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Island Ecological Vulnerability Assessment: The Case of Three Islands in Tangshan, China

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ABSTRACT

In response to an objective demand for island development and utilization, the paper has analyzed the progress on the study of island ecological vulnerability based on Three Islands in Tangshan Bay, Hebei Province, and developed an evaluation method of island ecological vulnerability on the basis of an island eco-resilience and disturbance analysis. Results reveal that the Three Islands of Tangshan Bay have in general a resilient ecosystem with moderate disturbance. Therefore, the Three Islands of Tangshan Bay are suitable for proper development and utilization activities. The evaluation method is applicable to island development and utilization in China, and is a reference of guiding value to island protection, development and utilization.

Keywords: Island; Ecosystem; Vulnerability Evaluation; Three Islands of Tangshan Bay

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Island is a special area in the economic development, and has particularity and importance for ecosystem protection. Subject to unique geographical location and particular weather conditions, islands have a quite unstable and vulnerable ecosystem and limited environmental carrying capacity, and thus may be easily damaged and leading to serious eco-environment problems. As one of the key factors that restricts the development and utilization of islands and coastal zones, eco vulnerability must be considered and respected. Eco vulnerability related concepts were first introduced at the 7thSCOPE Summit held in Budapest in 1989. It was at this summit that the concept of ecotone was officially confirmed, kicking off the studies on eco vulnerability. Henceforth, western scientists have unfolded studies on the contents, types and applications of eco vulnerability (Tuner et al,2003[1]; Schroter et al., 2005[2];Adger,2006[3]; De Lange et al.2009[4]). Recent years also have seen some scholars studying the vulnerability of islands and coastal zones and making progress in island environmental vulnerability and environmental management, types of environment vulnerability and driving mechanism of the island's ecosystem[5][6][7][8]. However, there are still lack of in-depth studies on evaluation tools ofeco vulnerability as the premise of island development and utilization.

For this reason, this paper reorganized the concepts in relation to island vulnerability, evaluated island eco vulnerability in cases of Yuetuo Island, Dawanggang Island and Shijiutuo Island of Tangshan Bay, Hebei Province, and developed an evaluation method of island eco vulnerability on the basis of island eco resilience and disturbance, providing theoretical basis and technical reference for rational development and utilization of island resources.

1. Concept System and Evaluation Method of Island Eco Vulnerability

1.1 Concept System of Island Eco Vulnerability

The concept of vulnerability originated in the study of natural disasters in the field of environmental research[9], and the studies on vulnerability have been unfolded in large quantities since the 1990s [10].Right now, the concept of vulnerability has been applied to many fields, such as disaster management, ecology, public health, climate change and land use. For different application fields, the definition and concept of vulnerability have very big difference. For eco vulnerability, scholars have focused on the following aspects in the definition: (1) Eco vulnerability is integral. It is closely associated with the composition of ecosystem and the conditions of natural environment to which it belongs. But whether adverse natural conditions and structural features of an ecosystem can transform potential harms into real eco vulnerability depend more on external disturbances [11]. (2) Eco vulnerability is characterized by sensibility and instability, or an ecosystem can easily change under external forces or disturbances.

(3) Eco vulnerability is a relative concept. (4) Disturbances on ecosystem are multi-dimensional.

As far as islands are concerned, eco vulnerability can be construed as the impact on the ecosystem subject to external forces forecast and evaluated from explorations on its structure and functions, and its ability to resist external forces and recover from adverse effects, quantitatively and semi-quantitatively analyzed, described and identified. Island eco vulnerability is mainly concerned with what the main disturbances the study object is faced with, what factors influencing the structure of eco vulnerability and how to reduce eco vulnerability. The evaluation on island eco vulnerability is aimed at laying a good foundation for island development from the understanding of formation mechanism and change rule of island eco vulnerability so as to reduce adverse effects on the ecosystem during island development and utilization. In addition, the purpose of the evaluation is to determine the development and utilization suitability of islands, and thereupon put forward rational resourceutilization methods and ecological protection and recovery measures, and push forward island sustainabledevelopment and utilization.

1.2 Quantification of Island Eco Vulnerability

Island eco vulnerability is formed by an interaction of many factors, but depending on a source, points can be divided into its own factors and ecological system, including natural factors and human factors. This study argues that an islands' ecosystem of their own structure and the integrity of the resources, such as water, mineral, shoreline, beach and the surrounding waters, etc., its function is to maintain the integrity of the islands' ecosystem, called the ecosystem of the islands resilience. From the system of natural or man-made interference of the outside world, brings the sign of ecosystem vulnerability of the islands, disturbance is a force to island eco vulnerability. This study suggests that a single island's ecosystem shows high resilience and low disturbance, it is suitable for utilization. Therefore, the study on island eco vulnerability can be unfolded from the resilience (state) and disturbance (pressure) of the island's ecosystem.

1.2.1 Quantification of resilience of island ecosystem

The resilience of the island's ecosystem reflects the natural, potential anti-disturbance ability of different island ecosystems, mainly influenced by factors such as landform, weather and biocoenosis of island, and complementary and coordinating ability between ecological elements and eco subsystems. The resilience of an island's ecosystem can be computed based on the formula of resilience of general regional ecosystem in combination of unique island factors as follows:

$$El = \gamma * H * S * V * E/c_1 * c_2 \quad (1)$$

Wherein, El is ecological resilience, γ represents the regulation coefficient, H is the landscape diversity index and S is the biodiversity index, V stands for the vegetation index and E the nearshore hydrodynamics index, are the annual gradient of island temperature and precipitation. The landscape diversity index and vegetation

index can indicate the landform and vegetation coverage of the island, the biodiversity index signifies the complexity of the island's ecosystem, the precipitation manifests the fresh water conditions of the island, the nearshore hydrodynamics index showcases the self-purification ability of the island on pollutants and the stability of sand-mud island, the annual gradient of island temperature and precipitation indicates the climatic conditions of the island.

1.2.3 Quantification of island eco disturbance

The study on island eco disturbance needs to take natural disaster, environmental pollution, artificial destruction and invasion of alien species into full consideration, and incorporate these elements into the criteria layer. The index composition is shown in the table below.

Table 1. Evaluation Index System Composition of Island Eco Disturbance

Objective Layer	Criteria Layer	Index Layer
Island Eco Disturbance	Natural disaster	Meteorological disaster grade
		Geological disaster grade
	Human disturbance (artificial destruction, environmental pollution)	Landscape fragmentation rate
		Natural shoreline ratio
		Artificial structure area ratio
		Water quality compliance rate
		Sediment quality compliance rate
		Biological pollution status
	Bio-invasion	Distribution area of invasive species
		Density of invasive species

In the table, objective layer means evaluation aim of the index system. Criteria layer is composed of several corresponding estimate factors, and it is estimate indexes integrated from factors of the same kind. Index layer is the basic of the index system, it could get the number directly.

The index system described in the above table applies to general island ecosystems. Different indexes may be selected for different types of island and island environments.

To give a holistic evaluation on the island eco vulnerability, the indexes should be weighted to generate a comprehensive index that indicates island eco vulnerability. The analytic hierarchy process is adopted in this study to determine the weights of the evaluation indexes.

As studies in island eco disturbance are rarely seen, there is great uncertainty about the determination of evaluation criteria. This study deploys the vector protection method to indicate the island eco disturbance through the projection distance of the evaluation object on the ideal object.

Given that the evaluation object set is $X = \{X_1, X_2, X_3, \cdots X_n\}$

X_i

, which can be a set of different islands or different development stages of an island; the index set is

value) of index K_i , denoted as (i=1, 2, ···, m; j=1, 2, ···, n); matrix reflects the evaluation matrix or attribute matrix of the evaluation object set X to index set K. Through the dimensionless method, the evaluation matrix composed of

The evaluation object consisting of the ideal value of evaluation

is the ideal evaluation object.

Under the action of weight vector W, the augmented weighted standard evaluation matrix is built:

If each decision-making objective is considered as row vector (vector), the modulus of vector will be the value of the row vector, which is,

The direction of vector forms a certain angle with vector

and the cosine of the included angle is:

j=1, 2,

, n

Therefore, the projection of each evaluation object

on the ideal object

The projected value

It's evident that $\theta <$ can be taken as the evaluation index for island disturbance.

<1 and is the greatest and optimum value, which means that the island ecosystem is under the strongest disturbance. Hence, a comprehensive evaluation can be conducted on the disturbance of the evaluation objects based on the projected value

1.3 Evaluation on Island Eco Vulnerability

1.3.1 Evaluation process

The resilience of the island's ecosystem is the supporting condition for eco vulnerability and can be taken as the first-level meaning of eco vulnerability, thus first grade evaluation takes the resilience of the island's ecosystem as the evaluation criteria. The disturbance of the island's ecosystem is the direct cause for eco vulnerability to show and can be taken as the second-level meaning of eco vulnerability, thus second grade evaluation takes the disturbance of the island's ecosystem as the evaluation criteria. The evaluation process is as follows:

(1) Island status survey: a survey focusing on the eco-environment of the island through such methods as remote monitoring, ground investigation, historical data collection and statistics.
(2) Island vulnerability evaluation: an evaluation on eco resilience and disturbance through quantitative evaluation methods based on the understanding of the eco-environment status of the island.
(3) Comprehensive analysis evaluation: A comprehensive evaluation on the vulnerability of the island's ecosystem based on the first grade and second grade statistic evaluation results, and a judgment on the suitability of island development and utilization.

1.3.2 Graded comprehensive evaluation

(1) Determination of evaluation score

We take analytic hierarchy process to consider weight factor for the index and in accordance with the quantitative evaluation methods of island eco vulnerability, we can obtain the evaluation index of island eco resilience and disturbance. To grade the evaluation, the evaluation must be determined as follows:

Existing standard may be used to determine the evaluation score. In case of no standard, the ideal value or target value may be taken as reference. The standard value is 100 points and the other values can be determined through the ratio of actual value to standard value as follows:

$$C_i = F_i/F_o \times 100$$

Wherein, is the value of Factor i; Fi represents the actual measured value of Factor i, and standards for the standard value, target or idea value of Factor I.

(2) Graded evaluation

The first grade evaluation mainly reflects how well the ecosystem can resist disturbance and recover and repair itself after the disturbance. Therefore, the greater the value, the more stable and less vulnerable the ecosystem. The second grade evaluation primarily indicates the disturbance of the island's ecosystem. Hence, the greater the value, the more vulnerable the ecosystem. See the graded evaluation criteria in the following table.

Table 2. Evaluation Grading Criteria of Island Eco Vulnerability

	<20	21~40	41~60	61~80	>81
First grade evaluation	Weak stability	Low stability	Moderate stability	Good stability	High stability
Second grade evaluation	Weak disturbance	Relatively weak disturbance	Moderate disturbance	Relatively strong disturbance	Strong disturbance

A graded comprehensive evaluation on the vulnerability of the island's ecosystem can present more accurate, clear and targeted evaluation results. For instance, the vulnerability of an island graded as high stability and strong disturbance indicates that the island has high eco resilience, but is under strong disturbance. Therefore, caution should be exercised in development to protect its ecological environment, an island graded as high stability and relatively weak disturbance in terms of vulnerability showcases that the island has high eco resilience and is under relatively weak disturbance, and development can be unfolded.

2. Island Eco Vulnerability Evaluation of Three Islands of Tangshan Bay

2.1 Island Status

Located in the coastal areas of Tangshan, Hebei Province, the Three Islands of Tangshan Bay is adjacent to Binhai New District in the west, Caofeidian Industrial Zone in the northwest, and Jingtang Port Area in the northeast. The three uninhabited islands, Yuetuo Island, Dawanggang Island and Shijiutuo Island, cover a land area of 11.96km2, 22.41km2 and 4.04km2, with a total land area of37.75km2.

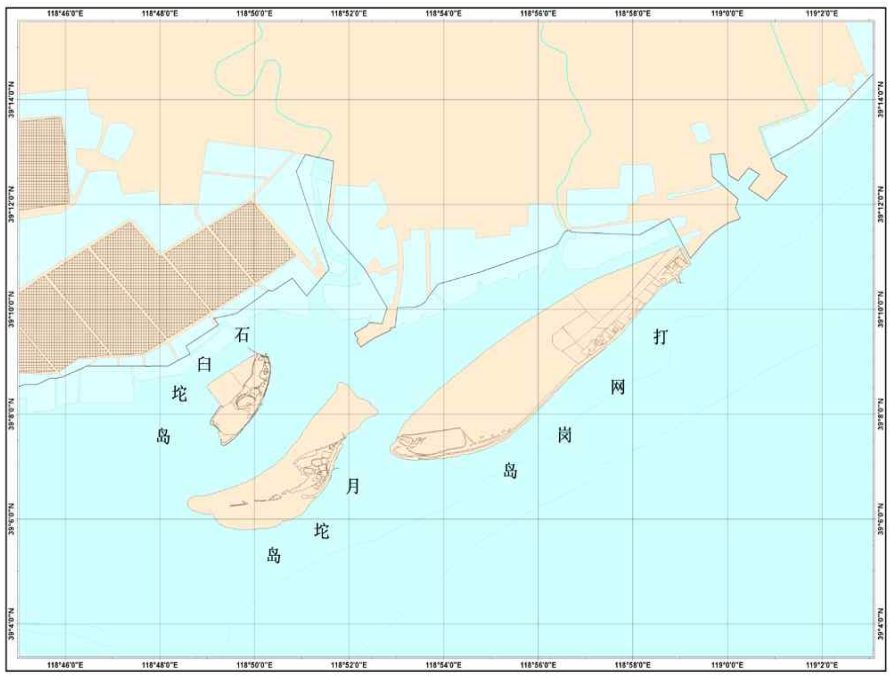

Figure 1. Geographical Location of Three Islands of Tangshan Bay

2.2 Data Acquisition

This study is designed to monitor the land resources, ecological resources, energy resources and marine environment conditions of the Three Islands of Tangshan Bay through such methods as remote sensing and interpretation, field investigation, questionnaire-based survey and historical data collection.

2.3 Island Eco Resilience Analysis of Three Islands of Tangshan Bay

The island eco resilience represents the foundation level of its eco vulnerability. As another important indicator of how well the ecological environment can support the island's economic activities, island eco resilience is the ability of self-maintenance and self-regulation of the ecological environment deviating from original balance under external disturbance. In accordance with the above-mentioned methods, the quantitative study on eco vulnerability reveals the results in the table below.

Table 3. Index Values Influencing the Eco Resilience of Three Islands of Tangshan Bay

	Dawanggang Island			Yuetuo Island			Shijiutuo Island		
Year	2003	2008	2010	2003	2008	2010	2003	2008	2010
H	1.6	1.64	1.5	1.87	1.9	1.72	1.92	1.9	1.92
S	0.302	0.256	0.301	0.376	0.361	0.433	0.372	0.296	0.336
V	0.283	0.278	0.261	0.293	0.296	0.299	0.315	0.274	0.337
E	0.632	0.715	0.678	0.611	0.62	0.63	0.532	0.566	0.526
C1	0.016	0.04	0.024	0.056	0.049	0.048	0.024	0.021	0.056
C2	0.374	0.17	0.355	0.14	0.145	0.392	0.362	0.348	0.264
EI	0.144	0.123	0.094	0.161	0.177	0.075	0.138	0.119	0.077

Notes: H, S, V, E, c1, c2 and EI in the table respectively represents the landscape diversity index, biodiversity index, vegetation index, nearshore hydrodynamics index, annual gradient of island temperature,annual gradient of precipitation, and eco resilience.

2.4 Island Eco disturbance Analysis of Three Islands of Tangshan Bay

2.4.1 Determination of index system

The evaluation on the island eco disturbance adopts the vector projection method by building the evaluation index system. Because of the differences of islands in terms of latitude and climatic zone, the evaluation index system is adjusted on the basis of the abovementioned index system framework according to the actual conditions of the Three Islands of Tangshan Bay. The adjusted evaluation index system is shown in the table below.

Table 4. Evaluation Index System of Eco disturbance of Three Islands of Tangshan Bay

Objective Layer	Criteria Layer	Index Layer
Island eco disturbance A	Natural disasterB1	Island geological disaster grade C1
	Human disturbance B2	Landscape fragmentation rate C2
		Natural shoreline ratio C3(%)
		Artificial structure area ratio C4(%)
		Water quality compliance rateC5(%)
		Sediment quality compliance rate C6(%)

In accordance with the meaning and valuation method of the indexes in the evaluation index system of eco disturbance, the base data of these indexes can be calculated and obtained in combination of the original index data collected, as shown in the table below.

Table 5. Base Data of Eco disturbanceof Three Islands of Tangshan Bay in 2010

	C1	C2	C3	C4	C5	C6
Yuetuo Island	Low	0.32	67	1.52	73.5	82.1
Dawanggang Island	Low	0.46	72	2.43	78.3	76.5
Shijiutuo Island	Low	0.22	53	1.58	80.6	86.6

2.4.2 Eco disturbance evaluation of Three Islands of Tangshan Bay

The eco disturbance of Three Islands of Tangshan Bay is evaluated based on the evaluation model introduced in the above section, complemented by the previously defined index system and base data, in two grades.

(1) Computation of second grade evaluation objectives

The second grade evaluation has 2 different objectives, namely, contributions of the indexes at different grades to the upper indexes. The evaluation results at two grades are computed as per the methods previously introduced, as shown in the table below:

Table 6. Computation of Second Grade Evaluation Index

Second Grade Evaluation			Yuetuo Island	Dawanggang Island	Shijiutuo Island
Evaluation Objectives	Index Layer Index	Weight Coefficient			
Natural Disaster	Island geological disaster grade	1	1.000	1.000	1.000
	Evaluation value		1.000	1.000	1.000
Human Disturbance	Landscape fragmentation rate	0.422	0.295	0.269	0.125
	Natural shoreline ratio	0.103	0.766	0.833	0.470
	Artificial structure area ratio	0.201	0.040	0.134	0. 030
	Water quality compliance rate	0.165	0.766	0.786	0.833
	Sediment quality compliance rate	0.109	0.719	0.697	0.848
	Evaluation value		0.416	0.432	0.337

(2) Computation of second grade evaluation objectives

The first grade evaluation objectives are the overall evaluation objectives, computed based on the results of the second grade evaluation through the same process of the second grade evaluation. The evaluation conclusion is the evaluation value under the overall objectives and the relative value of the eco disturbance of the Three Islands of Tangshan Bay, listed in Table7. It can be seen from the evaluation results that Dawanggang Island is under greatest disturbance, consistent with the fact that this island is most developed and utilized among the three islands.

Table 7. Computation of First Grade Evaluation Index

First Grade Evaluation			Yuetuo Island	Dawanggang Island	Shijiutuo Island
Evaluation Objectives	Index Layer Index	Weight Coefficient			
Eco disturbance of Three Islands of Tangshan Bay	Natural disaster	0.196	1.000	1.000	1.000
	Human disturbance	0.804	0.416	0.432	0.337
	Evaluation value		0.495	0.509	0.427

2.5 Comprehensive Evaluation on the Eco vulnerability of Three Islands of Tangshan Bay

The comprehensive evaluation results of eco vulnerability of Three Islands of Tangshan Bay are computed as per the previously defined comprehensive evaluation methods of island eco vulnerability and the results of eco resilience and eco disturbance, as shown in the table below.

Table 8. Evaluation Table of Eco vulnerability of Three Islands of Tangshan Bay

	Yuetuo Island			Dawanggang Island			Shijiutuo Island		
	2003	2008	2010	2003	2008	2010	2003	2008	2010
Resilience	79	67	51	88	97	40	75	65	42
Disturbance	~	~	42	~	~	49	~	~	46

The eco vulnerability of Three Islands of Tangshan Bay is measured through eco resilience and disturbance. Disturbance reflects the ability of the three islands to withstand external disturbance. The analysis on the eco resilience in 2003, in 2008 and in 2010 indicates that the three islands have increasingly deteriorating resilience which is moderate to high. By 2010, the three islands had been under moderate disturbance, revealing that they have relatively high eco resilience and are subject to moderate eco disturbance as a whole. Therefore, these three islands are suitable for proper development and utilization activities.

3. Summary

After defining the concept and meaning of island eco vulnerability, this paper has taken island eco vulnerability as the evaluation criteria for island development and utilization, and developed the quantification methods composed of island eco disturbance and eco resilience in combination of the typical characteristics and elements of an island ecosystem. The Three Islands of Tangshan Bay have been adopted for verification on the island eco vulnerability evaluation criteria. The evaluation results reveal the suitability of these three islands for development and utilization, providing theoretical basis and technical reference for sustainable and rational development and utilization of island resources, and protection of island ecosystem.

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