Nature in Future Cities: Prospects and a Planning Agenda

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As the world's population is increasing, the world is expected to become much more urban. The pressure on nature in rural areas is increasing at a decreasing rate. In the future, the main stage on which people will cause stress to ecosystems is within and near cities. In this paper we describe the processes of change in the spatial evolution of cities and systems of urban open spaces. We suggest how these processes may change in the future and speculate concerning the repercussions for urban nature. We conclude our review with an admission that much is obscure and that there is a need for a massive coordinated research effort to understand the interactions between built areas of cities and urban nature.

Since the Temple was destroyed, prophecy has been taken from prophets and given to fools and children

Babylonian Talmud: Tractate Baba Bathra, Folio 12b

At the end of the first decade of the twenty-first century, over 50 per cent of the world's population was living in cities. This is remarkable since the process of urbanization that brought this about started in earnest less than 200 years ago. At that time, the number of people living in cities was only about 2 per cent of the world's population. By 1900 the number of urbanites grew to 12 per cent (United Nations, 2002). In other words, the last 100 years witnessed a huge human migration into cities. The slow clustering of people into small settlements during early biblical times, into villages and towns some 3,000 years ago and eventually into cities some 200 years ago has given rise now to a veritable flood. While forecasts of the world's future urban population are marred by many difficulties, including issues associated with vagueness and differences among countries in the definition of cities and urban areas as well as in forecasting methods, the United Nations has prepared such forecasts. Of the more than 2.2 billion in the world's population that are expected be added by the year 2030, some 95 per cent will live in cities (Cohen, 2003). According to a revised forecast by the UN, the world's population will reach 9.3 billion by 2050. The urban population will reach 6.3 billion (United Nations, 2011). Thus, the world's population and economic activities are increasingly concentrated in space.

While it is not clear at what rate the migration into cities will continue, for how many years to come and whether the above forecasts will indeed materialize, the increasing urban population is already changing cities and creating various problems. Cities are growing outwards and upwards. It is a common notion that while the pressure on nature in rural areas is increasing at a decreasing rate, in cities the built areas are popularly presumed to be swallowing and destroying natural ecosystems. The pressure on urban nature depends on the behaviour of several types of agents and the rules that govern their interactions.

The behaviour of developers, especially those that are not risk-averse, of farmers operating at marginal profitability, and of planning authorities create non-linear spatial dynamics in cities and possible phase transitions that affect systems of open spaces. Ecological services that these systems create and whose value is a function of proximity to people, affect the demand for housing and the behaviour of developers. Should this process in fact continue the volume and nature of ecosystem services will decline and change causing a reduction in quality of life that may eventually affect patterns of spatial migrations at various scales.

In this paper we present a speculative view of the interactions among the various agents and the resulting spatial character of future cities. Based on these speculations we suggest implications for ecosystem function in cities and a planning mode of operation that potentially increases the general welfare in cities. Pointedly, we use the term speculative view. The very nature of urban dynamics makes long-term forecasting nearly impossible. The rest of the paper is comprised of three sections. In the next section we present an outline of models that simulate the spatial evolution of built areas in cities and speculate on the results. The mirror image of these simulations is the evolving network of open spaces. In the third section we present the repercussions of the evolving built environment on the resilience of the network of open spaces and on biodiversity. The last section presents discussion points concerning planning actions needed and some concluding remarks.

What will Happen to the Spatial Structure of Cities?[1]

According to the traditional urban model, the welfare of homogeneous agents is assumed to increase with proximity to a single source of employment. As a result cities are characterized by declining densities and rent gradients in all directions from this employment centre (Alonso, 1964; Mills, 1967; Muth, 1969). The analogy used to describe the resulting spatial structure of cities is a symmetric sand pile. Over time, as the population of cities grows, the outer limits of the built area expand outwards like a sea wave and all the open spaces in and around cities are eliminated – a doomsday scenario for urban nature. Many other insights concerning the spatial evolution of modern cities have been derived from this model. The literature reporting empirical validation of these insights, however, pertains to crude spatial resolution only.

The assumptions and the crude resolution of the model limit its usefulness for the purpose of forecasting urban spatial development. In reality, urban landscapes and agents that populate them are heterogeneous and display non-uniform time-space dynamics. Because cities are populated by agents with fat tail distributions, it is impossible to represent them by a typical element. For example, the size distribution of land developers is not Gaussian.[2]

There is a growing evidence that urban phenomena are characterized by power laws (Batty, 2005). Their presence at various geographic scales suggests self-organized criticality and possible phase transitions. It is reasonable to presume therefore that as a general rule urban systems are not at equilibrium. Indeed, there is no evidence that they tend towards it. The idea that economic systems are characterized by the presence of positive and negative feedbacks and fat tail distributions is more than half century old (Simon, 1955; Hayek, 1967). Nonlinear dynamics are the result of stabilizing negative feedback effects and de-stabilizing, self-augmenting, positive feedback effects. These processes are difficult to sort out without computer simulations. Prior to computer-based simulations, to make things manageable, processes were linearized, constant returns were assumed and equilibria were obtained. Furthermore, following aspatial economics, it is now recognized that urban evolution, powered by continuous flows, is characterized by abrupt and often striking changes in its organization (Broitman and Czamanski, 2014).

The idea that simulation is a means to understanding nonlinear dynamics was introduced in the middle of the twentieth century by Von Neumann (1945), much before the introduction of computers with sufficient computational capacity to make possible extensive modelling. The development of simulation software in the early 1990s led to an outburst of new models aiming to explain the births of cities, the dynamic processes governing their evolution, and the uneven geographic distribution of economic activities in general. The complexity approach to urban modelling was boosted by Paul Krugman's 1991 paper and later the award of the Nobel Prize in economics in 2008 (Krugman, 1991; Fujita and Thisse, 2009). It was followed by Michael Batty's books (Batty and Longley, 1994, and Batty, 2005) and papers by Benguigui and others (Benguigui and Czamanski, 2004; Benguigui *et al.*, 2000; 2004).

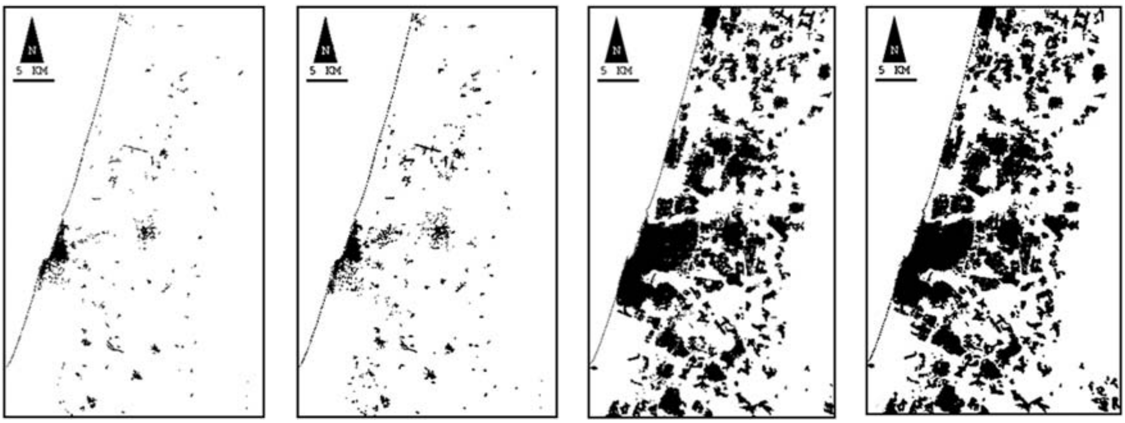
Economic models were challenged to explain the evolution of spatial heterogeneity from homogeneous agents and space. The importance of heterogeneity of agents and later of planning restrictions in generating polycentric urban structures was studied without attempts to explain the appearance of heterogeneous agents (e.g., Caruso *et al.*, 2007; Filatova *at al.*, 2009; Czamanski and Roth, 2011; Czamanski and Broitman, 2012). In these models a central driving force is the profit maximizing behaviour of land developers who are presumed to represent all the relevant information concerning urban markets. Planners' actions to restrict land development by adhering to land-use plans create land price profiles, that lead to leapfrogging and eventually to edge cities. These models are consistent with Henderson's claim (Henderson and Venables, 2009) that planning decisions constitute constraints and not the engines of urban evolution.

To generate these results, models must include urban and periurban areas, where, due to planning restrictions, land prices are very low, and at least one developer who is capable of and willing to purchase agricultural land for future development. The developer must possess savings and display some preference for risk-taking. As in the case of non-spatial economy, innovation and growth are associated with a particular size-distribution of firms. Growth is associated with idiosyncratic firm productivity improvements, selection of successful firms, and imitation by entrants (Luttmer, 2007). Zipf's law of the distribution of firms can be interpreted to mean that entry costs are high or that imitation is difficult, or both. The small number of entrants indicates that imitation must be difficult (Gabaix, 1999). In the case of land developers, entry cost is related to the present value of the opportunity cost of purchasing agricultural land and holding it until realization, termed characteristic time. Very few firms are not risk-averse and can withstand this entry cost. The equivalent of demand shock is population growth due to immigration at the urban level. When some developers are willing to take risks the result can be a size distribution of developers that is reminiscent of the size distribution of firms in growing economies. The behaviour of these developers leads to a polycentric urban structure.

Analyses of land-use maps, of aerial photographs and of satellite images provide extensive evidence of the discontinuous character of the evolution of urban built areas. Even casual examination of time series of the footprints of buildings in cities provide evidence for leapfrogging. There are, however, studies that document and explain this process and figure 1 illustrates this evolution (Benguigui *et al.*, 2001*a*; 2001*b*). The resulting patterns are fractal, especially as the spatial structure matures (Batty and Longley, 1994; Benguigui and Czamanski, 2004, Benguigui *et al.*, 2004). The leapfrogging process gives rise to contiguous built areas, termed clusters and patches of open spaces. Over time the clusters increase in number and later in the city's evolution are partly aggregated (Benguigui *et al.*, 2006). This results in urban landscapes nested within open spaces and semi-natural areas, and open spaces and semi-natural areas nested within cities. This hierarchically nested system, in turn, yields a rank-size distribution of open spaces, which is complementary to that of the urban clusters. Figure 2 illustrates the evolution of clusters in Tel Aviv. The rank-size distribution of these clusters is a telling indication of the dynamic process of urban spatial growth. See figure 3.

There is a myriad of simulation models that by generating these results lead to the identification of the critical factors responsible for them. By extrapolation it is possible to speculate what we can expect about the spatial structure of cities at the end of this century. It is our view that as long as planning practices are aimed at preventing sprawl, the price of land parcels in areas intended for buildings will be significantly higher than in areas reserved for open spaces. This and the presence of land developers who are not risk-averse will lead to efforts to develop open spaces. As long as there is a positive probability that zoning variance can eventually be obtained the profit motive will lead to leapfrogging. As a result cities will continue to sprawl and open spaces will remain in between the built areas.

Figure 4 illustrates the spatial evolution of a city that contains the above assumptions.



1935 1941 1993 2000

Figure 1. The footprint of building in Tel Aviv. (*Source*: see Benguigui *et al*., 2000)

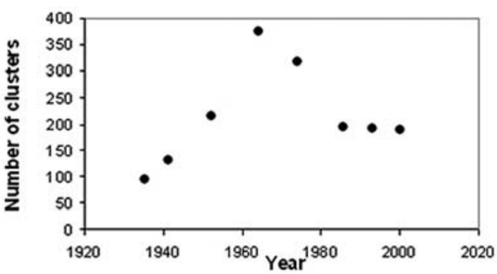


Figure 2. The number of clusters in the Tel Aviv Metropolitan Area with time. (*Source*: for details see Benguigui *et al*., 2006)

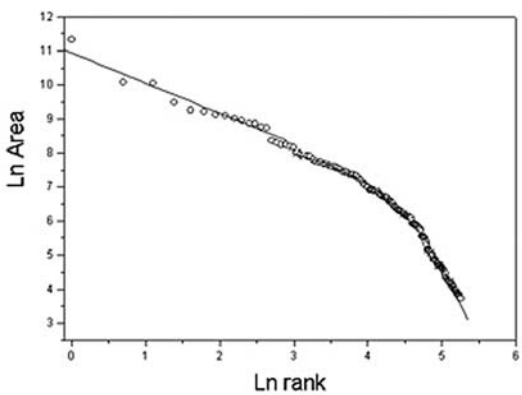


Figure 3. The rank size distribution of urban clusters in metropolitan Tel Aviv, 2000, lower part. (*Source*: for details see Benguigui *et al*., 2006)

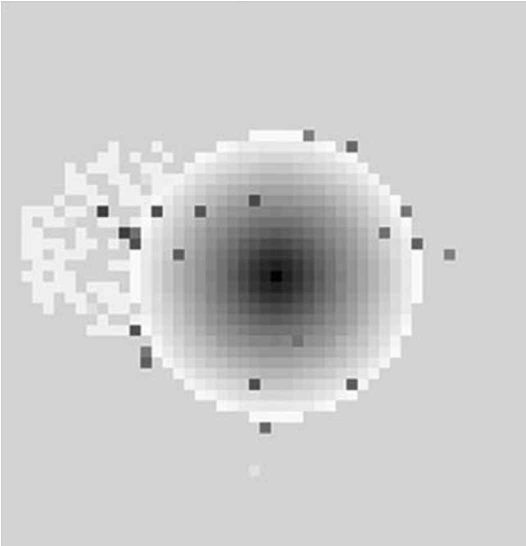


Figure 4. Simulated urban structure.

In the centre there is a regular Alonso type city in the area zoned for buildings. The tonal value indicates the height of buildings. The dark dots indicate purchased land for high-rise building that deviate from the rent gradient. The pale patches to the west of the city are land parcels purchased by risk-averse developers following the purchase of land by a speculating developer (the dark dot). The significant point is that the expected development is not contiguous. It is to be expected that patches of open spaces will remain for many years to come.

Moreover, even the central city at the heart of figure 4 is not a single block of built-up area. It is porous and contains patches of open spaces and corridors of unbuilt areas that provide living spaces and passage ways for dispersing plants and animals. In part, this is the result of planned parks, parcels of land that await building activities, abandoned parcels and spaces around buildings that serve as backyards. In fact, the extent to which the central city can provide room for nature is a function of urban morphology and the methods used to build cities. In very few cities are there Manhattan like regions in which adjacent buildings are joined together that do not leave open spaces. This type of morphology is rather rare.

Another noteworthy mechanism that may lead to similar dynamics is a growing trend, especially in North American cities, in which self-imposed local taxes are used to purchase open areas within the city boundaries, for the purpose of their preservation. During 1989–2011, 1,756 such initiatives were established in the United States and over US$75 billion were generated by taxes, and used for purchasing such open spaces (The Trust for Public Land, 2011). Such a process essentially removes open space lands within city boundaries from the pool of land available for development, and results in higher property values around these areas. This also feedbacks, and results in additional development pressure away from the city.

All said, this speculative view of the future spatial structure of cities may be an illusion. If indeed, cities are self-organizing and the simulations are indicative of the dynamic processes, it is to be expected that at some unknown future time cities will display phase transitions and their spatial structures may change in an unpredictable fashion. In the following we discount such a possibility, at least in the foreseeable urban future. Since the characteristic time of cities is very long, we presume that the above processes will continue for at least several decades.

Urban Nature

Just as in the case of the spatial concentration of populations, the discourse concerning nature and the welfare of ecological systems in the midst and at the boundaries of the built areas of cities is coloured by unsubstantiated facts, popularly believed to be true, and by theories with little empirical evidence to support them. This is particularly true in discussions concerning the resilience of systems of urban open spaces, their dynamics, and the character of the ecological systems that populate them. While extensive monitoring is being carried out in various cities, little interpretative research has been conducted to date and a clear understanding of the dynamics and system resilience is lacking. Therefore, all efforts to forecast the future welfare of ecosystems in cities is speculative. There are, however, examples of intensive efforts to map out and to understand these phenomena. Examples in this direction are the US Environmental Protection Agency's Green Infrastructure initiative (Wickham *et al*., 2010) and the European corridor conservation initiative (Van der Sluis *et al*., 2004).

While the common theories have not yet been confronted rigorously with empirical evidence, just as in the case of urban spatial dynamics, here also, there is already massive factual evidence that does not accord well with some of the accepted theories. In a major multi-disciplinary, multi-year study, we seek to present evidence that cannot be ignored and point out theoretical constructs that should be abandoned. We propose and analyze the dynamic processes of open space networks that conform well with the evidence and can serve as a basis for productive management of the built and the natural environments. Beyond the well established value of open spaces within the urban environment to human welfare, such patch networks may provide a critical 'infrastructure' for plants and animal movements within and through the urban area.

In a review paper concerned with the interaction of cities and nature (Czamanski *et al*., 2008) we concluded that in parallel with urban systems, identification of ecosystem boundaries is marred by fuzziness. In particular, the spatial arrangement of natural patches has critical implications to the dynamics of flora and fauna populations, and functionality of ecosystems nested within the city boundaries. Ecological corridors serve as important conduits within the landscape matrix for species movements. Furthermore (see Czamanski *et al*., 2008):

1. Species response to human presence is differential. Some species are strongly affiliated with human activities and thrive in areas dominated by human presence. Other species are extremely sensitive to anthropogenic intervention, which may result in their local extinction.

2. For some species, the biomass and abundance of individuals peak in urban areas due to the ample sources of food and water. Species richness that generally increases with increasing distance from urban centres may be highest in peri-urban areas, due to the presence of both native and introduced species.

As the human populations of cities grow, the spatial character of urban ecosystems changes. To extrapolate from the past, there is a need to model open space dynamics and to examine the impact of planning regulations on the systems. Historical analyses can provide insights and basis for such predictions. Based on historic aerial photographs and satellite images figure 5 presents data for Haifa, Israel. The upper series are the basis for the construction of a network map in the middle series. The lower series present an abstraction that illustrates the declining quantity of open spaces and the increasing fragmentation. The graphs suggest that while the network remains rather connected, fragmentation increases with time, resulting in some isolation of patches, particularly in the inner parts of the city. It is noteworthy that, starting from 1945, the number of patches increases until the beginning of the current century (see figure 6). In figure 7 we present the same data as a rank-size distribution. The results are suggestive of the dynamics of the network of urban open spaces and the possibility that we can expect drastic changes at some unknown future time.

Individual patch importance for overall open space network connectivity was analyzed by means of the betweenness centrality network metric (Urban and Keitt, 2001). The impact of node elimination on network

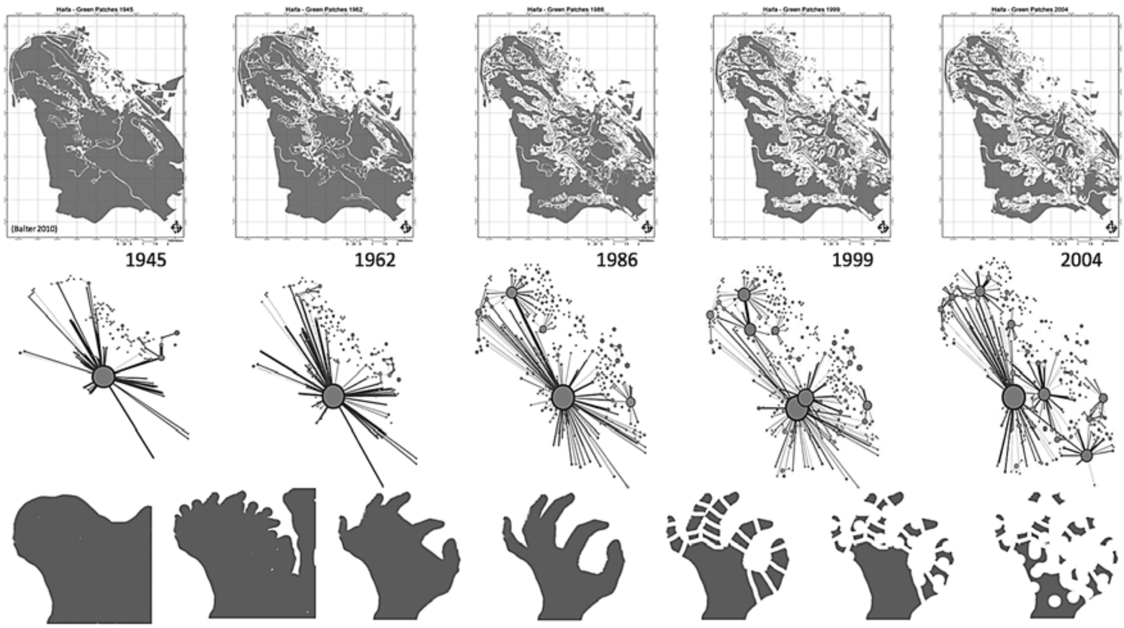


Figure 5. Open spaces time sequence in Haifa, Israel.

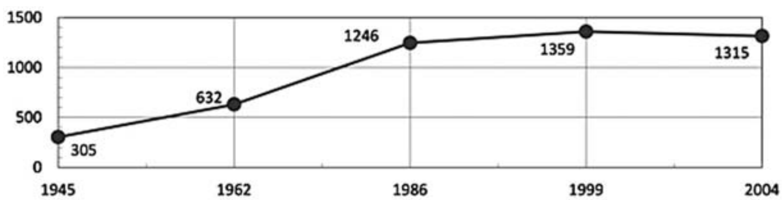


Figure 6. Number of open space patches in Haifa.

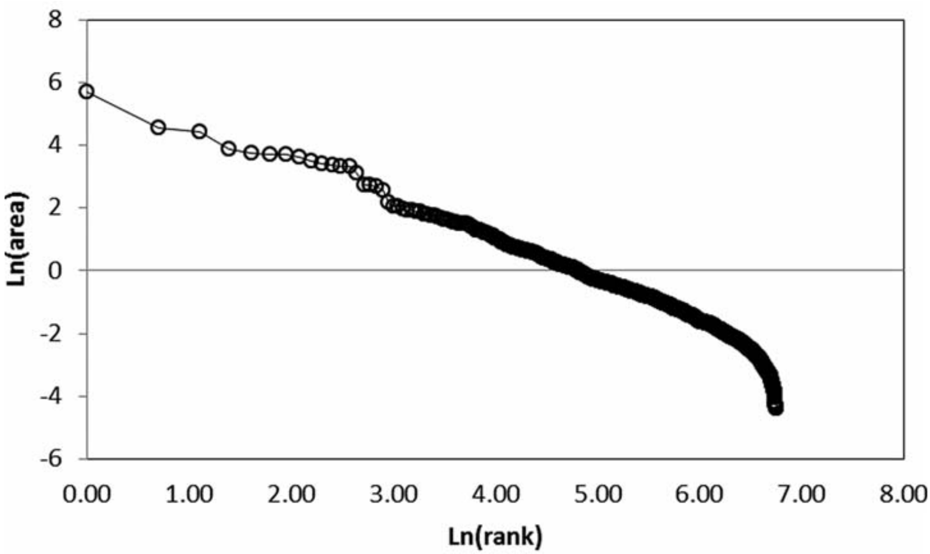


Figure 7. The rank size distribution of open space areas within the city of Haifa, 2012.

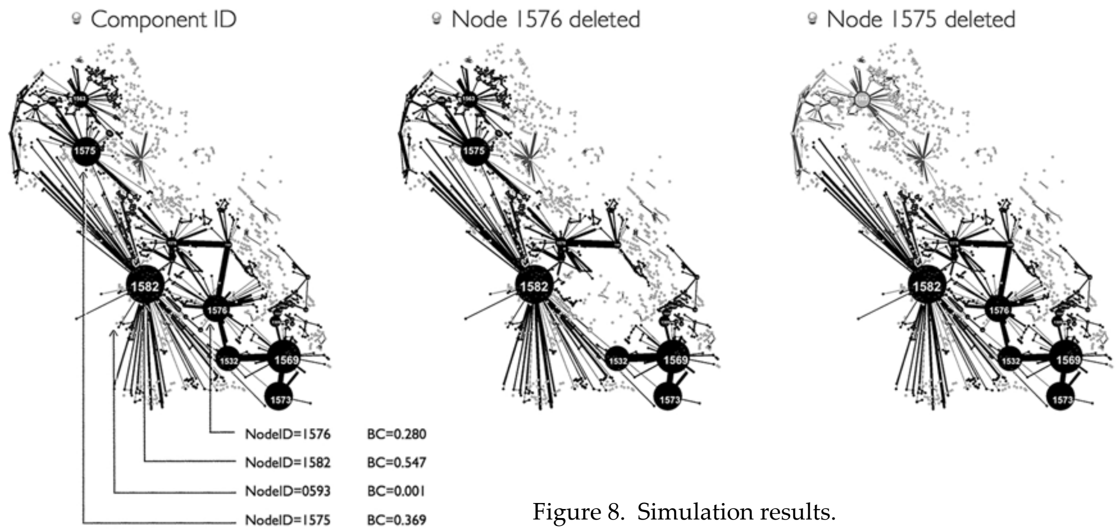


Figure 8. Simulation results.

connectivity and stability is illustrated in figure 8. The graphs suggest that the network remains rather robust, but that fragmentation increases with time, resulting in some isolation of small patches, particularly at the inner parts of the city. The figure presents the full network and the network after deletion of node 1574 and node 1584 based on 2004 configuration of open spaces in Haifa. Node size represents normalized betweenness centrality (BC) metric, small for low values, large for high. Node size represents patch area. The left panel represents the full network; black represents the largest connected component (giant) and grey all other connected components. The giant component (black) shows all the patches that potentially can serve a focal species, which can successfully disperse a minimal threshold distance, as habitat. It represents the network in 2004, dispersal distance (d) = 60 m. In the central panel node 1576 is deleted. The giant component (black) still spans almost the whole network. In the right panel node 1575 is deleted instead. The north-western part of the network was disconnected (grey) and the giant component (black) shrank considerably. The result of deleting nodes with moderate centrality values is not obvious. For example, a node with BC = 0.28 is deleted without significant damage to the network. When another node with BC = 0.36 is removed, a significant part of the open spaces is disconnected from the network. This suggests that for a given species a threshold centrality value can be found (as in our example, threshold betweenness centrality values are $0.28 < BC < 0.36$) and thus the important patches identified.

The temporal analysis of the networks reflects the fragmentation process that resulted from the development of Haifa city and suburbs. Several network metrics have shown the same process. First, there is an increase in the number of elements in the network. In later periods the trend changed as nodes and links started to disappear, and connectivity started to decrease, following urbanization of some of the open-space patches (see figure 9). Thus, even such an initial analysis can provide planners with an indication of the stability and resilience of open space networks within municipal boundaries.

From an ecological point of view, it is prudent to maintain a functional network. Network connectivity, however, need not only be functional within the city boundaries, but also linked with the open spaces surrounding the city. Robust networks will ultimately

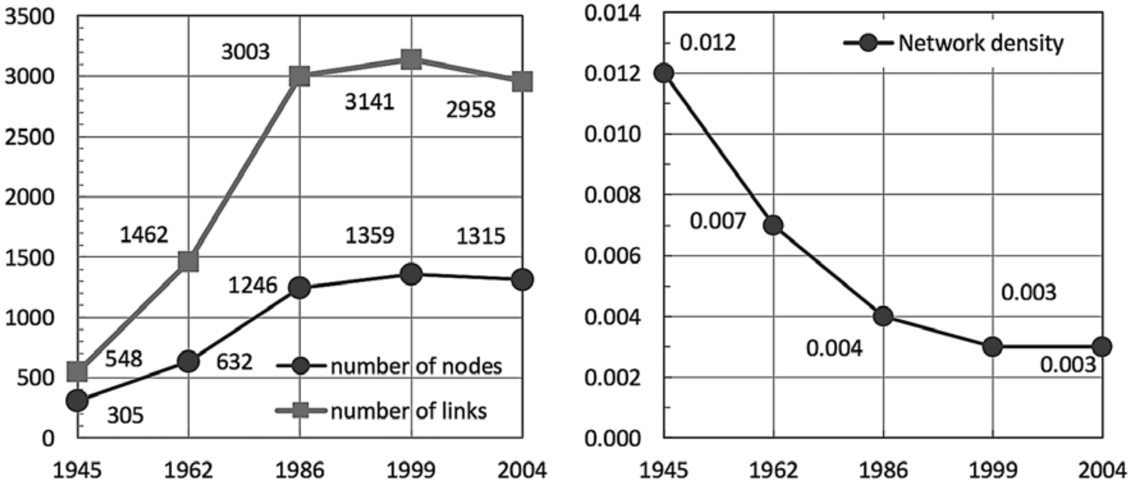


Figure 9. Number of nodes/links (left) and net-work density (right) evolution.

enable organisms to disperse successfully within the city, through the city and among the open spaces surrounding the cities.

The stability of the network is dependent critically on the nature of corridors between the various patches. The suitability of corridors depends on their length, width, steepness and other characteristics. They are influenced by the city's topography and morphology. The shape of buildings, the spaces left between buildings and obstructions in the form of fences may result in the absence of apparent corridors. There is a need for a much more detailed analysis of connectivity among the patches based on new metrics, yet to be developed. Nevertheless, the broad-brush picture of urban nature seems apparent. In the future, as urban populations grow, it is likely that the nature of leapfrogging development and our appreciation for ecological services can help preserve networks of open patches that can support nature. To ensure this prediction there is an urgent need for massive research effort as a basis for regulatory activities capable of preserving networks of open spaces and supporting biodiversity.

There is no doubt, however, that nature does live in cities. By means of motion-triggered cameras, we are documenting the presence of mammals in Haifa, Israel and in Hannover, Germany. The results are striking. In figure 10 we illustrate the various animals in the cities, including in the very core of the built area. It is evident that the presence of animals is not uniform throughout the built-up area. For example, in the heart of the city (centre of figure 11) the frequency of the observations of wild boar is relatively high. While the presence of rodents and domesticated animals is not surprising, the frequency with which jackals and wild boar are observed is surprising.

Discussion and Conclusions

To the best of our knowledge there is no typology of cities in terms of the character and state of their system of open spaces. There are some cities that experience increasing fragmentation of open spaces. In some of these the network is rather resilient and much of the network is interconnected. Perhaps it is possible to expect that in the future cities will succeed in reversing current trends of increasing fragmentation, e.g., by providing more open spaces by preventing construction on abandoned lots, by increas-

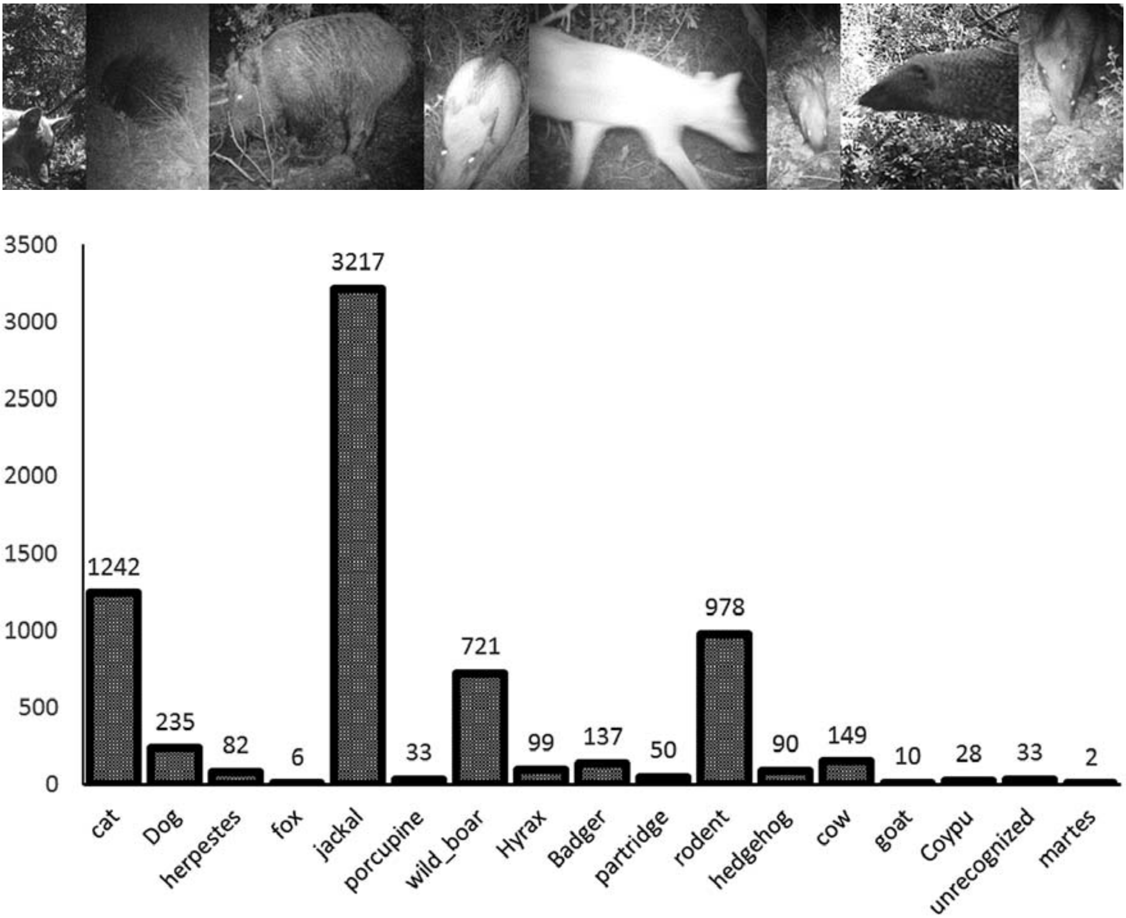


Figure 10. Animal observations in Haifa 2011–2012.

ing space devoted to community gardens and to green roofs. In such a case, the series of negative and positive feedback mechanisms discussed above may serve to maintain current urban dynamics. In contrast, should some of the feedback mechanisms collapse the dynamic processes may lead to congested, over densely populated cities, such as cities commonly found in developing countries, for example Cairo and San Paulo. In over congested cities open space (and their networks) have been overlooked.

In order to make sensible predictions concerning the future of networks of urban open spaces there is a need to understand their dynamic evolution and in particular to identify the critical thresholds from beyond which these networks will cease to function. The main issue to consider from the 'urban-nature' perspective, is where do the leapfrogging dynamics lead us? Will the porous structure of the urban matrix be constricted and clogged? If so, this may result in network collapse. Should extensive leapfrogging continue, will it be too intensive? It may lead to fragmentation of open spaces at the city outskirts, and dysfunctional performance of important rural open spaces. Since development will continue to take place, the challenge is to strike a balance between intra-city and extra-city development. The question is whether we have the requisite knowledge to regulate and control these dynamics, and whether, in case of wrongdoing, the processes

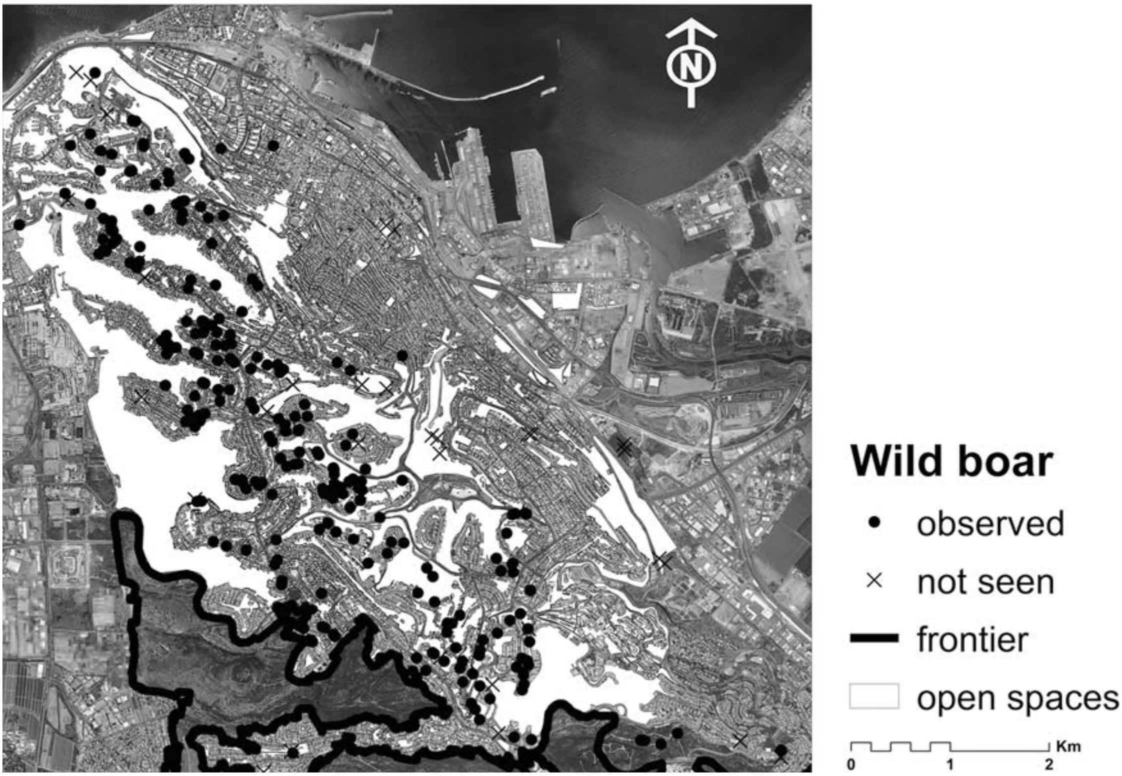


Figure 11. Frequency of observations of wild boar in Haifa.

are reversible. Current trends in large cities include construction of community gardens, and of green roofs, and reclamation of abandoned lots. Could this be sufficient to maintain network connectivity in light of the increasing fragmentation?

The question arises as to whether it is the Haifa morphology that is a contributing factor to the survival of nature within the city? Perhaps it is the topography of the city and the proximity of various neighbourhoods to the edges of natural areas that is responsible for these observations. What can be expected as the urban population grows? There is no doubt that should ideas concerning the compact city prevail and Haifa come to resemble the urban tissue of Manhattan, the network of open patches connected by corridors will disappear. Should the added population reside at the periphery of the city and the future morphology retain patches of open spaces, the current situation can be expected to continue for many years to come.

It should be stressed that if the survival of networks of urban open spaces is a necessary but not sufficient condition for nature to exist within city boundaries, it is imperative that the sprawl of cities outwards should be at the expense of agriculture and not at the expense of open large areas of nature. The survival of relatively large mammals is dependent on the large living spaces outside of the boundaries of built-up areas. Their observed presence within the city is for the purpose of foraging.

There is no doubt that the future of nature in and around cities will depend on urban topography, existing and future morphology of built-up areas and the evolution of areas around cities. In part the future depends on planners and future land-use regulatory practices. The fragile environment of natural areas in and around cities and their future will also depend on creativity in the design future morphologies and on the regulatory frameworks within which the actions of land entrepreneurs will affect urban morphology. Our speculations are based on the continuation of the present practices and sprawling patterns that in the future will be similar to the present. The future may be also affected by changes in the economics of small-scale agriculture. It may be that commercial agriculture in the vicinity of cities will give way to touristic activities and organic, small-scale, cultivation. These patterns may be more conducive to continued survival of nature within and around cities.

Another process that needs to be considered in thinking about future interactions between people in cities and nature is the effect of future technology and its effect on agent behaviour, and the consequent urban development. For example, increasing numbers of people working from home may impact the need for commuting and lead to increasing sprawl. If cities in the future have much improved public transportation systems it may contribute to different patterns in the evolution of urban structure/sprawl/leapfrogging and the system of open spaces. The repercussions of increasingly transport-congested cities is not clear. Indeed, it is not possible to forecast population trends in the long-run and it is even more difficult to predict future urban structure and the functioning of urban nature.

The bottom line of our analysis is that much remains obscure and that much work is required that focuses on the interactions between urban development and urban nature.

NOTES

1. Much of this section and its arguments have been presented at various conferences and were summarized in the November 2013 Newsletter of the Regional Science International under the title ‘Simulations in Regional Science (2): Complexity Research Lab: experimenting with cities’.

2. Since developers populate urban models there is a need to incorporate industrial organization considerations in characterizing the interactions among urban players.

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