UNIVERSITÀ DEGLI STUDI DI PADOVA

DIPARTIMENTO DI INGEGNERIA CIVILE, EDILE E AMBIENTALE - I C E A
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Winter school "Patterns of vegetation in water controlled ecosystems"

Lectures content:

Dan Malkinson University of Haifa, Israel
[Landscape Ecology]

Lecture 1/2

Fundamentals of ecology

Lecture 2/2

Interaction between plants and their effect on the patterns emergence. A case study in the Negev desert.

Several approaches have been proposed to explain the emergence of vegetation spatial patterns, particularly in water limited environments. One of the possible mechanisms generating these patterns are the interrelations between individual plants at various spatial scales. Intra and inter-specific facilitation and competition processes may be important drivers dictating the properties in such ecosystems. Equilibrium, feedback processes, and the role of disturbances will be discussed, alongside with presentation of a case study of sand-dune ecosystems in the Negev desert.

Applications, workshops and exercises
Spatial statistics modules in ARCMap

Ehud Meron Ben Gurion University, Boqer, Israel
[Non-linear dynamics and pattern formation, non-linear ecosystem physics]

Pattern formation - a missing link in the study of ecosystem response to environmental changes

Environmental changes can affect the functioning of an ecosystem directly, through the response of individual life forms, or indirectly, through interspecific interactions and community dynamics. The feasibility of a community-level response has motivated numerous studies aimed at understanding the mutual relationships between three elements of ecosystem dynamics: the abiotic environment, biodiversity and ecosystem function. Since ecosystems are inherently nonlinear and spatially extended, environmental changes can also induce pattern-forming instabilities that result in spatial self-organization of life forms and resources. This, in turn, can affect the relationships between these three elements, and make the response of ecosystems to environmental changes far more complex. Responses of this kind can be expected in dryland ecosystems, which show a variety of self-organizing vegetation patterns along the rainfall gradient. In these lectures I will describe the progress that has been made in understanding vegetation patterning in dryland ecosystems, and the roles it plays in ecosystem response to environmental variability. The progress to be described has been achieved by modeling pattern-forming feedbacks at small spatial scales and up-scaling their effects to large scales through model studies. This approach sets the basis for integrating pattern formation theory into the study of ecosystem dynamics and addressing ecologically significant questions such as the dynamics of desertification, restoration of degraded landscapes, biodiversity changes along environmental gradients, and shrubland-grassland transitions.

Lecture 1/2

A glimpse into pattern formation theory

1. Basics of nonlinear dynamics: positive feedbacks and instabilities, linear stability analysis, bifurcation diagrams.
2. Pattern formation by non-uniform instabilities of uniform states: stripe and hexagonal patterns.
3. Pattern formation by uniform instabilities that lead to multiplicity of stable uniform states: front dynamics and interactions.
4. Bistability of uniform and patterned states: localized structures and hybrid states.

Lecture 2/2

Pattern formation as a missing link in the study of ecosystem response to environmental changes

1. Pattern formation as a population-level response to water stress: the positive feedbacks that drive pattern-forming instabilities of uniform vegetation.
2. Mathematical modeling as a means for scaling up small-scale spatial processes to landscape-level patterns, and organism-level traits to community-level properties.
3. Pattern-formation links between the abiotic environment, biodiversity and ecosystem function.
4. Human intervention and ecological integrity.

References:
Meron E., Nonlinear Physics of Ecosystems, CRC Press 2015.
Meron E., Pattern-formation approach to modelling spatially extended ecosystems, Ecological Modelling 234, 70-82 (2012).
Meron E., Pattern formation - a missing link in the study of ecosystem response to environmental changes, Mathematical Bioscience 271, 1-18 (2016).

Vincent Deblauwe, Pierre Couteron Institute of Research for Development, Yaounde, Cameroon

[Vegetation Science, Climate Change]

Characterizing and interpreting vegetation patterns in natural landscapes

Lecture 1/2

a. The diversity of patterns (PC). Factors explaining the worldwide distribution of periodic patterns (VD)
b. Features for pattern characterization:
    I) Patch-oriented attributes: patch size distribution, shape indices, inter-patch distance distribution (VD)
    II) Textural attributes: gray-level histogram, spectra of spatial frequencies (Fourier, wavelets), anisotropy indices (PC/VD). NB: more emphasis on II

Lecture 2/2

c. From plant-plant interactions to patterns and vice-versa:
    I) crossing the scale gap thanks to modelling plant-plant interactions, examples from R. Lefever's non-local F-KPP modelling framework (PC)
    II) types of simulated patterns depending on modelling options; model measurements and field metrics (VD)
d. Using features to distinguishing classes of patterns: periodic, localized, scale-free, isotropic, … (VD/PC); Application to both simulated and real-world patterns.

Applications, workshops and exercises
Catching up with worldwide sources of spatialized data (Google Earth, SRTM, WorldClim, etc.)
Extracting patterns' features from real-world images using adhoc software (.exe programs and possibly Matlab® scripts)
Overlaying maps of patterns features and mapped environmental variables (topography, rainfall, …) in a free GIS software (QGIS/GRASS)
Some aspects on statistically unbiased map comparisons

Carrying out classical statistical analyses (R, mainly)

Question: "Go, track patterns"
Let's consider a dryland region which has not yet been studied in terms of patterns and for which suitable remotely sensed images are accessible. Make a preliminary map of vegetation pattern that may be hypothesized to result from self-organization processes. From internet, try to identify the vegetation types and the dominant plant lifeforms which seem to be involved in the patterns. Compare the spatial distribution of the main types of patterns and spatial variation in pattern characteristics with environmental variables. Build hypotheses based on existing models to explain the main types of patterns observed.

Jonathan Sherratt Heriot-Watt University, Edimburgh, Great Bretain
[Mathematical biology]

Lecture 1/2 and 2/2

Predicting the Wavelength of Semi-Arid Vegetation Patterns using Mathematical Models.

Key points:

1. Wavelength is an easily obtainable quantitative statistic for vegetation patterns.
2. The method of linear stability analysis of steady states provides important information about the wavelengths predicted by mathematical models.
3. Numerical calculations of the stability vegetation patterns provides a much fuller account of predicted wavelengths.
4. These approaches demonstrate that in models for semi-arid vegetation patterns there are typically a range of possible pattern wavelengths.
5. Models predict that pattern wavelength depends on wavelength history, as well as on current parameter values.
6. Degradation of uniform vegetation and colonisation of bare ground are both natural mechanisms via which vegetation patterns can arise.
7. These two mechanisms generate patterns with different wavelengths. Moreover the pattern wavelength increases with slope for degradation and decreases with slope for colonisation.

References: A general introduction to mathematical modelling of pattern formation is available in a number of books. I particularly recommend one (or more) of the following:
E. Meron, "Nonlinear Physics of Ecosystems" (CRC Press, 2015)
N.F. Britton, "Essential Mathematical Biology" (Springer, 2002), sections 7.1-7.4
J.D. Murray, "Mathematical Biology II: Spatial Models and Biomedical Applications" (Springer, 2003), sections 2.2-2.4
The following papers contain material more specifically related to these lectures:
C.A. Klausmeier (1999) Regular and irregular patterns in semiarid vegetation. Science 284:1826-1828.
J.A. Sherratt (2013) History-dependent patterns of whole ecosystems. Ecological Complexity 14:8-20.
J.A. Sherratt (2015) When does colonisation of a semi-arid hillslope generate vegetation patterns? Journal of Mathematical Biology, in press (DOI: 10.1007/s00285-015-0942-8).
K. Siteur, E. Siero, M.B. Eppinga, J. Rademacher, A. Doelman, M. Rietkerk (2014) Turing: the response of patterned ecosystems to environmental change. Ecological Complexity 20:81-96.

Groupwork proposal:
Colonisation on Hillslopes in Arid Environments: A Spanish Case Study

Lectures slides and project proposal can be downloaded at:
http://www.macs.hw.ac.uk/~jas/venice/index.html

Jost Von Hardenberg Istituto di Scienze dell'Atmosfera e del Clima, CNR, Italy
[Climate processes and dynamics, geophysical fluids dynamics, Vegetation-climate interactions in arid areas, the hydrological cycle and precipitation downscaling]

Possible Schedule

Sunday 03/01/2016: participants arrival and registration.

	Mon 04/01	Tue 05/01	Wed 06/01	Thu 07/01	Fri 08/01	Sat 09/01
8:30-10:15 (with 15' interval)	**[Malkinson 1/2]** Fundamentals of Ecology	**[Cout/Debl 2/2]** Interactions between plants (+ modelling), classes of patterns		**[Von Hard 2/2]** Downscaling from precipitation data to patterns	Group works, under the supervision of lecturers.	Group works, under the supervision of lecturers.
10:30-12:15 (with 15' interval)	**[Meron 1/2]** Pattern formation	**[Meron 2/2]** Ecosystem response to environmental changes	**[Sherratt 2/2]** Modelling the spread	**[Meron]** EXERCISES, GROUP WORK PROPOSAL	Group works, under the supervision of lecturers.	Group works, under the supervision of lecturers.
13:45-15:30 (with 15' interval)	**[Cout/Debl 1/2]** Diversity and features of patterns	**[Sherratt 1/2]** Predicting the wavelength	**[Von Hard 1/2]** Climate variability and vegetation intermittency	**[Sherratt]** EXERCISES, GROUP WORK PROPOSAL	Group works, under the supervision of lecturers.	Group works, under the supervision of lecturers.
15:45-17:30 (with 15' interval)	**[Malkinson 2/2]** Interactions between plants (+ a case study)	**[Malkinson]** EXERCISES, GROUP WORK PROPOSAL	**[Cout/Debl]** EXERCISES, GROUP WORK PROPOSAL	**[Von Hard]** EXERCISES, GROUP WORK PROPOSAL	Group works, under the supervision of lecturers.	Group works, under the supervision of lecturers.