***J. Ocean Univ. China*** (Oceanic and Coastal Sea Research)
DOI 10.1007/s11802-012-1895-9
ISSN 1672-5182, 2012 11 (2): 253-256
*http://www.ouc.edu.cn/xbywb/*
*E-mail:xbywb@ouc.edu.cn*

# A Study on Marine Region Carrying Capacity and Eco-compensation

MA Caihua, YOU Kui*, MA Weiwei, XIE Jun, and LI Fengqi

*Ocean University of China*, *Qingdao* 266003, *P. R. China*

(Received October 10, 2011; revised December 8, 2011; accepted January 23, 2012)


**Abstract** With the using up of land resources, people are beginning to pay attention to the exploitation of the ocean and the use of marine resources is becoming more and more intense. Whether and how the ocean can be sustainably exploited as it is being exploited is an academic hot topic. This question is addressed in this paper based on the theories of carrying capacity of a marine region and marine eco-compensation, and the amount of the loss is calculated by the method of Time Value of Capital. This thesis covers the study of eco-compensation between two specific subjects with clear compensation objects, and as a defined approach and standard, the proposed method has good operability and positive practical significance in the good use of the ocean.

**Key words** carrying capacity of marine region; marine eco-compensation; time value of capital

## 1 Introduction

The 21st century is generally acknowledged to be the 'century of the sea'. With the depletion of the land resources, people are beginning to pay more attention to the exploitation of the vast ocean to obtain what they need in as large a quantity as possible. All things have limits which, if surpassed, can lead to unexpected consequences, it being a truism which is particularly pertinent to the exploitation of the ocean. How to exploit the ocean to benefit mankind is a hot issue of shared concern today. The present paper proposes that it would be an effective measure to balance the carrying capacity of a marine region and the marine eco-compensation.

## 2 About the Issue

A comprehensive view of the many research findings on carrying capacity and ecological compensation shows that most studies are focused on a single aspect. For instance, some research regarding carrying capacity mainly refers to carrying capacities of water, land and forest resources. in relation to population and economy. Some research has proposed theoretic and creative definitions of carrying capacity of marine region, together with evaluation indicator systems and evaluation methods (Han *et al*., 2006). Research has also been conducted on marine sustainable development (Jin *et al*., 2001). As regards the research on eco-compensation, earlier eco-compensation theories and empirical studies mainly concentrate on freshwater areas such as rivers, lakes, *etc*., while for eco-compensation in oceans, there is little other than some general theoretical discussions on the application of marine ecological resource management (Han *et al*., 2007).

With regard to the practical research on marine eco-compensation, many studies can be found in the field of fishery resource management, but few are in other marine resource management fields. Endowed with rich resources, the ocean is not only one of the most important ecosystems in the biosphere, but also an essential foundation for supporting sustainable social development. Research by Chen *et al*. reveals that the service function value of the marine ecosystem in China is RMB 2.17 trillion Yuan per year, which is 1.73 times that of the GDP in the same year (Chen and Zhang, 2000; Murawski and Ten, 2007). In 2006, the added value of the main marine industries accounted for 4% of the gross domestic product in the corresponding time period (Qiu *et al*., 2008). It shows the supporting capacity of marine resources to socioeconomic development shall be in no way underestimated. However, with the aggravation of offshore pollution, deterioration and exhaustion of fishery resources, frequent marine eco-disasters and other ever-more severe ecological environmental problems, the supporting capacity is continuously impaired, resulting in the exceeding of the carrying capacity of marine regions. Therefore, the adoption of an ecosystem method for marine ecosystem management and the corresponding application of marine eco-compensation on this basis are particularly necessary.

* Corresponding author. E-mail: ykmch@ouc.edu.cn

## 3 Solution to the Issue

To elucidate the concept of environmental carrying capacity, we first need to comprehend it from the perspective of structure and function of the environmental system. The general system theory holds that a system is an aggregate composed of specific structures and functions. Thus, research on system can be carried out structurally and functionally. The structure of the environmental system comprises the occurrence of various environmental factors and the regular movements and variation of these factors. The function of the environment in a marine region or the environmental subsystem of a certain factor (specifically taking the ocean as the example here) refers to its capability of sustaining its own stable state, or self-organizational capability, and also its capability of interacting and its mode (s) of interaction (provision of natural resources and acceptance and purification of wastes) with the human system. The human subsystems most closely connected to marine ones are the social subsystem and the economic subsystem. The interaction between these subsystems and the marine environmental systems means that the ocean provides resources for human economic development. This economic development has certain impact on the marine environment, such as waste discharges, and, vice versa, as changes of the marine environment affect human economic development when they mean that the quality of resources bestowed by the environment is negatively affected, thereby impairing the harmonious development between the environment, economy and society. Given the importance of supporting a balanced interrelation between the marine system and the human system, this paper considers the carrying capacity of ocean regions and how marine eco-compensation can be determined.

### 3.1 Determination of Carrying Capacity of Marine Region

This paper consists of three parts, namely the supplying capacity of marine resources, the economic function of marine industry and the marine environmental capacity. In analyzing the selection of evaluation indicator system and the model of the carrying capacity of marine region, the state-space method is adopted to perform the measurement of carrying capacity and carrying state and, as a multidimensional space, each space is composed of a sub-factor. Based on the carrying bodies and the carried bodies of marine, human and land systems, the three aspects of human beings and their socio-economic activities, marine natural resource reserves and marine environmental capacity should be taken into primary consideration in establishing the evaluation indicator system of the carrying capacity of a marine region. On the basis of previos findings (Jin *et al*., 2001; Hui *et al*., 2001; Han *et al*., 2006.), the pressure indicators, carrying capacity indicators and interregional communication indicators are taken as the major contents of study (see Fig.1).

By adopting the state-space method to describe the state of the system (Mao and Yu, 2001), the system is generally represented by three-dimensional state-space axes representing the state vectors of various factors (human activity axis, resource axis and environment axis), and different carrying states of the marine system within a certain time scale can be represented by utilizing the carrying state point in the state-space method. The spherical spatial model of carrying capacity of marine system and carrying state is adopted as an example. It is regarded as loadable when on and in the spherical surface and overload when the other way round (see Fig.2).

In the spatial state-space shown in Fig.2, any kind of carrying state of the marine, human and land systems within a certain timescale can be represented through the

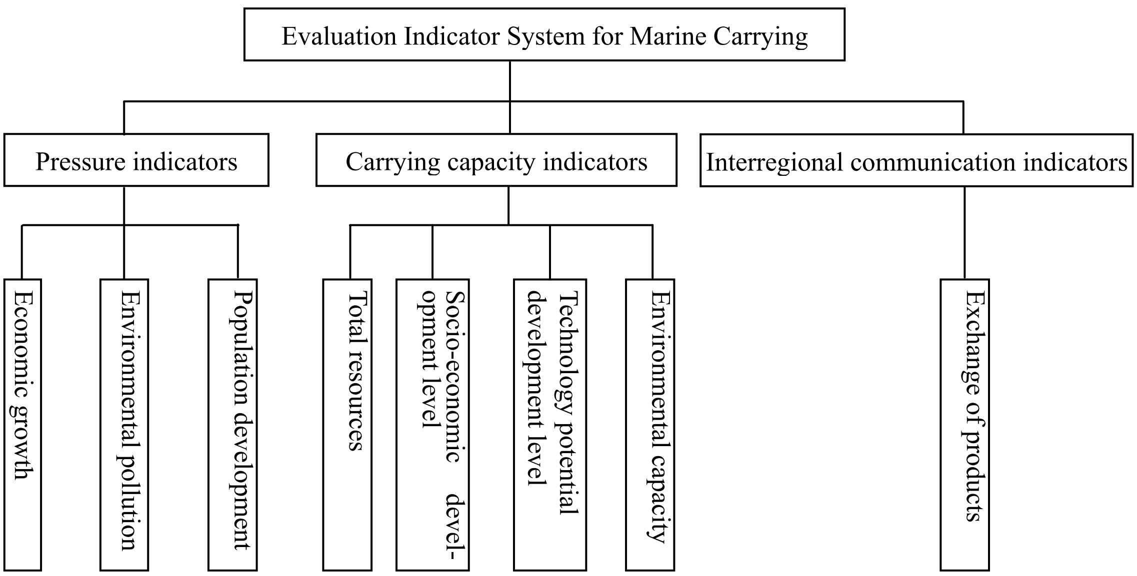


Fig.1 Evaluation indicator system for carrying capacity of marine region.

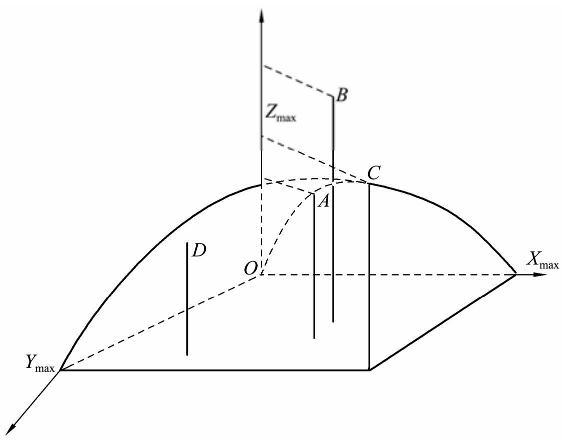


Fig.2 Spatial State-Space Model of Carrying Capacity and Carrying State. X, Resources activity axis; Y, Environment axis; Z, Human activity axis.

carrying state points, and the carrying state points representing that the marine, human and land systems stay under an ideal state (indicating that the state of best combination reached after the interaction and matching between human beings and the land in the marine, mankind and land systems within a certain period) refers to the position of the carrying capacity of marine region in the spatial space, like point C. Accordingly, points A and D signify the fact of lowering the carrying capacity of the specific marine resource environment combination, while the point B is just the reverse. All the carrying capacity points of marine regions formed by different resource environments in the spatial space constitute an $X_{max}OY_{max}$ curved surface, which can be called the carrying capacity curved surface of marine region. Based on this, the magnitude of carrying capacity of a marine region can be expressed by utilizing vector modulus involving an origin point and system state points in the spatial state-space, and the mathematical expression is:

$$P_{ccmr} = |M| = \sqrt{\sum_{i=1}^{n} x_{ir}^{2}}\ , \qquad (1)$$

where $P_{ccmr}$ indicates the magnitude of carrying capacity value of marine region; |M| indicates the modulus of the oriented vector of the carrying capacity of marine region; and $x_{ir}$ indicates the coordinate figures (i =1, 2, …, n) in the spatial state-space when human activities and resource environment are under an ideal state.

Considering the different functions of the carrying capacity of a marine region performed by various factors of human activities and resource environment, the weighting of the state axis should be taken into account, and the mathematical expression of the carrying capacity of marine region is:

$$P_{csmr} = |M| = \sqrt{\sum_{i=1}^{n} w_i x_{ir}^{2}}\ , \qquad (2)$$

where, $w_i$ indicates the weighting of $x_i$-axis.

According to the analysis of the conceptual model described above, the relation between the vector modulus of the carrying capacity state of a marine region and that under an ideal condition can be obtained, to judge the carrying capacity state of marine region $P_{csmr}$, that is, overload for the specific value larger than 1, full-carrying for the specific value equal to 1 and loadable for the specific value less than 1. As a matter of fact, there is a certain deviation of the actual carrying capacity state of a marine region from an ideal one in spatial state, and the deviation reflects the carrying capacity state of marine regions under actual conditions. As only the environmental carrying capacity under normal conditions is considered in this thesis, the deviation is not discussed here. Therefore, although the value of the carrying capacity state of marine region in a certain period can be determined, the judgment on the carrying capacity state can only be made by comparing the vector modulus in the spatial state, and the calculation in the thesis is also performed by adopting this point of view.

### 3.2 Determination of Marine Eco-compensation

On the basis of the carrying capacity of a marine region, the eco-compensation for overload and loadable cases is performed by the ecosystem approach to formulate an effective policy for reasonable exploitation and utilization of marine regions.

The ecosystem approach refers to an all-round way of protecting and managing natural resources on the basis of science, and is a framework for thoughts on ecosystem management and formulation of action plans in accordance with the principles of ecology and sustainable development. As is different from traditional, decentralized management based on a single species or a single problem, the relevant ecology, environment, economy, society and other factors are comprehensively taken into account in marine management employing the ecosystem approach, especially the human factors affecting the utilization of marine resources being considered (U. S. Commission on Ocean Policy, 2004).

In the past eco-compensation has mainly focused on three basic issues, namely the definition of compensation subject and compensation object, the selection of compensation approaches and the determination of compensation standards (Mao *et al*., 2002; Xiong *et al*., 2003). In this thesis, the compensation for the overloaded and loadable cases of a marine region is carried out from the perspective of quantity, and the magnitude is calculated for the eco-compensation in terms of time value of money.

### 3.3 Empirical Study – Economic Analysis Taking a ‘Pollution Problem’ as an Example

Given a case where an ironworks enterprise (S) produces a certain amount of steel ($Y$), and discharges a certain amount of pollutants ($X$) into the sea, and another enterprise (E) is a fishery located downstream of a marine region and it is suffering from the pollutants discharged.

It is assumed that the cost functions of the ironworks and the fishery are respectively $C_S(Y, X)$ and $C_E(Z, X)$, where $Z$ represents the output of fish. Within a certain range, the increasing of pollutant discharge volume reduces the production cost of steel on one hand, and can increase the production cost of fish on the other hand. If the carrying capacity of the marine region stays at $P_{csmr}=P_{ccmr}$, it is suggested that the waste discharge capacity of the marine region achieves a balance with its self-purification capacity, thereby not polluting its environment and causing fatal damage to the fishery. However, the ironworks and the fishery both strive for the maximization of profits, therefore two types of pollutant discharge occur as follows:

$$\left|P_{csmr}\right| - \left|P_{ccmr}\right| > 0 ,$$

indicating that the pollution surpasses the environmental capacity;

$$\left|P_{csmr}\right| - \left|P_{ccmr}\right| < 0 ,$$

indicating that the pollution is lower than the environmental capacity.

The objective functions of the two types of pollutant discharge are respectively:

Ironworks (S): $\max[P_s Y - C_s(Y,X)]$, $P_s$ indicating the steel price.

Fishery (F): $\max[P_s Z - C_s(Z,X)]$, $P_s$ indicating the fish price.

The prerequisites for the maximum profits of the two factories are respectively:

$$\frac{\partial C_s(Y^* - X^*)}{\partial Y} = P_s ; \quad \frac{\partial C_E(Z^* - X^*)}{\partial Z} = P_E , \tag{3}$$

where, $Y^*, X^*, Z^*$ respectively represent the optimum quantities of output of the ironworks, the most suitable discharge capacity and the optimum quantity of output of fish.

These prerequisites show that for the maximum level of profits, each good added - steel and pollution – its price should be equal to its marginal cost. In terms of the ironworks, the price of pollution for one of its products is zero, therefore the pollution will continue before the pollution cost of a newly-added unit becomes zero.

$$\frac{\partial C_s(Y^*, X^*)}{\partial X} = 0 . \tag{4}$$

Through the analysis above, it can be seen that the fishery has no way to control despite the concern about the discharge volume of pollutants. The ironworks, by contrast, can control its discharge volume but disregards the social cost incurred from the pollution to the fishery in consideration of its maximum profits. Therefore, the marine eco-compensation can play the coordinative role here, *i.e.* $\left|P_{csmr}\right| - \left|P_{ccmr}\right| > 0$, the fishery must be compensated by the ironworks accordingly. This is set as $D_{S\to E}$, that is to say, the ironworks compensates the fishery. If it were the other way round, *i.e.* $\left|P_{csmr}\right| - \left|P_{ccmr}\right| < 0$, the fishery should make certain compensation to the ironworks, being set as $D_{E\to S}$. On the assumption that the annual interest rate is i, the time limit (year) from $\left|P_{csmr}\right| - \left|P_{ccmr}\right| > 0$ or from $\left|P_{csmr}\right| - \left|P_{ccmr}\right| < 0$ is set as n. For the former, the ironworks should make certain compensation to the fishery; while for the latter, the ironworks should get a certain amount of compensation.

To conclude, it can be easily seen that this thesis covers the study of eco-compensation between two specific subjects with clear compensation objects, and, as a defined approach and standard, it has good operability and a positive practical significance.

## Acknowledgements

This work was supported financially by projects of the National Science and Foundation of China (41106094, 30800841) and Department of Science and Technology of Shandong Province (BS2010NY030).

## References

Chen, Z. X., and Zhang, X. S., 2000. Benefit value of chinese ecosystem. *Chinese Science Bulletin*, **45** (1): 17-22 (in Chinese with English abstract).

Han, Z. L., Di, Q. B., and Liu, K., 2006. Research on the theories and assessment method of carrying capacity of marine region. *Areal Research and Development*, **25** (1): 1-5.

Han, Q. Y., Huang, X. P., and Shi, P., 2007. Ecological compensation and its application in marine ecological resources management. *Chinese Journal of Ecology*, **26** (1): 126-130 (in Chinese with English abstract).

Hui, Y. H., Jiang, X. H., and Huang, Q., 2001. Research on evaluation index system of carrying capacity of water resources. *Bulletin of Soil and Water Conservation*, (2): 30-34.

Jin, J. J., Yun, C. X., and Gong, C. L., 2001. Concept and index system of coastal zone sustainable development – a case study on part of the cities in the Liaoning Province coastal zone. *Marine Science Bulletin*, **20** (1): 61-66 (in Chinese with English abstract).

Mao, H. Y., and Yu, D. L., 2001. Regional carrying capacity in Bohai Rim. *Acta Geographica Sinica*, **56** (3): 363-371.

Mao, X. Q., Zhong, Y., and Zhang, S., 2002. Conception, theory and mechanism of eco-compensation. *China Population, Resources and Environment*, **12** (4): 38-41.

Murawski, S. A., and Ten, M., 2007. Concerning ecosystem approaches to marine resource management. *Marine Policy*, **31** (6): 681-690.

Neng, Y., Wang, K. L., and Wang, C. H., 2003. Eco-compensation for restoring lake on farmland – a case study of the Dongting Lake area. *Rural Eco-Environment*, **19** (4): 10-13.

Qiu, J., Liu, R. Z., and Zhao, J. Z., 2008. Applying eco-compensation under the framework of ecosystem approach to Bohai Sea management. *China Population Resources and Environment*, **18** (2): 60-64 (in Chinese with English abstract).

U. S. Commission on Ocean Policy. 2004. An ocean blueprint for the 21st century, Washington, DC. *U. S. Commission on Ocean Policy*, 5-34.

**(Edited by Ji Dechun)**