# Self-organization in patch pattern dynamics along the climatic gradient of the Judean lowland in central Israel

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## ABSTRACT

The role of Self-organization in the formation, evolution and recovery of natural systems from organismic to global scale cannot be over-estimated. Many of these systems represent a type of patch pattern dynamic behavior where patches are created, spread, expanded, aggregated, dissected and dissolved in parallel, forming myriad patterns through their evolution. Self-organization concern the functioning of intrinsic mechanisms which intrinsically regulate pattern changes leading these systems toward order following phases of disturbance or structural transformation (e.g., from herbaceous ecosystem to shrublands). The aim of this paper is to present a new approach of Converging Self-Organization (CSO) coupling between information from geosimulated self-organization and remote sensing data.

Due to the scarcity of fully developed spatio-temporal data bases describing the evolution of these patterns from bare ground to full plant' cover, there was developed and implemented an implicit reconstruction technique to air photographs of three sites along a Mediterranean-arid transect. This technique facilitated the extraction of sequences of patch pattern maps that implicitly represent full cycles of vegetation and soil dynamics. Parameterizing patch patterns using measures of fragmentation and aggregation provided representation of the emergent properties of these patterns through their evolution. In parallel there was implemented Cellular Automata technique simulating different modes of self-organized patch pattern dynamics. These different modes concern the representation of different adhessive vegetation growth strategies: proportion of growth through expansión of existing vegetation patches relative to the proportion of growth gained through colonization of individual plants. Matching between the corresponding emergent pattern properties from the reconstructed and from the simulated dynamics served for inferring regarding the mode of functioning of self-organization along the climatic gradient.

High diversity of eco-geomorphic conditions characterize ecosystems along the climatic transect. The high similarity between the emergent properties of the reconstructed patch pattern dynamics, both for the different sites along the gradient and between them and those derived from the Cellular Automata, under this diversity of eco-geomorphic conditions suggest the functioning of self-organized behavior. From an eco-geomorphic perspective this convergence may be explained through the functioning of 'Tipping' forming patterns of source and sink areas. Similarity in lithologies would then explain similarities in these patterns which then may facilitate self-organized behavior. Indications for high adhessiveness of patch pattern dynamics together with this self-organized behavior may explain the resilience of landscapes across the climatic gradient to phases of human disturbance and of draughts. Further field work and simulations are needed for validating the preliminary results presented here regarding the functioning of self-organized behavior in patch pattern dynamics across the climatic gradient zone and its affinity to the 'Tipping' effect.

**Keywords**: Physical Geography Modeling, Self-Organization, Patch Pattern Dynamics, Tipping.

## INTRODUCTION

Studies of the climatic gradients of the Judean Mountains and Northern Negev had attracted most significant attention during the last 4 decades with emphasis on assessing the ecological, geomorphological and hydrological aspects of land degradation within the context of desertification (Lavee et. Al., 1998). However there is limited information and analysis regarding spatio-temporal properties of patch patterns evolving through degradation–recovery cycles. This represents a serious shortcoming since spatial variations in phase shifts in spatio-teporal pattern evolution may explain a substantial part of the observed ecological, hydrological and geomorphological complexity of this transition zone.

Self-organization is one of the spatial mechanisms which may facilitate stability and resilience in such spatio-temporal heterogeneous zones undergoing desertification threats both from human disturbances and global warming. Yet, fundamental questions concerning functioning of self-organization in patch pattern dynamics across such zones, modes of their spatial operation and their signatures have attracted limited attention in the geographical information science. This reported research is aimed at promoting the understanding of self-organization functioning across spatio-temporally complex environment by developing a new methodology for its exploration by coupling between geosimulations and remote sensing imagery. Cellular automata technique facilitated explicit representation of self-organized behavior (Shoshany and Kelman, 2006) while implementation of image reconstruction technique to air photographs of three sites along a Mediterranean-arid transect, facilitated the extraction of sequences of patch pattern maps that implicitly represent full cycles of vegetation and soil dynamics. Matching between these two information sources serves as means of searching for self-organized behavior. The methodology termed "Converging Self-Organization" was then implemented for three sites along the climatic gradient between Givat-Yearim in the north and Lehavim in the south.

## METHODOLOGY

Implementation of the "Converging Self-Organization" methodology was carried out in the three following steps:

### Information gathering : creation of chronosequences

i. Implementation of Cellular Automata technique on a grid domain (x,y) of a size 500X500 pixels producing self-organized maps **C**(x,y) for four adhesivity levels (*ad* of 5, 50, 500 and 5000) at discrete vegetation density (d) grades of 5% each. Where adhesivity levels represent the relative probability of vegetation growth through expansión of existing patches versus through the colonization of isolated patches.
ii. Implementation of the Image Reconstruction technique on 5 (*k*) image plot areas $\boldsymbol{G}_K$(x,y) of a size 500X500 pixels selected on north and south facing slopes represented by the air-photographs of each of the three sites: Givat Yearim in the north, Avisur Highland in the center and Lehavim in the south, producing binary maps $\boldsymbol{I}_{k:d}$(x,y) at discrete vegetation density grades *d* (5% intervals).

### Deriving Patch Pattern Properties (PPPs) Sequences

Using a clumping procedure, there were defined contiguous vegetation and soil patch objects (P ) from each of the geosimulated and reconstructed binary maps. For each vegetation and soil patch objects there were defined their absolute area, relative fraction from the total vegetation and soil areas respectively, and their perimeter. Then , the Shannon fragmentation metric (SW) and the Enhanced Dominance (ED) metric were defined separately for all vegetation and soil patches composing each map. Thus for each image plot area *k* there are formed four sequences of fragmentation metrics representing their emergent properties: SW and ED for vegetation patches and SW and ED for the soil patches.

**Assessing similarity between geosimulated and reconstrstructed Patch Pattern Properties' Sequences**:

Convergence would be first obtained if there is similarity between PPPs obtained for reconstructed chronosequences of the different image plot areas of the three sites. Such similarity is calculated by assessing the deviations between the individual PPPs sequences and a PPPs sequence representing the average for all plot areas of the three sites.

Secondly, there is conducted a search for a specific range of adhesivity levels (□) maintaining high similarity (minimal Root Mean Square Deviations) between PPPs from the CA simulations representing four different adhessivity levels and the reconstructed PPPs' sequences for all image plot areas.

## RESULTS AND DISCUSSION

The similarity found inbetween PPPs sequences for the reconstructed data would be facilitated if most of the habitats across the whole climatic gradient undergo both frequencies of severe land degradation due to draughts (represented by shifts northwards of the 200mm ishoyet) and human disturbances (such as fires and overgrazing), and in parallel frequencies of favorite growth conditions (represented by shifts southwards of the 400mm ishoyet) leading to almost complete recovery of shrub patterns (but not necessarily full successional cycles).

Assessing the Root Mean Square Deviation (RMSD) between sequences of simulated and reconstructed PPPs indicated that matching with minimal deviations exists between the two data sets for adhessivity level of approximately 1350. Thus, high adhesive growth is suggested to characterize the patch pattern dynamics across the whole climatic gradient.

Both results of similarity inbetween reconstructed PPPs sequences and their convergence arround CA simulated PPPs' sequences indicate similarity in patch patterns across the climatic gradient. Such similarity might be formed through sink-source divergence. Variations in micro-topography and resources distribution (seed banks, soil moisture, organic matter etc.) may lead during degradation periods, to spatial divergence between sink and source areas through the functioning of "tipping" effects (e.g., Thornes, 1985). While in local sinks there would be accumulated runoff water, soil rich with organic matter and nutrients, soil erosion in source areas will form "hard-core" erosional patches (mainly bare rock or lithosol). Similarities in microtopographies which are linked to the exposure of the same limestone formations may lead to such similarities in 'hard-core' erosional (source) and sink areas distributions. These similar distributions then may facilitate the functioning of self-organization across the climatic gradient.

## SUMMARY AND CONCLUSIONS

A new methodology was presented for the exploration of self-organized behavior in patch patterns dynamics in areas of high spatio-temporal variability. In absense of detailed empirical descriptions of full cycles of patch pattern dynamics, the methodology utilizes reconstructions from single date photographs (Kelman and Shoshany, 2005). Convergence of reconstructed PPPs sequences around those obtained from CA simulation, representing explicitly self-organized behavior despite variations in initial conditions and in hábitat conditions is regarded here as an implicit signature for the functioning of self-organized behavior. From an eco-geomorphic perspective this convergence may be explained through the functioning of 'Tipping effect' forming patterns of source and sink areas. Similarity in lithologies would then explain similarities in these patterns which then may facilitate self-organized behavior. Indications for high adhessiveness of patch pattern dynamics together with this self-organized behavior may explain the resilience of landscapes across the climatic gradient to phases of human disturbance and of draughts.

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