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The marine ecosystem services values for China based on the emergy analysis method

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ABSTRACT

The purpose of this research is to acquire knowledge and understanding of the value of marine ecosystem services in China's coastal regions. This evaluation involved combining existing research results, based on the theory of ecosystem services and emergy analysis, estimating marine ecosystem services values in 11 coastal provinces and cities for each year from 2005 to 2014, and analyzing the changes in marine ecosystem services values over time and across regions. The results showed that the values had in general increased during the time the study was conducted, and that Hainan, Guangdong, and Shandong accounted for most of the value. Applying the Theil index to analyze the regional differences of China's coastal marine ecosystem services values, we found that these disparities had shrunk; intra-region disparities were the primary cause of this shrinkage, but the developments of marine ecosystem services values of both intra- and inter-regions were unbalanced. Changes in the marine ecosystem services structure in China's coastal regions from 2005 to 2014 were analyzed using the information entropy theory. Over time, the information entropy and equilibrium degree of China's coastal marine ecosystem services structure consistently showed a fluctuating uptrend; across regions, the information entropy of the marine ecosystem services in the 11 coastal provinces and cities had larger discrepancies. Our results reveal emergy analysis is a helpful method for assessing marine ecosystem services, and our database can serve as a basis for more studies the future. Our research has also revealed the problems existing in the development of marine ecosystem services in China, such as the imbalance in the development of marine ecosystem service values between regions and the differences in the degree of development of various services, which is crucial to the future development of the ocean.

1. Introduction

The benefits humans derive directly or indirectly from ecosystem functions are called ecosystem services (Costanza et al., 1997). Building on this definition, Daily (1997) defined marine ecosystem services as the benefits provided to humans by the natural marine ecosystem and its ecological processes. In 1992, the United Nations Conference on Environment and Development emphasized that the sea was not only a key component of human life support systems, but also essential to sustainable development: The sea plays an important role in improving and balancing the global ecological environment. The marine ecosystem is one of the most productive, diverse, and valuable ecosystems on Earth (Souter and Linden, 2000; Spalding et al., 2001; Wilkinson, 2008); however, it is currently under threat worldwide due to a wide range of pressures, including unsustainable fishing practices, the development of tourism and urban infrastructure, pollution from land-based sources, ocean acidification, and sea level rise (Beharry-Borg and Scarpa, 2010; Cinner et al., 2012). This has resulted in significant losses and degradation of these important habitats, which in turn is likely to negatively impact the welfare and livelihood of people living in coastal areas (MA, 2005). Thus, assessing the value of marine ecosystem services is of strategic importance to furthering our understanding, development, and protection of the ocean and to promoting sustainable development.

Because of the unique nature of the marine ecosystem, research methods used to study land ecosystems must be adapted when used to study marine environments. The sheer volume of marine life and the complexity of marine ecological processes are as yet beyond our technological capabilities to fully and completely evaluate (Zheng and Shi, 2009); therefore, it is difficult to develop appropriate measures to assess and compare marine ecosystem services in different areas. A number of studies that have attempted to assess the value of marine ecosystems at different scales have been published. Costanza et al. (1997) valued global marine ecosystem services at 20.9 trillion USD, which accounted

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for 63.3 percent of the value of all global ecosystem services. Christie et al. (2015) assessed the benefits derived from alternative policy interventions and generated a wealth of evidence on the economic value created by the protection and enhancement of marine protected areas in St Vincent and the Grenadines. Brown and Hausner (2017) described and analyzed the distribution of cultural ecosystem values found in coastal areas in multiple countries, compared the results with non-coastal areas, and identified the type and intensity of ecosystem values located in coastal areas.

In terms of China specifically, Chinese scholars have also been studying marine ecosystem services and functions since the beginning of the twenty-first century. Chen et al. (2006) used the marine ecosystem services evaluation framework proposed by Millennium Ecosystem Assessment (MA) (MA, 2005) to summarize and identify the elements of marine ecosystem services and established a classification system for Chinese marine ecosystem services. Xia et al. (2014) estimated the ecosystem services value of the Jiangsu offshore system and analyzed its regional distribution characteristics by applying national standards in the "Technical Directives for Marine Ecological Capital Assessment" (GB/T28058-2011) (General Administration of Quality Supervision, 2011). Shi et al. (2007) proposed a method for evaluating typical marine ecosystem services, and Xu and Han (2003) discussed a framework for estimating the value of marine ecosystem services. In view of the development and utilization of China's offshore ecosystem, a framework that could be used to evaluate the quality and value of marine ecosystem services was established (Chen et al., 2013).

As evidenced by the aforementioned studies, domestic and international research focused on marine ecosystem service functions and value evaluation have been mostly confined to small geographic areas or single years and have been limited to assessing one or perhaps several marine ecosystem services values. Consequently, none have included a comprehensive and systematic analysis and evaluation of the value of marine ecosystem services. To fill this gap, we used Odum, 1996 emergy analysis method to assess the marine ecosystem services values for China's coastal regions, and then used the Theil index and the information entropy theory to further identify regional differences and structural changes in these values over time.

The remainder of this paper is structured as follows. Section 2 describes the methodology of ecosystem services and the emergy analysis theory. Section 3 presents the calculations, regional differences, and structural changes to the marine ecosystem services value. Finally, Section 4 provides some concluding remarks.

2. Materials and methods

2.1. Study area

China has about 3 million square kilometers under its jurisdiction, with abundant ocean resources and 5000 islands with areas greater than 500 m^2. Its coastlines extend for 32,000 km, including 18,000 km along the continent and 14,000 km on island territories. Many ocean species live in these waters, and its oil and gas reserves exceed $400 \times 10^8 t$ and $14.09 \times 10^{12} m^3$ of oil equivalent (Zhang et al., 2003). These areas are also extremely rich in sand mineral resources (Lou et al., 2005). China's coastal provinces, municipalities, and autonomous regions (excluding Hong Kong, Macao, and Taiwan), from north to south, include Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan. For the following analysis for the dynamic regional changes of marine ecosystem services values, these 11 coastal provinces and cities in China are separated into three major regions according to their location: the Northern region (Tianjin, Hebei, Liaoning, and Shandong), the Central region (Jiangsu, Shanghai, and Zhejiang), and the Southern region (Fujian, Guangdong, Guangxi, and Hainan). Therefore, the coastal areas can be divided into a three-level hierarchical structure: coastal China, three major regions of the coast (Northern, Central, and Southern), and the provinces. Implementing the principle of the Theil index, the disparities of values of marine ecosystem services were then disaggregated into intra- and inter-region disparities.

2.2. Framework for valuing marine ecosystem services in China's coastal areas

Several studies have proposed classification systems for ecosystem services. The first authoritative classification system was proposed by Costanza and his colleagues who divided ecosystem services into 17 types: gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation, and culture (Costanza et al., 1997). According to Millennium Ecosystem Assessment (MA, 2005) research, ecosystem services can be divided into four classes: supply, control, social, and support. Chen et al. (2006) and Zhang et al. (2007) combined the particularities of the marine ecosystem and divided marine ecosystem services into 15 services. Using the aforementioned studies as a baseline, we broke down marine ecosystem services into four types and 15 subtypes: food production, raw materials, genetic resources (supply services), climate regulation, gas regulation, waste treatment, biological regulation, disturbance regulation (control services), recreation, cultural, scientific (social services), primary production, nutrient cycling, species diversity maintenance, and providing habitat (support services), but because support service is the basis of the other three types of services, this value was incorporated into each of the other three values we calculated (Chen et al., 2006; Zhang et al., 2007; Li et al., 2011; Lai et al., 2013).

2.3. Research method

Emergy is the amount of flowing or stored energy that contains another kind of energy (Odum and Odum, 1987). It can be further explained as being the total amount of available energy applied directly or indirectly to the formation of a product or labor service (Odum, 1996). Emergy analysis is used to convert different kinds of energy into a uniform standard of measurement, thus facilitating comparisons and analyses of all types of energy; for further details on the derivation of emergy, see Lan et al. (2002).

We assessed the value of the marine ecosystem services of 11 of China's coastal provinces and cities from 2005 to 2014. As the process of evaluating these services involves conducting research on the ocean, we began by defining the study area. China has sovereign rights to explore, develop, maintain, and manage natural resources in its exclusive economic zone, and so we used this study area for our research. The original data used for this analysis included information on marine fishing, mariculture, sea salt, ocean power, mangrove areas, and sea areas taken from China's Statistical Yearbooks (State Oceanic Administration People's Republic of China, 2006–2015), as well as data on algae obtained from previous years' Chinese Fishery Statistics Yearbooks (Bureau of Fisheries, Ministry of Agriculture, 2006–2015). The method used to calculate emergy was based primarily on the research of Odum (1996), Lan et al. (2002), Brown and Ulgiati (1997, 2002), and Meillaud et al. (2005). We used $9.44 \times 10^{24} sej/a$ as the global emergy benchmark for our calculations, and the solar transformities of various substances and energy were based on the research results of Costanza et al. (1997) and Lan et al. (2002) (see Table 1 below).

2.4. Valuation method

2.4.1. Supply services value

Food production. Breeding aquatic species and fishing provide food and sustain human life. These aquatic products include mainly fish, shellfish, shrimp, and algae. In this paper, we calculated the value of