Constructing an assessment indices system to analyze integrated regional carrying capacity in the coastal zones — A case in Nantong

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ABSTRACT

As an indispensable homestead, the ecosystem witnesses a large number of human activities. Undoubtedly, socio-economic development consumes a variety of natural resources and causes stress to the ecosystem. Only when the ecosystem is in under-loading, socio-economic development can be sustainable. In this paper, the integrated carrying capacity (ICC), which is a comprehensive capacity measure, is calculated in given space and time frames to support the evaluation of long-term sustainable regional economic development. Combined with the conceptual mode of "*driving force − pressure − state − response − control*" (D−PSR−C), the ICC reveals the loading capacity between human activity and the ecosystem. In coastal zones, the ICC is more effective because of the rapid socio-economic development. Using a case study in the Nantong coastal area in China, we constructed an index system to assess the regional ICC and its variability in 2005, 2008 and 2009. The results indicate that (1) almost all county ICC states of land, shoals, marine and regional are under-loading with several exceptions that are full-loading. The highest value is the regional ICC of Qidong in 2009 (2.679 and under-loading). The lowest value is the Haian marine ICC in 2008 (0.171 and over-loading). (2) From 2005 to 2009, the ICC values of beach, marine and regional were increasing, but it was decreasing in land. (3) Based on the analysis of the carrying capacity of the secondary indicator contribution rate, the population pressure and the external contribution ability are nearly below 10%, and environmental pollution is also a critical indicator. In this paper, the assessment indices system contains almost all of the impacts of human activity, and the calculation method and the judgment standard can improve the traditional method's faultiness. The conclusions are a fundamental basis for the long-term balance between economic development and ecosystem health.

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1. Introduction

The theory of carrying capacity (CC) was first defined in a mechanics paper by Malthus (Malthus, 1798) in relation to a "population explosion". The theory was extended to other research fields, such as socio-economic development capacity, ecological accommodation CC, resource CC, environmental CC and ecological CC (Hadwen and Palmer, 1922; Leopold, 1941; Bishop and Crawford, 1997; Perry and Schweigert, 2008; Lane, 2010; Zacarias et al., 2011). In China, Tang define environmental CC as a capacity threshold for a specific period and a specific eco-system in which

the regional ecological environment can support human socio-economic destruction (Tang and Ye, 1998). As a core of human society and sustainable development, ecological CC refers to the self-sustaining and self-regulation capacity of the eco-system, which can supply resources and environment for socio-economic demands (Gao, 2001). In marine systems, the CC refers to the capacity to support a coordinated development of the economy and the environment (Mao and Yu, 2001a; Di and Han, 2005). Recent literature has presented successful applications of the CC, which is progress from the concept and theory stage. These applications can guide policy related to socio-economic development.

The ecosystem is comprised of natural processes and human activities. If the coordination of the two types of processes fails, then disasters occur. The ecosystem provides the necessary natural resources for human socio-economic development. Each CC

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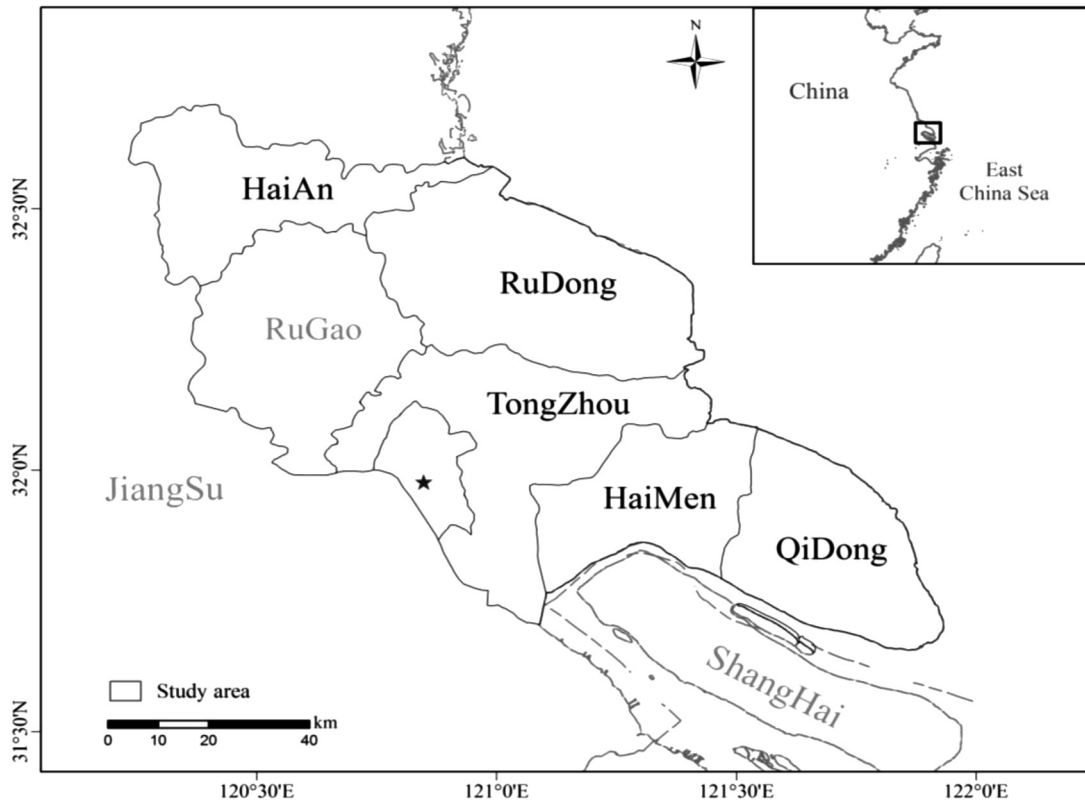[1] Tel.: +86 15921238236.

Fig. 1. Study area of Nantong coastal.

(e.g., natural CC, resource CC, environmental CC, and ecological CC) can only measure the carrying capacity of each independent system. Because the ecosystem is complex, we need to integrate the CCs of all subsystems to better reflect the entire ecosystem's capacity. In this paper, the regional integrated carrying capacity (RICC) represents an integrated capacity of the resources in a given period and space (e.g., material resource, energy resource, information resource, human resource, and social resource), which can support regional long-term sustainable development (Ye and Guo, 2012). The RICC can cover all of the various geographical spatial units, which includes a complex ecosystem of air, water, biology, land and humans. The assessment considers resources, the environment, ecology, economics and society.

In general, the coastal zone is a transitive area from land to sea, which is a geographical dividing line that is artificially defined (Kaluwin, 1996). The concept of the coastal zone was defined by the U. S. Coastal Management Act, International Geosphere-Biosphere Program (IGBP), National Environmental Policy of Mexico Marine and Coastal Sustainable Development and the resource survey of coastal and tideland in China (Sorensen and McCreary, 1990; Luan, 2004; Yan and Yuan, 2011). In this paper, we used the concept proposed by Chen (2000) who defines the coastal zone as an area of 0 m isobaths that extend landward and seaward to −10 m isobaths of the prefecture level city jurisdiction. At the provincial level (municipalities and autonomous regions), this zone refers to the land and the sea of the prefecture city jurisdiction.

The development of an economy is one of the primary needs of human society. An under-loaded ecosystem is the precondition of development. The coastal area is a compound ecosystem that is comprised of processes stemming from nature, human society and the economy. This research is an integration of reductionism and holism, micrograph and macrograph. The integrated assessment of the coastal carrying capacity can help support the coordinated and sustainable development of the economy and ecology. However, there is no systemic research of the theoretical system, assessment method, or evaluation standard, nor are there any demonstrations of developing an integrated carrying capacity (ICC) in the coastal areas of provinces, cities and counties. In this research, we developed an assessment indices system of ICC by using the "drive force − pressure − state − response − control" (D−PSR−C) conceptual model (Xu and Ye, 2008). This new ICC system integrates all of the sectors of the ecosystem and is a harmonic integration of resource CC (D), environmental CC (P), ecological CC (S), economic CC (R) and social CC (C).

2. Materials and methods

2.1. Study area

Nantong, which is located between 31°41′ N and 32°43′ N, 120°12′ E and 121°55′ E, lies on the north end of the Yangtze Estuary and is adjacent to Shanghai, China (Fig. 1). The land area of Nantong is 8 544 square kilometers, and the marine area is 4 485 square kilometers. The length of its coastal line is 210.4 km, and the river lines measure approximately 20 km. In this paper, the coastal area contains five jurisdictional counties and marine areas, in addition to Nantong coastal: Haian, Rudong, Tongzhou, Qidong and Haimen.

In 2011, the gross domestic product (GDP) of Nantong was 408.022 billion Chinese Yuan, which is an increase of 12.1% over the previous year. The GDPs of Suzhou, Wuxi and Nanjing in Jiangsu province ranked as the next highest (Statistical Year Book of Jiangsu, 2012). Agriculture is an important sector of the socioeconomy. Marine aquaculture, marine fishing and marine

Table 1
Basic parameters of Nantong coastal county (city).

Country (city)	Haian	Rudong	Qidong	Tongzhou	Haimen
Area of land (sq. km)	1 108	1733	1 208	1 166	939
Area of shoals (sq. km)	21.67	97.72	47.39	18.87	18.87
Area of marine (sq. km)	24.78	1 580.73	2 169.03	341.73	369.49
Long of coastal (km)	8	106	203	16.2	12.5
Fishery resource*(10^4 t)	2.78	24.94	32.41	5.46	7.84
Per. capital GDP (10^4 yuan/per.)	2.82	2.49	2.93	3.47	3.75
Marine economic output (10^8 yuan)	3.55	23.53	40.54	9.65	11.64

Note: Fishery resource is composed by the production of marine aquaculture and fishing.

Table 2
Assessment indices system of coastal ICC.

Assess model	First-class indicator	Second-class indicator
P	Coastal environment pressure	Pollution and energy consumption
	Coastal development intensity	Coastal line utilization intensity
S	Coastal available resource	Available space resource
		Available biology resource
	Marine environmental quality status	Ocean environmental quality
	Coastal population density	Population density
	Coastal economic development level	Regional economic development level
	Coastal ecological assets	Coastal ecosystem service value[2]
R	Scientific and technological support conditions	Science and technology innovation ability
	Society support conditions	External contribution ability
		Infrastructure and protection

industry are the development powers in Nantong. Thanks to the "Jiangsu coastal zones development planning (2009–2020)" and "National marine function zones (2011–2020)" strategic plans, Nantong has become an important region in the Jiangsu coastal area. The abundant resources within the five counties can able to support regional economic development (Table 1).

Because of differences in primary industries, economic foundations and policy directions, industries rank differently during socio-economic development. The effect also appears in shoals and marines in the coastal zone. In this research, we aim to assess the ICC of land, shoals and marine and analyze the contribution rates of those three ICC values to the regional ICC. The conclusions can aid planning policies for adjusting industrial layouts and help maintain long-term land-marine sustainable development.

2.2. Assessment indices system

2.2.1. Model applicability

The D–PSR–C model is based on the causal relationship chain between the pressure and the change of the ecosystem environment. Specifically, the model emphasizes that humans are the most important control on the ecosystem environment (Xu and Ye, 2008). This model contains all layers and sectors of the ecosystem energy flow and can produce the basic content and change of the RICC. The adaption of D–PSR–C is as follows:

(1) During a period (11th Five-Year), it is assumed that the change and the relationship of each indicator is linear and steady. The ICC is based on a summary of different aspects of national and regional issues.
(2) The model can match the demand of regional economic development. The external force is the precondition of the stable carrying state, which is defined as a single CC.
(3) The model considers environmental resources and the ecosystem. Due to the force deficiency, the ecosystem tends to degenerate, and the ICC deflects.

2.2.2. Index selection and filtration

In the RICC index system, each indicator should truly reflect its subsystem's carrying capacity. First, the indicator should be closely related to the coastal zone conditions. Furthermore, the definition of an indicator must be clear (i.e., the context is not too complicated or elaborate) to easily collect data. Second, the indicator should be distinguished as primary or secondary, highlight the most important information and represent the entire sector to obtain scientific and effective conclusions. Third, by combining qualitative analysis with quantitative calculations, we can analyze all of the indicators of the ICC.

The coastal ICC is controlled by nature, humans and society. The demands of humans are the driving force of ecosystem

development and utilization, and all of the layout policies are the controlling force. In this research, we assume that the driving force and the control force exist in a certain ecosystem state. Therefore, we do not choose an indicator to calculate the carrying capacity. According to the conceptual model, the index system contains three sectors: pressure indices, state indices and response indices. The indices are divided into three classes: first-class indicator, second-class indicator and third class indicator. The filtration principles of the index system are as follows:

(1) Pressure indices. Each indicator should reflect the impacts of humans, society and the economy on the coastal ecosystem. Principally, they should include environmental pressure and developmental intensity, such as industrial wastewater discharge, solid waste discharge, and energy consumption per million (GDP).
(2) State indices. Each indicator should reflect the coastal economic development, for example, available resources, environmental quality, population density, economic development level and ecological assets.

An ecological asset is the sum of all of the material values that the ecosystem can provide to human activities (Odum, 1953; Costanza, 1992; MA, 2003; Zhang et al., 2008). The theory and research context of ecological assets are novel and at the forefront of scientific inquiry. The net primary productivity (NPP) is the surplus asset minus the ecosystem consumption. Thus, it is an important indicator for assessing the ICC in this research.[2] (Ye and Guo, 2012)

(3) Response indices. To continue socio-economic development, the government must change the development layout and increase technology, environmental protection and new energy. This indicator represents a compensation program that allows humans to maintain and improve the stability and carrying capacity of the ecosystem (e.g., research and development investments, foreign investments, and environmental expenses).

Based on the principles of selection and filtration, the index system of coastal ICC is developed (Table 2). This system chiefly contains nine first-class indicators and eleven second-class

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[2] The research of ecological assets is important and is to be quoted from the final report of the National Marine Public Scientific Research Fund Project of China (No. 200805080).

indicators. When the data becomes available, third-class indicators can be refined.

Because of the complexity of coastal zones, especially the various contributions of socio-economic development, the study area is divided into three parts: the land, the shoals and the marine. Using the data availability and the various regions, the second-class and the third-class indicators can be adjusted.

2.3. Data source and processing

2.3.1. Data source

Based on investigations and surveys of Nantong coastal, the study years are 2005, 2008 and 2009. The data are collected according to the indices system. To conduct assessments, compare conclusions, and develop a reference, the data must be available, reliable and uniform. In this research, the data are collected from statistical yearbooks, statistical bulletins, marine bulletins, and historical data of Jiangsu Province and Nantong City. Supervised classification of remote sensing (RS) of Nantong is added to the ICC assessment.

Using field survey data of in 2010, the data are composed with corrected RS analysis data. Beyond the stakeholder[3] discussion conference, the index system will be further improved to obtain accurate conclusions.

2.3.2. Data standardization

The indicators are associated with, influenced by and constrained by each other, and the magnitudes and units are also different. Thus, the data cannot be calculated directly unless they are standardized.

According to the difference of an indicator's contribution to the ICC, all of the indicators are divided into two types: pressure-bearing and pressure. The pressure-bearing indicator refers to the capacity of natural resources and human control to load the pressure of socio-economic development (e.g., per capita arable land area and industrial wastewater discharge compliance rate). The pressure indicator represents the environmental stress from human activity (e.g., population density and energy consumption per million GDP).

In this study, the data are normalized by using the method of maximum and minimum values. Based on an indicator's property, the method is as follows:

$$\text{Pressure} - \text{bearing indicator}: \quad b_j = \frac{x_j - \min(x_j)}{\max(x_j) - \min(x_j)}$$

$$\text{Pressure indicator}: \quad b_j = \frac{\max(x_j) - x_j}{\max(x_j) - \min(x_j)}$$

where b_j is the indicator normalized value, x_j is the original value, $\max(x_j)$ is the original maximum value, and $\min(x_j)$ is the minimum value.

2.4. Assessment model

The state-space method is a Euclidean geometry space state that is constructed by a three-dimensional axis of system element vectors (Mao and Yu, 2001b; Wang and Zou, 2007). In the ecosystem, the three-dimensional axis reflects the development of human and social economics, the regional resources and the

environment (Fig. 2). This model matches the ICC index system. Thus, the state-space method is an effective and important method to quantitatively describe and assess the value and state of the ICC.

Beyond the different economic conditions and sustainable development, an XYZ curvature of the carrying capacity exists in the space. Any point (B) on that surface refers to a balanced state of human activities, resources and environmental pressures (Fig. 2). In the ecosystem, the carrying capacity can be considered the modulus of a three-dimensional space vector. By comparing the modulus and radius of curvature, we can determine the carrying state of the ecosystem. The formula is as follows:

$$\text{RCC} = \sqrt{\sum_{j=1}^{m} \omega_j x_j^2}$$

where x_j is the indicator normalization value, w_j is the weight of x_j, n is the total of the indicators and RCC is the RICC.

2.5. Assessment standard

2.5.1. Weight

The weight refers to a quantitative distribution of the object's importance during the research process (Xu and Da, 2002). The index system of ICC contains all sectors of the ecosystem. Each indicator's impact on socio-economics and the ecosystem is different, and the contribution of an indicator's carrying capacity is also different. Thus, the data must be multiplied by a weight prior to the calculation.

In the multi-indices comprehensive assessment, the calculation method of the weight contains two categories: subjective weight and objective weight. The subjective method relies on the importance of the evaluator's judgment to array the indicator's sequence (e.g., adjacent indicator comparison, efficiency coefficient method, and analytic hierarchy). The objective method relies on the information and interrelation of an indicator's original data to distribute the indicator's importance (e.g., principle component analysis, entropy method and factor analysis).

In the coastal zone, the resources and environment of provinces, cities, and counties are shared. Thus, the ecological influence is also equally shared. Because the weight should reveal each indicator's actual importance during socio-economic development, it must be
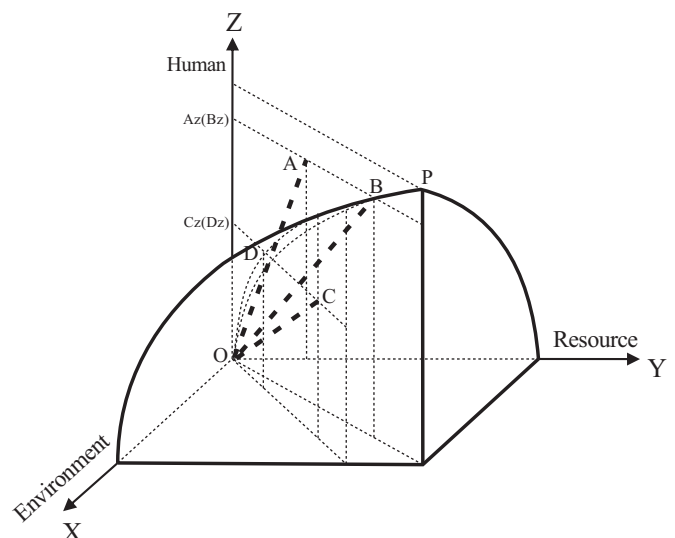

Fig. 2. Space-state analysis model.

calculated by using the entropy method (Sault, 2003) and adjusted based on stakeholder discussions. The steps are as follows:

(1) Based on the index system and normalized data, construct a judgment matrix of $R = (x_{ij})_{m \times n}$ ($i = 1,2,...,m$; $j = 1,2,...,n$):

$$R = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}_{m \times n}$$

where m is the total of the assessment units, n is the total of the third-class indicators, and x_{ij} is the indicator's normalized value.

(2) Use the maximum and minimum method to normalize matrix R:

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix}_{m \times n}$$

where y_{ij} is the normalized data value.

(3) Indicator normalization. Use the ratio between y_{ij} and all of the vectors of matrix Y to normalize the indicator's data.

$$f_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

(4) Based on the entropy theory, H_j is the entropy of indicator j.

$$H_j = -\frac{\sum_{i=1}^{m} f_{ij} \ln f_{ij}}{\ln m}$$

If $f_{ij} = 0$, then $\ln f_{ij} = 0$.
So, the weight of indicator j is w_j.

$$\omega_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}$$

where $0 \leq \omega_j \leq 1$, $\sum_{j=1}^{n} \omega_j = 1$.

2.5.2. Ideal value

In the space-state model, the ICC state is judged by comparing the ICC modulus with the curvature radius. The radius size is the key basis to judge the ICC adequacy. It is defined as the ideal value of the ICC.

The balanced state can be defined as maximum, average or minimum of all of the indicators' CC. According to the interrelation of all of the research regions, the average is chosen as the balanced state, and the average of all of the units' ICC values is the ideal value. The formula is as follows:

$$RCC' = \frac{1}{m} \sum_{i=1}^{m} \sqrt{\sum_{j=1}^{n} \omega_j \bar{x}_j^2}$$

where RCC' is the ICC ideal value, m is the total of the assessment units, n is the total of the third-class indicators, $\bar{x}_j$ is the indicator's ideal value and ω_i is the indicator's weight.

2.5.3. Adjustment coefficient

Along with regional economic development, many new resources, technologies and policies to support sustainable development are available. However, the average ideal value merely refers to a universal development state, and it cannot reflect the socio-development trend. Therefore, the ICC cannot be exactly assessed, and the ideal value must be adjusted. The formula is as follows:

$$I = k \times p \times RCC'$$

where I is the actual ideal value, k is the adjusting coefficient, and p is the regional development stage coefficient (DSC). According to the complexity of the ecosystem and the dynamics of nature, the k value is 1.2 as obtained from the stakeholder discussion conference.

The DSC is defined as a parameter that measures the social development scale of the regional economy, population, consumption and other variables (Wang et al., 2002). The equation is as follows (Pearl and Reed, 1920; You et al., 2009):

$$p = \frac{1}{1 + e^{(3 - \frac{1}{En})}}$$

where p is the regional development stage coefficient and En is the Engel coefficient.

2.5.4. Assessment standard

According to the space-state model, the conclusion of the ICC contains three states: under-loading, full-loading and over-loading. Because the ecosystem is in a dynamic transition, we assume that full-loading is a relative state, which does not mean that the assessment result must equal the ideal value. There is a tolerance range of ICC to produce a relative balance of human activities, natural resources and environmental impacts. The assessment standards of the ICC are as follows:

If $RCC > I$, then the state is under-loading;
If $I - r \leq RCC \leq I + r$, then the state is full-loading;
If $RCC < I$, then the state is over-loading.

where RCC is the assessment result of the ICC, I is the ideal value and r is the ideal value tolerance. Based on the ICC results in the five counties of Nantong coastal and the collective suggestions from stakeholders and scientific experts, r is equal to 0.1.

2.5.5. Contribution ratio

The index system is constructed of social, environmental, natural resource, human, economic and other factors. The results present the ecosystem's carrying state with the socio-economic development. However, it cannot directly reflect the key indicator, which tends to cause the ICC to over-loading or full-loading. In this research, the contribution ratio reveals a percentage of the second-class indicator's CC in the ICC. The larger the contribution ratio of the pressure-bearing indicator, the more significant the impact for the ICC, and vice versa. The formula is as follows:

$$r_l = \frac{R_l}{RCC} \times 100\%$$

$$R_l = \sum_{j=1}^{w} RCC_j$$

where r_l is the contribution ratio, R_l is the second-class indicator's CC value, l is the total of the second-class indicators, RCC is the ICC value, w is the total of the third-class indicators that belong to the

Table 3
Indicator ideal value and weight of Nantong coastal regional ICC in 2008.

First-class indicator	Second-class indicator	Third-class indicator	Units	Ideal value	Weight
Coastal environment pressure	Pollution and energy consumption	Industrial waste emission produced	10^4 t	0.184	0.039
		Solid waste residue produced	10^4 t	0.178	0.040
		Energy consumption of per. ten thousand	10^4 t (SCE)	0.287	0.039
Coastal development intensity	Coastal line utilization intensity	Shoals reclamation area	sq. km	0.702	0.037
Coastal available resource	Available space resource	Available being utilized of marine area	sq. km	0.108	0.034
		Distance of coastal line	km	0.083	0.033
		Per capita area of farmland	per person of sq. km	0.083	0.040
	Available biology resource	Plant NPP	g C of sq. m	0.110	0.040
		Maine NPP	g C of sq. m	0.145	0.034
		Fishery resource	10^4 t	0.176	0.036
Marine environmental quality status	Ocean environment quality	Sea eutrophication index		0.426	0.034
Coastal population density	Population density	Registered population	100 million person	0.108	0.040
Coastal economic development level	Regional economic development level	Per capital GDP	Per person of 100 million yuan	0.363	0.040
		Engle coefficient		0.461	0.040
		Output value of marine economic	100 million yuan	0.213	0.037
		Annual growth rate of GDP	%	0.184	0.040
		Cargo handled of seaport	100 million ton	0.852	0.040
Coastal ecological assets	Coastal ecosystem service value	Service value of production and supply	100 million yuan	0.251	0.040
		Service value of cultural and entertainment	100 million yuan	0.760	0.040
		Service value of climate adjustment	100 million yuan	0.778	0.040
Scientific and technological support conditions	Science and technology innovation ability	Persons engaged in scientific and technical activities	Person	0.159	0.040
		Ratio of scientific research and GDP	%	0.140	0.039
Society support conditions	External contribution ability	Foreign investment	%	0.096	0.039
	Infrastructure and protection	Investment on environment protection	%	0.363	0.040
		Hospital Beds	Per 100 person of bed	0.294	0.040
		Load operation mileage	km	0.233	0.040

second-class indicators, and RCC_j is the CC of the third-class indicator j.

3. Results and discussion

The ICC calculation model is implemented as a copyrighted software system (ID: 2012SR050925). From the input data, this system can directly output the indicator's CC, ICC and carrying state of the study area.

In this paper, the research is divided into two layers. First, the entire county is set as the study unit, and the result is the regional ICC state of each county. Second, according to the assessment index system of land, shoals and marine, the results are the various units' ICC states. Using 2008 as the base assessment year, according to the second-class indicator's contribution ratio analysis (land/shoals/marine/regional), the ratio can reveal the key indicator of the limiting ICC value.

Based on the statistical yearbook, the marine bulletin, the historical data of Nantong, RS analysis and field surveys of Nantong coastal, the assessment database is constructed. The third-class

Table 4
Assessment value of Nantong coastal ICC.

County	Year	Land	Shoals	Marine	Region
Haian	2005	0.968	0.471	0.287	0.989
	2008	0.949	0.511	0.171	0.804
	2009	0.950	0.453	0.285	0.832
Rudong	2005	1.325	1.495	1.476	1.141
	2008	1.027	1.402	1.28	1.062
	2009	1.028	1.448	1.122	1.107
Qidong	2005	1.134	1.241	1.991	1.349
	2008	0.991	1.384	1.876	1.511
	2009	0.991	1.383	1.642	2.679
Tongzhou	2005	1.038	0.547	0.594	0.842
	2008	0.928	0.666	0.755	0.849
	2009	0.926	0.599	1.181	1.093
Haimen	2005	1.068	0.68	0.451	0.826
	2008	0.946	0.661	0.665	1.081
	2009	0.947	0.845	1.013	2.007

indicator's ideal value and weight of the Nantong coastal ICC in 2008 are listed in Table 3.

By using the assessment model, the ICC values of land, shoals, marine and regional in coastal Nantong are listed in Table 4. Based on the ICC ideal value and judgment standard, the ICC states are evaluated. In this paper, the conclusions for land, shoal, marine and regional ICC values are drawn as a thematic map by using ArcGIS 10.1 software (Fig. 3).

According to the analysis, the five counties' ICC values are mainly under-loading, but some are full-loading or over-loading. The ICC values of marine and regional areas are more accurate in some areas, but the land is full-loading or over-loading.
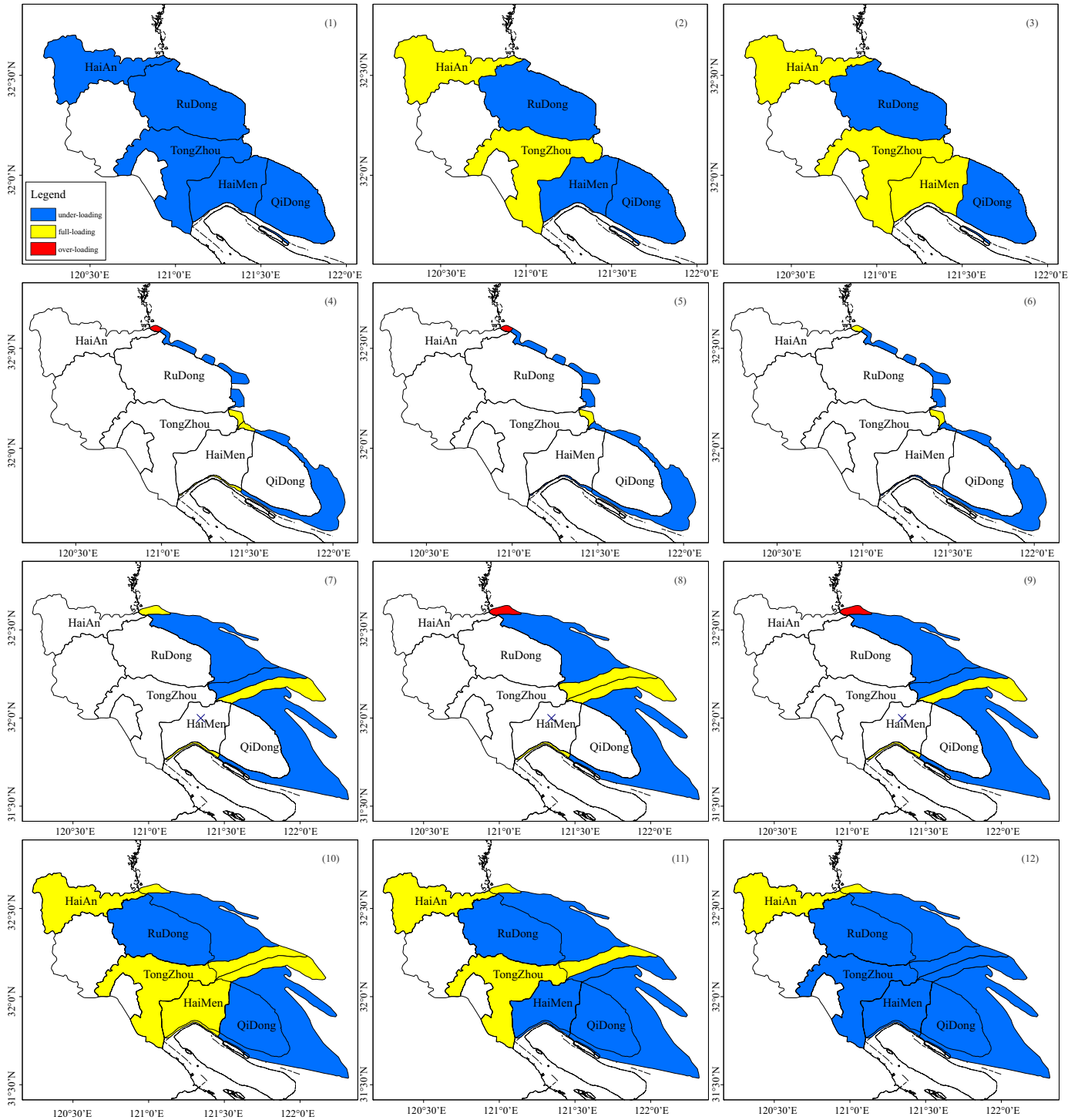
3.1. Land ICC

In the historical socio-economy, the industry layout is always on the land. However, the land resources were exhausted quickly and cannot support the development demand of the socio-economy. According to Table 4, the land ICC values of the five counties are basically less than 1 and tend to be characterized as full-loading (except in Rudong). From 2005 to 2009, the ICC value exhibits a declining trend. The ratio drop in Rudong is the most rapid and changes from 1.325 to 1.028 (a 22.4% decrease).

Based on the contribution ratio model, the land second-class indicator contribution rates of the five counties in 2008 are assessed (Table 5). The highest indicators are pollution and energy consumption, regional economic development level and infrastructure level (all over 15%). The lowest indicators are land ecological assets and external contribution ability (less than 3%). In the future development of land industries, we should decrease industrial wastewater and solid pollution while improving technology to increase the land carrying capacity and maintain sustainable development.

3.2. Shoals ICC

In the Nantong coastal zone, the area of shoals that are adjunct to the land and sandbank is approximately 2 350 square kilometers,

Note: (1) Land ICC in 2005; (2) Land ICC in 2008; (3) Land ICC in 2009; (4) Shoals ICC in 2005; (5) Shoals ICC in 2008; (6) Shoals ICC in 2009; (7) Marine ICC in 2005; (8) Marine ICC in 2008; (9) Marine ICC in 2009; (10) Regional ICC in 2005; (11) Regional ICC in 2008; (12) Regional ICC in 2009

Fig. 3. Thematic map of Nantong coastal ICC.

and the boundary can extend seaward to 10–200 m annually. The shoals are an important natural resource to support agriculture and industrial development. According to Table 4, the shoals ICC of the five counties vary. From 2005 to 2009, Rudong and Qidong are always perfect, but the others are over-loading. The difference in the shoal areas of the five counties may lead to the distinct ICC

conditions. The ICC values of Qidong, Tongzhou and Haimen tend to increase. The most rapid increase occurred in Qidong (a change from 1.241 to 1.383), which increased 11.4%.

Based on the contribution ratio model, the shoal second-class indicators' contribution rates of the five counties in 2008 are assessed (Table 6). The highest indicators are environment pressure

Table 5
The second-class indicators' contribution ratio of land ICC in 2008 (%).

Second-class indicator	Haian	Rudong	Qidong	Tongzhou	Haimen
Pollution and energy consumption	20.3	18.8	31.2	28.2	26.2
Available space resource	8.9	16.0	9.9	10.4	9.0
Land ecological asset	4.6	7.7	5.2	5.3	4.2
Population pressure	7.8	11.7	7.4	6.9	6.7
Regional economic development level	17.6	17.6	17.9	20.2	20.2
Infrastructure level	14.4	14.5	15.5	17.8	19.2
Science and technology innovation ability	16.6	9.5	7.8	8.1	10.8
External contribution ability	9.8	4.2	5.2	3.1	3.5

and economic development level, which together account for over 35%. The lowest indicators are ecology resources and shoal ecological asset (as low as 3.3%). Differences exist in the space resources, shoal ecological assets and labor force among the five counties. Qidong has the best cumulative resources at 52%. Based on the results, we should change the economic development layout and increase the shoal usage and efficiency. In regions that lack shoal resources, we must improve scientific technology to maintain the long-term sustainable development.

3.3. Marine ICC

The marine area is an important natural resource that comprises two-thirds of the area of earth. Marine resources can continuously support the demand of human activities and the ecosystem cycle. In the Nantong coastal zone, there are many marine industries (e.g., sea fishery, seawater aquatics, wind power and oceanic shipping). According to Table 4, the marine ICC values of the five counties are mostly under-loading. However, Haian is full-loading because of the ocean jurisdiction differences. From 2005 to 2009, the ICC values of Tongzhou and Haimen increased by 98.7% and 79.6%, respectively. The values in Rudong and Qidong slightly decreased due to land-based environmental waste-water and solid pressure.

Based on the contribution ratio model, the marine second-class indicators' contribution rates in the five counties in 2008 are assessed (Table 7). The highest indicators are marine biological resources and marine environmental quality, which accumulate to 50%. However, differences exist in each county. The lowest indicator is the marine ecological asset (1.5%). In the future, we must control the land pollution beyond the ocean self-purification capacity and attempt to find more marine resources and improve the utilization efficiency.

3.4. Regional ICC

In the Nantong coastal zone, due to differences in natural resources, the industry layouts are judged individually. According to Table 4, the regional ICC values of Rudong, Qidong and Haimen are perfect, but Haian and Tongzhou are full-loading. From 2005 to 2009, the ICC values of Qidong, Tongzhou and Haimen increased by

Table 6
The second-class indicators' contribution ratio of shoal ICC in 2008 (%).

Second-class indicator	Haian	Rudong	Qidong	Tongzhou	Haimen
Environment pressure	31.3	16.1	16.9	38.9	14.6
Space resource	6.1	28.0	30.8	7.0	9.9
Biological resource	6.8	13.3	7.9	18.9	20.0
Economic development level	32.3	20.2	22.5	19.8	20.6
Shoals ecological asset	4.6	18.1	10.9	3.3	6.2
Labor force	18.9	4.4	11.1	12.2	28.8

Table 7
The secondary indicators' contribution ratio of marine ICC in 2008 (%).

Second-class indicator	Haian	Rudong	Qidong	Tongzhou	Haimen
Marine space resource	1.5	24.9	23.4	5.1	8.1
Marine biological resource	41.9	34.1	31.6	23.6	48.2
Marine ecological resource	1.5	24.9	23.4	5.1	8.1
Marine environmental quality	55.1	16.0	21.7	66.1	35.6

98.5%, 29.8% and 142.9%. In contrast, Haian and Rudong declined, whereas Haian tends to be over-loading.

Based on the contribution ratio model, the regional second-class indicators' contribution rates in the five counties in 2008 are assessed (Table 8). The highest indicators are pollution and energy consumption, ocean environmental quality and regional economic development level. The lowest indicators are coastline utilization intensity, population density and external contribution ability. The contributions of ocean environmental quality in the five counties differ (i.e., it is over 57.7% in Qidong and merely 0.8% in Haian).

3.5. Discussion

By contrasting and analyzing the five counties' ICC values in 2005, 2008 and 2009, we observe that most of the regional ICC are characterized as under-loading. The marine and the shoals reflect an increasing trend, but the land value is decreasing and nearly full-loading. The ICC states of Rudong and Qidong are perfect, especially in the marine areas and shoals, which is related to their jurisdiction areas. Haian and Tongzhou have worse values in which some ICC values are full-loading. This trend is inconvenient for socio-economic development. Based on the assessment value analysis, the regional ICC is increasing along with the improvement of shoal and marine carrying capacities, which play a leading role in the coast's regional ICC.

Based on the second-class indicator's contribution ratio analysis, the key impact indicators of the ICC are pollution and energy consumption, ocean environmental quality, biological resources and ecosystem services value. In the future socio-economic development, we must attempt to control the land environmental pollution and increase the resource utilization efficiency to maintain long-term efficiency and sustainable development.

According to the "Development planning of Jiangsu coastal area (2009–2020)", "Development planning of national economic and society of Nantong (12th Five-Year)" and "Shoals reclamation and development of Nantong coastal (12th Five-Year)", we should promote the development and utilization of marine resources (i.e., renewable energy, seaports, offshore tourism and shoals) and insist on a balance between land and marine utilization to improve the blue marine economic development.

Table 8
The second-class indicator's contribution ratio of regional ICC in 2008 (%).

Second-class indicator	Haian	Rudong	Qidong	Tongzhou	Haimen
Pollution and energy consumption	16.1	10.4	7.4	15.4	7.9
Coastal line utilization intensity	3.0	3.9	2.0	2.0	1.1
Available space resource	3.9	12.9	6.8	4.3	2.3
Available biology resource	4.4	13.5	6.3	4.9	2.7
Ocean environmental quality	0.8	7.1	57.7	31.1	62.5
Population density	6.2	6.5	1.8	3.7	2.0
Regional economic development level	22.5	17.5	7.7	14.2	7.5
Coastal ecosystem service value	10.9	12.8	3.7	8.7	3.8
Science and technology innovation ability	13.2	5.2	1.8	4.4	3.3
External contribution ability	7.7	2.3	1.2	1.7	1.1
Infrastructure and protection	11.4	8.0	3.7	9.7	5.8

4. Conclusions

According to the assessment results, the coastal ICC is changing with socio-economic development and has exhibited a downward trend. Based on D—PSR—C, the pressure of socio-economic development can decrease the ICC value. To continue long-term ecosystem stability, this system needs an external control force to maintain the complex ecosystem balance. Human economic activities can achieve sustainability only if the ecosystem is under-loading.

Based on the D—PSR—C indices conceptual model, the index system of the coastal ICC was constructed and is considered effective. This system contains three classes; first-class indicators and second-class indicators are defined in this paper. Combined with coastal regional differences and data availability, the study area is divided into four units: land, shoals, marine and regional. All third-class indicators are defined by the data available. For each county, the ICC of land, shoals, marine and regional are evaluated. This analysis model of the coastal ICC is proposed as a new research method to assess the coastal carrying capacity.

Based on the regional development stage coefficient theory, the standard of the ICC ideal value can be adjusted to obtain a scientific and comparable ICC assessment value. This improves the faultiness of the traditional method. Using the contribution ratio analysis of second-class indicators, the key indicator that worsens the ICC is identified. The conclusion can support regional socio-economic development planning.

Using Nantong coastal as the study area, the ICC theory is demonstrated by county. The index system, methodology and judgment standard are verified and improved via stakeholder discussions. According to the assessment results and the indicators' contribution ratios, the ICC state and primary impact factors are also assessed to propose a regional development policy for coastal Nantong in the 12th Five-Year report. This modeling system is an effective way to assess the carrying capacity of coastal socio-economic development. The conclusions may provide useful information for future development plans.

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