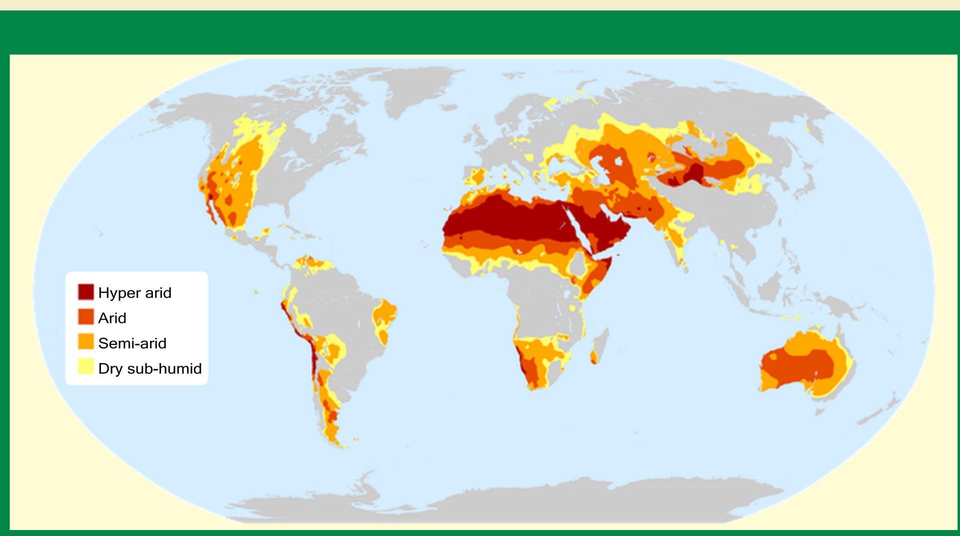
Pattern formation model to simulate clonal plants under drought conditions

Andrea Davin[1], Mara Baudena[2], Angeles G. Mayor[3], Enrico Magazzino[4], Jost von Hardenberg[2, 5]

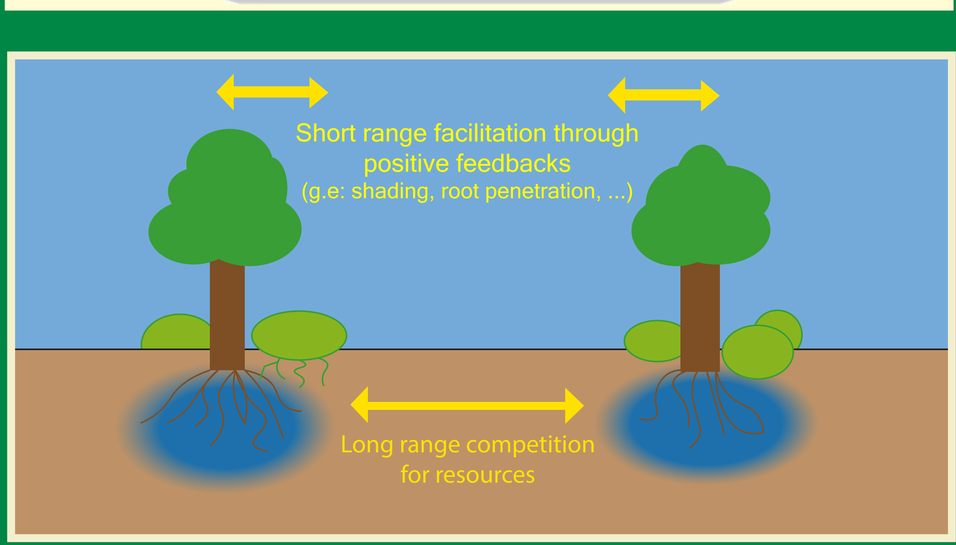
1 Università degli Studi di Torino, Torino, Italy, 2 National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC) Torino, Italy, 3 Complutense University of Madrid, Madrid, Spain, 4 Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, Netherlands, 5 Department of Environment, Land, and Infrastructure Engineering, Politecnico di Torino, Torino, Italy

BACKGROUND

Drylands are regions characterized by water scarcity (AI index <0.65). They constitute 41% of the Earth's land area and are inhabited by approximately two billion people.



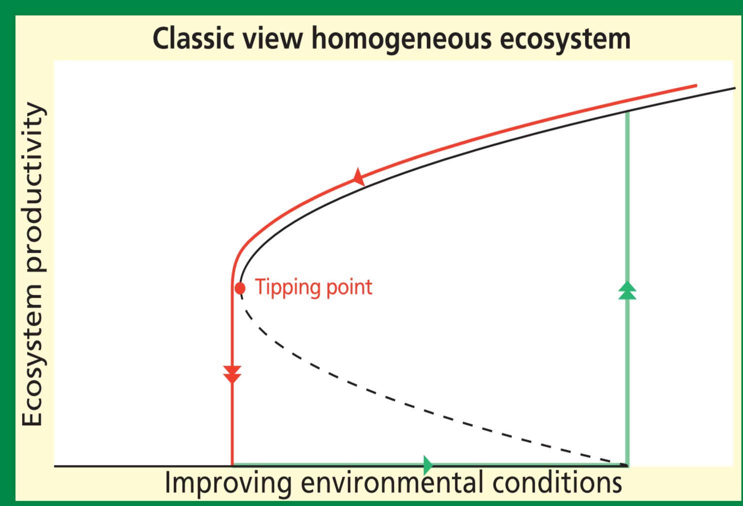
The trade-off between competition for water and the facilitation among neighboring plants, leads vegetation to form patterns.

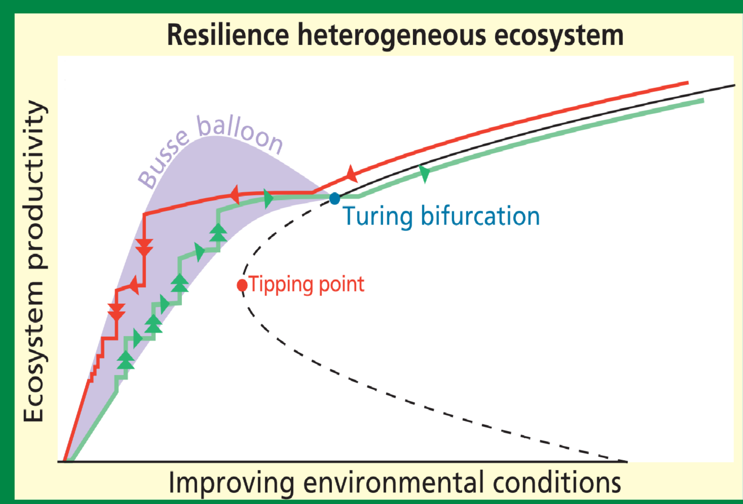


Understanding patterns' dynamics highlights ongoing deterioration processes. However, the large spatio-temporal scales involved require the coupling of mathematical models to observational data.

Current models fail to simulate clonal growth, although it is a common reproductive strategy

"Classic" (non spatial) models predict that with increasing environmental stress the ecosystem undergoes a critical transition to the alternative stable state ("tipping"). The stress has to decrease further below the tipping point in order to trigger another critical transition and restore the original value (hysteresis loop)





Spatially heterogeneous systems employ self-organization as a mechanism for evading this abrupt shift. The evasion of tipping point, allows the formation of different spatially heterogeneous stable solutions (the patterns), even beyond the tipping point: for this reason is necessary to employ spatial-explicit models to reproduce this kind of vegetation dynamics

MODEL

Here we present a new model for patter formation in clonal plants: it is a PDE system representing aboveground biomass and soil water.

The equations are derived from a well-known model in literature (Gilad et al., 2007). The latter was modified introducing a "clonal expansion term", specifically concieved to reproduce the complex behaviour of these plants

Logistic equation modulated by a kernel term (plant can absorb water from neighbouring areas)

Plants' mortality

Clonal expansion

Vegetation diffusion

$$b_t = \upsilon G_b b(1-b) - \mu b + c\,\nabla\cdot\left(bw\frac{\nabla b}{|\nabla b|}\right) + \delta_b \nabla^2 b$$

$$w_t = p - \upsilon w - \beta G_w w + \delta_w \nabla^2 w$$

Water diffusion in ground

Precipitation input

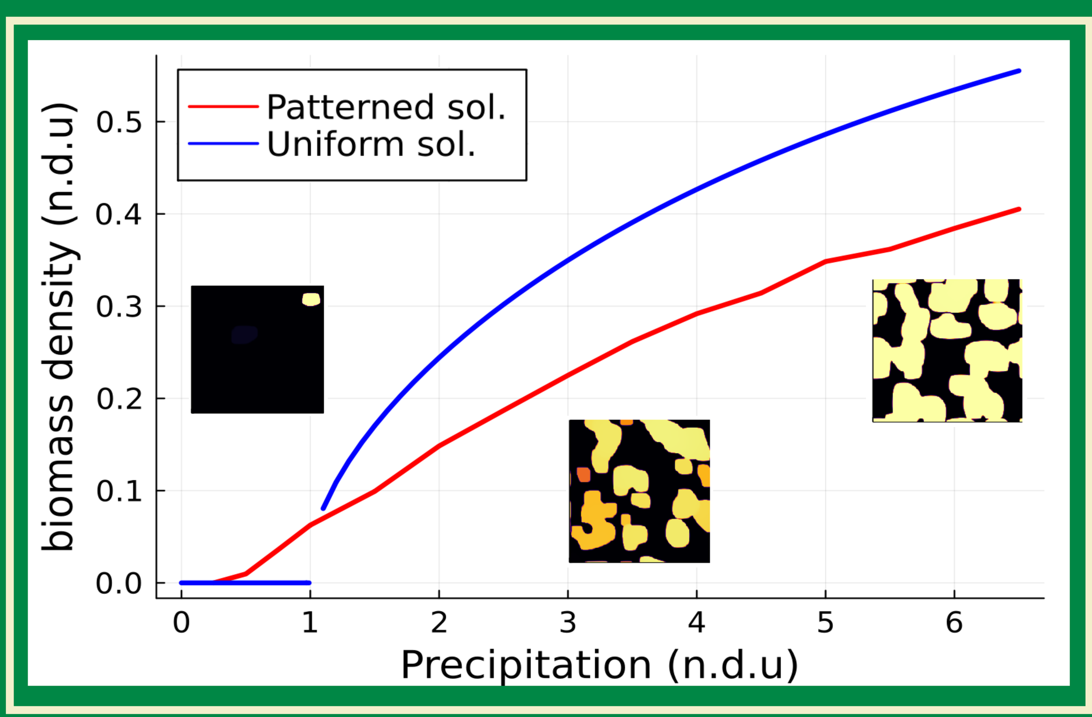
Evaporation

Water uptaken by neighbouring roots

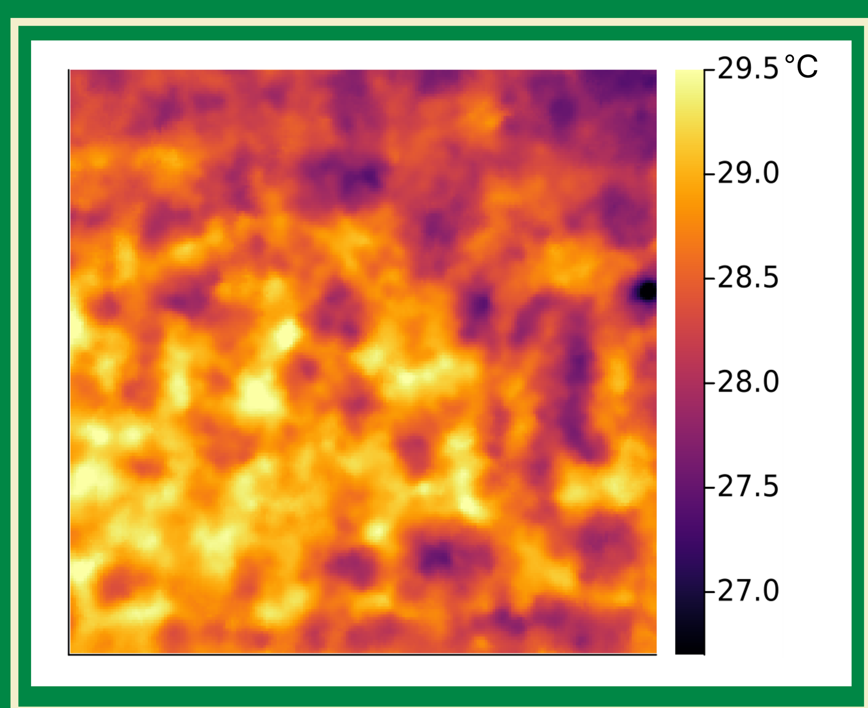
RESULTS

The introduction of the clonal growth term leads the model to produce amorphous and aperiodic patterns.

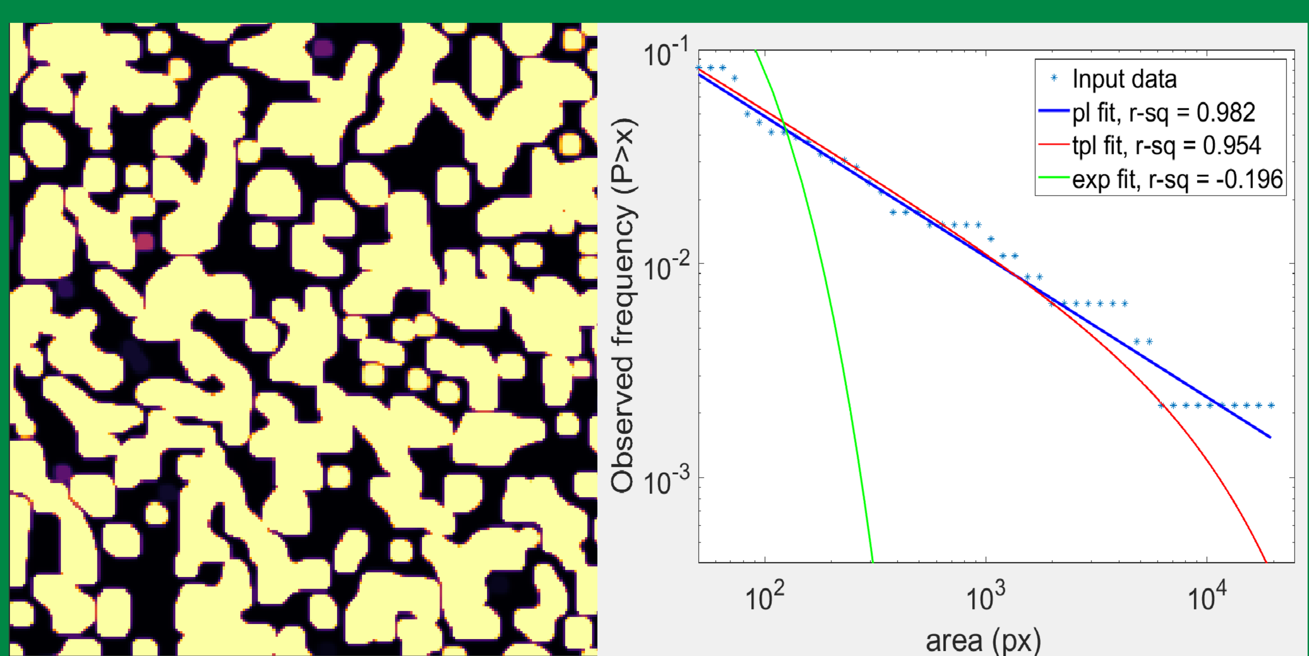
Results further confirm how pattern formation allows vegetation survival beyond the tipping point



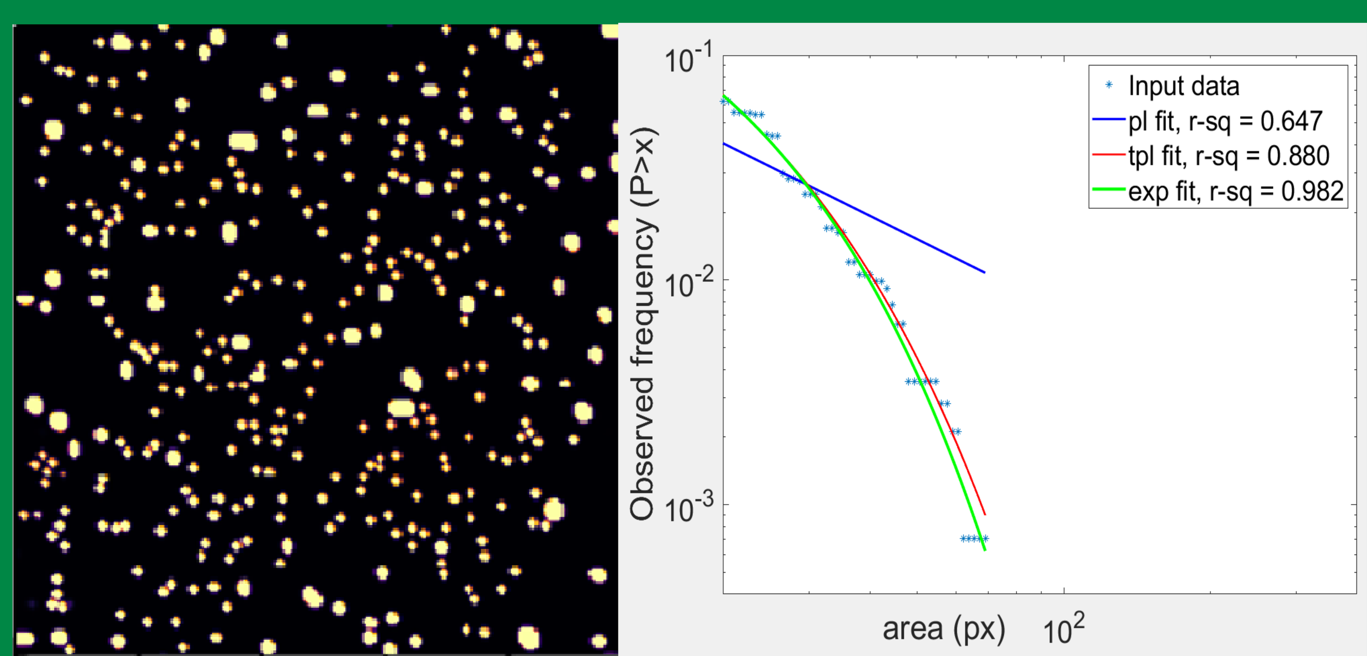
Amorphous and irregular patches produced by the model are in agreement with both literature and manipulative experiments conducted on clonal plants. The image shows a termic pattern in *P.vaginatum*: higher temperatures imply more stressed vegetation



The model can be employed to test spatial early warning signals of desertification: both observed and simulated vegetation patterns show a patch size distribution that transits from a power-law to an exponential function with increasing drought stress



High precipitations\weakly stressed



Low precipitation\highly stressed

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