Ocean and Coastal Management 157 (2018) 138–146

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

A Space-Scale Estimation Method based on continuous wavelet transform for coastal wetland ecosystem services in Liaoning Province, China

Baodi Sun[a,b], Lijuan Cui[a,b,*], Wei Li[a,b], Xiaoming Kang[a,b], Manyin Zhang[a,b]

[a] *Institute of Wetland Research, Chinese Academy of Forestry, Beijing, 100091, China*
[b] *Beijing Key Laboratory of Wetland Services and Restoration, Beijing, 100091, China*

ARTICLE INFO

Keywords:
Continuous wavelet transform
Coastal wetland ecosystem services
Space up-scaling
Characteristic scales
Evaluation

ABSTRACT

Wetland ecosystem services are attracting increasing public attention. It is crucial that management decisions for wetland ecosystem services quantify the economic value of the ecosystem services. This study aimed to analyze the use of a new method that incorporated the scale and space-distance factors to evaluate the provincial scale of wetland ecosystem. We cased Coastal Wetland Ecosystem Services in Liaoning Province, China, using a Continuous Wavelet Transform-based Space-Scale Estimation Method to identify the total value and characteristic scales in the provincial areas. The result showed that the total value of the coastal wetlands in Liaoning Province in 2013 was estimated as 213 billion RMB. The characteristic scales were 8, 17, 35 and 55, which corresponded to the spatial distances of 160km, 340km, 700km and 1100km, respectively. When the wetland evaluation was up-scaled to spatial ranges of characteristic scales, its value underwent obvious changes, known as scale effects. We use the new method that incorporated the scale and space-distance factors to evaluate the provincial scale of wetland ecosystem. Understanding the scale effects and characteristic scales can provide a theoretical basis and reference for wetland evaluation on a larger scale for future research.

1. Introduction

Coastal wetlands are located in the confluence of fresh- and saltwater ecological systems, and experience a high edge ecological effect, including high biological productivity and ecological environment regulation effects (Camachovaldez et al., 2014; Zorrilla et al., 2014; Cui et al., 2016; Litaor et al., 2016; Sun et al., 2017). Although coastal residents and communities may interact in different ways with the wetland ecosystem, it is increasingly well understood that the coastal wetland ecosystem plays a crucial role in determining the well-being of human populations (Barbier et al., 2008; Robertson and Wood, 2010; TEEB, 2010; Mitsch et al., 2014).

Moreover, some coastal wetlands along bird migratory routes, such as the large tidal flats of the Chinese coastal wetlands - Chongming Island in Shanghai, supply food for millions of birds (Eppink et al., 2014; Zou et al., 2014). Thus, coastal wetlands are not only important for human survival, in particular for those relying on local fish, but also for the survival of millions of migratory birds and other organisms. At present, although the public's perception of the protection of the coastal wetland ecosystem is improving, wetland protection measures are still lacking and many coastal wetlands are under serious pressure, which could lead to a decrease in the size, functioning, or value of wetlands (Graham and Mendelssohn, 2014; Ivajnšič and Kaligarič, 2014; Rao et al., 2015; Sanders et al., 2015; Trebitz et al., 2016). In addition, considering the locations of coastal wetlands, they are ecologically highly sensitive, and are exposed to substantial environmental volatility (Barbier, 2007; Ghermandi et al., 2013). Therefore, to guarantee the sustainable development of a coastal economy while protecting and using coastal wetlands, we should not only consider economic outputs, but also quantitatively and comprehensively evaluate coastal wetland ecosystem services. While coastal wetlands offer a wide variety of benefits that are difficult to quantify, estimating their value can still improve our understanding of the drivers for coastal wetland ecosystem service, and in turn inform policy.

At present, based on market prices, shadow project method and replacement cost method for the evaluation of typical coastal wetland ecosystem services are mature. Some studies applied direct extrapolation through the value per unit area for the analysis of services at larger spatial scales, such as for a province or river basin (Zhang et al., 2009; Jiang et al., 2010; Brander et al., 2012; Ding et al., 2015). However, no research has been undertaken some professional up - scaling methods into large spatial wetlands. Furthermore, the quantification and prediction of spatial patterns of ecosystem services provided by coastal wetlands on provincial or national scales are complicated by large

* Corresponding author. Tel. & Fax: +86-10-62824155 , . Beijing Key Laboratory of Wetland Services and Restoration, Beijing, 100091, China.
E-mail addresses: lkyclj@126.com, wetlands108@126.com (L. Cui).

https://doi.org/10.1016/j.ocecoaman.2018.02.019
Received 13 September 2017; Received in revised form 10 February 2018; Accepted 25 February 2018

geographical scale and complex types of coastal wetlands.

Wavelet Transform is a relatively recent and precise method for space and time series processing (Cazelles and Stenseth, 2008; Hsu and Li, 2010; Araghi et al., 2015; Bakhtadze and Sakrutina, 2016; Pour, 2016; Funashima, 2017). While the general theory behind Wavelet Transform is quite similar to that of Short Time Fourier Transform (STFT), and Wavelet Transform allows for a completely flexible window function (called the mother wavelet), which can be changed over space based on scale and distance factors. As the mother wavelet moves across space during Wavelet Transform process, it generates several coefficients that represent the similarity between the space and mother wavelet (at any specific scale). There are two main types of Wavelet Transform: Continuous and Discrete.

Wavelet transform can help to interpret multi-scale and non-stationary space-series data, and reveals the features of coastal wetlands that are not apparent (Mount et al., 2013; Pour, 2016; Yusaf et al., 2016), and it is thus becoming an important addition used to analyze space-series, and therefore has many practical applications in environmental sciences (Fabec and Ólafsson, 2003; Biswas and Si, 2011; Goh et al., 2013; Funashima, 2017). Wavelet transform can localize space scales, balance the wavelet coefficients of localization space. The aim of data-clustering methods is to group the objects in databases into meaningful subclasses. The grid-based algorithm quantizes space into a finite number of cells and then carries out operations on this space. WaveCluster, a spatial data-mining method belongs to this category, with low computational complexity (Gustavo et al., 2014), and its results are less affected by noise and the method is not sensitive to the order of input objects. The main idea of WaveCluster is to transform original feature space by applying wavelet transform and then to find the dense regions in the new space. This procedure makes finding the connected components in transformed space easier than that in the original feature space, because the dense regions in feature space will be more noticeable. Given this property, Wavelet Transform can be used to analyze the space-distance characteristics of any type of wetland evolution. In recent years, Wavelet Transform has been widely used for the analysis of many ecological environments (Furlanetto et al., 2006; Li et al., 2010; Krause et al., 2011; Mount et al., 2013; Wenigera et al., 2016).

Larger-scale studies on coastal wetland ecosystem services in China using up-scaling method are still lacking. The studies based on continuous wavelet transform can be a useful in measuring the principal value of coastal wetland ecosystem services. This study aimed to Estimate Coastal Wetland Ecosystem Services in Liaoning Province, China, using a Continuous Wavelet Transform-based Space-Scale Estimation Method: 1. measuring the total value of the coastal wetlands; 2. analyzing the scale effects and characteristic scales of the coastal wetland; 3. testing the robustness of applying Continuous Wavelet Transform to the field of wetland evaluation by up-scaling. These results provide support for evaluating wetland ecosystem services, implementing the wetland ecological compensation system, planning national wetland protection engineering, accounting for the so-called “Green GDP”, and meeting the targets set by the Ramsar Convention (Blasco, 1997; Art, 2006; Gardner and Davidson, 2011; Wittmann et al., 2015).

2. Materials and methods

2.1. Study area

The study area is located along the northeast coast of China, delimited by Yalujiang Estuary to the east and Shanhaiguan Old Faucet to the west, a coastline with about 2920 km of coastline. and its wetland area is nearly 713200 ha, including seven coastal wetland types: shallow marine waters, rocky marine shores, sandy stone sea beaches, sludge sea beaches, intertidal marshes, estuarine water area and estuarine delta (Fig. 1). The classification criteria of coastal wetlands and proportion of each type and proportions are shown in Table 1. It is the northernmost location along the Asia-Australia migration route. The mean annual temperature is 4°C–10 °C and the mean annual rainfall is around 715 mm (Zhu et al., 2008).

Based on the coastline of the six coastal cities in Liaoning Province, belt transect method was adopted for sampling, including four transect lines (A, B, C, and D in Fig 1). Each sample coastal wetland is 1×10^4 ha, the interval between two adjacent samples is about 20 km, the total number of samples is 39, including eight in Huludao, four in Jinzhou, four in Panjin, two in Yingkou, eighteen in Dalian, and three in Dandong.

2.2. Organization method of basic data

Based on the Millennium Ecosystem Assessment and double accounting (MA, 2005; Li et al., 2014; Li et al., 2016), the ecosystem services can be classified as provisioning, regulating, and cultural services, including eight services: substance production, shipping, flood control, carbon sequestration, gas regulation, climate regulation, wave reduction, the addition of new land, recreation and scientific research. The economic values of substance production, shipping, gas regulation and the addition of new land in coastal wetlands were calculated using market price method (Chaikumbung et al., 2016). The economic values of flood control and climate regulation were calculated using replacement cost method (Cui et al., 2016), the economic value of water conservation was calculated by shadow project method (Bull et al., 2014; Saunders et al., 2015), the economic value of carbon sequestration was calculated using carbon tax method (Adhikari et al., 2009; Rong et al., 2015), the economic value of wave reduction was calculated using expert evaluation method (Ledoux and Turner, 2002; Radaev, 2007), and finally the economic values of recreation and scientific research were calculated using travel cost and simulate market methods (Zhang and Lu, 2010; Roebeling et al., 2016).

Table 2 listed the coordinates (latitude and longitude), the main coastal wetland types in the sample, and the ecosystem service value for each sample. Based on the results in Table 2, we selected the Morlet Continuous Wavelet Transform in Matlab 2015b to extend the wetland value, and then to calculate the wavelet coefficients.

2.3. Continuous wavelet transform

With the basic data from section 2.2, we measured the value of the ecosystem services in each sample, and then applied continuous wavelet transform to up-scaling for the different geographical units of coastal wetland value. Based on spatial scale analysis and WaveCluster, we clustered the different geographic units of coastal wetland, and then transformed the value of same cluster of coastal wetland ecosystem services using layers of scales to account for the up-scaled values. Finally, we calculated the total value of coastal wetland ecosystem services in Liaoning Province.

Because the number of data was small and the wavelet coefficients of each scale had strong correlations, we used Continuous Wavelet Transform, popularized by Torrence (1998). Our description of Continuous Wavelet Transform below is from Torrence (1998) using the notation and development of Sadowsky (1996), Biswas and Si (2011) and Mount (2013). In this description, f(x) denotes the spatial evolution results of coastal wetland ecosystem services. We define Continuous Wavelet Transform W(s, τ)-as the complex conjugation of f(x) with a detailed and translated “mother” wavelet function Ψs, τ(x):

$$\Psi_{(s,\,\tau)}(x)=\frac{1}{\sqrt{s}}\Psi\left(\frac{x-\tau}{s}\right) \tag{1}$$

$$\mathrm{W}(s,\tau)\ =\frac{1}{\sqrt{s}}\int_{-\infty}^{+\infty} f(x)\Psi\left(\frac{x-\tau}{s}\right)dxs>0 \tag{2}$$