reviewed paper

Size of the Patch

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1 ABSTRACT

The creation of liveable, healthy, and prosperous cities is, quite simply, a matter of proportion. Urban agglomerations are partitioned or nested into a quilt of functions and spaces, of which ecological patch structures are a vital aspect of human-environmental sustainability. This paper examines the how specific types of ecological patches exist and perform within urban agglomerations. Patches are describable by "landscape signatures" containing attributes such as origin, contrast, age, size, and shape and also have characteristic and measurable "environmental responses" such as biodiversity and –GHG. Following Alberti (2008) and others, a general approach to studying the existence and performance of patches is developed at the scale of the city or larger metropolitan region. The emphasis in this paper is to show how existing and/or alternative "emergent patch structures" contribute to the overall human-environmental quality of life, with particular attention paid to the size and shape of patches. Because context matters, both the overall approach and the proposed methodology are illustrated for the specific instance of Warsaw, Poland.

2 THE RECOGNITION OF HUMAN-ECOLOGICAL ECOSYSTEMS

The sustainability movement has placed an artificial wedge between human needs and environmental needs. Analytical models associated with the sustainability movement simplify either the human dimension to reach an ecological conclusion or simplify the ecological dimension to reach a human conclusion. For example, the classic economic models based on the Alonso bid-rent dynamics do not consider the environment at all; conversely, urban ecosystems models such as those developed by Odum and follows tend to simplify human needs, wants, and behaviors. To overcome these methodological dilemmas and to foster an understanding of the human-ecological interface as an integrated system, a series of research efforts are underway that emanate from the landscape ecology research community. Alberti (2008) and others have develop an integrated human-ecological model of urban ecosystems.

Urbanization changes land use from a formerly pristine ecological regime to another regime. In so doing, the process of urbanization fragments the earlier ecosystem. The resulting urban eocystems are "heterotrophic ecosystems" – dependent on large amounts of energy and materials and a vast capacity to absorb emissions and waste. But, detailed knowledge about this overall phenomenon is lacking, due in large part to methodological inconsistencies among studies. Alberti and others have asked the general question: is there a relationship between patterns of urbanization and environmental performance. For planners, the answer to this question must be YES! It defines their position in society. Yet, scientists, for a number of reasons, have yet to confirm this conclusion, due in large part to faulty thinking and the failure to recognize the scale implications of their work. The basic conclusion reached by Alberti (1999) and others is: we don't know. But this conclusion is argued within a context of the need for further, longer lasting, research.

This paper is organized as follows. In the next section, we review the major theoretical treatments of the human-ecological interface, focusing on both systems thinking and the conceptual and methodological advances within the landscape ecology research tradition. We then briefly describe the ecological and urban development patterns in Warsaw. The research problem is simply to explore the possibility of human-ecological patch type analysis in the situation of Warsaw. The methodology sections focuses on how "landscape signatures" are created for our situation. The results focus on three individual case studies: a comparative patch analysis, a gradient analysis, and a single-area dynamic analysis. Results are expressed in terms of similarities and differences. The final part is an overview of our results, an assessment of contribution to the literature, possible recommendations for the improvement of both planning and real dynamics in Warsaw, and suggestions for future research.

3 ADVANCES IN UNDERSTANDING THE HUMAN-ECOLOGICAL ECOSYSTEMS

The conceptual and methodological approaches to the study of human-ecological urban system are undergoing rapid change. There are two major threads: systems and complexity, and advances in the landscape ecology research traditions. The first focuses on how to more appropriately capture the joint dynamics of both human and ecological needs. The second focuses on methodology. Both are briefly reviewed here.

3.1 Systems and Complexity [+ Ecological Performance]

Advances in human-ecological thinking seem to focus on the work of five research nodes: Marina Alberti's at the University of Washington, Nancy Grimm at Arizona State University (e.g., 2000), Stewart Pickett and colleagues at the Cary Institute of Ecosystem Studies in New York (e.g., 2001), Mark McDonnell at the Australian Research Center for Urban Ecology (e.g., 2000), and Herbert Sukopp in Germany (e.g., 1995). In this body of work, much emphasis is placed on the twin notions of cities as systems and complexity theory.

3.2 Cities as Systems

Perhaps the most fundamental idea is that cities and regions can be represented as systems. In a system, there are four major elements: drivers, patterns, processes, and effects/changes. The dynamic is basically from "inside-outside" but there are two important feedback loops: one internal between patterns and processes; and one external in which changed conditions lead to changes in the behavior of the drivers. Figure 1 is an adaptation of one such model, drawn from Alberti (2008, drawn from Alberti et al, 2003).

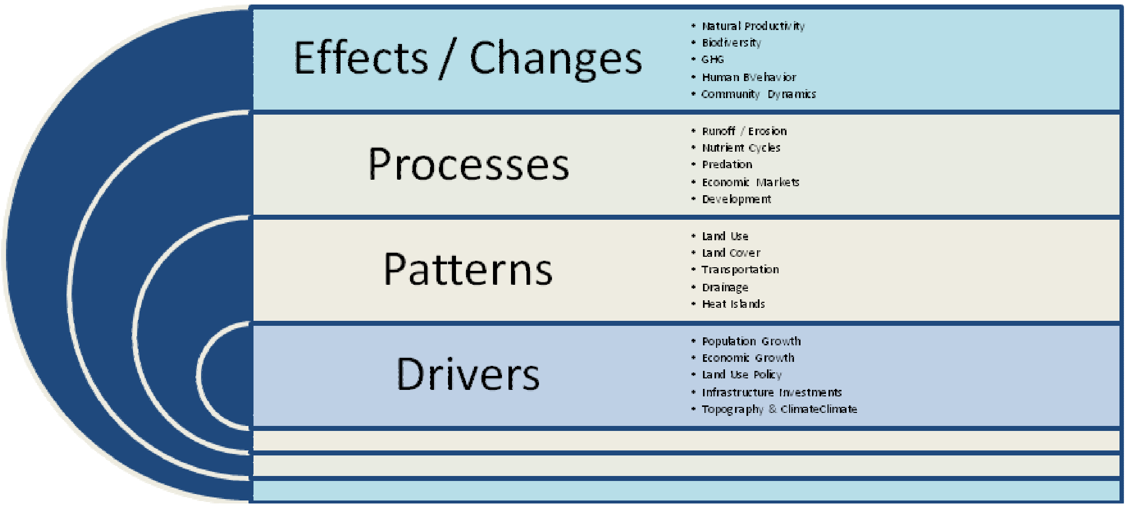

Figure 1: Systems Characterizations

Drivers are external events but are of three types: socio-economic forces, natural forces, and planned interventions. Patterns are mostly physical representations observable at a general scale. Processes are also physical but are generally observable at different scales.

Effects and changes are differences in the levels of some behavior. None of this matters of course if there were not certain emergent properties of interest. This is the area of environmental performance. How is it measured? What does it mean? The normal environmental performance variables include things such as clean air, clean water, and more recently, reduction of GHG and other carbon related things.

3.2.1 <u>Complexity</u>

Characterization of the human-ecological urban system is not enough to capture how such systems operate. Complexity theory, which underlies most system characterizations and whose rudiments can be found in Nicolis and Prigogine (1997), Portugali (2000), Batty (2005) among others, contains a number of important concepts including: emergent properties, feedback, self-organization, and resilience.

An emergent property is a characterization of what we see or observe at a certain time. It is in a sense a temporally defined "product" of processes at work. It is a static description. The current pattern is either, depending on one's point of view: (1) to be changed if one is a planner; or (2) to be made sustainable (or resilient). The choice between change and sustainability/resilience is of course the fundamental matter of ideological debate. Feedback is the general dynamic of growth/decline. Feedback can be positive (reinforcing) or negative (dampening) for the process under consideration. Note that positive feedback is not positive in an ideological sense; the continuing erosion of the polar ice cap is an example of positive feedback. Feedbacks are defined in terms of processes, not net results. Self-organization is an idea that systems, by virtue of carrying out its process will result in a certain emergent state. More often than not, these are described in terms of agent-based models, where simple decision rules at the scale of the individual result in patterns at the scale of the aggregate. Finally, resilience is the ability of a system to stay in the same regime state (emergent property) while experiencing shocks. Moreover, resilience is defined for certain scales within a system.

3.3 Landscape Ecology

Landscape ecology is generally understood as the science of analyzing and improving the dynamics between urban land uses and ecological processes at a variety of scales. There are, of course, a few basic terms that need to be defined. The first is landscape. It is generally agreed that the word landscape refers to a spatially heterogeneous area characterized by diverse interacting patches or ecosystems, ranging from the relatively natural terrestrial and aquatic systems such as forests, grasslands and lakes to human-dominated environments including agricultural and urban settings. The second is ecology. It is generally agreed that the word ecology refers to the interdisciplinary study of the interactions between organisms and their environment, or more colloquially, ecosystems. Landscape ecology is the scientific study of the relationship among pattern, process, and scale, and more recently of the need to couple biophysical and socio-economic systems. Wu and Hobbs (2002) suggest that there are five topics of current interest: (1) ecological flows in landscape mosaics, (2) land use and land cover change, (3) scaling, (4) relating landscape pattern analysis with ecological processes, and (5) landscape conservation and sustainability.

More specifically, current landscape ecologists suggest that there are various “signatures”, indeed “urban” signatures in the current landscape. These signatures contain elements that can be described and measured. For example, Alberti (2008) suggests that these important variables include: (1) scale and heterogeneity (composition, structure, and function); (2) patch and mosaic; (3) boundary and edge; (4) ecotones, ecoclines, and ecotopes; and (5) disturbance and fragmentation.

3.3.1 Theory of the Patch

Patches are the basic units of the landscape. They simultaneously exist and change. The literature devoted to the categorization and measurement of patches is illustrated by the work of Mora and Iverson (2002), Watson (2002), Watling and Donnelly (2006) among others. A patch is normally defined as a discrete area of relatively homogeneous conditions. We distinguish between patch characteristics and patch dynamics. Patch characteristics can be defined by/as:

- Shapes and configuration and can be described compositionally by variables such as number of trees, number of tree species, height of trees, or other heterogeneity descriptors.
- Centers.
- Boundaries and/or edges. The zone composed of the edges of adjacent ecosystems is the boundary. Edge means the portion near its perimeter, where influences of the adjacent patches can cause an environmental difference between the interior of the patch and its edge. The edge effect includes a distinctive species composition or abundance. Adjacent patches have a boundary between them which can be either defined or fuzzy.
- Existence of colonization processes, disturbance regimes, and succession.
- Scale. Human and biophysical processes have defined scales of impact.
- Connectivity. Connectivity is the measure of how connected or spatially continuous a terrestrial place or corridor is. For example, a forested landscape (matrix) with fewer gaps in forest cover (open patches) will have higher connectivity. Particularly in urbanized landscapes, corridors have important functions as strips of a particular type of landscape differing from adjacent lands.
- Networks. A network is an interconnected system of corridors.

Patch dynamics, which are the processes and change and fluctuation, normally focus on the spatial structure, function, and changes in the above set of relatively discrete concepts or elements. The emphasis is on changes in values of any of the variables above. Clearly, if a human-ecological ecosystem is improving it will exhibit, among other things, a stronger center, better defined edges, resilience, connectivity to larger ecosystems, etc. The key idea is to capture processes occurring over time.

3.3.2 Ecosystem Services

The concepet of ecosystem services is focused on dynamics. Alberti (2008, p. 261) suggests five themes for observation and/or research endeavors. First, urban ecosystems are dynamic, hierarchically structured, patch mosaics resulting from the interactions of humans and ecology. Second, urban ecosystems are drive between multiple states in regard to the amount of urbanization. Third, interactions between socio-economic and biophysical patterns and processes lead to emergent properties, such as sprawl. Fourth, the effects are non-linear and are found in various levels of disturbance and resilience. And, finally, ecosystem functions are moving targets with multiple and unpredictable futures. The implications for planning are immense. As Alberti argues (p. 261), policies that aim to achieve fixed goals cause a loss of resilience and are destined to fail.

3.3.3 Urban Landscape Signatures / Typical Measaurement Schemes

Three basic concepts create the language of measurement: patch, class, and landscape. As before, there are two issues: what to measure and in what methodological framework.

What to Measure

Alberti (2008) suggests that these signatures are composed of two major properties: composition and configuration; and, four elements: form, density, heterogeneity, and connectivity. With enough data, it is possible to develop eight sets of measurements. However, as Alberti herself points out, many of the measures are joint composition/configuration concepts. Figure 2, drawn from Alberti, show some of these measures.

Form	Density	Heterogeneity	Connectivity
Land Use (% land in certain categories) Land Cover (% urbanized) Fragmententation (mean patch size) Shape (circular, rectangular)	Clustererd v. Dispersed Overall Patch Density (number of patches per square unit of land)	Number of Elements Diversity v. Evenness Number of Patches of Specific Land Use Number of microclimates	Connected or Dispersed Interspersion (distance between patches) Evidence of Colonization, Other Disturbances, and/or Succession

Figure 2: Concepts and Measurements

Methodological Frameworks

Four major frameworks to analyze “urban landscape signatures” are in common use. Taken together, they represent a way to observe variations among different landscapes. These methods are: gradients, single-area analysis, networks, and hierarchies. A truly universal methodology would use all four methods.

- The gradient method focuses on the human impacts on ecosystems at different distances from the city center. Gradient methods are similar to the new urbanism transect concept – an attempt to look at certain variables at different distances from a center. Typically, the categories are things like: urban, suburban, and rural. Variables typically studied could include things such as microclimates, nutrient loads, plant distributions, stream health, and richness.
- Single patch analysis is normally used to study situations in which urbanization creates discontinuous patches, which are further modified with further human interaction. The outcome variables are typically: landscape heterogeneity and connectivity. So this is an overall measure of the place.
- Network analysis focuses on the interactions between and among ecosystem components. These interactions can be proximate, direct, or some other functional form. Moreover, the study of interactions implies that many ecological systems are far from random; displaying organizing principles that are evident at certain scales of resolution.

- Hierarchical analysis focuses on complexity theory constructs applied to urban ecosystems. These would include concepts such as nested phenomena, thresholds, and differential process rates and spatial extents.

3.3.4 The Size of the Patch … Matters

The key idea is that urbanization creates discontinuous and smaller patches, which are further modified with further human interaction. Patch performance, defined in terms of typical variables such as biodiversity, etc. are related to patch size. The general conclusion is that larger patches perform better in terms of most environmental variables than smaller ones. The fragmentation of formerly large patches into a series of smaller patches created by the urbanization process, limits the ability to the ecosystem to perform at high levels.

4 CONTEXT: BASIC DESCRIPTIONS OF WARSAW

The Warsaw Metropolitan Region contains approximately 2.8M people and covers an area of 6.1K square km (approx 2,355 square miles). The City of Warsaw contains 1.7M people and covers an area of 517 square km (approx 200 square miles). It is the 16th largest metropolitan area and the 9th largest city in terms of population in Europe. Warsaw is the main employment node for the surrounding region and over 20% of employment consists of commuters. Sixty percent of the population lives on less than 10% of the land area. The average population density is about 3,270 person per square km (varies from 380 to 9600). The most densely population portions are in and near the old, central districts, see Figure 3.

Fig. 3: Warsaw: Land Use, Geological, and Environmental Conditions

4.1.1 Basic Ecological Conditions

Warsaw is located on the border of two geographical units: Warsaw's Plain and the central part of Vistula Valley, in the center of geological unit called Mazovia Syncline. The steep edge of Warsaw's Plain is a main landscape feature of the city. The height of the Warsaw Escarpment ranges from 6m in the northern part, up to 25m in the city center, and slopes slightly towards south. The geomorphology of the area was shaped by two processes: glacial accumulation and river erosion. The ecological core of the city is the Vistula Valley; which although is relatively uninfluenced by anthropogenic changes, the water is very much polluted. The whole valley within the levees is a protected Natura 2000 area. Complicating the matter is that water resources are minimal, about 3 times smaller than the average in Europe. Another important ecological feature is the forests, which make 14% of the city area. The forests remain in either protected areas (several nature reserves) or are linked to them (Kampinoski National Park, Mazowiecki Landscape Park, and Chojnowski Landscape Park surrounding the city). Together, natural and semi natural greenery covers around 23% of the city area.

The basic issue, however, is not the total amounts of any of these features, but how they function as ecosystems. Green spaces in the eastern and southeastern part of the city are quite compact and continuous while they are fractured and isolated by urban development pattern in the western parts.

Ecological problems in the city are: heat island covering 30% of the area (central districts), air pollution caused by transportation and usage of fossil fuels, noise (65% of population lives in areas where noise level is over quota), and, fragmented area and linear green spaces, and water pollution.

4.1.2 Basic Urbanization Contexts

Warsaw exhibits a variety of development patterns, some "in conflict" with each other. It contains remnants of the historical urban fabric, elements of social realism planning, and some garden type settlements. As the economy transitions from an industrial base to a service base, older industrial sites have been abandoned, brownfields emerge, the primacy of the capital emerges, and attention is given to creating a global business district and a global brand. Conflicts arise between ecologists and investors – between environmental needs and human needs, especially regarding developments located adjacent to valuable natural areas.

The basic land use pattern does not create a clear structure. The major concentration is on the western border of the Vistula River, on the escarpment. The city center has almost a grid pattern, but it is fragmented and filled by free standing blocks. The city center is surrounded by newer districts built in 60s, 70s and 80s. The fastest growing districts from 1990 are suburban districts to the north-west, north-east and south. Suburban employment centers emerge (e.g., Piaseczno to the south), as do planned ring roads and planned airports.

5 RESEARCH PROBLEM

The purpose of this paper is to begin to apply the concepts and measures of the human-ecological approach outlined above in the context of Warsaw. Our intent is to frame and begin to analyze selected ecological issues and areas within the city. Our building block is the notion of "landscape signature", describable as a set of statements about both ecological attributes and ecological performance. We frame and conduct three types of studies: (1) the comparison of "landscape signatures" for two land segments; (2) the comparison of "landscape signatures" in a gradient-type analysis on five sections along the Vistula River; and (3) a discussion of the changing "landscape signature" for Wilanow, the site of a major ongoing development.

Ecological Variable	Measurement
Number of Patches	Number of Patches in each Study Area
Form	
Land Use	% of Land Residential, % of Land Other Urban, % of Land Natural
Land Cover	% of Land Developed
Fragmentation	Mean Patch Size
Density	
Clustered v. Dispersed	Clustered or Dispersed
Overall Patch Density	Number of Patches / Area of study areas
Heterogeneity	
Number of Tree Types	Count
Number of Species	Count
Diverse v. Evenness	Diverse or Even
Microclimates	Yes or No, Describe
Connectivity	
Aggregation	Grouping: Yes or No
Shape	Describe: circular, rectangular, linear
Distance Between Patches	Distance
Connected	Yes or No (to another patch)

Table 1: Synthesis of Human-Ecological Concepts and Measures

6 METHODOLOGY

6.1 Definitions and Terms

The “heart” of this paper is the development of definitions and terms for attributes and/or elements, that, taken together, are capable of describing the “landscape signature” of any geographically-defined area. Some of these measures are indicators of individual patches; some are measures of a geographically defined area, see Table 1. So, it is possible, even likely, that any geographically defined area will have multiple patches (or ecosystems within it).

6.2 Approaches and Definition of Study Areas

Three case studies are developed to begin to use the human-ecological “landscape signature” approach. The first is a comparative analysis of landscape signatures in what are a priori, completely different sections of the overall city spatial structure. The first, named Bielany (because it is in the political district of the same name), is located north/northwest of the urban center, has a geological topology of glacial heritage, and has witnessed urban growth and decline. The second, named Wawer is located in the southeast portion of the study area and is mostly pristine, has a geological topology of river valley with glacial accumulation and is on the fringe of urban development. The expectation is that these areas will have significantly different landscape signatures.

The second case study is a traditional gradient analysis, but instead of areas at different distances from the urban center, we focus on the Vistula River, which runs in a roughly north-south direction through the urbanized area. Although much of the riverbank is protected as part of the Natura 2000 plan, we also expect that landscape signatures will be different as distance from the center increases. We examine both “upstream” and “downstream” impacts by focusing on gradients in both directions.

The third case study is an example of a “single area” analysis, with a focus on dynamics. The case study is conducted for Wilanow, the current site of a major urban transformation from rural to urban. From a city-wide perspective, this development is absolutely appropriate since it is adjacent to existing urbanized areas and reflects an “organic” model of city growth. Nevertheless, the prior ecosystem is being changed. The focus of this study is to explore some of these dynamics. The study areas are shown in Figure 4.

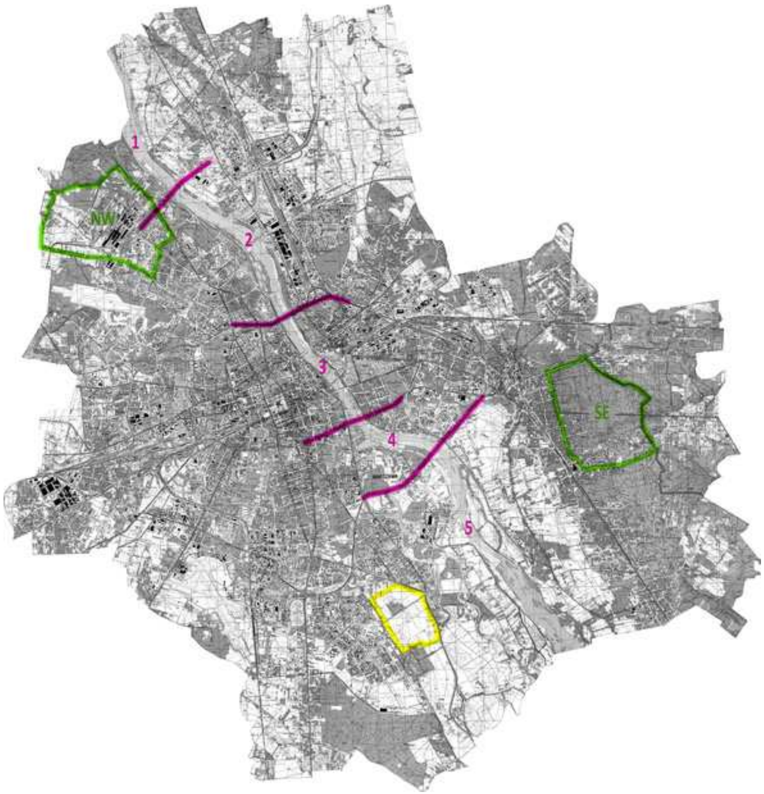

Figure 4: Definitions of Study Areas

6.3 Gathering Data for the Warsaw

To present both data and results, a topographical map of the city at the scale of 1:25000 is used. The environmental, and where possible ecological, data are drawn from two studies produced by the municipality: (1) Study of the conditions and the directions of the spatial development for the city of Warsaw and, (2) Ecophysiographical study for the city of Warsaw. It is important to note that much of this data is "environmental" and not "ecological".

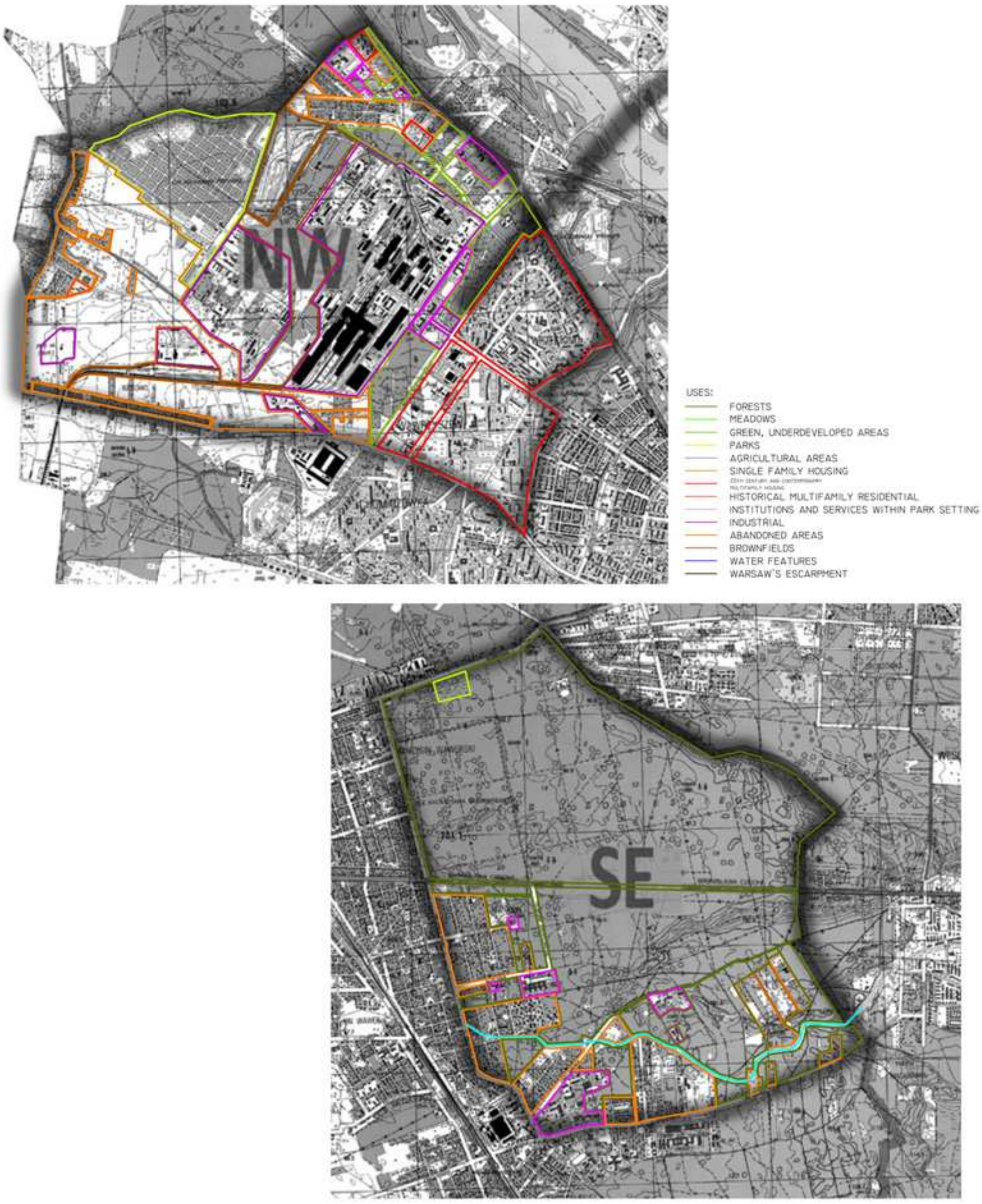

Figure 5: Comparative Analysis: Bielany and Wawer.

7 RESULTS

Results are presented in the order identified above.

7.1 Urbanized Versus Rural Landsapes

To show the difference between an urbanized landscape and a more pristine suburban landscape, we mapped the number of patches in each of two areas, see Figure 5. This comparative analysis between the Bielany and Wawer regions generally shows what would be expected. The Bielany area contains many more fragmented patches, patches which are not functionally related to each other, but indeed adjacent to one another. Thus, for example, there are commercial patches next to industrial patches. There is no set of connected green or natural ecosystems (there is a low level of connectedness, there is no apparent network, sizes and shapes vary wildly, etc.). On the other hand, the Wawer region contains a strong single ecosystem. There is a strong core to the patch and boundaries are relatively easy to identify. Patches adjacent to the main central patch are more appropriate to the center core.

While this comparison is, to some degree, extreme by choice, the comparative analysis does show how important "landscape signature" elements vary between the two areas. Similar types of studies could be developed for other comparative areas throughout the city.

7.2 Gradient Analysis along the Vistula River

Here, we partitioned the landscapes along the Vistula River into five sections (or study areas) starting in the center, and doing a gradient analysis "away" from the center. The basic hypothesis is that ecological characteristics would vary among these sections. Even though the Vistula is a "wild river", we expect to see different ecological dynamics and processes in these three different sampled sections.

Patches are identified for each section along the river, see Figure 6. As can be seen, ecological patches in areas three and four are dominated by urbanized uses. Only area five starts to show more pristine ecological areas. The sizes of the individual patches tend to increase with distance from the city center, a finding anticipated from the literature, which is confirmed by our analysis. The green areas along the Vistula are narrower in sections 1, 2, and 3 showing the historic pressure for development close to water-based transportation. Only in section 5 do we find ecological patches consistent with the expectation of riparian ecosystems.

While the mapping of patches along five different segments of the Vistula provides evidence of urbanization effects on the natural water-based ecosystem, further hydrological models are needed to determine the true biodiversity and other characteristics of water-based issues in these ecosystems.

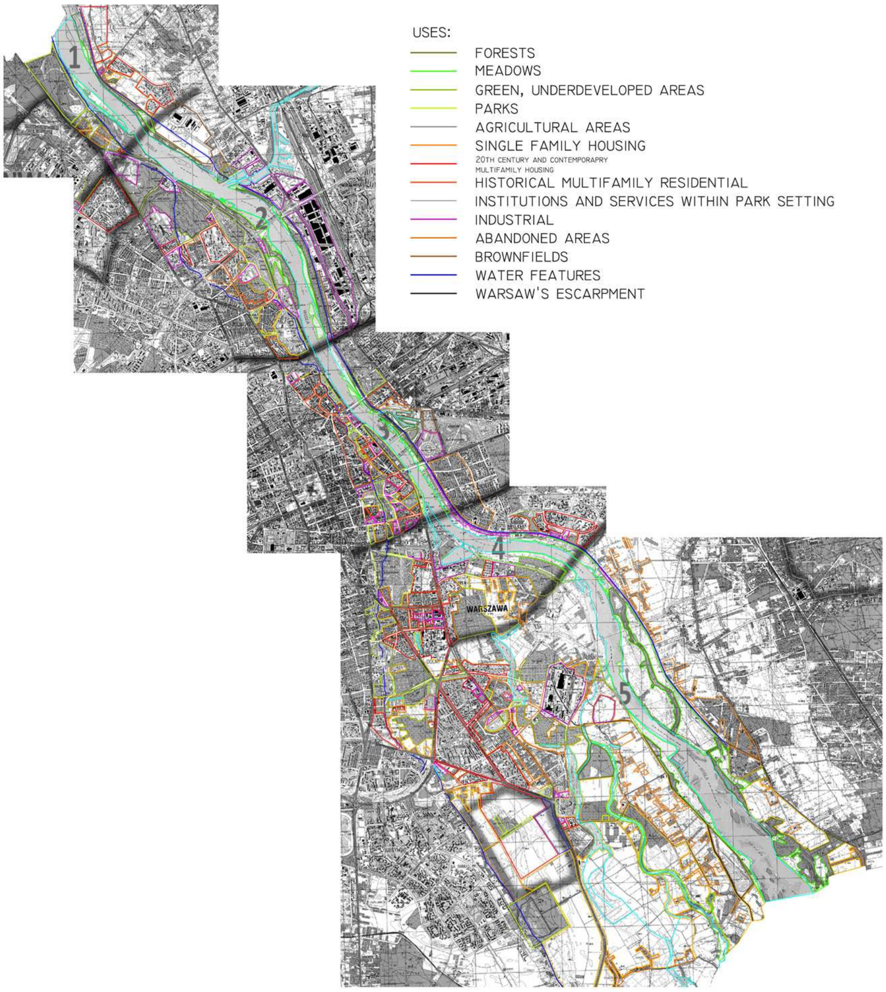

Figure 6: Gradient Analysis along the Vistula River

7.3 Wilanow Project Area

The third case study is an example of a single district, in this case one that is currently under development. Wilanow possesses both a precious cultural and natural heritage as well as huge development potential. The Wilanow West project is a 420 ha site of post-agricultural land that is being developed in accordance with the overall master plan (see location on Figure 4). The surrounding landscape is highly natural with majority of open space, the lowest development density in Warsaw, and several areas of nature protection.

Under the current development, the status of Wilanow West has been changing from an undeveloped area of fields and meadows, abandoned and growing with a birch wood, to a highly urbanized area with the development density factor exceeding 1 or even 1.5 which is typical for a city center. Such a change involves several effects, especially in the environmental performance of the area. For sure the micro-climate will begin to exhibit urban heat island, the flow of storm water will grow, and noise and pollution will increase. Furthermore, biodiversity and GHG absorption will dramatically fall with the elimination of more natural habitats. Although the master plan provides around 40% of biologically active area on the building lots, which has mitigating meaning, it will be still an anthropogenic landscape, designed and built, and it will need time to achieve full performance.

Finally, it is fair to say that this project, which will eventually provide housing for 40-50K people, that the impacts on the surrounding areas (that is, the rest of the metropolitan region) have not been fully assessed in

8 CONCLUSIONS / EXTENSIONS

Our summary comments are presented here in outlined form, due to space limitations. The final part is an overview of our results, an assessment of contribution to the literature, possible recommendations for the improvement of both planning and real dynamics in Warsaw, and suggestions for future research.

We have shown how the mapping of human-ecological patches leads to different landscape signatures for different types of geographical areas. Both in the terrestrial comparison and in the riparian gradient, significant differences were found and illustrated. The human-ecological approach seems to offer a better way to consider human impacts on the environment and environmental impacts on urbanization that either does from a singular perspective.

We have attempted to develop an empirical approach based on the theoretical and conceptual literature. To some degree, our attempt was limited by the lack of true ecological data. The important point is that environmental features are not ecological data. Ecology is the science of interactions and transactions, not merely counts.

So, it follows that the major recommendation is the pursuit of more sophisticated ecological data sets and models that capture the human-ecological interactions. We have barely touched the surface in this paper; a full analysis of the human-ecological model for Warsaw would take years of concerted effort. This is a call to begin that effort.

Finally, with regard to future research, we see the obvious need for a more sophisticated model based on the approaches outlined here. The model would overlay identified patches with their environmental conditions, in order to examine their interactions and functioning.We would have liked to have been able to say, for example, “there is a need for a network structure for green areas in or near Wilanow”. But, the data and the existing models do not yet permit such statements. In our opinion a complex patch model of the city would help to solve the conflict between human and environmental needs, and let the city develop in a more sustainable way.

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