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Ecological Risk Assessment and Ecological Security Pattern Optimization in Binzhou City

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In this research, we created an assessment model based on ecological footprint and ecological carrying capacity (EC) to detect the trend of urbanization in Binzhou city. In this model, we utilized four new indicators based on EF and EC by adding economic and social dimensions and categorized six types of ecological footprints into three main kinds of ecological footprints. The results indicated that (a) the EF and the EC have had enormous increment and decrement respectively; (b) ecological tension and ecological occupancy presented an obvious increasing trend while the ecological security was continuously decreasing in this period, and Binzhou city was in an unsafe level. We suggest that (a) a diversified and optimized energy structure and an energy-saving urban regulation should be accomplished in the future urban ecological security pattern optimiation both in time and spacial scale; (b) fisheries productive land should be protected in the future, especially coastal protection and offshore fishing should be prioritized.

1. Introduction

Although missing the Industrial Revolutions and suffering a long period of being predominantly agrarian, China still achieved a significant advancement in urbanization and an unprecedented growth rate in urban population after the economic reforms in 1978, to which resource-based cities (RBC) made enormous contributions (Ma et al., 2008; Zhang et al., 2014; Wu, 2014). In China, most of RBC are the result of resource-based industrialization processes and were built on mining areas, leading to heterogeneous composition and distribution of urban areas which were lacking of proper urban planning guidance (Duque et al., 2015; Fernández and Simonetti, 2013; Dirutigliano et al., 2017; Fichera et al., 2016). The unique urbanization processes in RBC resulted in severe fragmentation of habitats and environmental exacerbation and generated negative impacts to human well-being (Costanza, 2008). A large number of sustainable urban planning approaches, covering environmental, social, and economic dimensions, have been developed recently. However, most published approaches just utilized different weighting methods to evaluate three dimensions, not interpret the linkages and relationship among them (Fisher et al., 2009; Bastian et al., 2012). Meanwhile, due to over-relying on resource-based industry, the economic-social-natural urban system in RBC is quite different from that in other cities (Breuste and Qureshi, 2011; Ernstson and Sörlin, 2013; Kocaslan, 2017; Zhang, 2018; Zhou, 2014). Therefore, it is urgent to develop a place-based, problem-driven, and comprehensive sustainable urban planning approach that both explicitly considers all three pillars of sustainability and expound how they link with each other so that an improvement in human well-being can be achieved (Ramalho and Hobbs, 2012). Ecological footprint was first put forward by Canadian ecological economist William Rees in 1992 and was optimized by doctoral student Wackernagel in 1996. Since then ecological footprint has been utilized and developed in different fields: it measures human consumption (Ecological Footprint) and the biosphere's provision (Ecological Carrying Capacity) of ecosystem goods and services based on the area of bio-productive land and sea (Zhang et al., 2017); it is an efficient tool for assessing environmental sustainability on multiple scales and measuring planetary boundaries and the extent to which humanity is exceeding them; it can be used to detect the limits of resource consumption and the international distribution of the world's natural resources (Xie and Zhang, 2018). Various researches and

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practices deepened our understanding of ecological footprint and broadened the application of it. However, ecological footprint analysis, simply comparing the human demand for and the supply of natural resource, is not insufficient for guiding the urban planning. Additional efforts, enhancements in modeling, and improvements in application about ecological footprint are required (Zhang and Lu, 2014; Eigenbrod et al., 2010).

2. Materials and methods

In this research, an assessment model based on EF and EC was used to detect the trend of urbanization in Binzhou city. It differentiates from other regulation approaches in two ways. First, the process not only combines EF and EC perspectives, but also creates four new indicators which could enrich EF and EC with economic and social dimensions. Second, the process categorized six types of ecological footprints into three main kinds of ecological footprints: biology, energy, and service footprints, which provides us a comprehensive perspective to decompose the urban system and enable us to locate the existed problems. Since Chinese resource-based cities are over-relied on industrialization and are facing much more severe social-economy-environmental problems, this assessment model would be much more suitable for supporting the ecological regulation in RBC (Boone et al., 2012).

2.1 Study area

Binzhou City is in the northern part of China and in the central part of Bohai Economic Rim (BER). It located at 36°41'-38°16'N and 117°15'-118°37'E in the temperate climatic zone with a mean annual temperature of 14.1°C. The total area of and the total population of Binzhou city is 9453 km2 and 3.8 million respectively. Binzhou city has abundant and various resources, an advanced transportation system, and a rapid trend of industrialization. With its natural advantages, Binzhou achieved a rapid growth in economy, especially after 1990s, which made enormous contribution to the economic development of Shandong province and China. However, due to the requirement of regional development in BER, Binzhou city needs to provide resources, especially oil, to the residents in city, as well as to the residents in other cities in BER. In this case Binzhou city is suffering much more pressure than its ecological capacity. Besides, the RBC urban planning usually prioritizes economic development ignoring the importance of environment, which results in severe environmental problems and an unsustainable urban mechanism, both within the city and in the whole region. Therefore, it is urgent to assess the current ecological risk and develop a synthetic ecological security optimization approach for achieving sustainable development in city and regional scale.

2.2 Data and approach

According to the 2011 Edition of the National Footprint Accounts (NFA) and the previous editions, six indicators were selected in this research (Table 1): ecological footprint (EF), ecological carrying capacity (EC), ecological tension (ET), ecological occupancy (EO), ecological-economic-social coordination (EESC) and ecological security (ES). The Ecological Footprint is usually measured in six demand categories, while Ecological Carrying Capacity is represented in five distinct land use types (Table 1). This discrepancy is caused by the competition between timber and energy products, for the same Ecological Carrying Capacity category: forest land. For standardization and comparability across land use types, Ecological Footprint and Ecological Carrying Capacity are usually expressed as global hectares (gha) or global hectares per capita (ghp), and two important types of coefficients, the yield factors and the equivalence factors, are adopted. All the calculation methods and details for the selected indicators are showed in Table 1.
Most of the economic and social data of Binzhou city stem from the standard yearbooks, which are compiled by the central government and subordinate ministries. As ecological carrying capacity is represented by a compatible and detailed land-use classification, we utilized the Landsat-7 remote sensing data (30m*30m) of Binzhou to assess the land-use change from 1990 to 2010 (Vanderhaegen et al., 2015; Kroll et al., 2012; Grêt-Regamey et al., 2013).

3. Results

3.1 Ecological footprint and ecological carrying capacity.

All components of EF and EC per capita from 1990 to 2010 were calculated based on formula (1), (2), and (3), and the final results were showed in Figure 1 and Figure 2. The results indicated that the EF per capita and the EC per capita have had enormous increment and decrement respectively, both in total and in each component. EF started exceeding EC and human entered in an overshoot situation in the early 1990s, and the ecological deficit was increasing at a rapid speed since then. The rapid EF growth was mainly caused by the continuous increasing carbon footprint, with a 0.693 ghp increment and a 57.5% growth rate. Fishing ground footprint had the most significant increment, with a 0.132 ghp increment and a 198.6% growth rate. Meanwhile, cropland, grazing, forest, and built-up land footprint also expanded explicitly, with 30.9%, 65.5%,

Table1: Overview and Quantification of the selected six indicators

Indicators	Quantification models		Variable description
Ecological Footprint (EF) (1)Biological footprint *(crop, timber, livestock, fish)* (2)Energy footprint *(coal, gas, oil)* (3)Service footprint *(built-up land)*	$EF = EF_P + EF_I - EF_E$ $EF_P = N \cdot ef = N \cdot \sum_{i=1}^{n} [EQF_i \cdot (P_i/Y_i)]$	(1) (2)	EF is the total ecological footprint; EF_P is the Ecological Footprint of production and EF_I and EF_E are the Footprints embodied in imported and exported commodity flows, respectively; ef is regional ecological footprint per capita;; N is the total population; EQF_i is the equivalence factor for the land use type producing products i; P_i is the amount of each primary product i that is harvested (or carbon dioxide emitted); Y_i the average world yield for commodity i.
Ecological Carrying Capacity (EC) *(cropland, forest, grazing land, water, and built-up land area)*	$EC = \sum_{j=1}^{n} (EQF_j \cdot B_j) = \sum_{j=1}^{n} (EQF_j \cdot YF_j \cdot M_j)$	(3)	EC is the total ecological carrying capacity; EQF_j is the equivalence factor for the land use type producing products j; YF_j is the city-specific yield factor for the land producing products j; M_j is the bio-productive area that is available for the production of each product j in Tangshan city.
Ecological Tension (ET)	$ET = EF_R / EC$	(4)	EF_R is regional ecological footprint of renewable resources, means the total of crop, grazing, forest and fishing ecological footprint; EC is regional ecological carrying capacity; ET reflects regional ecological security.
Ecological Occupancy (EO)	$EO = ef / \overline{ef}$	(5)	ef is ecological footprint per capita; $\overline{ef}$ is world ecological footprint per capita; EO reflects economic development degree.
Ecological Economic Coordination (EEC)	$EEC = EO / ET$	(6)	EO is ecological occupancy; ET is ecological tension; EEC reflects coordination between economic development and ecological environment
Ecological Sustainability (ES)	$ES = \left(\frac{ET_{MAX} - ET}{ET_{MAX} - ET_{MIN}}\right) + \left(\frac{EO - EO_{MIN}}{EO_{MAX} - EO_{MIN}}\right) + \left(\frac{EEC - EEC_{MIN}}{EEC_{MAX} - EEC_{MIN}}\right)$	(7)	ET_{MAX} and ET_{MIN} is the maximum and minimum value of global ecological tension, EO_{MAX}, EO_{MIN} is the maximum and minimum value of global ecological occupancy, EEC_{MAX}, EEC_{MIN} is the maximum and minimum value of global ecological economic coordination.

50.0%, and 82.7% growth rate respectively. As to the decline of EC, the shrinkage of forest carrying capacity was the main factor, with a 0.278 ghp decrement and a 23.6% decreasing rate. Similar with fishing ground footprint, fishing ground carrying capacity has the most significant reduction, with a 0.171 ghp decrement and a 66.5% decreasing rate. Cropland, grazing, and built-up land carrying capacity had decreased 31.6%, 24.4%, 45.2% respectively (Kroll et al., 2012;).

3.2 Ecological tension, ecological occupancy, ecological-economic coordination, and ecological security.

The results of ecological tension, ecological occupancy, ecological-economic coordination, and ecological security calculation using formula (4), (5), (6), and (7) were showed in Table 2. The results demonstrated that ecological tension and ecological occupancy presented a constant increasing trend, with a 131.2% growth rate and a 208.3% growth rate respectively, while the ecological security was continuously decreasing in this period, with a 32.0% decreasing rate. Ecological-economic coordination kept declining during 1990 to 2005 and had subtle increment since 2005 (Grêt-Regamey et al., 2013).

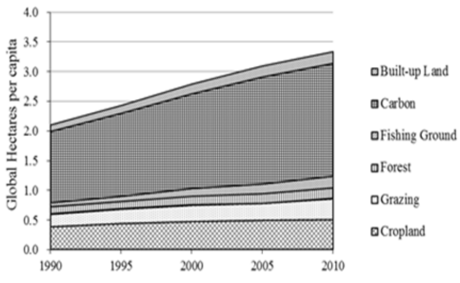

Figure 1: Binzhou city's ecological footprint per capita, by component, 1990 to 2010

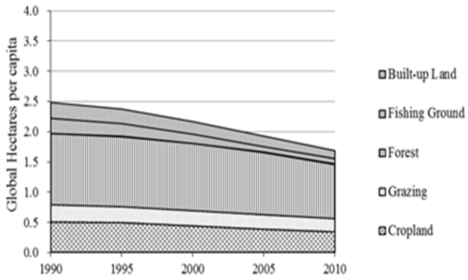

Figure 2: Binzhou city's ecological carrying capacity per capita, by component, 1990 to 2010

Table 2: Ecological tension, ecological occupancy, ecological-economic coordination, and ecological security of Binzhou city from 1990 to 2010

Year	EF	ECC	ET	EO	EEC	ES
1990	2.102	2.489	0.316	0.893	0.354	1.033
1995	2.427	2.382	0.375	1.256	0.299	0.965
2000	2.784	2.174	0.471	1.780	0.265	0.817
2005	3.096	1.934	0.573	2.330	0.246	0.708
2010	3.336	1.692	0.731	2.753	0.265	0.702

3.3 The grading system of ecological tension, ecological occupancy, ecological-economic coordination, and ecological security.

Based on the ecological footprint and ecological carrying capacity data of 147 countries in the world provided by Global Footprint Network from 1990 to 2010 and formula (4), (5), (6), and (7), we calculated the ET, EO, EEC, and ES of all of the 147 countries in the world and put forward a comprehensive grading system by categorizing all of the data from 147 countries (Table 3). In this case Binzhou city could be placed into the corresponding grade. The grading results indicated that Binzhou city's ET was in grade 5 during 1990 to 2000, meaning the ecological security was at a very safe status in this period, while its ET was in grade 4 after that, meaning city's ecological security was suffering much more threats than before. The EO was in grade 2 in 1990, and was in grade 3 during 1995 to 2000, and turned into grade 3 since 2005. Binzhou city's EEC had always been in grade 1, meaning that the urban system was not balanced between economy and environment. The city's ES was in grade 3 and turned into grade 2 during 1995 to 2010, meaning a decline in ecological security.

Table 3: Worldwide grading system of ET, EO, EEC, and ES

Grade	1	2	3	4	5
ET	>2.00 Very unsafe	2.00~1.51 Unsafe	1.50~1.01 Relatively safe	1.00~0.50 Safe	<0.50 Very safe
EO	<0.50 Very poor	0.50~1.00 Poor	1.01~2.00 Relatively good	2.01~3.00 Good	>3.00 Very good
EEC	<1.00 Very poor	1.00~2.00 Poor	2.01~3.00 Relatively good	3.01~4.00 Good	>4.00 Very good
ER	<0.50 Very poor	0.50~1.00 Poor	1.01~1.50 Relatively good	1.51~2.00 Good	>2.00 Very good

4. Conclusions and Discussion

4.1 Ecological footprint and ecological carrying capacity.

Given the enormous increment and decrement in EF and EC respectively, Binzhou city is facing the most severe ecological deficit than ever. The significant increasing carbon footprint revealed highly demand for energy consumption in Binzhou city. It is caused by the specific urban structure, which mainly consists of resource-based industry. The other components of EF and EC also demonstrated the conflicts between human demand and natural provision (Pickett and Cadenasso, 2006; Zhao et al., 2014). In this case two suggestions are put forward below:

(1) Although the mechanism about how forest dedicated to long-term carbon uptake was not identified, there is no doubt that forest is the most valuable land that providing EC to neutralize the carbon footprint. However, the forest land EC still declined 50% during the research period. Thus, we suggest that a diversified energy consumption structure and an energy-saving urban system should be accomplished in the future urban regulation, and the decision maker should prioritize the forest protection.
(2) The decline in fishing ground EC was mainly caused by the rapid industrialization in coastal area. During the past 20 years, a huge number of factories had moved to the coastal area of Binzhou city from Beijing and Tianjin, which was intended to reduce the burden of these two cities and to achieve a sustainable development in BER. However, the over-speed industrialization resulted in a significant degradation in coastal area and a 66.5% decrement in fishing ground EC.

4.2 Ecological tension, ecological occupancy, ecological-economic coordination, and ecological security.

Higher ecological tension means lower ecological security (Gómez-Baggethun and Barton, 2013). Therefore, the increment of ET in Binzhou city from 1990 to 2010 indicated that the former urban development mechanism has threatened the ecological security. Although the current ecological security status is still safe, it is close to grade 3 and represents a continuous increasing trend in the future. Ecological occupancy denotes the degree of urban development, especially in economy. Binzhou city has achieved a constant increment in EO, and consequently has earned a higher degree of urban economic development. As to ecological-economic coordination, higher score means better coordination between ecology and economy. Binzhou city's EEC has been stayed in grade 1 during this period, illustrating an uncoordinated ecological-economical urban system. ES is the most comprehensive indicator for it combined ET, EO, and EEC together. Also, higher ES reflects higher sustainability in city's ecological dimension (Zhang et al., 2015).

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