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Short communication

Assessment of coastal zone sustainable development: A case study of Yantai, China

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ABSTRACT

The assessment of sustainable development is a challenging task as its measuring is rather complex without a mature framework. In this paper, as a case study, a coastal city of China-Yantai was assessed for sustainable development in the period from 1998 to 2007. We used a methodological framework based on 36 indicators and three composite indices from the dimensions of environment, economy and society subsystems. The assessment results indicated that Yantai was almost in the potentially unsustainable development or intermediate sustainable development, except in 1998 and in 2007. Accordingly, the progress of sustainable development was divided into two stages in the light of the relative changes of three subsystems. Some relevant issues, such as natural capital, GPI vs. GDP in sustainable development assessment were discussed. Finally, an uncertainty analysis was also given in the assessment. In conclusion, the sustainable development in Yantai had experienced a shift from environment-based to social–economic-based in the past 10 years.

1. Introduction

As a result of the rapid development of industrialization and urbanization, the coastal zone in China showed a rapid change during the past few decades. In particular, the issues about coastal ecology and environment had brought about a serious challenge for coastal zone sustainable development (CZSD) (Chen and Chen, 2002; Huang et al., 2008). Ecological sustainability has also been put forward due to the foreseeable threats represented by a serious worldwide environmental degradation, this gives rise to an increasing awareness of the profound impact of humans on the functioning of marine ecosystems (Marques et al., 2009).

According to the definition of sustainable development (Brundtland, 1987), the sustainable development of coastal zone not only meets the increasing demand, but also protects ecology and environment, without prejudice to future generations access to adequate food security. However, the concept of sustainable development is a rather vague nonoperational definition, researchers from different disciplines attempt to understand and define more precisely the meaning of sustainable development, which requires a suitable quantification in socio-economic, cultural and scientific terms (Marques et al., 2009). In order to provide a scientific basis for decision-makers, therefore, it is very necessary to comprehensively assess the status of regional development with regard to economy, resources and environment (UNDP, 2007). Although a lot of effort had been done by the Government and the non-governmental organizations (Alves et al., 2007; Nader et al., 2008; UNDP, 1990), the methodology of monitoring and evaluation was still in issues. Meanwhile, people had investigated the sustainable development from different perspectives, such as the separate indicators and composite index (Krajnc and Glavic, 2005; López-Ridaura et al., 2002; Shi et al., 2004; Singh et al., 2007, 2009; Xiong, 2007). But a versatile method was still an open question. A Pilot Program was established in 2003 under the auspice of intergovernmental Oceanographic Commission (IOC) of UNESCO to promote the development and use of ICOM indicators (IOC and Heileman, 2008), by developing, selecting, and applying indicators to measure, evaluate, and report on the progress and outcomes of integrated coastal and ocean management initiatives (DEDUCE, 2006, 2007). The EU ICZM Expert group in November 2004 also called for an integrated approach to monitor and measure the sustainable development of the coastal zone (Breton et al., 2006). DEDUCE (Développement Durable des Zones Côtières Européennes), supported by the Interreg III-south Community Initiative Programme, gave a core set of

Abbreviations: CZSD, coastal zone sustainable development; ENS, environmental subsystem; SO, Ssocial subsystem; ECS, economic subsystem; DCZ, integrated coordinate degree; SCZ, developmental sustainability; KSD, sustainable development degree; GDP, gross domestic production; GPI, genuine progress indicator.

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27 indicators, composed of 46 measurements, to monitor sustainable development of the coastal zone by means of environmental, social and economic indicators for measuring the degree of sustainable development of the European coastal zones (Breton et al., 2006; DEDUCE, 2006). In Europe, besides, Belgium had pioneered in implementing a set of 20 indicators for the coast through developing an interactive website, a publication 'the coastal compasses, a SWOT-analyses and evaluation of the indicators, etc. (Hannelorel et al., 2007)'.

Although there have been proposed many principles and theoretical frameworks about sustainable development assessment, cases studies are still scarce. This paper is such an interesting study that a detailed analysis of sustainable development of a coastal city of China will be presented. The methodology was introduced to assess the coastal sustainable development progress, which designed a framework of 36 indicators represent environmental subsystem (ENS), social subsystem (SOS) and economic subsystem (ECS). As an example, the method was extended to analyze the regional development of Yantai as a case for one decade (1998–2007) by examining economic performance and considering various eco-environmental factors.

2. Materials and methods

2.1. Study area

Yantai is a coastal city, which is located in the middle part of Jiaodong peninsula, the largest peninsula in China (see Fig. 1 for more details). The coastline is 909 km (702.5 km mainland coastline and 206.5 km island coastline) and the coastal zone in Yantai amounts to 2100 km^2. Since the implementation of the reform and opening up policy, Yantai is one of the most rapid developed areas in China.

2.2. Data and methods

2.2.1. Data sources

Data collection is an important work before operating an assessment. The good indicators should be easy to be understood, sensitive to changes and relevant among themselves (OECD, 2008; UNDP, 2007). Especially, they will be evaluated to be scientifically sound and statistically valid, capable of providing quantitative information. According the designed index system (Appendix A), the data collected was ranging from socio-economic (population, ports, GDP, etc.) to environmental data (arable land, SO_2 emissions, forest cover, etc.). That is, the data of population, social and economic mainly came from local public statistical administration, while the environmental data came from local environment, forest, sea bureaus administrations. In total, the number of final dataset was consisted of more than 400 including information of eco-society and resource environment in the period of 1998–2007.

2.2.2. Index system and models

The index system framework can be seen from Appendix A, which consisted of 36 indicators (I_1–I_{36}). I_j is the variable from the raw data normalized with max–min method (Salvati and Zitti, 2009; UNDP, 2007). Among them, six indicators were grouped into a set called thematic index (B_1, B_2, B_3, B_4, B_5 and B_6). B_1, B_2 and B_3 were designed to represent the coordination degree of three subsystems, while B_4, B_5, and B_6 represented the sustainability of three subsystems. And three models that represent integrated coordinate degree (D_{CZ}), developmental sustainability (S_{CZ}), and sustainable development degree (K_{SD}) were also given (Niu, 1999; Xiong, 2007). D_{CZ} measures the development level and coordination degree of ENS, SOS, and ECS, S_{CZ} measures the size of sustainability of three subsystems, and K_{SD} comprehensively measures the development

Fig. 1. Map of Yantai, China, Its administrative area includes five districts (Zhifu, Fushan, Laishan, Muping and Economic Development Zone), seven county-city (Laizhou, Zhaoyuan, Longkou, Penglai, Laiyang, Haiyang, and Qixia), and one island county (Changdao).

level, ability and state of CZSD.

$$D_{CZ} = \sqrt{\sum_{i=1}^{3} (W_i B_i)^2} \quad i = 1, 2, 3 \tag{1}$$

$$S_{CZ} = \sum_{i=1}^{3} W_i B_i \quad i = 4, 5, 6 \tag{2}$$

$$B_i = \sum_{j=6i-5}^{6i} (\omega_j I_j) \quad i = 1, 2 \ldots, 6, \ \ j = 1, 2, \ldots, 36 \tag{3}$$

$$K_{SD} = \sqrt{D_{CZ}.S_{CZ}} \tag{4}$$

where D_{CZ} is the index of integrated coordination degree of CZSD, $0 < D_{CZ} < 1$. B_1, B_2 and B_3 represent the capacity level of ENS, ECS and SOS, respectively, and B_4, B_5 and B_6 represent the sustainability level of ENS, ECS and SOS, respectively. W_i is the weight of criteria layer corresponding B_i, $\sum_{i=1}^{3} W_i = 1$ and $\sum_{i=4}^{6} W_i = 1$; ω_j is the weight of indicator layer I_j, $\sum_{j=6i-5}^{6i} \omega_i = 1$, I_j is the indicator treated through normalization of raw data of individual indicator, $0 < I_j < 1$; S_{CZ} is the index of sustainability of CZSD, $0 < S_{CZ} < 1$. K_{SD} is an index of CZSD which is the geometric mean of D_{CZ} and S_{CZ}, $0 < K_{SD} < 1$.

2.2.3. Weight-determining

A combination of subjective and objective methods was employed to determine the weight of index system using Analytic Hierarchy Process (AHP) (Saaty, 1980) and Principal Component Analysis (PCA) methods in this paper (Blancas et al., 2009; OECD, 2008).

(1) ω_j: Calculation of the weight in indicator layer was based on PCA. Due to the different indicators included in each thematic indicator of criteria layer (Alves et al., 2007; Salvati and Zitti, 2009), each set was then calculated by PCA to determine its indicators' weight. Weights were expressed in percentages and range between 0 and 1. The weight calculations were performed in SPSS 13 software running on the Windows platform. We normalized the value of eigenvector of first component, which meant computing the sum of normalized weights and then divided each weight by the sum, then took this value as indicator's weight. The eigenvector of first component in each thematic was chosen because its contribution rate of the total variance is at least more than 50%.

(2) W_i: application of PCA was not sufficient because the principal components are linear combinations of the original variables. There was a drawback that hinders the comparative analysis (Blancas et al., 2009). This problem was solved by the application of AHP method. AHP was a suitable approach for undertaking quantitative as well as qualitative analysis which can assist with identifying and weighting selection criteria to analyze the data collected for the criteria layer.

3. Results

After the raw statistica data treated by the max–min method, the weight ω_j were calculated by PCA method in each set composed of six indicators. Then, the index value of thematic index (B_i) can be got by Eq. (3). Finally, the composite index of D_{CZ}, S_{CZ} and K_{SD} were computed through Eq. (1), Eq. (2) and Eq. (4), respectively. All the index value were summarized and shown as following (Table 1).

3.1. The status of CZSD

In order to vividly demonstrate the status of CZSD, an improved 'barometer of sustainability' was used. Fig. 3 shows the status of CZSD in Yantai. As a comprehensive sustainability indicators, the Barometer of Sustainability (Hannelorel et al., 2007; Prescott-Allen, 1995; Prescott-Allen and IUCN, 1997)is a tool for measuring and communicating social welfare and progress towards sustainable development. The meaning of CZSD includes two aspects: sustainability and coordination of environmental–economical–social subsystems. According to Eq. (4), K_{SD} was computed through the two indexes of S_{CZ} and D_{CZ}. Both coordination and sustainability are equally important, and neither can be neglected. It indicates that S_{CZ} and D_{CZ} were equally important from the starting point of the barometer. The judgment of CZSD was based on the axes with the lower score (the worse performance). This can avoid trade-offs between D_{CZ} and S_{CZ}, e.g. in 2007, we can see that the values of D_{CZ} and S_{CZ} in 2007 are 0.46 and 0.80, respectively. Namely, S_{CZ} had arrived at an excellent state while the D_{CZ} was just in a medium state. Obviously, the K_{SD} was determined simultaneously by them, and then located in good state (see Fig. 2) In addition, we can see that the state of D_{CZ} in 2004 was smaller than that in 2003 when the regression development happened. Summarily, directly judged by the barometer of sustainability, the development degree of coastal zone in Yantai during the ten years was almost in the potentially unsustainable development or intermediate sustainable development, except in 1998 and in 2007.

Table 1
Values of indices calculated in Yantai coastal zone.

Year	B_1	B_2	B_3	D_{CZ}	B_4	B_5	B_6	S_{CZ}	K_{SD}
1998	0.43	0.06	0.17	0.14	0.35	0.05	0.18	0.22	0.17
1999	0.45	0.04	0.34	0.18	0.45	0.04	0.37	0.32	0.24
2000	0.41	0.19	0.41	0.20	0.60	0.06	0.42	0.41	0.29
2001	0.55	0.23	0.44	0.24	0.40	0.12	0.55	0.38	0.30
2002	0.59	0.32	0.47	0.26	0.51	0.24	0.54	0.45	0.35
2003	0.57	0.49	0.50	0.30	0.54	0.39	0.68	0.55	0.40
2004	0.52	0.54	0.50	0.30	0.52	0.55	0.55	0.54	0.40
2005	0.43	0.71	0.62	0.36	0.68	0.71	0.64	0.67	0.49
2006	0.46	0.78	0.74	0.40	0.56	0.84	0.63	0.65	0.51
2007	0.54	0.89	0.83	0.46	0.76	0.95	0.74	0.80	0.61

The meaning of B_1, B_2, B_3, B_4, B_5 and B_6, see Fig. 4.

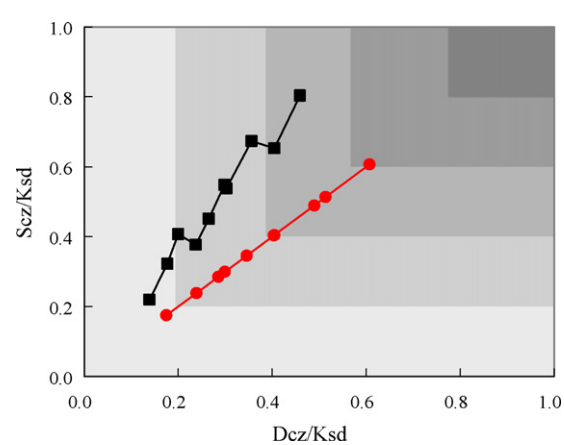

Fig. 2. The barometer of sustainability in Yantai. The two indices consist of a suite of indicators that are rated to give performance scores that are plotted as coordinates on a two-dimensional scale to yield a visual representation. Both indices are measured on a performance scale. The barometers scale is divided into five sectors given a fully controlled scale. The index range is also divided into five grades, displayed as −10%, −20%, −30%, −40% and −50% gray values, respectively. Every point on the curve indicate a year within study period, ■ represents the coordinate (S_{CZ}, D_{CZ}) and ● represents coordinates (K_{SD}, K_{SD}). K_{SD} will be much large only when S_{CZ} and D_{CZ} are both large simultaneously. And therefore we can determine the state of CZSD based on position where K_{SD} located in the barometer.

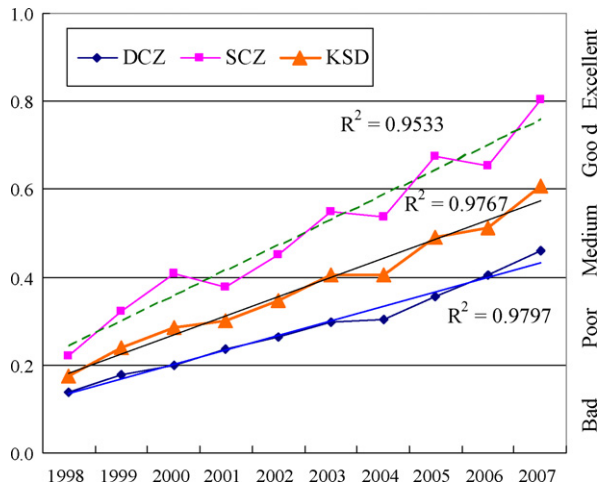

Fig. 3. The development trends of D_{CZ}, S_{CZ} and K_{SD}. The vertical coordinate denotes the value of the index, and the index value is in the range of 0–1. In order to reflect the status of each index, the index range is divided into five grades: bad (0, 0.2), unsustainable; poor (0.2, 0.4), potentially unsustainable; medium (0.4, 0.6), intermediate; good (0.6, 0.8), potentially sustainable; excellent (0.8, 1.0), sustainable.

3.2. Trend of D_{CZ}, S_{CZ} and K_{SD}

In Fig. 3, the curves of D_{CZ}, S_{CZ} and K_{SD} denoted for the variation trends of coordination, sustainability and sustainable development level of regional economic, social and the environment, respectively. From the perspective of coordination, it showed trends of continuously increasing, and only weak variations among the three subsystems can be found. From the perspective of sustainability, it appeared a continuous and steady growth for the three subsystems.

It was shown that D_{CZ}, S_{CZ} and K_{SD} were rapidly becoming better between 1998 and 2007 (Fig. 3). The index value of $D_{CZ,}$ S_{CZ} and K_{SD} were up from 0.14, 0.22 and 0.19, to 0.46, 0.80 and 0.59 in 1998–2007, respectively. Sustainability (S_{CZ}) was fast from weak sustainability to strong sustainability than the other two (D_{CZ} and K_{SD}), which were from unsustainable state (bad) into intermediate state (medium). The linear regression for $D_{CZ,}$ S_{CZ} and K_{SD} are as follows:

$$y = 0.0332x + 0.1012 \quad (5)$$

$$y = 0.0574x + 0.1836 \quad (6)$$

$$y = 0.0437x + 0.1360 \quad (7)$$

where x is the ith year evaluated. It took nine years, two years and five years for D_{CZ}, S_{CZ} and K_{SD} to arrive the medium sustainable development status (0.40–0.60) since 1998, respectively.

3.3. Progress analysis of sustainable development

Within the study area, we got the radar figures to observe the coordination and sustainability of three subsystems by processing the data (Table 1). Thus, we can understand the relationships of complex systems by radar figure. To sum up, the total situation of radar figure in 1998–2007 seemed from 'thin' to 'fat'. It followed two stages: in 1998–2003, the coordination level and the sustainability of ECS were lower than the two others when started from 1998, and so the whole radar looked 'thin'; in 2004–2007, the coordination level and the sustainability of ENS decreased slightly, those of society increased slowly, while the speed of ECS grows fast, and accordingly the whole of radar looked 'fat'.

3.3.1. First stage (1998–2003)

The three subsystems were very uncoordinated in 1998, and the level of sustainability was also very low. In particular, the coordination level and the sustainability of ENS were significantly higher than the level of ECS ($B_1 > B_3 > B_2$, $B_4 > B_6 > B_5$). ECS initially performance the weak level and ability of the sustainable development. The situation changed in 1999–2003, and the three subsystems capacities had been improved so that ECS was promoted by the other subsystems. The capacity and sustainability of ECS had made significant progress, which reached 0.49 and 0.68 in 2003 respectively. Hence, the ability of sustainable development of the coastal zone was further improved by natural capital and social capital. In contrast, those of ENS and SOS had increased slowly. Nevertheless, the development level of the economic subsystem was still in the "bottleneck". Although the capacity and sustainability level of three subsystems was from bad into poor, the sustainable development degree (K_{SD}) of Yantai is still in the state of potentially unsustainable development keeping unchanged (Fig. 2).

3.3.2. Second stage (2004–2007)

As a result of reduction critical natural capital (Ekins et al., 2003) of arable land resources and influence of industrial pollution, the carrying capacity of ENS showed a slow downward trend in the process of transformation.

3.3.2.1. Coordination (D_{CZ}). The capacity level of ENS in 2004 was slightly lower than 2003, while the sustainability of ENS also decreased slightly, or even lower. Likewise, the capacity level of SOS was gradually enhanced after keeping stable in 2004. And yet, the capacity level of ECS was greatly enhanced and arrived at a high stage after its value was more than the other systems in 2004. At last, its value reached 0.89 in 2007.

3.3.2.2. Sustainability (S_{CZ}). ENS slightly declined after 2003 and arrived at 0.76 in 2007. SOS increased with a small growth rate after the sudden drop in 2004, whose value was 0.74 in 2007. Still, ECS appeared a significant increase and got a high stage because its value was more than other two. By the end of the study period, ECS nearly got the highest value, 0.95 in 2007.

4. Discussion

In this paper, we presented a whole assessment process from three dimensions of environment, economy and society subsystems and chose a coastal city of China-Yantai as a case study. Regarded as one complex system including ENS, SOS, and ECS, the coastal zone can be measured by reference to multiple indicators. By monitoring and evaluation of the gap of the coastal zone, it can reflect the multi-objective of environment, economic and social harmonious development in coastal zone, and can also reflect the level and problems of regional sustainable development comprehensively.

The results showed that Yantai has experienced a highly development period, and D_{CZ}, S_{CZ} and K_{SD} all stayed with a rising "tunnels" during the past decade years. On one hand, from an improved 'barometer of sustainability', the results directly indicated that the level of coordination and sustainability of coastal zone within the study area continuously improved for 10 years. On the other hand, comparing with the two stages from radar figure, as an illustration of weak sustainability at the first stage, man-made and natural capital are substitutable (Pearce and Atkinson, 1993; Ekins et al., 2003; Wen et al., 2007). The economic growth attributed to the availability of natural resources for the production of consumption goods and the environment condition (Neumayer, 2003; Kulig et al., 2010), or sacrifice of social welfare. In contrast, at the second stage, the index value of each subsystem was relatively so

equal that radar figure looks "good" in 2004, when the capacity and sustainability value of ECS (B_2 and B_4) surpass the two others for the first time. It also indicated that Yantai experienced a period dependent on from environment-based to social–economic-based in the past 10 years. However, the capacities of three subsystems were radically changed in the process; the capacity level of environment subsystem perhaps gets the ecological criticality in 2002, which is the maximum in ten years. Later, it restored gradually after arriving at 0.43 at the lower level in 2005. Obviously, we can see that natural resources cannot be substituted by physical or human capital only as the essential inputs in economic production, consumption, or welfare (Wen et al., 2007). Therefore, it is essential that natural capital, human capital and their interactive relationship should be paid special attention for sustainable development assessment.

4.1. Sustainable development, critical natural capital and ecological resilience

CZSD is a complex multi-dimensional synthesis system, thus, the final goal of CZSD at the top-level should be sustainable, steady and healthy development of natural–economic–social complex system. In other words, it can be summed up into three interrelated and indivisible characteristics which are ecological sustainability, economic sustainability and social sustainability (Hediger, 2000; Ronchi et al., 2002; Spangenberg, 2004). Among them, the maintenance of critical natural capital (Turner, 1993) is an important objective of sustainable development. Critical natural capital in weak sustainability is not substitutable to human well-being with other types of capital, such as the food, raw materials or drinking water, which can provide the essential and life-securing ecosystem functions. Brand (2009) and Marques et al. (2009) thought critical natural capital is an important step in quest for sustainable development, which may help environmental policy and management to identify the natural capital that ought to be preserved in any circumstances for current and future generations.

In all of coastal natural capital, critical natural capital is important for the quality of life and the survival of humans as an important objective of sustainability. Importance and degree of threat are described as the two ecological aspects of critical natural capital. Human activities can bring changes of ecosystem types, the vulnerability of species richness or pressure on ecosystems, resulted in the ecological, socio-cultural or economic importance of critical natural capital; the degree of threat is assessed based on changes in quantity and quality of the remaining natural capital (Brand, 2009).

In order to estimate the degree of threat that specific ecosystems face, besides vulnerability, integrity and ecosystem health, etc., ecological resilience can help a great deal in specifying the 'ecological criticality' of specific renewable parts of the natural capital. Ecological resilience is defined as the capacity to absorb shocks and still maintain "function", or defined as the capacity of an ecosystem to resist disturbance and still maintain a specified state. Ecological resilience cannot be measured directly, it must be estimated by means of resilience surrogates to empirically estimate surrogates for ecological resilience (Carpenter et al., 2005). The degree of ecological resilience is inversely related to the degree of threat ecosystems are prone to. So, the empirical estimates of ecological resilience can be used as a further criterion for the criticality of natural capital (Brand, 2009).

4.2. GDP vs. GPI

While the natural capital in environment subsystem provide the essential foundation on which market production can take place, higher economic growth does not guarantee that welfare will be increased. The present GDP account takes almost no account of the adverse impact of economic activity on the environment. The activities like CO_2 emissions, pollution, and resource depletion and environment degradation can lead harm to the natural subsystems. And in society subsystem, people have to accept longer hours and reduce job security, so that the activities like income inequality, unemployment, and crime can also cause harm to the well-being. As having adverse economic impacts, these important factors on the human, social, and natural capital not all recognized in GDP should be explicitly integral components of sustainable development.

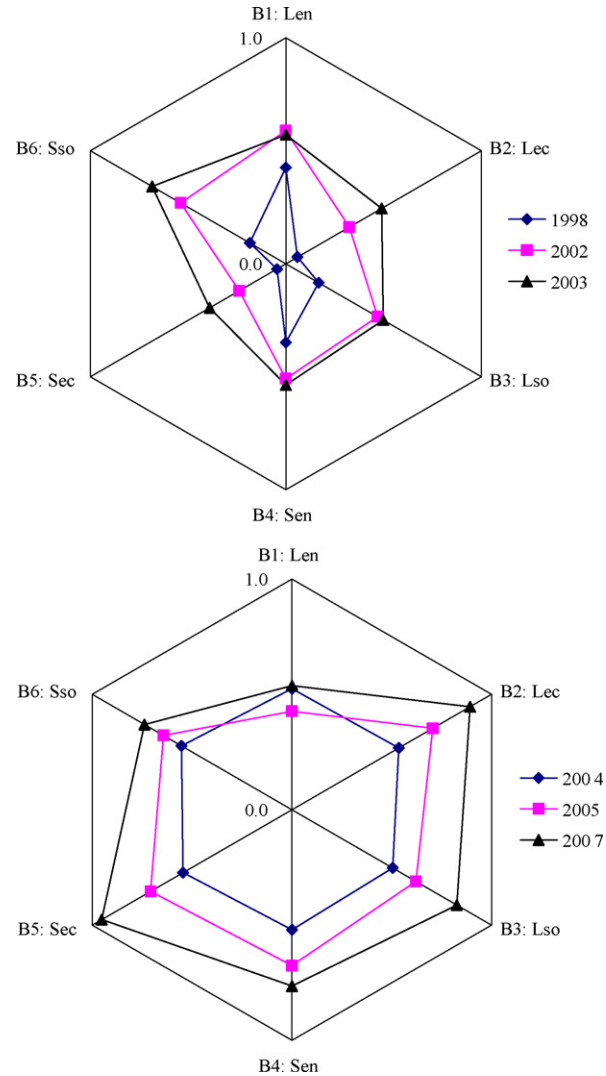

Fig. 4. Comparison of coordination and sustainability of the coastal zone in different time of Yantai. B1, B2 and B3 represent the capacity level of ENS, ECS and SOS, respectively; B4, B5 and B6 represent the sustainability level of ENS, ECS and SOS.

Developed to consider those costs, from the GPI perspective (Cobb et al., 1995; Anielski and Rowe, 1999), GPI attempts to overcome these shortcomings. In addition, GPI also include the components such as the estimated value of household work as positive contributors which ignored by GDP (Fig. 4).

Based on those factors above, we did not use GDP as an indicator of ECS in the index system, but calculated the GPI of Yantai (the calculation method of GPI of Yantai see Hamilton, 1999; Lawn, 2001; McDonald et al., 2009). Fig. 5 shows GPI a totally different picture of social progress from that of GDP's in Yantai from 1998 to 2007. The gap between the two lines (GDP and GPI) has widened for the first three years. Afterwards, GPI that peaked in 2006 is growing faster than GDP. At the end of years, the gap of them became larger again. Namely, the GDP raised from over ¥50,000 million to just under

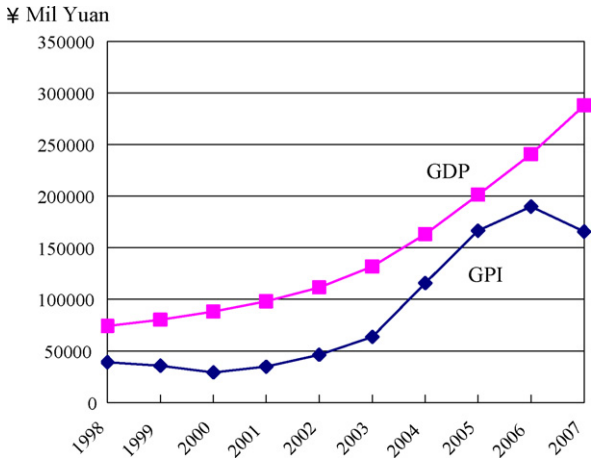

Fig. 5. Comparison of GDP and GPI in Yantai between 1998 and 2007.

¥300,000 million, in contrast, the GPI has increased from ¥38,989 million to ¥165,528 million over the same period. It shows that the GPI of Yantai has grown much more slowly than the growth in GDP. Although the GDP growth is traced as an upward-increasing curve, the GPI growth is traced as a relatively changeable line.

This suggests that GDP growth has not incorporated social costs incurred by economic activities aiming at high economic growth performance, which captures only one aspect of well-being and it is not a sufficient indicator of people's comprehensive well-being. When Yantai had achieved high economic growth, as the large gap between GDP and GPI shows, a substantial proportion of GDP growth has been made at the expense of environmental degradation and social costs.

At present, local governments in China, especially in the coastal zone, are still putting their efforts to improve GDP level, which incurred critique about the importance and effectiveness of economic growth. In a word, the sustainable development is not equal to the growth of economic, which cannot ensure truly social and economic welfare and people's well-being.

4.3. Uncertainty analysis

Sustainable development itself is a multi-dimensional concept and demands consideration of trade-offs among environmental, social and economic impacts. In this paper, we concentrated on coastal zone development assessment using system analysis method by mainly taking statistical data, but the necessary information was not incomplete. Thus, some limitations of this study were surely existed for that the assessment of CZSD in Yantai was only for the past period. The sustainability required a long-term perspective, but currently available evidence was short-term and incomplete.

Although many indicators can be used to monitor the process of sustainable development, indicators and models used in this paper have their own shortcomings in practice. Moreover, not all the selected indicators are suitable, by evaluating and adjusting the set of indicators, the indicator set should provide a more real status of coastal development. The analysis in this paper has focused on both environmental sustainability and eco-social sustainability. In making this assessment, particular consideration have not been given to data-weighting issues that were likely to have a seriously impact on the result. For example, the weight of some indicators appeared not consistent with the reality (Appendix A). On one hand for D_{CZ}, some indicators (per capita arable land, GDP energy consumption per 10,000 Yuan, Forest cover, Regional GPI, Port total cargo throughput per year, the level of urbanization, Engle coefficient), their weights were relatively high, which indicated that land resources, environmental quality, economic prosperity and quality of social life have more effects on CZSD. On the other hand for sustainability (S_{CZ}), several indicators (*the proportion of Environmental investment accounted for the region GDP, Gas emissions per unit area, Forest cover*), their weights were relatively large, which reflecting the environmental management play an important role for sustainability. However, the weight of the population density was higher than the contribution rate of science and technology and the weight of the natural population growth rate, which did not highlight an important contribution on society sustainable development by the progress of science and technology, and can not be stressed excessive pressure on social sustainable development by excessive population growth, either. Therefore, the weight of some indicators calculated in this paper also needed to revise and improve.

5. Summary

The research presented here is therefore a tentative attempt to extrapolate from what has been learned during the study by drawing upon experience elsewhere. In this assessment, perhaps, there might be some limitations in selecting the indicators or determining the indicators' weight, e.g., the indictors chosen in this study cannot completely represent the whole status of coastal zone. Thus, we made our effort to replace GDP for GPI in index system. Not withstanding some limitations, this study does focus on the coordination of economic and environmental development, and take account of the damage of economic development on environmental and depletion of natural resources in assessment. Actually, it leads to a good outset to comprehensive assessment of coastal zone sustainable development.

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Appendix A. The index system in assessment of CZSD.

Target layer		Criteria layer and weight	Indicator layer and weight	
			I	ω_i
K_{SD}	A_1: D_{CZ}	B_1: L_{EN} $W_1 = 0.2905$	I_1: per capita arable land	0.2100
			I_2: SO_2 emissions per unit area (−)	0.1770
			I_3: annual per capita water consumption (−)	0.0626
			I_4: GDP energy consumption per 10,000 Yuan (−)	0.2045
			I_5: COD of industrial waster (-)	0.1417
			I_6: Forest cover	0.2043
		B_2: L_{EC} $W_2 = 0.3548$	I_7: Regional GPI (Genuine Progress Indicator)	0.1927
			I_8: Regional GPI per capita	0.1893
			I_9: The added value of tertiary industry accounted for the proportion of GDP	0.0814
			I_{10}: The actual utilization of foreign investment	0.1809

Appendix A (*Continued*)

Target layer	Criteria layer and weight	Indicator layer and weight	
		I	ω_i
		I_{11}: The output value of marine industries accounted for the proportion of GDP	0.1646
		I_{12}: Port total cargo throughput per coastline	0.1911
	B_3: L_{SO}	I_{13}: The region's total population	0.1671
		I_{14}: The level of urbanization	0.1682
		I_{15}: Numbers of scientists and technicians per 1000	0.1624
	$W_3 = 0.3548$	I_{16}: Ratio of Urban and rural residents per capita annual income (–)	0.1683
		I_{17}: Engel's coefficient (–)	0.1685
		I_{18}: The average annual consumption expenditure of urban and rural residents per capita	0.1654
	B_4: S_{EN}	I_{19}: The proportion of Environmental investment accounted for the region GDP	0.1227
		I_{20}: The rate of industrial waste water discharge standards	0.0267
		I_{21}: Wastewater discharge per 10,000 Yuan (–)	0.1626
A_2: S_{CZ}	$W_4 = 0.4254$	I_{22}: Gas emissions Per unit area (–)	0.2302
		I_{23}: Nature Reserve coverage	0.2135
		I_{24}: Forest cover	0.2443
	B_5: S_{EC}	I_{25}: Regional GPI per captia	0.1674
		I_{26}: Regional GDP growth rate	0.1453
		I_{27}: Coastal Zone economic density	0.1721
	$W_5 = 0.2494$	I_{28}: Urban per capita disposable income	0.1714
		I_{29}: Per capita savings deposits	0.1735
		I_{30}: Port total cargo throughput per coastline	0.1703
	B_6: S_{SO}	I_{31}: Population density	0.1848
		I_{32}: The natural population growth rate (–)	0.1133
		I_{33}: Numbers of scientists and technicians per 1000	0.1847
	$W_6 = 0.3256$	I_{34}: The proportion of R & D funds accounted for GDP	0.1638
		I_{35}: Engel's coefficient (–)	0.1928
		I_{36}: The contribution rate of science and technology	0.1604

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