no growth
- Once a certain height is reached, tree randomly falls
    - can take down neighbors too
- New trees can grow on empty spots

Paper: Solé and Manrubia, 1995

"Many computer simulations have been performed"



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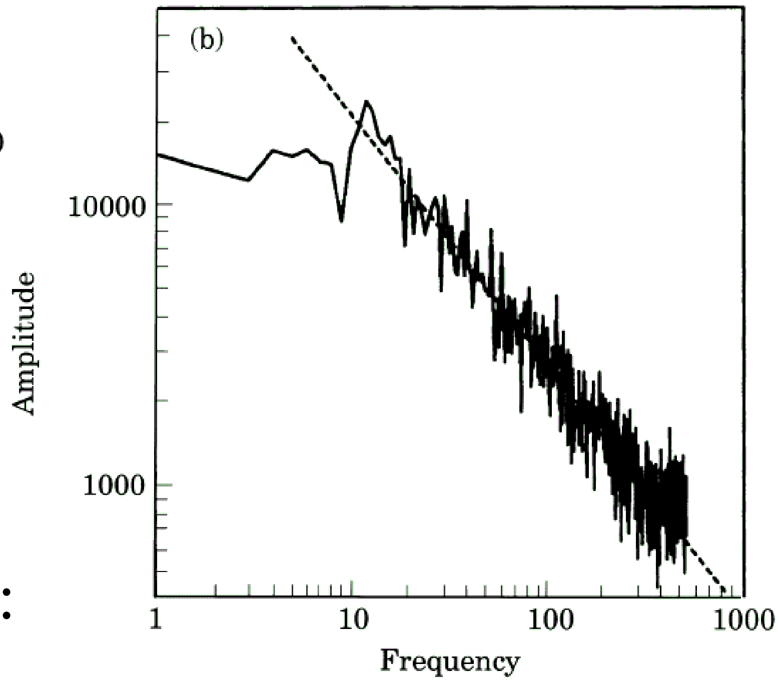

Paper: Solé and Manrubia, 1995

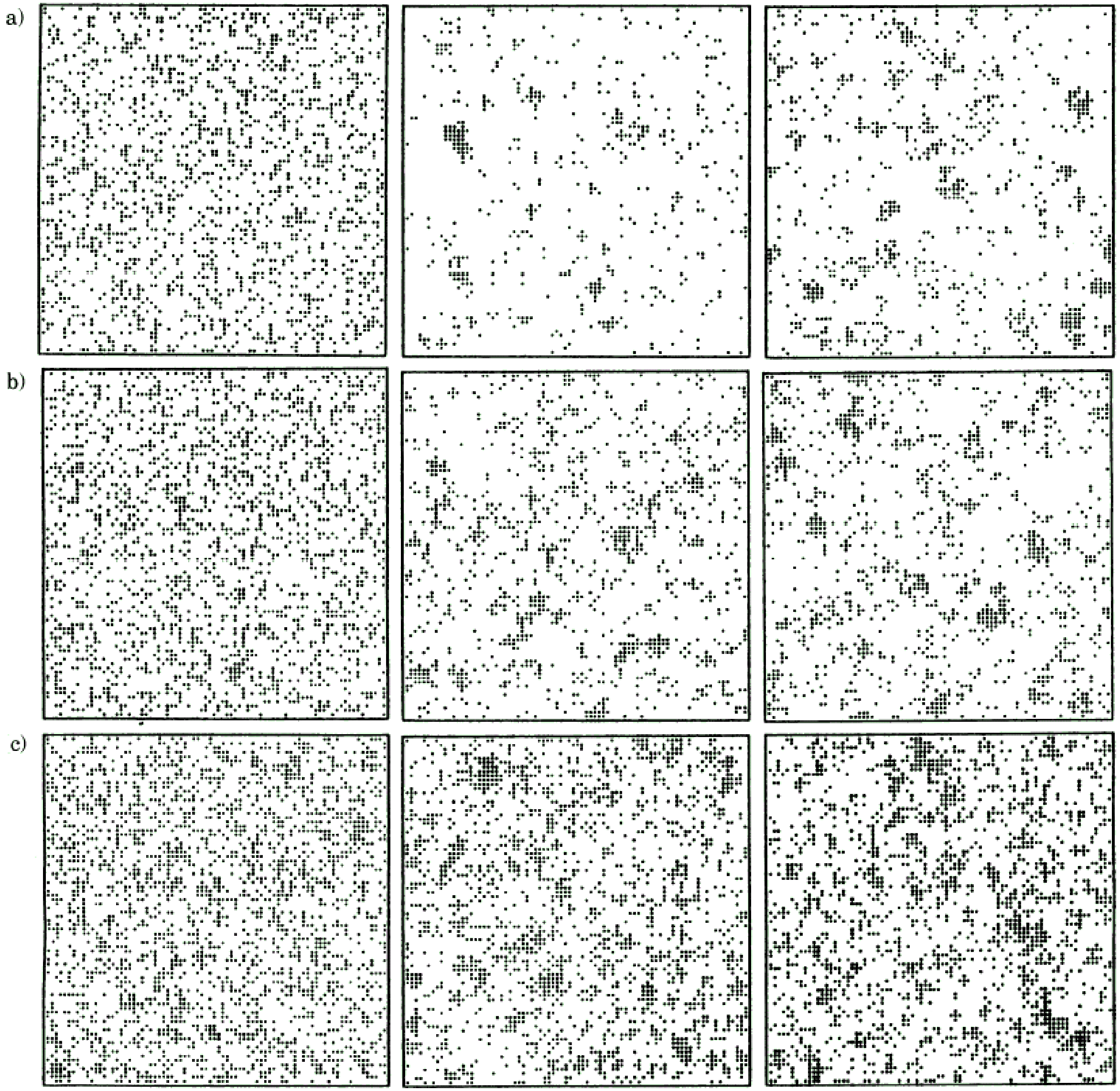

FIG. 6. Simulation model. Here a 81×81 lattice has been used, with $p_b = 0.3$ and $S_c = 30$. Probability of death is (a) $p_d = 0.01$ (b) $p_d = 0.025$ and (c) $p_d = 0.05$. Three time steps are shown. From left to right, $t = 5$, $t = 50$, and $t = 150$.

Simulation results, three paramaters, three timesteps

Paper: Solé and Manrubia, 1995

The simulation results are fractal too:

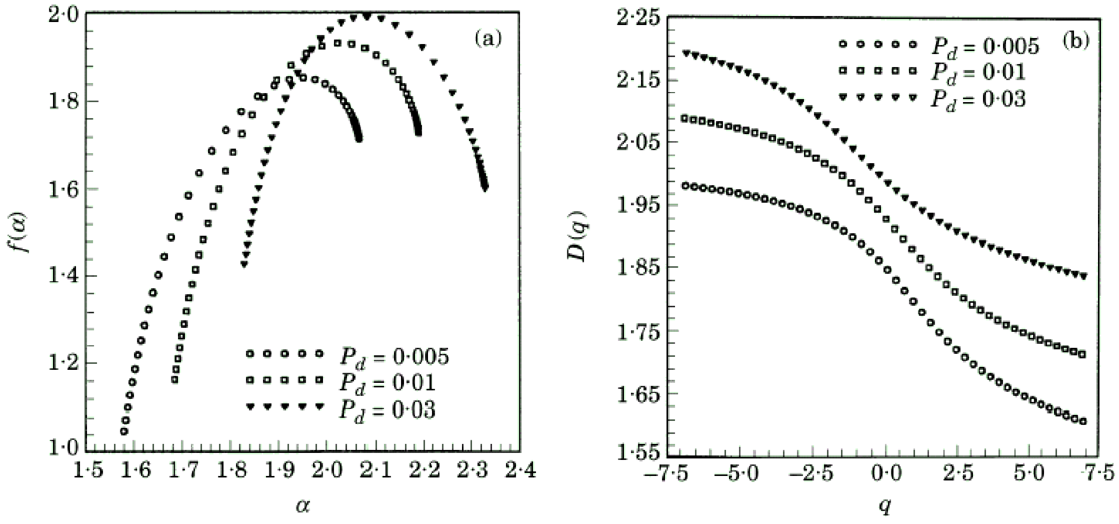

FIG. 7. (a) Multifractal spectrum $f(\alpha)$ and (b) correlation dimensions $D(q)$, for three simulated ecosystems. Here we have used 80×80 lattices, $p_b = 0.3$ and several values of p_d, as indicated.

'It is important to mention that if only D_0 were available, our conclusion would be "random pattern". The multifractal approach allows us to observe the system at a higher resolution.'

Question:

Is criticality static, in terms of size of patches extant, or dynamic, like in sand avalance model, in terms of size of tree fall events? Or both?