Geosimulation Modelling Final Project Presentation

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Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems

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Humans and climate affect ecosystems and their services[1], which may involve continuous and discontinuous transitions from one stable state to another[2]. Discontinuous transitions are abrupt, irreversible and among the most catastrophic changes of ecosystems identified[1]. For terrestrial ecosystems, it has been hypothesized that vegetation patchiness could be used as a signature of imminent transitions[3,4]. Here, we analyse how vegetation patchiness changes in arid ecosystems with different grazing pressures, using both field data and a modelling approach. In the modelling approach, we extrapolated our analysis to even higher grazing pressures to investigate the vegetation patchiness when desertification is imminent. In three arid Mediterranean ecosystems in Spain, Greece and Morocco, we found that the patch-size distribution of the vegetation follows a power law. Using a stochastic cellular automaton model, we show that local positive interactions among plants can explain such power-law distributions. Furthermore, with increasing grazing pressure, the field data revealed consistent deviations from power laws. Increased grazing pressure leads to similar deviations in the model. When grazing was further increased in the model, we found that these deviations always and only occurred close to transition to desert, independent of the type of transition, and regardless of the vegetation cover. Therefore, we propose that patch-size distributions may be a warning signal for the onset of desertification.

It is of the utmost importance to find early warning signals of transitions that can alter ecosystems' services in fundamental ways, causing losses of ecological and economic resources[2-4]. Determining proximity to transitions is especially important for arid ecosystems, which may convert into deserts[2,4,5]. According to the Millennium Ecosystem Assessment, increasing external pressures by human activities or climate change will lead to desertification, affecting the livelihood of more than 25% of the world's population[1]. A mechanism playing a dominant role in the functioning of arid ecosystems is local facilitation among plants[6-9]. Local facilitation is the biophysical ameliorative effect of sessile organisms, such as plants, on their neighbouring environment. Such local positive interactions induce vegetation patchiness[6,7,10] and determine the response of this patchiness to environmental change[5].

We investigated how the spatial organization of vegetation is influenced by the degree of external stress by combining modelling and field data from three grazed Mediterranean arid ecosystems in Spain, Greece and Morocco. In each of these ecosystems, we collected data on three sites that differed with respect to the livestock grazing pressure (Table 1; Methods). In each of the nine (3 × 3) sites, we analysed the number and the sizes of the vegetation patches (see Methods), and plotted the number of patches, $N(S)$, as a function of their sizes, S. We fitted these patch-size distributions to two different models: a power law, $N(S) = CS^{-\gamma}$; and a truncated power law, $N(S) = CS^{-\gamma}e^{-\frac{S}{S_x}}$, where γ is the estimated scaling exponent of the model, S_x the patch size (in centimetres) above which $N(S)$ decreases faster than in a power law, and C is a constant[11,12]. To understand the mechanisms that may be responsible for the spatial organization of the vegetation, the observed distributions were compared with distributions generated by a stochastic cellular automaton model (see Methods).

We focused first on the spatial organization of the field sites with the lowest grazing pressure. In the three ecosystems, a power law best fitted the patch-size distribution characterized by a linear relation on a logarithmic scale (Fig. 1a, d and g). This power-law relation implied that vegetation patches were present over a wide range of size scales, with many small patches and relatively few large ones. The values of the scaling exponents γ of these power laws are similar among the three ecosystems, which is consistent with the hypothesis of a universal mechanism of Mediterranean ecosystem organization. At the

Table 1 | Characteristics of the three Mediterranean ecosystems

	Ecosystem type*	Dominant species	Climate	Effective stocking rate (animals per hectare per year)	Transect size (m)
Cabo de Gata-Níjar	Scattered matorral	Stipa tenacissima, Chamaerops humilis	Average rainfall, 200 mm mean	Low, 0; middle, 0.27; high	32 m (30 transects

Aim

- Create a model similar to the given model from the paper

- Model the effects of
  - Increased grazing pressure (= mortality)

    and of
  - Local positive interactions (= local facilitation & seed dispersal)

    on vegetation in a specific ecosystem

- Reproduce all of the 6 graphs/model runs from the paper which might eventually lead to desertification:
  - 3 graphs/model runs with increasing grazing pressure
  - 3 graphs/model runs with decreasing local positive interactions

Research question

- How does different level of grazing pressure gives rise to desertification?

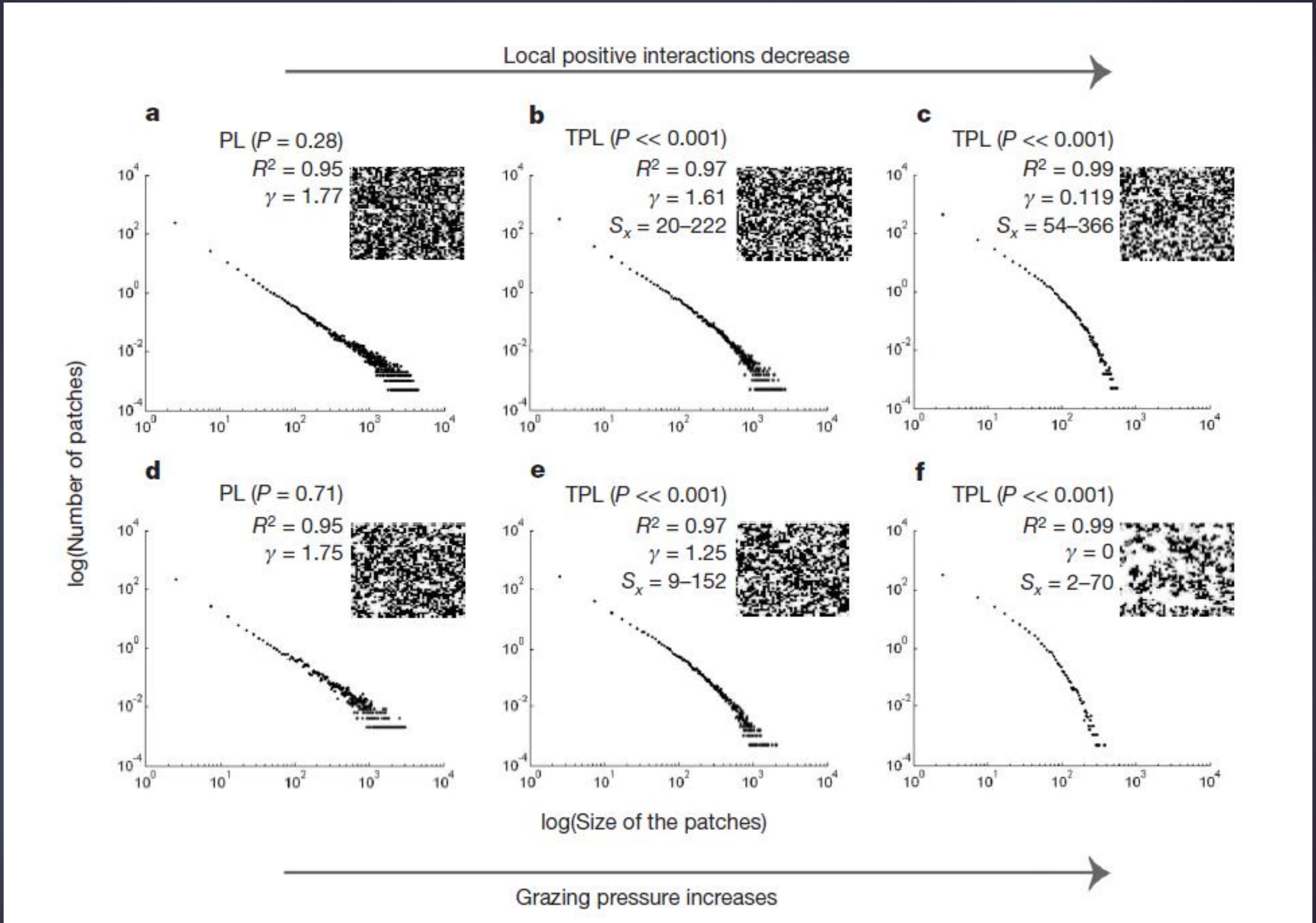


Figure 2 | Effect of local positive interactions and grazing pressure on the patch-size distribution in the model.

Difficulties met

- Understanding the paper
- Conceptualizing the idea of the researchers‘ model
- Figuring out all the variables for the different formulas
- Trying to guess which values to use for
  - „β“ (= intrinsic seed production rate)

    and for
  - „ε“ (= establishment probability of seeds in a system without vegetation)

The answer was encapsulated in the paper but very difficult to tell even after thorough reading.

What we did…..

- …chose **NetLogo** for the project
- …setup study scenario by generating random size patches of 3 colours green, brown and grey
- …implemented the 4 transition functions from the paper
- …tweaked with the values for the different variables
- …ran the model
- …visualized and analyzed the result

Formulas used….

- Colonization $w_{\{0,+\}} = \beta(\delta\rho_+ + (1-\delta)q_{+|0})G(\rho_+),$

  $\rho_+ : G(\rho_+) = \varepsilon - g\rho_+$

- Mortality $w_{\{+,0\}} = m.$
- Degradation $w_{\{0,-\}} = d.$
- Regeneration $w_{\{-,0\}} = r + fq_{+|-},$

Values:
m=0.15, b=0.8, d=0.2, c=0.3, r=0.0001
f=0.52, d=0.58
f=0.45, d=0.65
f=0.4, d=0.7
d=0.1, b=0.6, f=0.9, d=0.2, c=0.3, r=0.0001
m=0.12, m=0.13, m=0.15

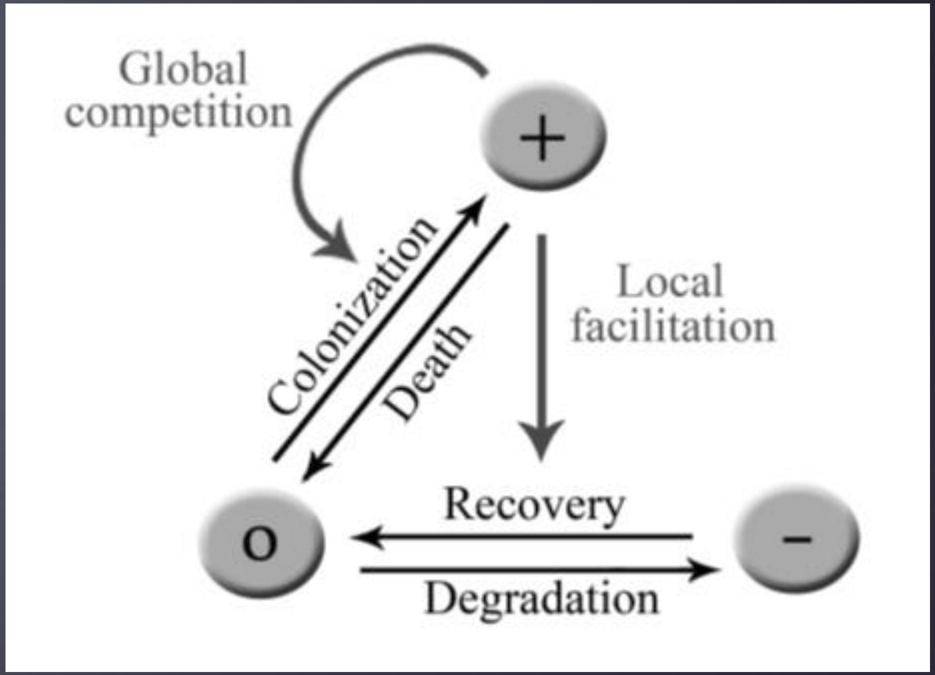
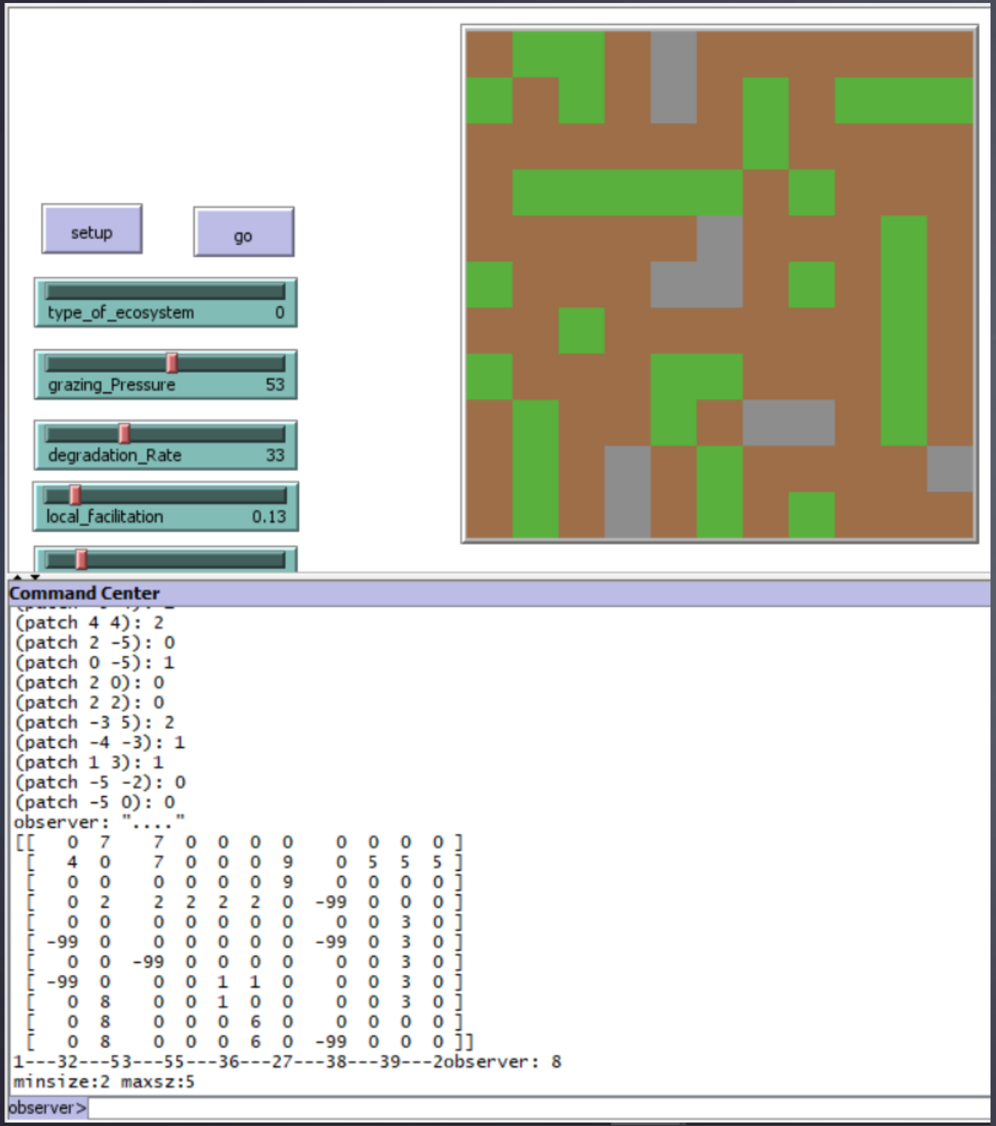


Fig.2 (Local facilitation, bistability and transitions in arid ecosystems)

DEMO

Our results….



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degradation_Rate 33
local_facilitation 0.13
Command Center
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(patch 2 0): 0
(patch 2 2): 0
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(patch -4 -3): 1
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(patch -5 -2): 0
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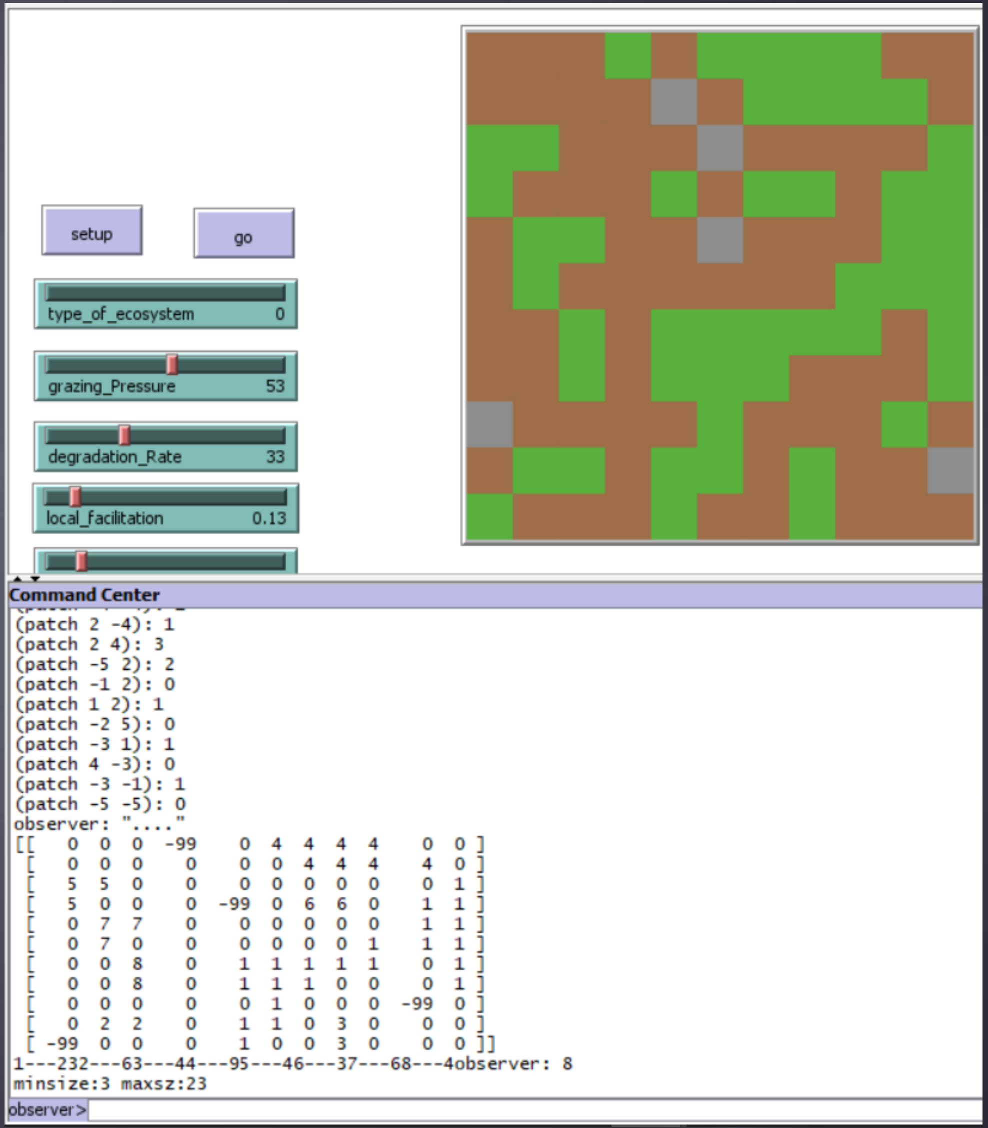

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grazing_Pressure 53
degradation_Rate 33
local_facilitation 0.13
Command Center
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(patch -5 2): 2
(patch -1 2): 0
(patch 1 2): 1
(patch -2 5): 0
(patch -3 1): 1
(patch 4 -3): 0
(patch -3 -1): 1
(patch -5 -5): 0
observer: "...."
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[-99 0 0 0 1 0 0 3 0 0 0]]
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minsize:3 maxsz:23
observer>

Our results….

- All in all replicating the researcher‘s model and reproducing the results worked out just fine with the desired outcome.

BUT

- For some reason we had to increase the grazing pressure (= mortality rate „m“) dramatically to see any effects of desertification.
- We couldn‘t find out the reason for that although we think that it must either be due to a misinterpretation of the paper or due to a programming flaw.

Conclusion

- We were able to see a

References

- Ke´fi, S., Rietkerk, M., van Baalen, M. & Loreau, M. Local facilitation, bistability and transitions in arid ecosystems. Theor. Popul. Biol. 71, 367–379 (2007).
- Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. Sonia Ke´fi1, Max Rietkerk1, Concepcio´n L. Alados2, Yolanda Pueyo1, Vasilios P. Papanastasis3, Ahmed ElAich4 & Peter C. de Ruiter1,5