GEOGRAFICKÝ ČASOPIS

60 2008 2

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COMPLEXITY AND LANDSCAPE

M. Lehotský, J. Novotný, A. Grešková: Complexity and landscape. Geografický časopis, 60, 2008, 2, 5 figs., 31 refs.

The rapid acceleration of global changes in all spheres of human life requires implementation of holistic, integrative approaches. The aim of this paper is to outline the main ideas concerning the complexity theory in general as well as in landscape investigation. A system is said to be complex when the whole cannot be fully understood by analysing its components. Such systems usually do not move in a continuous and linear progression from the simpler to the more complex type, but they leap by the sudden emergence of successive levels of organization, towards strange attractors. The evolution of any landscape, as complex, open and self-organized system, can be explained by using synoptic analysis, where the global laws are considered in their geographical and temporal context. This approach is applied here to the problem of land cover evolution of the riverine landscape in the suburban area of Bratislava. Generally, the landcape of a river reach as an inundation area represents a space of conflicts between urban development and the flood regime of a large river. We recognized ten land cover categories of floodplain. The evolution of the area (1949-2004) can be divided into three evolutionary phases-fluctuations and we identified nine types of initiators/attractors. The modern evolution of the land cover pattern in the study area resulted in changes of geo-and biodiversity and increase of the landscape complexity.

Key words: complexity, landscape, fluctuation, evolution, synoptic analysis, river landscape

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INTRODUCTION

At present humankind is undergoing closely interwoven changes, embracing all spheres of human life from the biological-ecological to the social-cultural, the economic, technological and political spheres (Naveh 2004). These global changes are driven by the rapid development of worldwide computer networks of information, allowing the rapid economic build-up, expansion and globalization. This acceleration of overwhelming global processes and threats gives additional weight to the claim of Laszlo (1994) that for the choice of further biological and cultural evolution, a far-reaching ecological, social, cultural and political sustainability revolution in all spheres of life is essential. It can be achieved only by a great effort of global dimensions, driven by all those who are concerned with the future of life on earth and the welfare of all its inhabitants and who can provide the scientific and professional leadership of this revolution. Of special relevance for this purpose are those sciences dealing with the fate of the landscapes and seascapes, their geophysical, bio-ecological and human-ecological, socio-economic and cultural aspects with broad, integrative approaches (Naveh 2004). Amongst these sciences, geography and landscape ecology occupies a special place. The fate of all these landscapes is closely linked through mutually amplifying feedback relations with these cultural evolutionary trends of human society and its choice between further evolution and extinction. The true meaning of future-oriented and mission-driven holistic landscape science can be fully comprehended only in the broader context of the present holistic and transdisciplinary scientific revolution. Naveh (2000 and 2001) has presented detailed discussions on the holistic nature of landscapes and their multidimensional functions. The landscape should be regarded as the overarching conceptional supersystem for both these physical geospheric and mental and spiritual noospheric spatial spheres. Such a complementary systems view enables us to view the evolution of landscapes in the light of the new holistic and transdisciplinary insights as a tangible bridge between nature and mind, and as an integral part of the dynamic self-organization and co-evolution in nature and in human societies. It opens the way for a better comprehension of the multifunctionality of landscapes and their natural and cultural multidimensions (Naveh 2001) when the "new paradigm" in science views landscape systems as open, spatially he-terogeneous, deterministic-chaotic, non-equilibrial, and with patterns and processes that are highly scale and time dependent. However, a note of caution is needed here: rather than an "either/or" dichotomy (deterministic versus stochastic), geography can profit from a balanced view recognizing that various landscape phenomena may dominate under different conditions and at different times. Evolution is not constrained to biology and ecology. It is basic principle behind the emergence of nearly all complex systems, including science itself. Whereas the elementary actors and fundamental agents are different in each system, the emerging properties and phenomena are often similar. Thus interdisciplinary text inevitably covers a wide range of subjects, from psychology to social geography, physics to geomorphology, ecology to landscape ecology. In Czechoslovak and Slovak geography there are only a few articles dealing either with the methodology of complexity (Hampl 1971, Paulov 2004) and self-organization of geomorphic systems (Urbánek 2004 and 2005), or with complex qualitative study of regional structures (Lehotský and

Podolák 1987, Brunet et al. 1990, Lehotský and Mariot 1992, Lehotský et al. 1993).

The main aim of this paper is to outline ideas concerning complexity theory in general as well as the landscape complexity. Their application in landscape investigation is briefly illustrated by applying the so called "synoptic approach" which addresses the understanding of the land use pattern evolution of the river landscape in Bratislava's suburban area.

COMPLEXITY THEORY

The scientific study of complexity, frequently associated with terms such as complexity theory and synergetics (Haken 1985), is often linked to non-linear dynamics, self-organization, and other theoretical and methodological constructs. Recently, complexity has been outlined in many books and articles in many scientific disciplines. The difficulty with the term complexity is that it suffers a semantic hangover from its well-accepted dictionary definition; only a decade ago, "complex" simply meant made of many interrelated parts, synonymous with complicated (Reitsma 2003). Many authors have failed to note the difference between complicated and the new interpretation of complex found in Complexity Theory. A system is complicated if it can be given a complete and accurate description in terms of its individual constituents, no matter how many, such as a computer or the process of programming; complication is a quantitative escalation of that which is theoretically reducible. A system is said to be complex when the whole cannot be fully understood by analysing its components. Many techniques under the banner of Complexity Theory have little or nothing to do with complexity as such. The word complexity is used to describe complicated or difficult systems, typically with many parts as if the world can be explained in a reductionist manner and ''complexity'' is not qualitatively different from "simplicity" but merely quantitatively different (Reitsma 2003).

According to Haigh (1995) the essential control over the behaviour of a system is the energy budget. Jantsch (1980) defined three impacts of energy on systems: (1) if a system can assimilate energy, then it may evolve, becoming more organized and complex, until it reaches a minimum entropic level which represents the maximum energy differentiation achievable by the strategy of energy incorporation; (2) if a system loses energy then it devolves, becoming less organized and complex, until it reaches the maximum entropic level which represents the minimum energy differentiation achievable by the energy output; and (3) if a system exists in balance with its energy flow, then it preserves a level of organization at, or between, the maximum and minimum entropic levels which are appropriate for its current energy supply. If the system has moved to its current energy level from a lower energy level, then this state must be maximally entropic for the system's current energy level. If, however, the current energy level has been exceeded in the past, the system may contain structures which were produced by those higher energy levels but which still serve to promote the efficient operation of the system. In this case the system is in its minimum entropic state for the current energy level. All this really says is that evolving systems move towards minimum entropy but exist at their maximum entropic state for the current energy level. Devolving systems move towards maximum entropy but tend to exist at a minimum entropic state for the current energy levels. This, of course, assumes that it requires more energy to create a structure than it requires to maintain it. The threshold of manifestation of a phenomenon is often well separated from the threshold of extinction for the same phenomenon. The tendency to resist a change of system state is called systems inertia. Inertial forces are one reason why the concept of system equilibrium must be so carefully qualified. Complex systems may contain many components whose current operations and current energy balance are the result of past history. The same component subsystems at the same energy level could exist in a completely different equilibrium state and include completely different patterns of organization if those systems have had a different history (Haigh 1995).

The leading edge of the theory of systems evolution is contained in the writings of Nicolis and Prigogin (1977) and Jantsch (1980) which have contributed the theory of dissipative structures and a new theory of evolution. Jantsch's new paradigm of dynamic micro- and macro-co-evolution of self-organization in nature has laid the transdisciplinary foundations for a synthetic view of cosmic, geological, biological, ecological and socio-cultural evolution. It leads to an all-embracing conception of co-evolution, emphasizing cooperation as the creative play of an entire evolving universe. In his seminal study on the "Grand Evolutionary Synthesis" Laszlo (1994) further examined the co-evolutionary patterns of change and transformation in the cosmos, organisms and in modern society. In such synthetic evolutionary patterns, systems are not moving in a continuous and linear progress from the simpler to the more complex type of system, and from the lower to the higher level of organization. They leap by the sudden emergence of successive levels of organization from quarks to global socio-cultural systems and to cosmic systems. Following the findings of Prigogine and his co-workers, these non-linear evolutionary processes can be explained from the thermodynamic viewpoint as new ordering principles that "create order through fluctuations" (Nicolis and Prigogine 1977) and even "order out of chaos" (Prigogine and Stengers 1984). Prigogine stressed that two types of change are found in nature: reversible or dynamic changes and irreversible or thermodynamic changes. He argues with Max Planck that certain states, like maximum entropy, tend to "attract" systems and that a system will not move to a condition which is less "attractive" than the initial. From such a viewpoint, reversible processes are seen as limiting cases where the system has an equal propensity for a number of states (cf. catastrophe theory and Prigogine and Stengers 1984). Irreversibility, however, is merely recognition of the fact that open systems are influenced by their history. In stable systems irreversibility tends to mean entropy increase. Fluctuating, unstable systems, however, may sporadically develop the capacity to move through the entropy barrier towards a new "attractor", an identity associated with a lower entropy state (Haigh 1995). Prigogin and Stengers (1984) also showed that non-linear thermodynamics of irreversible processes in open systems exchanging energy and material with their environment could lead to the evolution of such new, dynamic globally stable systems. They proved that through the break in time and space symmetry, the non-equilibrium of irreversible processes became sources of order and became a creative evolutionary process. These non-equilibrium systems are called dissipative structures because they maintain continuous entropy production and dissipate accruing entropy, which does not accumulate in the system, but forms part of the continuous energy exchange with their environment. Dissipative structures constitute the simplest case of spontaneous self-organization in evolution. This fact has opened the way for realizing that evolution toward increasing complexity and organization is the result of structural *fluctuations (divergence)* and innovations that can appear suddenly in previously metastable systems. When they drive it subsequently to a new regime at a more complex state in evolutionary processes these are expressed as *bifurcations* (Prigogine and Stengers 1984). In these, abrupt discontinuous changes in system behaviour occur as a result of certain parameters crossing an apparent boundary of their domains of attraction in such metastable systems. As a result of such subtle "catastrophic" bifurcations, these systems may turn chaotic or disappear or lead to a new state of metastability on a higher level of organization. Their mutually reinforcing auto- and cross-catalytic feedback loops are triggered chiefly by technological innovations. On each level, the amount of cultural information is greater than that on the lower level, due to a greater diversity and richness of the components and structures (Naveh and Carmel 2003). While it is possible, therefore, to examine complexity on a discipline-by-discipline basis, breaking complexity research into three major divisions affords a more coherent understanding of complexity theory. The complexity sciences can be seen as comprising three major streams. First, algorithmic complexity in the form of mathematical complexity theory and information theory, contends that the complexity of a system lies in the difficulty faced in describing system characteristics. Second, deterministic complexity deals with chaos theory and catastrophe theory, which posit that the interaction of two or three key variables can create large stable systems prone to sudden discontinuities. Third, aggregate complexity is focused on how individuals working in concert create complex systems, such as economies or ecosystems. All three apply generalized templates to an array of phenomena in a way not seen since general systems theory (Manson 2001). An alternative categorization of the varying types of complexity found across numerous disciplines rallying under Complexity's banner involving a careful analysis of their underlying definitions or measures of complexity per se is presented by the works of Reitsma (2003). He considers that the types of complexity may be divided into seven (not mutually exclusive) groups, covering most of the main variations found in the literature and which are briefly summarized as:

1. *Deterministic complexity*. This type of complexity is based on information theory and is measured as the algorithmic content of a string of bits, defined as "the length of the shortest programme that will cause a standard universal computer to print out the string of bits and then halt". This category also includes computational complexity, a measure based on processing time. Thus complexity is equated with randomness.

2. *Statistical complexity*. Statistical measures of complexity attempt to measure the degree of structure or pattern present in a complex system, circumventing the problem of statistical complexity where randomness equals maximal complexity. The boundary conditions of extreme order and disorder are satisfied by vanishing at these limits.

3. *Phase transition*. Maximal complexity is defined as the mid-point between order and chaos, the edge of chaos.

4. *Chaos derivatives*. The measures of complexity developed under Chaos Theory are typically based upon the Lyapunov exponent or the Fractal dimension. The former "defines in precise mathematical terms a system's sensitivity to initial conditions"; the latter defines complexity through a measure of the irregularity of an object.
5. *Connectivity*. Complexity is measured by the degree of connectivity within the system, where the greater the number of connections or interactions the higher the complexity.
6. *System variability*. Complexity is defined whereby an increase in system variability (e.g. spatial variability or between scale variability) results in an increase in the complexity of the system.
7. *Relative and subjective complexity*. These types of complexity hold that it is a consequence of human perception and is therefore relative to the observer; „the complexity of an object is in the eyes of the observer".

The divisions imposed are not mutually exclusive, they are used as a heuristic device to enhance understanding. Mapping complexity produces four classes: complex system structure, landscape, behaviour, and organization. Complex system structure defines the complex system as composed of elements and relations or connections. Complex system landscape defines the state space of the complex system within which attractors are found and the importance of scale is recognized. Complex system behaviour is defined by self-organization and can be divided into elemental behaviour, or element – element interaction, system – environment behaviour, and the complex whole behaviour that emerges from the two former types of behaviour. Complex system organization is described as a continuum, the opposing extremes of which are defined as order and chaos. Between these two end points lies the edge of chaos (Reitsma 2003).

COMPLEXITY AND LANDSCAPE

Geographical complexity can be defined as research that combines complexity science with geographical concepts of space and place and uses modelling as a key mode to examine systems spanning multiple spatial, temporal, and societal scales (Manson 2007). Geography is inherently concerned with landscape and spatial systems as typical real systems which are open and embedded in or connected with other Earth systems and may exhibit an autogenic pattern and structure formation (Murray and Fonstad 2007). Self-organized landscape needs a constant and continuous input of outside energy and information which are dissipated and the landscape is able to create and build-up an abstract organizer in form of critical states or strange attractors (Fromm 2004). Its self-organization is typically manifested in spatial patterns, be they characterized by convergence toward some sort of characteristic forms (for instance, a stable slope), divergence into more diverse spatial mozaics, or some combination of the two. On divergent behaviour is based the concept of landscape self-organization arising from deterministic chaos which is grounded in the idea that initially small perturbations governed by an attractor grow unstably over some finite time or to some finite magnitude to produce the broader-scale landscape patterns of organizations. Divergence indicates that the landscape does not move toward a single destination and the effects of perturbations or disturbances, internal or external, tend to persist and grow over time (Phillips 1999).

Of great relevance for the complexity of landscape are the insights gained on the self-organization of living systems. In these, the spontaneous emergence of new order, creating new structures and new forms of behaviour within network patterns is made possible by their self-regulating feedback loops. Such systems on relatively high organizational levels, which can renew, repair, and replicate themselves as networks of interrelated component-producing processes, in which the network itself is created and recreated in a flow of matter and energy, are called *autopoietic systems* (from the Greek = self-creating or self-renewing) (Naveh 2004). This is true not only for cells and organisms and ecosystems, but also for landscapes. This autopoietic process is made possible by *autocatalysis* by which one of the products of the reaction enters a cycle that helps to reproduce itself by creating its own synthesis. In cycles of *crosscatalysis* two or more subsystems are linked, so that they can support each other by catalysing each other's synthesis and thereby mutually increase their growth. This is the case with living cells, which can produce more of themselves and in the same time they preserve themselves in a changing environment (Naveh 2004). Landscape complexity is well reflected by the concept of "perfect landscape" (Phillips 2007). The concept is based on the notion that any specific landscape system represents the combined, interacting effects of a set of generally applicable global laws and a set of geographically and historically contingent local controls. Chaos theory showed that even dauntingly complicated, apparently random (stochastic) behaviours may stem from simple underlying interactions. Non-linear interactions often involve multiple feedbacks that lead to surprising and rich, perpetually changing behaviours that create themselves, in the sense that "events" do not correspond to changes forced. To put it simply non-linear system when the outputs (or responses or outcomes) are not proportional to the inputs (or stimuli, changes, or disturbances) local non-linear interactions can provide the basis for the self-organization of global patterns that do not correspond to any forcing template. Thus, non-linearity creates possibilities for complex behaviour not possible in linear systems (Phillips 2006b). The related emergent-phenomena perspective points out that analysing the building blocks of a system – the small-scale processes within a landscape – may not be sufficient to understand the way the larger-scale system works. The collective behaviours of the many small-scale degrees of freedom synthesize into effectively new interactions that produce large-scale structures and behaviours, the way that molecular dynamics in a fluid give rise to what we characterize as macroscopic variables, which can then interact to form water waves, for example. And these emergent structures can then strongly influence the smaller scale processes, the way that waves affect molecular motions or an eolian dune determines the patterns of wind-blown sand fluxes and avalanches. Thus, when nonlinear feedbacks lead to the self-organization of large-scale patterns and behaviours, causality extends in both directions through the scales, and the most "fundamental" scale on which to base an analysis may not be the smallest (Murray and Fonstad 2007) and landscapes show emergent properties, such as, stability, resilience, fragility and diversity that can be empirically evaluated (this theory can also be adopted for other entities, Farina and Belgrano 2004).

A perfect landscape approach (Phillips 2007) views landscapes as circumstantial, contingent outcomes of deterministic laws operating in a specific environmental and historical context. Thus, explaining the evolution of complex landscapes requires the integration of global and local approaches. Landscape complexity arises from local interactions and external impacts. Because perfection in this sense is the most important and pervasive form of complexity, the study of landscape complexity is not restricted to non-linear dynamics, self-organization, or any other aspects of complexity theory. Beyond what can be achieved via complexity theory, the details of historical and geographic contexts must be addressed. One way to approach this is via synoptic analyses, where the relevant global laws are applied in specific situational contexts (Phillips 2007).

SYNOPTIC ANALYSIS AND EVOLUTIONARY ANALYSIS OF THE BRATISLAVA'S SUBURBAN RIVER LANDSCAPE

Methodology

Synoptic analysis is most often associated with climatology and meteorology, where it has taken on rather specific meanings deriving from analysis of weather maps and circulation patterns. Fundamentally, however, synoptic analysis is situational, where the global laws of atmospheric chemistry and physics are considered in geographical and temporal context, facilitated by typologies derived from a catalogue of events and event sequences. Synoptic or situational analyses may be based on the structure and function of the system in question, as well as being event-based. Developments in geography have resulted in an approach to landscape modelling based on the fundamental, phenomenological, qualitative behaviour of a system rather than the quantitative (Phillips 2007). Qualitative modelling has traditionally been perceived as a fall-back option when the data or knowledge is inadequate to specify the quantitative relationships. While quantitative specifics are usually quite variable, qualitative features are often universal. The principle is intuitively evident for many landscape problems. For instance, while the specific quantitative relationships between vegetation cover and wind erosion resistance are highly variable in space and time, the qualitative link (more vegetation cover = less wind erosion) applies everywhere and always. Parsimonious qualitative models, particularly when adapted to specific field situations, are one path to synoptic analysis of perfect landscapes. Another is a more direct, evolutionary approach to system trajectories when reconstructions, landscape interpretations, or historical inferences helps build a synoptic catalogue, and directly addresses the possibility of dynamical instability, chaos, and divergent/convergent landscape evolution (Phillips 2006b). The evolutionary approach applied here to the problem of the modern evolution of the complexity of the study area as a self-organized spatial system, is based on the identification of a non-linear trajectory designated by its fluctuation phases as well as by the identification of attractors influencing the development of the particular landscape pattern in individual phases.

The evolutionary approach consists of the following steps:

- Selection of the parameters of landscape by which its spatial pattern is identified;

- Analysis of the landscape pattern on selected time horizons;
- Identify fluctuation phases/phase spaces of the landscape pattern (a phase space is understood as an imaginary map of all the possibilities open to the landscape. As the landscape changes, a succession of patches/landforms in state space are invoked, the sequence of their appearance is the time trajectory of the system in state space);
- Interpret fluctuation phases by determining initiators and attractors (*initiators* are ideas, decisions, rules or events that start new developments in an area, which may be remote or directly and physically linked to the place were the initiator is located. A new road for example can initiate new land development for the region that becomes disclosed. Decisions of the European Commission concerning agricultural policy initiated many changes in agricultural landscapes all over Europe. *Attractors* can be defined as places that initiate irreversible changes in their surroundings. Clearly, the development of many settlements can be considered as attractors. However, many smaller ones can be recognized, such as a road crossing or a particular viewpoint. An attractor is a particular case of an initiator, one that is materialized and located in the geographical space it will change (Antrop 2000). There are three groups of attractors: a homogeneous steady state is characteristic of a point attractor, the state of sustained oscillation found in a cyclic attractor, and the well known chaotic behaviour characteristic of a strange attractor (Allen 1999);
- Assess divergent or convergent landscape evolution (self-organization of landscape is typically manifested in spatial patterns, be they characterized by convergence toward some sort of characteristic form, divergence into more diverse spatial mosaics, or some combination of the two (Phillips 1999);
- Appraise the appearance of emergence/emergent properties (landscape emergence refers to the appearance of new landscape patterns with higher-level properties and behaviours that while obviously originating from the collective dynamics of that landscape's components – are neither to be found in nor are directly deducible from the lower-level properties of that landscape. Emergent properties are properties of the "whole" that are not possessed by any of the individual parts making up that whole. An air molecule, for example, is not a tornado; and a neuron is not conscious).

The application of the procedure of evolutionary analysis of landscape is illustrated in brief using the example of the riverine landscape in the suburban area of Bratislava.

River landscape in the suburban area of Bratislava

During the past tens or hundreds of years, the structure and dynamics of many river landscapes have been significantly affected by human interventions such as land use changes, urbanization, canalization, dams, diversions, gravel and sand mining. They have become complex spatial structures (Fig. 1). Urbanization as a complex process causes profound changes in the vicinity of cities – suburban space and creates new and highly heterogeneous riverine landscapes. Nearly all major city around the world has been built in riverine landscapes as important natural networks as well as cultural and recreational resources. Hence, a riverine landscape is certainly a phenomenon requiring special attention, both from researchers and managers. Contemporary riverine landscapes consist of dynamic mosaics of spatial elements arrayed hierarchically and reflecting processes occurring over a wide range of time and spatial scales (Fig. 2).

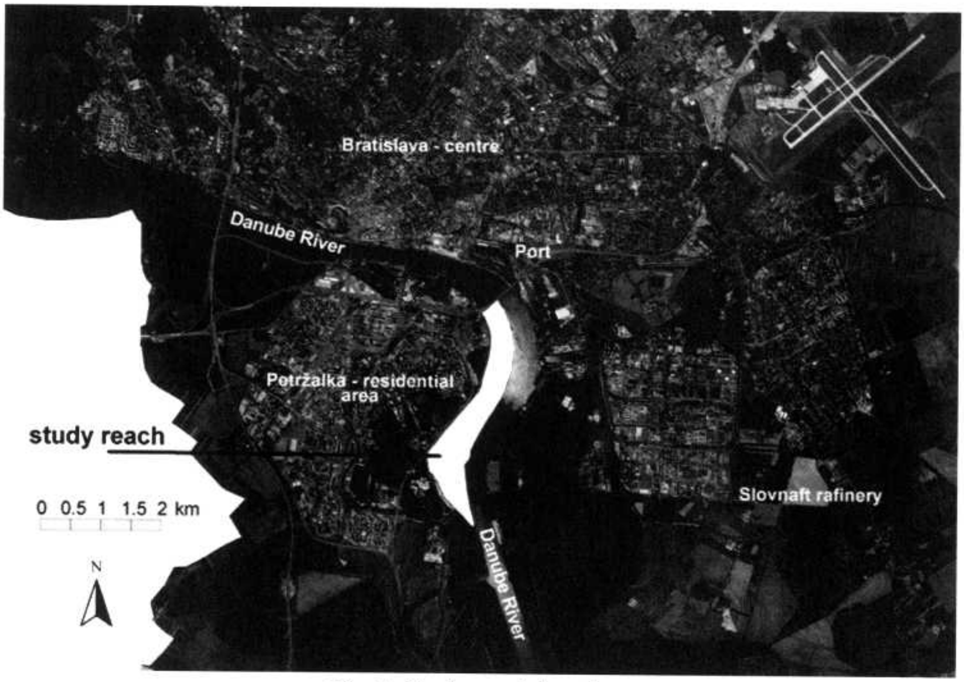

Fig. 1. Study reach location

The studied riverine landscape represents the apex of an extensive alluvial fan (inland delta) of the Danube river that was formed in the territory of Bratislava. During the 18th to 19th centuries, this river landscape system was reduced to one main channel with the floodplain limited by dikes in order to protect the city against floods (Pišút 2002). The riverine landscape unit includes the right-side inter-dyke inundation area (active floodplain) of 300-600 m width as a unique tectonically determined bench of the Danube river which is about 5 km long with the present width of 1.5 km. The channel width is 350 m. Today, the studied area upstream represents a follow-up to the urban section with a straight simple channel and embankment. Downstream, the impoundment reach ends in the Gabčíkovo Waterworks. As far as the regional type of the riverine landscape is concerned, the studied area of the Danube river is part of the suburban zone of the city of Bratislava with urban as well as agricultural and forest elements. It has been designated the inundation area under the flood-control measures. It also serves as the suburban riverine recreation zone and is part of the Danube river Biocorridor of European scope and its forest constitutes the Protected Landscape Area of Dunajské luhy. This riverine landscape unit represents one of the most problematic (in terms of management) Slovak reaches of the Danube river landscape.

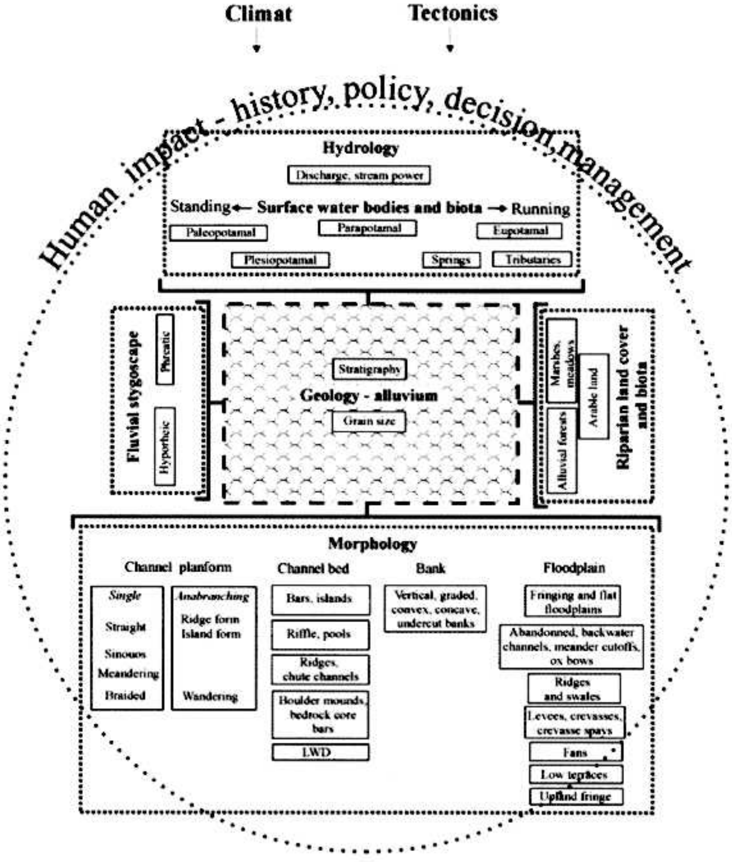

Fig. 2. A conceptualization of the river landscape system

Data and Methods

The basic sources of data gathering were aerial photographs and the orthophotomaps for 1949, 1969, 1985, 1997, 2004 time horizons and field works. Land cover structures were identified from aerial photographs and orthophotomaps for the above mentioned time horizons as well as by field works. All the data were processed in the GIS ArcView 3.2. Ten land cover categories of floodplain (1 – water bodies, 2 – unvegetated sandy or gravel areas, 3 – grassland, 4 – scarce shrubs, 5 – scarps covered by reed cover, 6 – young forest with low shrub floor, 7 – mature forest with low and high shrub floors, 8 – built-up ground, 9 – gravel mining area, 10 – routes and paths) were determined visually by the interpretation of aerial photographs from the above mentioned time horizons and were simply investigated by means of the identification of their surface areas.

Results – phases of fluctuation

As far as land cover variability is concerned the study area comprises floodway controlled by dikes, remnants of the older riverine landscape and modern land cover structures. With regards to the historical pathway, three specific developmental phases that explain the causes of the existing state are identifiable in the modern development of the studied area and nine initiators and strange attractors were identified as follows:

- flood protection measures in the proximity of a large town – Fw,
- gravel sources in the study area – Gs,
- construction of the Petržalka residential area – Cp,
- construction of the Waterworks Gabčíkovo – Gw,
- operation of Austrian Waterworks – Aw,
- woodland succession – Ws,
- leisure – L,
- mobility of people – M,
- nature protection policy – N.

The first phase (Fig. 3, Fig. 4 and Fig. 5) is approximately limited by the years 1949 and 1970. It is characterized by completion of the continuous dike system resulting in the total confinement of the river into a limited space by reduction of the original active floodplain and that of the river landscape. The relatively original structure of the floodplain land cover with the spatial dominance of mature forest and scarce shrub areas was typical in 1949. As a result of flood event in 1965 the bank line of the channel bend was straightened and the great part of the study area was stripped of vegetation cover in 1966-1967 and in several spots graded up to the level of the gravel horizon to improve the protective conditions of Bratislava. The areas of mature forest decreased and unvegetated sand and gravel spots as well as gravel mining areas and built-up ground started to enlarge their areas due to the construction of the large prefab housing estate of Petržalka at the end of that phase. The route and paths density was relatively low and Fw and Gs were the main attractors in that phase.

The second phase of development spanned the years 1970-1992. A new gravel mill was built outside the study area and a new artificial channel was constructed as a waterway. Hence, gravel areas, grassland, built-up ground and higher density of routes characterize this phase. In order to augment channel capacity and thus avoid flooding of the large-scale prefab housing estate of Petržalka extraction of gravel in the channel continued. Another effect that emerged was that of activities connected with the construction of the Gabčíkovo Waterworks. During the preparatory works, the old dike was increased and rebuilt and block fills fixed the riverbanks. In addition, construction of water reservoirs went on in Austria and five dams were set in operation which presumably led to fining of grain size of over bank sediments and thus to changing physical conditions of floodplain habitats. During the phase, the bank retreat progressed in length of 15-30 m along the bend. Due to construction activities the route density was relatively high at the beginning and lower at end of the phase. Fw, Gs, Cp, Gw and Aw attractors dominated this phase.

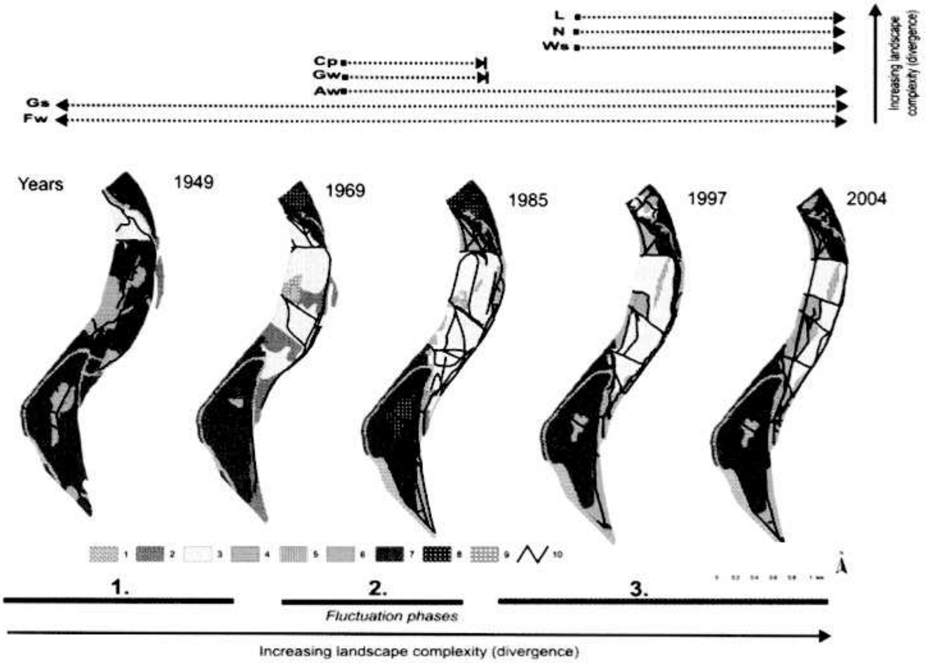

Fig. 3. Phases of fluctuation

(1 – water bodies, 2 – unvegetated sandy or gravel areas, 3 – grassland, 4 – scarce shrubs, 5 – scarps covered by reed cover, 6 – young forest with low shrub floor, 7 – mature forest with low and high shrub floors, 8 – building site, 9 – gravel mining area, 10 – routes and paths)

The third phase started in 1989 with the change of the political situation in the country and "new construction" of the Petržalka residential area. The free market economy has conditioned the inhabitant's mobility as well as changes in their live style. The study area thus became space for leisure and recreation. Besides, on unvegetated areas, grasslands, built-up grounds and gravel mining areas shrubs woodland succession and natural protection policy in the study area are typical in that phase. The mobility of inhabitants (by car, on foot, on horses) influenced the development of a new dense network of roads and paths. During 2006 and 2007, a large new gravel mound of channel gravel mining has arisen on the bank as an anthropogenic landform. The main attractors for this phase are Fw, Gs, Aw, Ws, L, M and N.

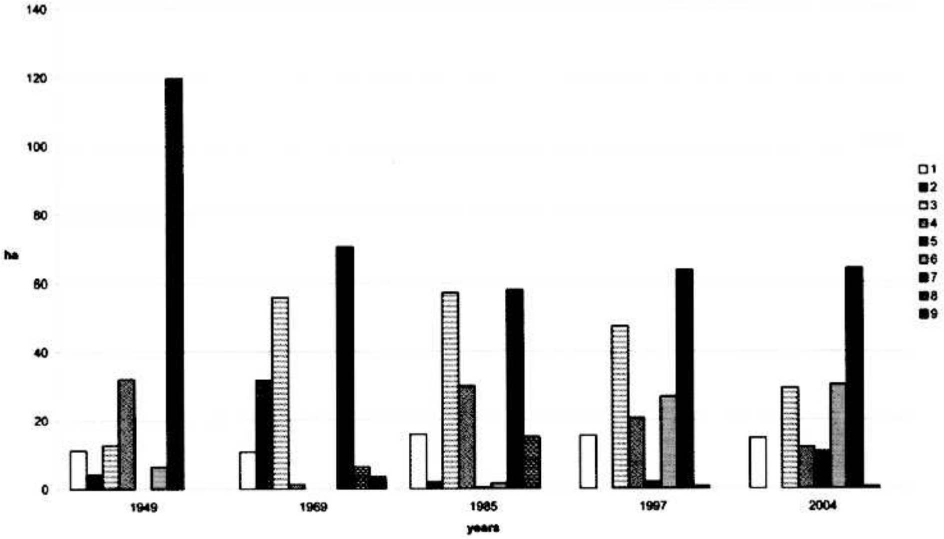

Fig. 4. Land cover categories area changes

(1 – water bodies, 2 – unvegetated sandy or gravel areas, 3 – grassland, 4 – scarce shrubs, 5 – scarps covered by reed cover, 6 – young forest with low shrub floor, 7 – mature forest with low and high shrub floors, 8 – building site, 9 – gravel mining area)

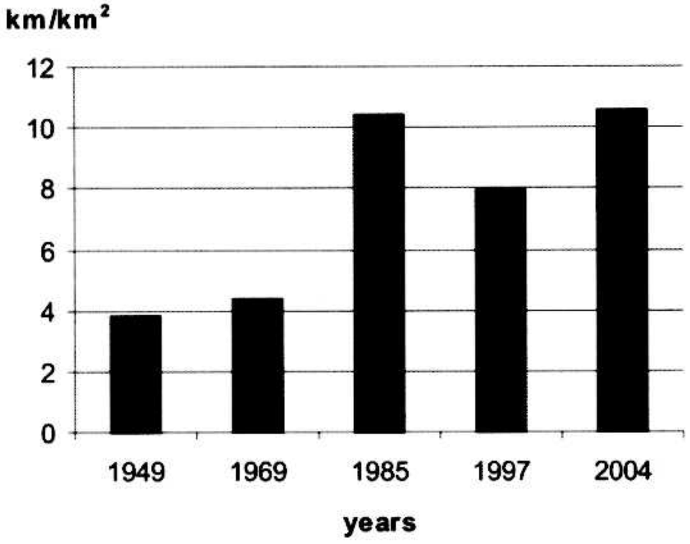

Fig. 5. Routes and paths density changes

CONCLUSIONS

Coupled human and natural systems are integrated systems in which people interact with natural components. Although many studies have examined human-nature interactions, the complexity of coupled systems has not been well understood. The lack of progress is largely due to the traditional separation of ecological and social sciences. We outlined the main ideas concerning the complexity theory in general as well as in landscape investigation. Non-linearity, and complex dynamics in landscape systems suggest that we are quite limited in discerning universal laws applicable to predicting landscape response to environmental change. Rather, the suggestion is to refocus on a search for lessons – typologies, patterns, and synoptic situations we can learn from. We applied the so called "the synoptic approach" which addresses the understanding of the river landscape evolution in Bratislava's suburban area. The study area can be perceived as a non-linear landscape system, which exhibits complex behaviour including dynamic instability. Very generally, the reach as the inundation area represents a space of conflicts between urban development and the flood regime of a large river. The system was evolutionary in the sense of being path dependent, and historically and geographically contingent not only in the past. Its modern operation depends on new strange attractors that influence the land cover changes.

Generally, the area of the studied area during the period 1949-2007 exhibits on the one hand reduction of its surface due to bank retreat as well as to the diminishing of water bodies, and on the other hand there are non-linear changes in land cover categories and increase in geo- and biodiversity and complexity.

The research was supported by the Science Grant Agency (VEGA) of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (grant No. 2/6040/27) Digital orthophotomaps were used by the permission of Eurosense, Ltd. and Geodis, Ltd.,Bratislava.

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KOMPLEXITA A KRAJINA

Globálne zmeny, evokované rapídnym rozvojom informačných technológií a ekonomickým rastom, zasahujú všetky sféry ľudského života (Naveh 2004). Pre existenciu našej planéty je potrebné, aby prebehla rozsiahla zmena vo sférach ekologického, sociálneho, kultúrnho aj politického myslenia v intenciách paradigmy udržateľnosti. Vo všetkých oblastiach bádania narastá význam implementácie a aplikácie holistických prístupov. Tento trend neobchádza ani disciplíny zaoberajúce sa výskumom krajiny (Naveh 2004). Krajinu, ako objekt štúdia geografie, je potrebné chápať ako konceptuálny supersystém fyzických geosférických, mentálnych a duchovných noosférických priestorových sfér, ktorý je otvorený, priestorovo heterogénny, deterministicko-chaotický, nerovnovážny, so štruktúrou a procesmi závislými na priestore a čase (Naveh 2000 a 2001). Ťažiskovým cieľom článku je načrtnúť základné idey teórie komplexity a ich uplatňovanie pri chápaní a výskume krajiny. Okrem prezentovania teoretických aspektov komplexity a komplexity krajiny príspevok v hrubých rysoch prezentuje na príklade riečnej krajiny suburbánneho úseku Dunaja tzv. „synoptický prístup" ako jednu z možných procedúr výskumu nelineárneho vývoja krajinných štruktúr.

V teórii komplexity sú za „komplexné" považované hierarchizované autoregulačné disipatívne štruktúry, ktorých štruktúru úrovní, správanie a vývoj nie je možné pochopiť len na základe analýzy ich komponentov. Takýto pohľad na realitu (Nicolis a Prigogin 1977, Jantsch 1980) ukazuje, že krajinné systémy sa nevyvíjajú postupne a lineárne, ale nelineárne, t. j., fluktuáciami, alebo bifurkáciami prejavujúcimi sa novými vlastnosťami systémov (emergenciami), pričom významnú úlohu zohrávajú „zvláštne (divné) atraktory" – vplyvy, impulzy, spôsobujúce prechod systému do nového stavu, resp. na vyššiu úroveň organizovanosti. Koncept „ideálnej krajiny" (Phillips 2007) vychádza z predpokladu, že krajinný systém vzniká vzájomným interaktívnym pôsobením súboru všeobecne platných globálnych zákonov a súboru lokálnych geograficky a historicky podmienených vplyvov. Pochopenie vývoja komplexnej krajiny si teda vyžaduje integráciu globálnych a lokálnych prístupov. Toto umožňuje napr. „synoptický" (situačný) prístup, pri ktorom sú relevantné globálne zákony aplikované v špecifickom priestorovom a časovom kontexte. Jedným z variantov synoptického prístupu je analýza evolúcie krajinného systému. Jej hlavným cieľom je zostavenie tzv. „synoptického katalógu" – jednotlivých fáz vývoja krajinného systému. Vývojová (evolučná) analýza krajinného systému spočíva v nasledujúcich krokoch: 1) výber parametrov, na základe ktorých je možné identifikovať štruktúru krajiny; 2) analýza štruktúry krajiny vo vybraných časových horizontoch; 3) identifikácia fáz fluktuácie; 4) interpretácia týchto fáz na základe stanovenia „ iniciátorov" (myšlienky, udalosti, rozhodnutia) a „zvláštnych (divných) atraktorov" (faktory, ktoré iniciujú ireverzibilné zmeny vo svojom okolí); 5) posúdenie divergentného/konvergentného vývoja krajiny; 6) vyhodnotenie novo vzniknutej štruktúry krajiny a jej vlastností ako emergencií. Tento metodický postup aplikujeme na príklade modelového územia, ktoré predstavuje systém riečnej krajiny (obr. 2) – pravostrannú aktívnu nivu, priliehajúcu k tektonicky podmienenému oblúku rieky Dunaj, ktorá je systémom protipovodňových hrádzí obmedzená do šírky 300-600 m (obr. 1). Krajinný systém parametrizujeme štruktúrami krajinnej pokrývky. Štruktúra krajinnej pokrývky bola identifikovaná na základe analýzy leteckých snímok a ortofotomáp v časových horizontoch v rokoch 1949, 1969, 1985, 1997 a 2004, pričom sme rozlíšili 10 kategórií krajinnej pokrývky (obr. 3 a 4). Vo vývoji územia za vyššie uvedené časové obdobie sme identifikovali tri vývojové fluktuačné fázy a deväť iniciátorov/atraktorov: Fw – protipovodňová ochrana, Gs – ťažba štrkov, Cp – výstavba sídliska Petržalka, Gw – výstavba VD Gabčíkovo, Aw – výstavba priehrad v Rakúsku, Ws – sukcesia lesa, L – voľnočasové aktivity, M – mobilita ľudí, N – ochrana prírody (obr. 5).

Prvá fáza fluktuácie (1949-1970) je charakteristická dokončením systému protipovodňových hrádzí, čím bol redukovaný priestor aktívnej nivy. Postupne dochádza k úbytku lesa a nárastu plôch bez vegetácie, vznikajú areály ťažby štrkov a stavebné priestory. V dôsledku ochrany Bratislavy a novobudovaného sídliska Petržalka pred povodňami bola z územia v rokoch 1966-1967 úplne odstránená vegetácia a územie bolo splanírované, miestami až do až po štrkovú fáciu. Súčasne bol narovnaním oblúka presunutý jeho breh o cca 15-30 m. Z podobných dôvodov bolo prehĺbené aj koryto Dunaja. Hlavnými atraktormi boli Fw a Gs.

Na začiatku druhej fázy fluktuácie (1970-1989) boli v súvislosti s výstavbou VD Gabčíkovo prebudované protipovodňové hrádze a spevnené brehy Dunaja. Na nive sa rozširujú plochy ťažby štrkov a stavebných aktivít. Spomedzi atraktorov dominovali Fw, Gs, Cp, Gw a Aw.

Za začiatok tretej fázy fluktuácie možno považovať rok 1989, po ktorom zmeny v politickej situácii viedli aj k významným spoločenským zmenám a zmenám v životnom štýle obyvateľov Bratislavy. Študované územie sa stáva priestorom pre voľnočasové aktivity a rekreáciu, vzrastá dĺžka ciest a chodníkov a najtypickejším procesom je sukcesia lesa a krovín. V tejto fáze došlo tiež k zmenšeniu plochy územia v dôsledku umelého rozšírenia koryta Dunaja. Hlavnými atraktormi sú Fw, Gs, Aw, Ws, L, M a N.

Krajina študovaného územia ako súčasť suburbánneho priestoru bola, je a aj v budúcnosti bude priestorom konfliktu medzi ochranou mesta pred povodňami spolu s jeho komplexným rozvojom na jednej strane (lokálnymi „zákonitosťami“) a prirodzeným režimom rieky na strane druhej (globálnymi-fyzikálnymi zákonmi). Časová štruktúra jeho fáz fluktuácie je podmienená pôsobením rôznymi kombinácií viacerých atraktorov. Výsledkom je nárast komplexity krajiny sprevádzaný divergenciou krajinnej pokrývky ako aj divergenciou geo- a biodiverzity.