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Change of urban ecosystem development—A case study of Beijing, China

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Abstract

Considering its characteristics in terms of structure, function, performance and evolution, the urban ecosystem can be regarded as a vital organism. Based on the concept of urban vital organism, the framework of urban vitality index covering producing power, living status, ecological ascendancy and vital force, is constructed to represent the urban ecosystem development status from the economic subsystem, social subsystem, natural subsystem and ecological regulatory subsystem, respectively. Meanwhile, set pair analysis, an assessment method which can link different objects and describe their relationships, was combined with the urban vitality index to evaluate the relative urban ecosystem development levels. Choosing the situation of Beijing city from 1986 to 2005 as the case, the change of urban ecosystem development levels during the period were analyzed, by using the relative assessment model based on urban vitality index. Based on the results of the urban vitality index and its each factor, the change of urban ecosystem development on the scales of the whole ecosystem and each studied subsystems can be revealed, which implies the focus of urban ecological planning and management in the future.

Keywords: Ecosystem development; vital organism; urban vitality; urban ecosystem management; Beijing city

1. Introduction

In the context of socio-economic development and environmental degradation associated with rapid urbanization, objective assessment and calm review of urban development status has become increasingly necessary for understanding the urban development trend and supporting urban ecological planning, construction, and management toward a sustainable development [1,2]. On the one hand, urban systems emerge as distinct entities from the complex interactions among natural, social, and cultural attributes, and information, energy, and material stocks and flows that operate on different temporal and spatial scales [3]. On the other hand, the assessment outputs must provide clear and practicable support for the actual urban management, which can be regarded as an administrative or political demand. Therefore, a suitable tool that can link the theoretical background of the complex

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urban ecosystem and the practical management requirement is needed developed [2]. Just as stated by Flood: "there will be no indicators without policies and no policies without indicators.'' [4,5] Indicator is selected as a well-suited tool to assess urban ecosystem due to its characteristic of simplification and linkage [6].

The definition of scientific and effective assessment indicators of urban ecosystem development is a complex objective due to the complexity of the phenomena concerned and the difficulty to integrate them in a sound way [5]. Zhang et al. assessed the urban ecosystem development status of ten cities in Shanxi Province, China, by constructing indicators from aspects of economic power, social development, open degree and environment [7]. Yang et al. established indicators including economic development, social progress, and environmental infrastructure to evaluate the urban ecosystem development levels of five cities in Jilin Province, China [8]. Huang et al. measured the urban development in Taiwan from four aspects covering economic production, social living, natural environment, and human security [9]. It should be noticed that sustainability indicators have been widely applied and developed amongst various kinds of urban ecosystem assessment indicators [9]. They are expected to guide political decision-making based on their capability to help determine how successful strategies and policies enforced have been in the attainment of sustainability goals [10]. Even though different practices use different indicators according to their particular needs, it is common that the key intellectual challenge is a fuller understanding of the complexity of urban systems and their environment [3], so that a system perspective is needed for establishing urban ecosystem development indicators.

When rescanning the urban ecosystem, the performance of a vital organism can be tracked from many aspects including structure, function, and evolution [11]. Therefore, urban vitality index is developed in this paper based on the acknowledgement of urban vital organism to comprehensively represent the urban ecosystem development status. Considering the human preference and uncertainty of urban ecosystem development, set pair analysis, a method suitable for relative comparison, is also combined with urban vitality index to objectively measure the urban ecosystem development status. Based on the indicators and method, the change of urban ecosystem development levels for Beijing city during 1986—2005 is analyzed to point out the focus of urban ecological planning and management in the future.

2. Methodology

2.1. Conception model of urban vitality index

As a huge complex system, urban ecosystem is composed of economic, social and natural subsystems [12] that interrelate and interact with each other, while the human dominance plays significant rule on the system's development orientation and value estimation. This characteristic of urban ecosystem reminds us of constructing the urban vitality index in an overall way to denote the urban ecosystem development status.

For a holistic organism, its comprehensive status is determined by each component and the relationship amongst them, which can be understood in the systems science viewpoint. Correspondingly, the urban vitality index should integrate the situations of each subsystems and the coordination status amongst the subsystems under human management and regulation, when regarding the urban ecosystem as a well-organized organism. Therefore, based on dividing urban ecosystem into economic, social, natural subsystem and the comprehensive ecological regulatory one which intends to emphasize the roles played by human interference, the conception model of urban vitality index can be described as a tetrahedron (see Fig. 1), in which the three profiles include producing power, living status and ecological ascendancy, representing the development states of economic, social, and natural subsystem respectively, while the basis named vital force denotes the development state of ecological regulatory subsystem, i.e., the coordination ability amongst above three subsystems. For this urban vitality index tetrahedron, each side is essential among which the producing power and living status linking close with human living and social production can be easily understood and noticed, while the ecological ascendancy depends much on the natural condition and reflects the eco-environment quality, and vital force expressing the overall harmony within the urban ecosystem is basic but usually invisible.

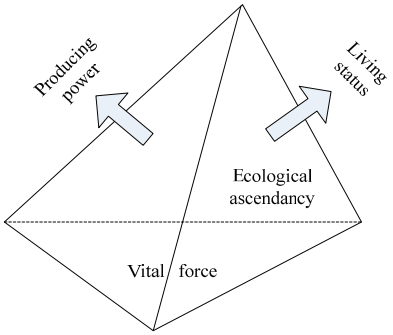

Fig. 1. Conception model of urban vitality index (After [13])

2.2. Indicator selection of urban vitality index

After establishing the concrete indicators that can describe the status of each aspect based on the conception model, the urban vitality index can be actualized. When it comes to indicator selection, there are such common principles as systematic, independence, practicability, and dynamics [14]. Regarding the characteristics of urban ecosystem at scales of structure and function as well as the object of describing the urban ecosystem development level, the key points of indicator selection for urban vitality index is restricted from three aspects (see Fig. 2), i.e., containing the urban ecosystem's maintenance and development itself based on the environmental condition and its providing services for human beings, regarding the internal organizational structure of the urban ecosystem and the external system function, and concerning the status quo and also the development potential in the future.

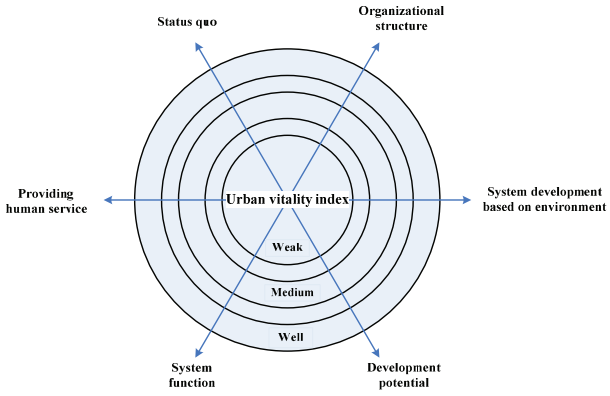

Fig. 2. Conception model of urban vitality index

According to the above principles, the urban vitality index is finally constructed in a hierarchy framework (see Table 1), by taking indicators of eco-city, health urban ecosystem and urban sustainability [2,9,14,15] as references and conducting relevance analysis for different indicators visa SPSS software.

Table 1. The indicator constitution of urban vitality index

Index name	Inclusive aspects	Embodied factors	Describing Indicators	Weight
Urban vitality index	Productivity power	Economic development level	Per capita GDP	0.1305
			GDP growth rate	0.0228
		Economic structure	Proportion of information industry to GDP	0.0106
			Growth rate of the secondary industry	0.0434
		Economic competitive power	Proportion of foreign investment to GDP	0.0297
			Proportion of gross export to GDP	0.0155
	Living status	Social justice	Registered urban unemployment rate	0.0515
			Difference between Per capita incomes of rural and urban resident	0.0100
		Scientific and educational level	Authorized rate of application patent	0.0063
			Popularization rate of junior and middle school education	0.0031
			Number of college students per 10000 persons	0.0264
			Number of public library collections per 10000 persons	0.0085
		Population health	Human birth rate	0.0236
			Number of hospital beds to per 10000 persons	0.0030
		Living quality	Annual average wage per employee	0.1583
			Per capita housing area of urban residents	0.0193
			Angel's coefficient	0.0087
			Number of public bus per 10000 persons	0.0156
	Ecological ascendancy	Resources utilization	Per capita domestic water quantity	0.0060
			Per capita area of paved road	0.0316
			Per capita public green area	0.0174
			Repeated utilization rate of industrial water	0.0010
		Environmental quality and eco-security	Excellent and good rate of air quality	0.0483
			Reach-to-the-stand rate of industrial wastewater discharge	0.0331
			Treatment rate of urban domestic water	0.1493
			Comprehensive utilization rate of industrial solid waste	0.0046
	Vital force	Management and regulatory power	Popularization rate of environmental education in junior and middle school	0.0167
		System coordination	Material consumption per capita GDP	0.0787
			Energy consumption per unit GDP	0.0266

2.3. Relative urban ecosystem development level assessment model based on urban vitality index

As indicated in Fig. 2, the urban ecosystem development levels represented by urban vitality index have different grades, that was simply shown from weak to medium and then to well. Usually, the gradation for urban ecosystem assessment is realized through setting certain criteria points or ranges of different grades in advance and checking the membership situations of the assessment results. Taking the uncertainty existing in urban ecosystem research caused by the system's openness, complexity and human dominance into account, it is very difficult to set up a scientific and reasonable gradation criteria of urban ecosystem development level. Therefore, set pair analysis, an uncertainty method suitable for relative comparison, is combined with urban vitality index to objectively analyze the

change of relative urban ecosystem development levels during study period rather than directly confirming the grades based on the subjective setting criteria.

As for the concrete calculation process of set pair analysis, it can be found in the reference by Su et al. [16]. When this method is combined with urban vitality index to measure the change of urban ecosystem development levels, the assessed interval set is composed of the urban ecosystem development levels of assessing city in each year during the study period, while the indicators set is composed of that of the urban vitality index. After calculating the relative approximate degree between each assessed interval set and the generated optimal evaluation set, usually marked as r_k (k means the kth assessed interval set), the relative development levels of assessing urban ecosystem in each year based on urban vitality index can be acquired, through which the change of urban ecosystem development levels can be revealed.

3. Results

3.1. Change of urban ecosystem development levels at scale of the whole system

After collecting the data of indicators of urban vitality index for Beijing city during 1986—2005, the weight of each indicator as shown in the last column of Table 1 can be calculated based on the information entropy method. According to the value of each indicator and their weights, the assessment results of the relative development levels in view of the urban vitality index for Beijing city during 1986—2005 can be obtained as indicated in Fig. 3, with a roughly continuous rising but two fluctuations in 1988 and 1992.

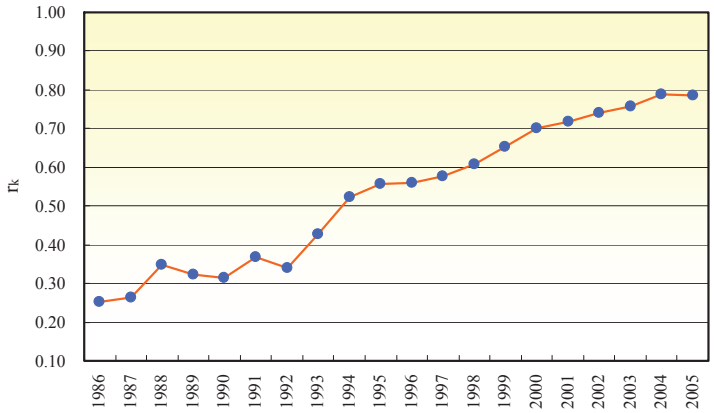

Fig. 3. Relative ecosystem development levels of Beijing during 1986—2005 based on urban vitality index

What advances the continuous rising of urban ecosystem development levels and what is the cause of those fluctuations? Figure 3 only shows the change of development levels of Beijing during 1986—2005 at scale of the whole urban ecosystem, based on the urban vitality index and set pair analysis method. If set pair analysis is conducted for the four aspects of urban vitality index, it may be helpful to further understand the trend of urban ecosystem development on more concrete layers and analyze the underlying reasons of the above-mentioned continuous rising and several fluctuations. Anyway, it is satisfied to see that the development level of Beijing city is heightening since 1992, which gives local urban managers much confidence to further improve the comprehensive development level of the urban ecosystem.

3.2. Change of urban ecosystem development levels at scale of the subsystem

By applying set pair analysis on the four aspects of urban vitality index, the change of relative urban ecosystem development levels during 1986—2005 at scale of the corresponding four subsystems can be obtained as presented in Fig. 4.

With regard to producing power that representing the development status of economic subsystem, the basic change trend during 1986—2005 is rising with couple of relative obvious fluctuations happened in 1988, 1990, 1994 and 2003. As for living status that expressing the development status of social subsystem, it shows a continuous improving trend during 1986—2005 only with a few slight vibration. In terms of ecological ascendancy denoting the development status of natural subsystem, the general change during 1986—2005 is rising with a relative obvious fluctuation happened during 1992—1993. With respect to vital force meaning the development status of ecological regulatory subsystem, it also indicates a basically rising trend during 1986—2005 with a relative obvious fluctuation in 1988.

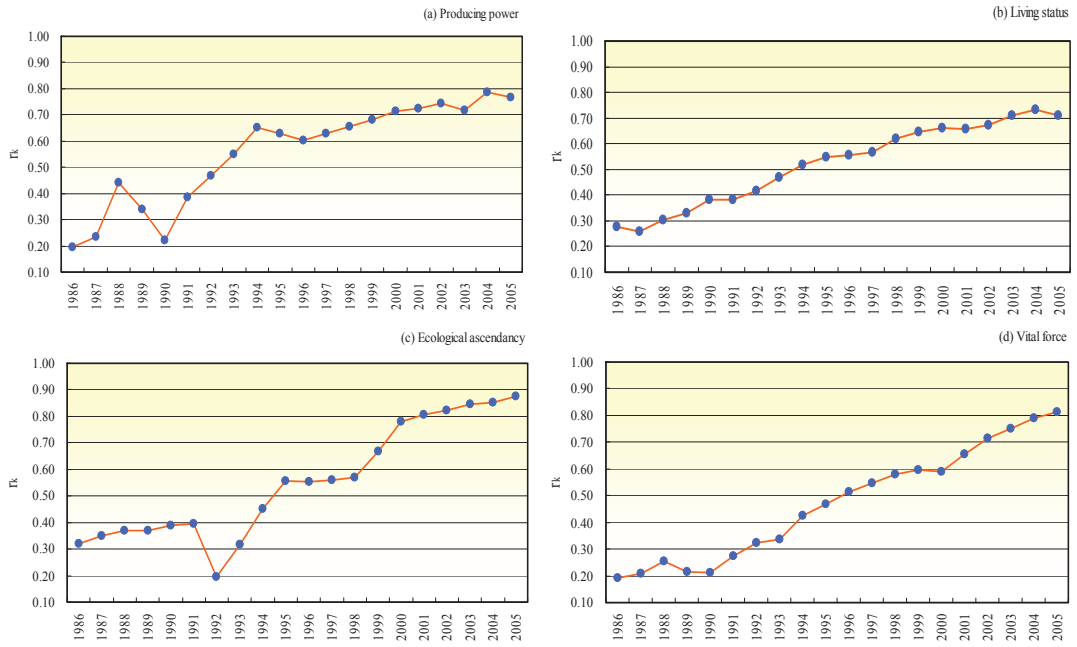

Fig. 4. Relative development levels of Beijing during 1986—2005 based on each aspect of urban vitality index

Comparing the assessment results of development levels at scales of the whole urban ecosystem and the subsystem, it is concluded that the basic change trend of urban ecosystem development levels is coherent, i.e., the roughly heightening of each subsystem's development promotes the continuous rising of the whole urban ecosystem's development. And the fluctuations of economic and ecological regulatory subsystems in 1988 may contribute to the fluctuation of the whole urban ecosystem in that year, while the fluctuation of natural subsystem in

1992 may contribute to the fluctuation of the whole ecosystem in the same year. Considering these impacts of each subsystem on the whole system, the status of natural subsystem represented by ecological ascendancy is important for the whole system, which implies the vital role of the natural foundation for the urban ecosystem, and that the effective resource utilization, sustaining improvement of environmental quality and eco-security should be paid attention in a long run.

4. Discussion and conclusion

In order to represent the comprehensive development status of urban ecosystem, the characteristics of urban ecosystem should be considered in a holistic way. Since the performance of urban ecosystem is similar with a vital organism in terms of structure, function, performance and evolution, the urban vitality index is established to describe the overall development status of the urban ecosystem, by integrating producing power, living status, ecological ascendancy and vital force that represents the development status of the economic subsystem, social subsystem, natural subsystem and ecological regulatory subsystem respectively. Based on this framework of urban vitality index, the concrete indicators that can link the ecological theory with actual management together is selected according to certain principles, such as integrating the urban ecosystem's development and its providing human services, containing the internal structure and external function, and concerning the status quo and the dynamic development. It is undoubtedly that the indicator has direct influence on the final assessment results of urban ecosystem development levels. Even though the indicator selection principles has been considered and the relevance analysis has been done by related software, it is still a deserved research to establish a better indicators paradigm to scientifically represent the characteristics of the complex urban ecosystem, through which to implement urban ecological management and regulation.

When it comes to the assessment for urban ecosystem, there is a tough problem that there is not a scientific and objective criteria, which is caused by the complexity, openness, strong human dominance of urban ecosystem. Therefore, a suitable method for relative comparison named set pair analysis is combined with urban vitality index to analyze the change trend of urban ecosystem development levels during study period. Not setting the assessment criteria subjectively, set pair analysis can realize the objective comparison of the urban ecosystem development levels in different years by calculating the relative distance between the situation in study year and the generated optimal evaluation set. Set pair analysis is needed developed further to be applied into urban ecological assessment and management more extensively and deeply, wish to measure the characteristics of urban ecosystem from more concrete practicable layers.

In this paper, the change of urban ecosystem development levels for Beijing city from 1986 to 2005 is studied at scales of the whole ecosystem and four subsystems including economic, social, natural and ecological regulatory subsystems. The basic change trend of urban ecosystem, development levels can be sketched by the relative assessment model based on urban vitality index, based on which the urban management can be orientated. In order to put forward effective and practicable planning scheme and management measure to optimize the urban ecosystem, the relationship between the development status and the important macro regulative policy should be analyzed deeply from aspects of economic reformation, industrial adjustment, environmental legislation and enforcement, ecological conservation and construction.

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