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Addressing the Modelling Precision in Evaluating the Ecosystem Services of Coastal Wetlands

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Abstract: Wetlands are one of the world's most productive ecosystems, and therefore it is crucial that management decisions regarding wetlands incorporate awareness of accurate assessments of the value of their respective ecosystem services. In this paper, we seek to improve the modelling precision in the scale transform process of ecosystem service evaluation. Firstly, we selected eight services as the criteria to calculate wetland ecosystem values: substance production, flood control, carbon sequestration, gas regulation, climate regulation, wave reduction, adding new lands, recreation and education. Then, six coastal wetlands of Liaoning province were chosen as the case study areas, and their ecosystem values were calculated by empirical method. Next, we simulated ecosystem values of the six cases by two spatial-scales transform methods named meta-analysis and wavelet transform. Finally, we compared the two groups of simulated values with the empirical measured values to examine their evaluation precisions. The results indicated that the total precision of the wavelet transform model (0.968) was higher than that of meta-analysis (0.712). In addition, the simulated values of single services such as substance production, flood control, carbon sequestration, gas regulation, and climate regulation were closer to the measured values using wavelet transform model. This research contributes to identifying an evaluation model with higher precision for evaluating wetland ecosystem services in the process of scale transform.

Keywords: model precision; meta-analysis; wavelet transform; spatial scales transform; coastal wetlands

1. Introduction

Increasing attention has been paid to the evaluation of wetland ecosystem services from resource managers, researchers, and the wider public [1–5]. The evaluation can monetize and quantitatively illustrate the values of wetland ecosystem services, strengthening the public's awareness of protecting wetlands [6,7]. Located in the confluence of fresh and saltwater ecological systems, coastal wetlands with high productivity and biodiversity provide rich material and a number of ecosystem services for human beings, such as raw materials, food production, carbon sequestration, wave reduction, climate regulation, and gas regulation, etc. [6,8–10]. Moreover, some coastal wetlands located along bird migratory routes, such as the large tidal flats of the Chinese coastal wetlands, supply food for millions of birds travelling across East Asia and Australia [11,12]. 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. However, the ecosystem services provided by coastal wetlands vary according to special scales when calculating the ecological and geographical processes [13,14]. Errors exist when evaluating the ecological services of large-scale coastal wetlands since they are not as simple as the sum of small pieces of coastal wetlands [15]. Thus, methods for scale transformation of coastal wetland ecosystem service evaluation are particularly urgently needed [16,17].

Two methods, named meta-analysis and wavelet transform, are actively used for larger scale wetland ecosystem service estimation in contemporary research [18–22]. Meta-analysis is a commonly used scale transform method that can attain the value per unit area by adjusting the function [23,24]. Through statistical integration and systematic reviews of previous research, meta-analysis can obtain comparatively accurate values on large scales by value transfer functions [19]. However, meta-analysis is still criticized for its credibility for the extraction and analysis of spatial information since the results generated by its value transfer functions are still services value per unit [15,25]. By contrast, wavelet transform can localize the space scales (i.e., it has the performance to localize large-scale wetlands) to balance the wavelet coefficients of the localization space. It can also provide multi-scales of resolution from large to small and an arbitrary direction of rotation, which can be used to extract the directional characteristics of wetlands [26,27]. Clustering aims to detect groups and assign labels to the objects based on the cluster that they belong to. The grid based algorithm quantizes the space into a finite number of cells and then carries out operations on this space.

Some previous research has used meta-analysis and wavelet transform for wetland ecosystem service estimation [19,23]; however, few of them compared the model precisions of these two methods. Thus, in this paper, we seek to explore whether these two methods give consistent results when assessing the ecosystem services values of the same wetland. This research contributes to identifying a more accurate and efficient scale transform method for wetland evaluation at a larger space-scale, providing a technique tool for establishing wetland ecological compensation systems at different spatial patterns, conducting large-scale wetland protection projects, and accounting for green GDP [28–31]. The high-precision model can also be used in evaluating the ecological services of cross-regional, national and even international wetlands in further application.

2. Methods

2.1. Study Site Description

The study sites are located along the northeast coast of China, delimited by Yalujiang Estuary to the east and Shanhaiguan Old Faucet to the west. The study contains approximately 2920 km of coastline (Figure 1). The coastal wetland area in Liaoning province is nearly 713,200 ha, which constitutes 51.10% of the total wetlands in Liaoning Province. Liaoning Province is the only coastal province in northeast China. The mainland coastline within the territory accounts for 12% of the total length of the coastline through the whole nation [32].

Six wetlands in Liaojing province, named Liuguhe wetland, Linghe estuary wetland, Shuangtai estuary wetland, Yongyuanjiao wetland, Banhaibao wetland and Yalujiang estuary wetland, were selected as case study areas (Figure 1). Those cases were designed to cover as many types of coastal wetland as possible. Table 1 illustrates how each case represents specific types of coastal wetlands, including shallow marine waters, rocky coast, sandy stone sea beaches, sludge sea beaches, intertidal salt marshes, estuarine waters, and estuarine delta.
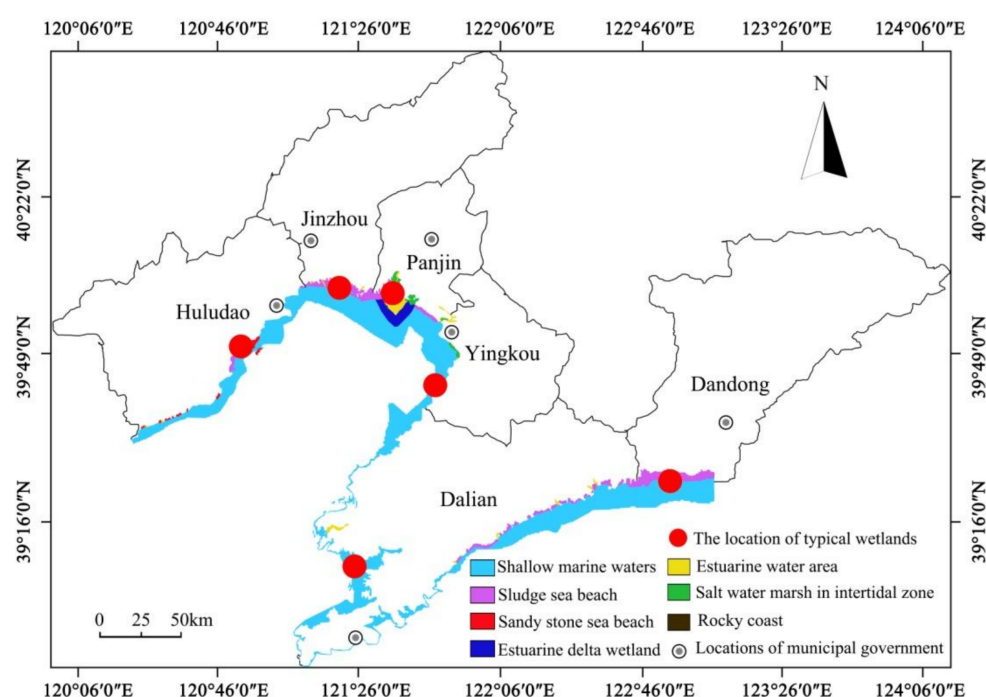
Figure 1. Different types and typical cases of coastal wetlands in Liaoning Province, China.

Table 1. The statistical acreage of different coastal wetland types in typical cases (10^4 ha).

No	Wetland Name	Coastal Wetland Types							Total
		Shallow Marine Waters	Rocky Coast	Sandy Stone Sea Beaches	Sludge Sea Beaches	Intertidal Salt Marshes	Estuarine Waters	Estuarine Delta	
01	Liuguhe wetland	–	–	0.02	–	–	0.02	–	0.04
02	Linghe estury wetland	5.48	–	–	1.20	–	0.09	–	6.77
03	Shuangtai estury wetland	0.77	–	–	1.23	0.51	1.37	0.60	4.48
04	Yongyuanjiao wetland	–	–	–	–	0.01	–	–	0.01
05	Banhaibao wetland	6.49	0.02	–	–	–	–	–	6.51
06	Yalujiang estury wetland	5.12	–	–	2.62	–	–	–	7.74
	Total	17.86	0.02	0.02	5.05	0.52	1.48	0.60	25.55

2.2. The method for Empirical Measurement

Based on the Millennium Ecosystem Assessment and double accounting [33–35], the dominant ecosystem services of the six cases can be classified as provisioning, regulating, and cultural services, containing eight more specific services: substance production, flood control, carbon sequestration, gas regulation, climate regulation, wave reduction, the addition of new land, recreation and scientific research [9,11,36]. The gross and separating ecosystem service value of each case was evaluated by empirical evaluation methods, which provide a control group for later model precision comparison. The economic values of substance production, gas regulation and the addition of new land in the coastal wetlands of Liaoning were calculated using the market price method [23]. The economic values of flood control and climate regulation were calculated using the replacement cost method [2], the economic

value of water conservation was calculated by the shadow price method [37–39], the economic value of carbon sequestration was calculated using the carbon tax method [40,41], the economic value of wave reduction was calculated using the expert evaluation method [42,43], and finally the economic values of recreation and scientific research were calculated using the travel cost and the simulate market methods [44,45].

2.3. The Methods for Space-Scale Transform

The techniques of scale transformation applied in this research belong to scaling up, which means estimating the ecological services of a large-scale wetland based on those of some small-scale wetlands that are more prone to be evaluated. We selected meta-analysis as one scaling up model because it is a useful tool to account the total value of the coastal wetland ecosystem services. Meanwhile, we used the method of wavelet transform to interpret multi-scale and non-stationary space-series data and reveal the features of coastal wetlands that are not apparent.

2.3.1. The Meta-Analysis Method

The process of meta-analysis includes three steps. The first step is related to data preparation: we carefully selected primary studies on the theme of coastal wetland evaluation (including both peer reviewed and non-peer reviewed studies) to populate our meta-analysis database. In the second step, we statistically estimated the impact of geospatial, environmental and socio-economic characteristics on coastal wetland ecosystem services. In the final step, the fitted model was used with the specific characteristics of the test areas in the typical cases to estimate the value of coastal wetland ecosystem services provided by each typical case.

A multi-variable model for the meta-regression analysis was conducted using a weighted least square (WLS) model in Equation (1):

$$\text{Ln}V_{ij} = \beta_0 + \beta_w X_{Wij} + \beta_m X_{mij} + \beta_c X_{cij} + U_{ij} \tag{1}$$

where subscripts i and j refer to the ith observation in the jth study. The dependent variable V_{ij} is the value of the coastal wetland ecosystem service for observation i in study j, measured in 2013 USD per ha per year. β_0 is the intercept and β_w, β_m and β_c are the coefficients to be estimated for the explanatory (independent) variables including wetland characteristics, the evaluation techniques and environmental characteristics. As is the case for most meta-analyses on wetland ecosystem service values [18,46], the economic values (V_{ij}) were natural-log-transformed prior to analysis. X_w represents wetland characteristics. X_m represents the evaluation techniques, X_c represents environmental characteristics.

2.3.2. The Wavelet Transform Method

Based on spatial scale analysis and WaveCluster, we clustered the different geographic units of the coastal wetland in typical cases, and then transformed the value of the same cluster of the coastal wetland ecosystem services using layers of scales to account for the up-scaled values. Finally, we calculated each value of the coastal wetland ecosystem services in six typical cases. Because the number of data was small and the wavelet coefficients of each scale had strong correlations in each typical case, we used continuous wavelet transform. In this description, $f(x)$ denotes the spatial evolution results of coastal wetland ecosystem services. We can define continuous wavelet transform, which we denote by W(s, τ), as the complex conjugation of $f(x)$ with a detailed and translated "mother" wavelet function Ψ_s, $\tau(x)$ [47]:

$$\Psi_{(s,\,\tau)}(x) = \frac{1}{\sqrt{s}}\Psi\left(\frac{x-\tau}{s}\right) \tag{2}$$

$$W(s, \tau) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} f(x) \Psi\left(\frac{x-\tau}{s}\right) dx \quad s > 0 \tag{3}$$

where s represents the dilation (scale) of the wavelet function and τ represents the degree of distance translation along the series. The term $1/\sqrt{s}$ normalises the wavelet function energy at each scale. Equation (2) emphasizes that the wavelet function is in fact a "basis" function. $W(s,\tau)$ in Equation (3) represents the coefficients of wavelet transform at different scales.

2.4. The Method for Precision Comparison

Three indicators were selected to verify the consistency between the simulation values and the empirical measured values, including the determination coefficient (R^2), the root-mean-square error ($RMSE$), and the relative mean deviation (RMD). R^2, also called goodness-of-fit, represents the interpretive degree of independent variables to the dependent variable. Thus, the higher the value of R^2, the higher the precision. RMD was used to measure the deviation between simulated values and measured values. The smaller the value of RMD, the higher the precision. Further, RMD refers to the outcome of mean variation divided by average value. The smaller RMD means closer repeated measured values. The equations of R^2, $RMSE$ and RMD can be seen in Equations (4)–(6) below.

$$R^2 = \left(\frac{\sum (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum (O_i - \overline{O})^2 \sum (P_i - \overline{P})^2}}\right)^2 \tag{4}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{5}$$

$$RMD = \frac{100}{\overline{O}} \sum_{i=1}^{n} \frac{P_i - O_i}{n} \tag{6}$$

where O_i and P_i represents the empirical measured values and simulated values, while $\overline{O}$ and $\overline{P}$ represents the average values of the empirical measured values and simulated values. n represents the observation frequency.

3. Results

3.1. The Measured Ecosystem Service Values of the Six Cases

The various types of ecosystem service values of the six cases in Liaoning coastal wetlands were calculated based on the empirical measurement methods listed in Section 2.2. The detailed results are shown in Table 2. It can be seen that Yalujiang estuary had the highest gross ecosystem service value (3,464,077,670 USD), followed by Linghe estuary (3,397,896,440 USD). In contrast, Yongyuanjiao wetland had the lowest ecosystem service value (9,708,738 USD), which was only 0.2% of that of Yalujiang estuary. However, the great disparity in value was related to the measured areas of cases rather than the wetland quality. The results of value on per unit area confirmed this deduction. The highest value on per unit area belonged to Yongyuanjiao (965,372,168 USD/10^4 ha), while the lowest value on per unit area belonged to Banhaibao estuary (374,433,657 USD/10^4 ha). In terms of the single ecological value, the average value peaked at 437,378,641 USD in the value of carbon sequestration and reaches to the bottom at 62,297,735 USD in the value of recreation and education.

Table 2. The values of ecosystem services based on measured methods.

Ecosystem Services	Wetland Values (USD)					
	Liuguhe	Linghe Estury	Shuangtai Estury	Yongyuan Jiao	Banhaibao	Yalujiangestury
Substance production	4,692,557	748,705,502	324,433,657	1,456,311	745,792,880	723,948,220
Flood control	8,252,427	406,634,304	388,673,139	1,132,686	330,420,712	482,847,896
Carbon sequestration	7,928,803	833,009,709	473,139,159	2,427,184	492,071,197	815,372,168
Climate regulation	4,045,307	562,135,922	368,608,414	2,103,560	362,783,172	446,116,505
Gas regulation	3,074,434	440,453,074	276,051,780	1,294,498	234,789,644	352,912,621
Adding new lands	161,812	65,533,981	117,152,104	161,812	58,414,239	170,873,786
Wave reduction	2,750,809	249,190,939	205,339,806	161,812	87,378,641	372,653,722
Recreation and education	647,249	92,394,822	62,297,735	970,874	118,284,790	99,190,939
Gross value	31,553,398	3,397,896,440	2,215,857,605	9,708,738	2,429,773,463	3,464,077,670
Value on per unit area	789,320,388	501,941,748	494,660,194	965,372,168	374,433,657	447,572,816

3.2. The Ecosystem Service Values Stimulated by Meta-Analysis and Their Differences from Measured Values

The ecosystem service values of the six cases were stimulated by meta-analysis based on the methods presented in Section 2.3.1, and the results are shown in Table 3. In general, the simulated values revealed a similar pattern to the empirical measured values. Yalujiang estuary had the highest gross ecosystem service value (3,271,359,223 USD), while Yongyuanjiao wetland had the lowest ecosystem service value (4,692,557 USD). The highest value on per unit area also belonged to Yongyuanjiao (466,666,667 USD/10^4 ha). Similarly, the average value peaked at 453,074,434 USD in the value of carbon sequestration and reached to the bottom at 61,003,236 USD in the value of recreation and education.

Table 3. The ecosystem services values of the six cases based on meta-analysis.

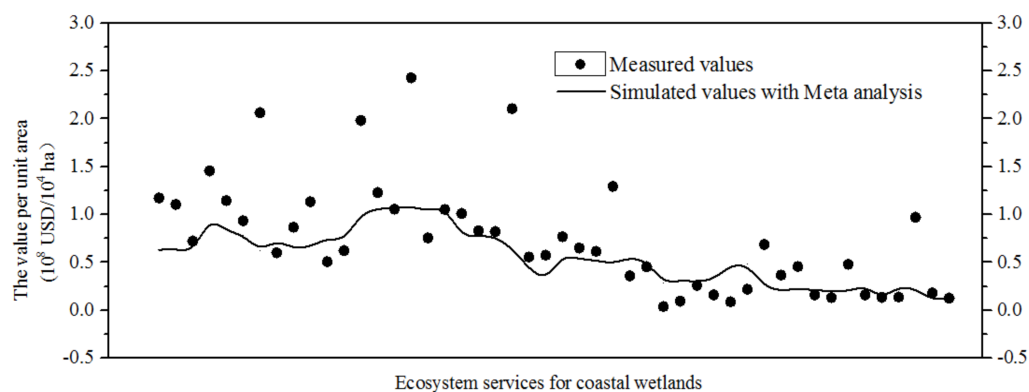| Ecosystem Services	Wetland Values (USD)					
	Liuguhe	Linghe Estuary	Shuangtai Estuary	Yongyuan Jiao	Banhaibao	Yalujiang Estuary
Substance production	2,588,997	436,731,392	269,255,663	970,874	539,967,638	609,385,113
Flood control	2,427,184	498,381,877	288,187,702	647,249	491,423,948	560,032,362
Carbon sequestration	4,045,307	718,446,602	479,773,463	1,132,686	675,566,343	839,320,388
Climate regulation	3,074,434	524,919,094	346,116,505	647,249	283,818,770	236,731,392
Gas regulation	2,265,372	361,326,861	234,951,456	485,437	360,355,987	398,058,252
Adding new lands	1,132,686	212,944,984	133,656,958	323,625	308,090,615	372,006,472
Wave reduction	970,874	137,216,828	103,074,434	161,812	132,362,460	15,4692,557
Recreation and education	970,874	83,009,709	111,650,485	323,625	69,255,663	101,132,686
Gross value	17,475,728	2,972,977,346	1,966,666,667	4,692,557	2,860,841,424	3,271,359,223
Value on per unit area	437,216,828	439,158,576	438,996,764	466,666,667	440,776,699	422,653,722

Meanwhile, the data analysis results suggested generally that the simulated values of the six cases by meta-analysis were slightly lower than the empirical measured values. The model of meta-analysis was constructed based on the nation-wide cases and then implemented at the provincial level—Liaoning province. This process lowered the ecological values of the selected cases. The detailed comparisons between simulated values and measured values suggest differences exist in the veracity of simulation, either in different cases or targeting different single ecological values (see Figure 2). The smallest difference existed in the case of Shuangtai estuary wetland (Figure 2c) while the largest difference existed in Yongyuanjiao wetland (Figure 2d). From the aspect of wetland types, the method of meta analysis collected all the coastal wetland types to establish the database, so the wetlands had more types and the simulated values would be more closer to the measured values. Among six cases, Shuangtai estuary wetland included five coastal wetland types and Yongyuanjiao wetland included only one coastal wetland type (see Table 1).
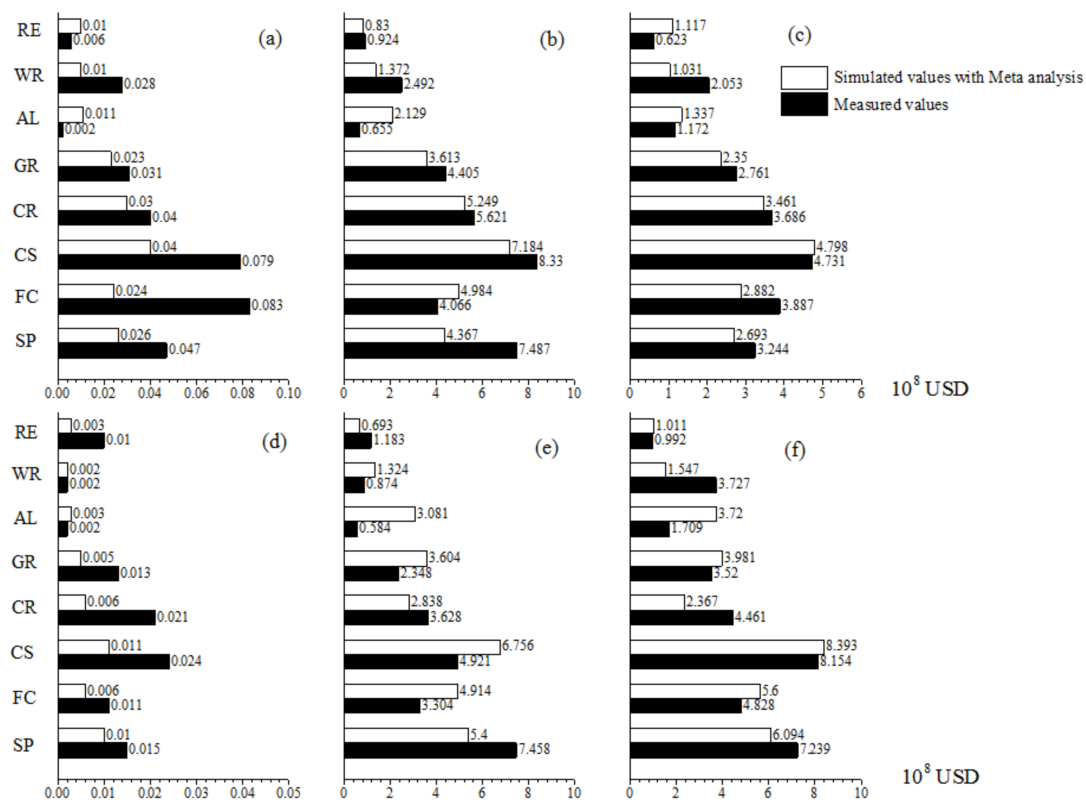
Figure 2. Simulated values with meta-analysis and measured values in typical coastal wetlands. Note: SP, Substance production; FC, Flood control; CS, Carbon sequestration; GR, Gas regulation; CR, Climate regulation; WR, Wave reduction; AL, Adding new lands; RE, Recreation and Education. (**a**) Liuguhe wetland; (**b**) Linghe estuary wetland; (**c**) Shuangtai estuary wetland; (**d**) Yongyuanjiao wetland; (**e**) Banhaibao wetland; (**f**) Yalujiang estuary wetland.

In order to improve the comparability, we converted the values into per unit area (1.0×10^8 USD/ 10^4 ha). Figure 3 illustrates the dispersion of the conserved simulated values from 48 groups of data. It can be seen that the distinction between simulated values and measured values varied from -1.50×10^8 USD/10^4 ha to 0.25×10^8 USD/10^4 ha. The percentage of distinction between -0.16×10^8 USD/ 10^4 ha and 0.16×10^8 USD/10^4 ha reached to 31.25%.

Figure 3. Values (per unit area) with simulated values in meta-analysis model and measured for coastal wetlands ecosystem services.

3.3. The Ecosystem Service Values Stimulated by Wavelet Transform and Their Differences from Measured Values

The ecosystem service values of the six cases were stimulated by wavelet transform based on the methods presented in Section 2.3.2, and the results are shown in Table 4. The simulated values showed a slight difference from both the measured values and values simulated by wavelet transform. The Linghe estuary had the highest gross ecosystem service value (3,199,676,375 USD), followed by Yalujiang estuary (3,193,851,133 USD) with a narrow margin. The Yongyuanjiao wetland remained the lowest ecosystem service value (8,414,239 USD). The highest value on per unit area also belonged to Yongyuanjiao (841,423,948 USD/10^4 ha), which was more than twice as much as the lowest value (Banhaibao, 334,304,207 USD/10^4 ha). The average value peaked at 421,359,223 USD/10^4 ha in the value of substance production and reaches to the bottom at 37,864,078 USD/10^4 ha in the value of adding new lands.

Table 4. The ecosystem services values of the six cases based on wavelet transform.

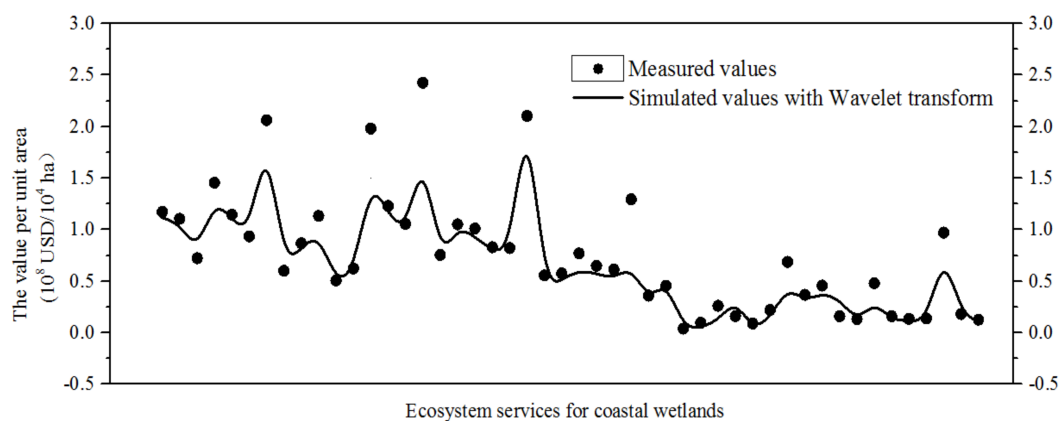| Ecosystem Services	Wetland Values (USD/10^4 ha)					
	Liuguhe	Linghe Estuary	Shuangtai Estuary	Yongyuan Jiao	Banhaibao	Yalujiang Estuary
Substance production	4,530,744	715,372,168	350,161,812	1,294,498	717,961,165	73,8834,951
Flood control	7,766,990	440,129,450	369,093,851	970,874	313,430,421	446,763,754
Carbon sequestration	5,987,055	783,171,521	431,229,773	1,779,935	453,883,495	803,721,683
Climate regulation	3,721,683	541,100,324	324,919,094	2,265,372	291,585,761	393,042,071
Gas regulation	2,427,184	389,482,201	243,042,071	647,249	198,543,689	373,462,783
Adding new lands	161,812	42,233,010	54,045,307	323,625	16,828,479	113,106,796
Wave reduction	1,779,935	207,605,178	173,300,971	323,625	70,550,162	235,598,706
Recreation and education	485,437	80,582,524	47,249,191	809,061	113,106,796	89,320,388
Gross value	26,860,841	3,199,676,375	1,993,042,071	8,414,239	2,175,889,968	3,193,851,133
Value on per unit area	671,521,036	472,653,722	444,822,006	841,423,948	334,304,207	412,621,359

The detailed comparisons between simulated values and measured values suggested differences exist in the veracity of simulation, either in different cases or targeting different single ecological values (see Figure 4). The smallest difference existed in the case of Linghe estuary wetland (Figure 4b) while the largest difference existed in Liuguhe wetland and Yongyuanjiao wetland (Figure 4a,d). From the aspect of wetland areas, the method of wavelet transform adopted belt transect lines for sampling, so the wetlands had more areas, and the simulated values would be more close to the measured values. Among six cases, Linghe estuary wetland had the largest areas (6.77×10^4 ha), Liuguhe wetland and Yongyuanjiao wetland had relatively smaller areas (0.04×10^4 ha & 0.01×10^4 ha).

Figure 5 illustrates the dispersion of the conserved simulated values from 48 groups of data. It can be seen that the distinction between simulated values and measured values varied from -0.65×10^8 USD/10^4 ha to 0.16×10^8 USD/10^4 ha. The percentage of distinction between -0.16×10^8 USD/10^4 ha and 0.16×10^8 USD/10^4 ha reaches to 81.25%, which is far more than that of meta-analysis.
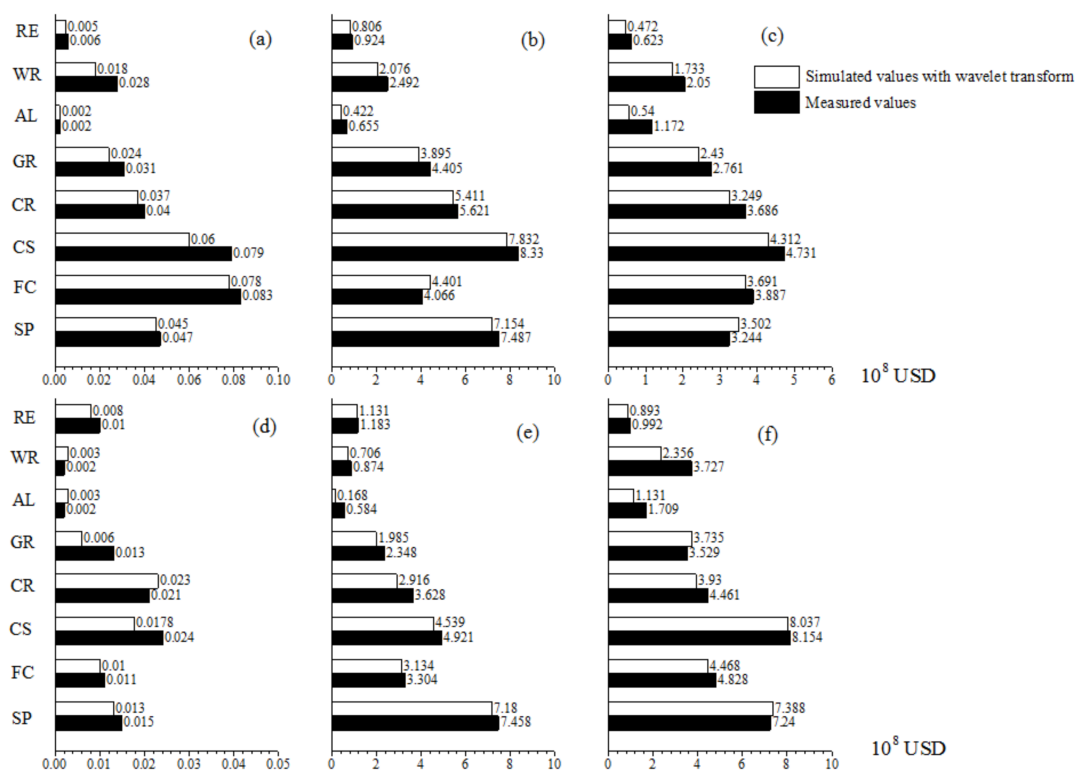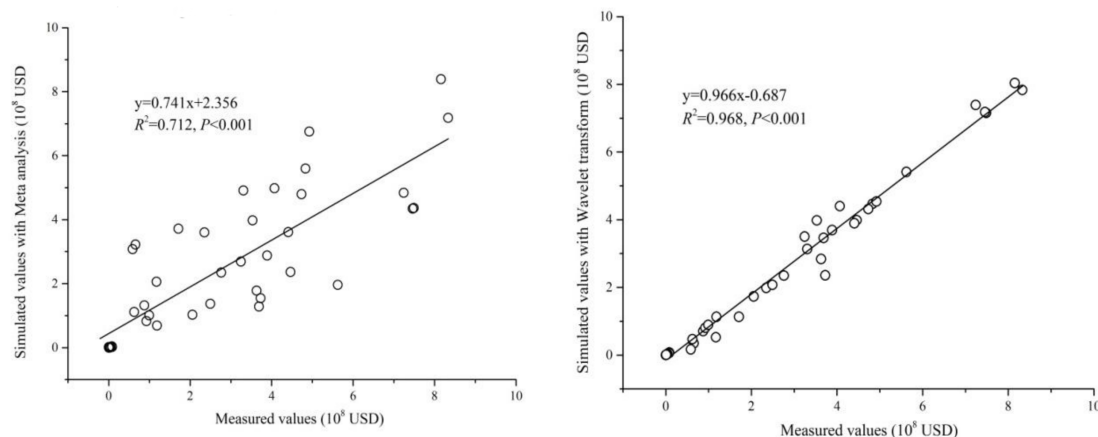
Figure 4. Simulated values with wavelet transform and measured ecosystem service values in classical coastal wetlands. Note: SP, Substance production; FC, Flood control; CS, Carbon sequestration; GR, Gas regulation; CR, Climate regulation; WR, Wave reduction; AL, Adding new lands; RE, Recreation and Education. (**a**) Liuguhe wetland; (**b**) Linghe estuary wetland; (**c**) Shuangtai estuary wetland; (**d**) Yongyuanjiao wetland; (**e**) Banhaibao wetland; (**f**) Yalujiang estuary wetland.

Figure 5. Values (per unit area) with simulated values in meta-analysis model and measured for coastal wetlands ecosystem services.

3.4. The Precision Comparison between Meta-Analysis and Wavelet Transform

The simulated values by meta-analysis and wavelet transform were correlated to the measured values, respectively, and the results are presented in Figure 6. The results showed both values simulated by meta-analysis and wavelet transform illustrate significant correlativity with the measured values. However, the R^2 of wavelet transform reached to 0.968, which was higher than that of meta-analysis (0.712).

Figure 6. Precision comparisons of simulated values in two scale transform models and observed for coastal wetlands ecosystem services.

The values of eight single ecological services simulated by meta-analysis and wavelet transform were compared with the corresponding measured values (see Table 5). The data from the meta-analysis indicated that the simulated value of substance production, flood control, carbon sequestration, climate regulation and gas regulation had significant correlations with the measured values. The R^2 are 0.945, 0.880, 0.933, 0.891 and 0.853 ($p < 0.01$), *RMSE* were 9.96%, 5.67%, 5.50%, 5.75% and 4.05%, while *RMD* were -27.08%, 13.80%, 3.60%, -20.08% and 3.74%. The simulated value of wave reduction showed a certain correlation with the measured values.

Table 5. Precision comparisons of simulated values in two scale transform models with observed values for different ecosystem services.

Observed vs. Simulated	Meta Analysis			Wavelet Transform		
	R^2	*RMSE* (%)	*RMD* (%)	R^2	*RMSE* (%)	*RMD* (%)
Substance production	0.945 **	9.96	−27.08	0.996 ***	1.33	−0.82
Flood control	0.880 **	5.67	13.80	0.988 ***	1.40	−2.46
Carbon sequestration	0.933 **	5.50	3.60	0.994 ***	1.20	−4.14
Climate regulation	0.891 **	5.75	−20.08	0.987 ***	2.45	−9.75
Gas regulation	0.853 **	4.05	3.74	0.962 ***	2.21	−6.45
Adding new lands	0.612	5.87	98.35	0.932 **	2.54	−47.10
Wave reduction	0.712 *	6.80	−42.39	0.957 **	3.73	−24.89
Recreation and education	0.646	1.77	−2.00	0.989 ***	0.55	−11.30

Note: *** stands for $p < 0.001$, ** stands for $p < 0.01$, * stands for $p < 0.05$.

4. Discussion

In this paper, we compared simulated values calculated by two transform scale methods. Data was acquired from six coastal wetlands in Liaoning province. The obtained results showed that the precision of the wavelet transform model was higher than that of meta analysis.

By analysing those two space-scale methods, it can be found that the important step of meta analysis is determined by data collection. Thus, the themes of coastal wetland evaluation were carefully selected based on the previous studies [46,48–50]. Finally, a model based on the impact of geospatial, environmental and socio-economic characteristics on coastal wetland ecosystem services was constructed to calculate the value of each wetland type [36,51]. While wavelet transform is a relatively new and precise method for space series processing, 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 [20]. As the mother wavelet moves across space during the wavelet transform process, it generates several coefficients that represent the similarity between the space and

mother wavelet at any specific scale [21,52]. Therefore, the wavelet transform method can identify nonlinear changes of values in different geographical spaces for coastal wetland ecosystem services in Liaoning province, China.

Thus, according to the theory of each method (Equations (1) and (3)), meta analysis would be affected by ecological factors and some other related environmental characteristics including wetland area, the GDP per capita, the population density, latitude, the distance from the wetland to the city centre and the evaluation year, while the wavelet transform would be mainly affected by two parameters including scale factors and distance factors. In order to precisely analyze the influence of each factor for two methods, sensitivity analysis method was used to test each possible parameter that affected the simulated result [53–55]. The sensitivity of parameter variables is the variation with the corresponding parameters, which increased by 10% [56–58]. This step is called local sensitivity analysis: total parameter variables are the changes with all parameters increased by 10% at the same time [59], and this step is called global sensitivity analysis. Through the model computation (Table 6), the random error from the affected factors with the method of meta analysis attained +14.60%, and +8.70% for wavelet transform, which further proved that wavelet transform has higher simulation precision than meta analysis.

Table 6. The results of local sensitivity analysis for meta analysis and wavelet transform.

	Meta Analysis		Wavelet Transform	
Parameter Num	Parameter Variables	Sensitivity (%)	Parameter Variables	Sensitivity (%)
01	V_{Size}	−4.8	Scale factors	+8.7
02	V_{GDP}	+7.0	Distance factors	
03	$V_{Density}$	+9.1		
04	$V_{Latitude}$	−1.5		
05	$V_{Distance}$	+4.6		
06	V_{Year}	+2.5		
Total		+14.6		+8.7

Note: The sensitivity of parameter variables was the change proportion with the corresponding parameters, which increased by 10%; total parameter variables were the change proportion with all parameters, which increased by 10% at the same time. V_{Size} stands for the variable of wetland size, V_{GDP} stands for the variable of the GDP per capita, $V_{Density}$ stands for the variable of the population density, $V_{Latitude}$ stands for the variable of Latitude, $V_{Distance}$ stands for the variable of the distance from the wetland to the city center, V_{Year} stands for the variable of the evaluation year. Values for all important factors were printed in italics, with the most important factor being underlined. "+" stands for the increased change of sensitivity, also called the increased ratio of the wetland per unit value, "−" stands for the decreased change of sensitivity, also called the decreased ratio of the wetland per unit value.

By applying the meta analysis to simulate the whole provincial coastal wetland values, the results indicated that three services, named adding new lands, wave reduction, recreation and educationm had relatively lower precision (the R^2 were 0.612, 0.712 and 0.646). The analysis of the database revealed the reasons for the lower precision may be the absence of raw data, which was also different from previous research [19,60]. Meanwhile, for the value of recreation and education, distinctions would exist between different coastal wetlands because of geomorphology and tourist attraction etc. [61–64]. There was no relationship between the value of recreation and education and wetland area, and social-economic characteristics around the wetlands. Thus, if we use the Meta analysis to evaluate a larger scale of wetlands, the ecosystem services with higher precision can directly apply the model. However, three services with relatively lower precision can combine with some other methods such as the method of direct extrapolation [65–69] to achieve better evaluation results.

This study contributes to a more precise evaluation model of wetland ecosystem services in the process of scale transform, providing information on wetland valuation and guidance on how evaluation should be conducted in larger wetlands. The accurate economic valuation of wetlands helps policy makers and planners realize the significant values of wetlands. It could also be necessary for

wetland planning, conservation projects, and generally wise use. However, this study still has some limitations. For example, all types of coastal wetland should be selected in Liaoning province. Due to restrictions of labor inputs, the six cases we selected can only cover some types of coastal wetland. We hope that there will be some other more reasonable methods to resolve this limitation in the future.

5. Conclusions

In this paper, we compared the simulated values provided by two scale transform methods with the measured values in six typical coastal wetlands in Liaoning province, in order to acquire the precision of both methods. The total precision of the wavelet transform model (0.968) was higher than that of meta-analysis (0.712). In addition, the simulated values of single services such as substance production, flood control, carbon sequestration, gas regulation, and climate regulation were closer to the measured values using wavelet transform model. Therefore, this information could be useful for relevant decision makers to select appropriate methods in wetland evaluation projects at larger scales. The wavelet transform method would be helpful to calculate budgets and optimize project coats by providing more efficient and precise results.

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