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Ecosystem services assessment based on emergy accounting in Chongming Island, Eastern China

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ABSTRACT

Chongming Island, the largest alluvial island in the world, is an ecologically sensitive area. Due to its green space, farmland, estuaries and coastal wetlands and its proximity to the city of Shanghai (45 km, home to 24.2 million people), the island supports important agricultural and fisheries economies. This paper carries out an evaluation of the ecosystem services (ES) on Chongming Island, Shanghai, based on the emergy analysis method, identifying the service supply and flow between ecosystems and urban area. Results show that from the ecosystem-type perspective, the tidal wetland ecosystem provides the most service to Chongming Island, accounting for 45.2% ES emergy in 2012, followed by the agricultural ecosystem (34.5%) and the freshwater wetland ecosystem (6.3%). From ecosystem service-type perspective, water supply, flood storage and aquatic product supply are the main emergy outputs of the wetland ecosystem and account for 51.1%, 17.6% and 25.2% of the emergy, respectively. Food supply is the main emergy of the cropland ecosystem output and accounts for 58% of the emergy. Organic matter production and water retention are the main services provided by the forest ecosystem, accounting for 33.6% and 30.0% of the total emergy respectively. Based on the systematic emergy dynamic analysis, on the one hand, the wetland and forest ecosystems played more significant roles in water supply and retention while the cropland ecosystem had a less important role in food supply from 2002 to 2012. On the other hand, the urban ecosystem has gradually transformed from a positive to a passive participant in the role of supplier and user for ecosystem services. Finally, policy options are proposed to promote land use planning and restore/maintain ecosystem services.

1. Introduction

Humanity is increasingly urban but continues to depend on nature for its survival. Cities are dependent on the ecosystems beyond the city limits, but also benefit from internal urban ecosystems. Ecosystem services (ES) have been defined differently by a diverse group of organizations and researchers, a general definition is that ES are benefits people receive from nature and are thought of as being wholly inclusive, with any benefit derived from an ecosystem considered an ecosystem service (Seppelt et al., 2011; Campbell and Tilley, 2014). They include for example nutrient cycling, carbon sequestration, air and water filtration, and soil conservation (Costanza et al., 1997). Since 1990 numerous studies have been conducted to estimate the values of various ecosystems. Some notable examples include an assessment of the ES value for tropical forests (Martínez et al., 2009), constructed wetlands (Yang et al., 2008), protected areas (Nel et al., 2007; Porter-Bolland et al., 2012), and biodiversity conservation (Gopal et al., 2001; Dawson et al., 2011). Urban ecosystem services are crucial for human well-being and the livability of cities (Ernstson et al., 2010; Lu and Chen, 2017). Cities must depend on the ecosystem services provided by ecosystems beyond the city limits. Peri-urban ecosystems are essential for regulating and maintaining ecological processes and life support services for urban residents (Huang and Chen, 2005). It is important to analyze the ecosystem services supply and flow between cities and the ecological reserve (Deng et al., 2016a). Many studies have examined the land use of the areas surrounding mega cities. Verburg et al. (2009) combined multi-functional urban and rural land use and ecosystem services, so that Land Use and Land Cover Change (LUCC) research areas can be expanded. Overbeek (2009) emphasized the importance of understanding the dynamics of peri-urban ecosystems and the services they provided to cities. Strategy was also suggested that urban and peri-urban stakeholders and land users should establish a dialogue to assess the benefits distribution of the ecosystem services (Deng et al., 2015; Deng et al., 2016b).

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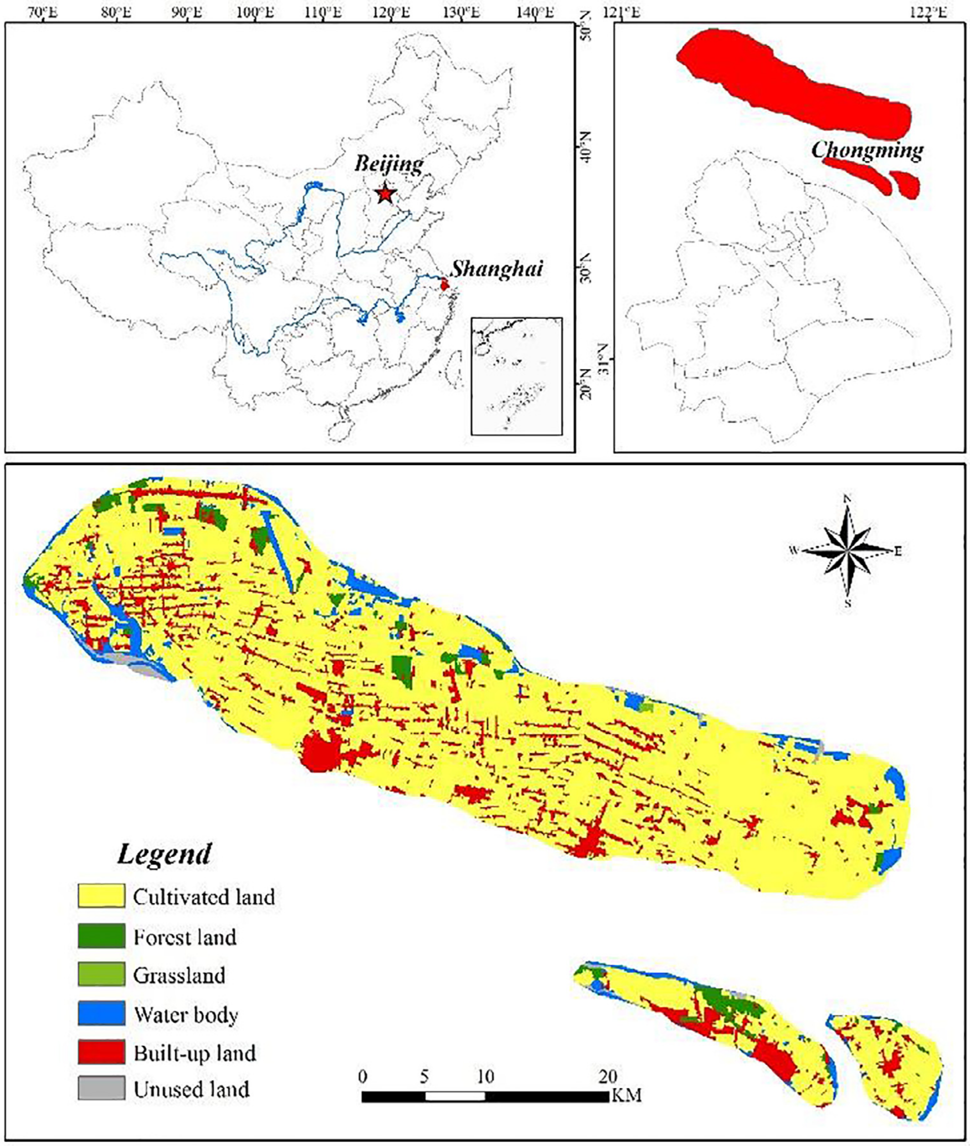

Fig. 1. Regional context and land use of Chongming Island.

A lot of researches have been implemented focusing on urban ecosystem service. Through neglecting the integrated effect of combination and interaction of urban ecosystem service and other services, these researches help greatly in understanding the influences of land use and cover change on the ecosystem services (Board, 2005). In order to clarify the relationship of energy flows between different ecosystem services, emergy analysis of ES flow has been suggested (Chen and Chen, 2006). Emergy is defined as the direct and indirect work previously done to make a product or service which can provide a unified numéraire for accounting of energy, material and information of different levels. For example, Pulselli et al. (2007) applied the emergy analysis method to a building to account for the main energy and material inflows to the processes of building manufacturing, maintenance and use. Chen et al. (2009) estimated the local sustainability of a constructed wetland, and Su et al. (2009) assessed urban ecosystem health based on an emergy analysis and concluded that this method can serve as an effective relative measure to compare different ecosystem health levels of urban ecosystems. However, many of these studies were mainly based on the relationship between cities and the surrounding areas, and have not quantified the ecosystem services that the surrounding areas supply, in this respect, we carry out an evaluation of the ecosystem services on Chongming Island, Shanghai, based on the emergy analysis method, identifying the service supply and flow between ecosystems and urban area.

Chongming Island is not only a transition zone between urban and rural area, but also an interaction zone between urban and rural activities, and the landscape features are subject to rapid modification by human-induced activities (Yang et al., 2016). As the ecological conservation development area of Shanghai, this island should be considered an extension of the city rather than an entirely separate area. The island not only consumes natural and productive lands by converting forests and agricultural land into developed environments but also fragments, degrades and isolates remaining natural areas (Huang et al., 2008). Chongming Island is a valuable protected area with forested hills, prime agricultural lands, and important freshwater and tidal wetlands. These ecosystems are essential for regulating and maintaining ecological processes and life support services for urban residents, such as food provisioning (Raudsepp-Hearne et al., 2010), water conservation (Haase and Nuissl, 2007) and climate regulation (Lamptey et al., 2005), etc. Therefore, Chongming Island is the appropriate study area to analysis the effects of conversion of rural to urban land on ecosystem functioning and the subsequent effects and on feedback related ecosystem services.

The valuation of ecosystem services must encompass a full appreciation of the value of natural and semi-natural environments in terms of their contribution to societal well-being (Huang et al., 2007). Ecosystem services are generated by complex natural cycles, driven by solar energy, and operate on many temporal and spatial scales (Daily, 1997; Campbell and Tilley, 2014). Odum (1996), and Brown and Ulgiati (2004, 2010) provided the details on the concept and mechanism of emergy synthesis. Theoretical developments in emergy analysis, as well as illustrations of the application of emergy evaluation in the assessment of the economic value of resources can be found in related emergy references (Chen et al., 2006; Brown and Ulgiati, 2010; Yang et al., 2010). These studies are good examples on the methodology and mechanism. In some sense, more attention needs to be concentrated on the emergy supply and flow between ecosystems and urban area in a particular region. Based on these findings, an emergy approach is applied to establish a framework for evaluating the ecosystem services by identifying systemic roles of each components. The mainly objectives include: (1) an emergy evaluation of energetic flows of ecosystem services and (2) an impact matrix to analyze systemic roles of services in the analyzed system.

2. Study area

Chongming Island (31°25′–31°38′N and 121°50′–122°05′E) is an alluvial island located in northeastern Shanghai at the mouth of the Yangtze River. Covering 1200 km^2 and increasing in size by approximately 500 ha annually through the deposition of sand, silt, and mud from the Yangtze River, the island is the third largest in China and the largest alluvial island in the world (Zhao et al., 2004). It supports a population of approximately 695,000 at the time of the 2016 Chinese census. The cultivated land area was 107.2 thousand ha in 2012, accounting for 76.3% of total land area, and the per capita cultivated land area was 0.13 ha. The areas of the forest land and built-up land are 26.5 thousand ha and 7.05 thousand ha, respectively (Fig. 1).

With hyper-fast urbanization processes and mega-scaled developments in the vast majority of Chinese cities, Chongming Island is becoming one of the most typical pilot sites in China for ecological communities studies (Yang and Zhang, 2016). It has a comfortably warm and humid climate with sufficient rainfall and distinct changes of seasons (Tian et al. 2008). The island has an average elevation of 1.6–2.6 m above sea level, with the northwest and central areas somewhat higher than the southwest and eastern ones. Because of far away from the center of Shanghai city, which is home to 24.2 million people, Chongming Island committed to the development of ecological agriculture and cleaning industry, which made it become an ecological area. The major ecosystem types in Chongming Island are agricultural ecosystem and wetland ecosystem. The agro-ecosystems dominate most of the land use and provide most of the food supply, and the natural wetland ecosystems are widely distributed along the coastline and provide important habitats for many wildlife species.

3. Framework for evaluating ecosystem services

3.1. Delineation of ecosystem

This study is with research focus on spatial delineation to describe the different ecosystems in Chongming Island. Our study uses a land cover classification data set developed by the Chinese Academy of Sciences (CAS). The data set is derived from Landsat TM/ETM images of bands 3, 4, and 5 with a spatial resolution of 30 m × 30 m. TM/ETM images are used to interpret the spatial distribution of different land covers to delineate the boundaries of all the ecosystems. The data set includes times series data for six periods and the classification containing six types of land uses and land covers. Different land covers may have related to different ecosystem services. For example, forest ecosystems are relation to timber and water supply; cropland ecosystems are associated with food and recharge ground water.

3.2. Identification of the services provided by ecosystems

To elucidate how a sub-ecosystem, identified in step 1, the first task is to diagram the stocks and flows among different system components of each ecosystem. The components within each subsystem are verified by the characteristics of the study area, and the subsystems represent the primary ecological and socioeconomic aspects in the study area (Burkhard et al., 2009). We used the ecological energetic diagrams developed by Odum (1996) to trace the energy flows among different components and identify the ecosystem services which are important to the urban systems. Then we classify each energy flow as supporting, regulating, provisioning and cultural ecosystem services. Inter-and intra-system linkages can be determined via energetic and material flows between system components. Intra-linkages between system components can be regarded as supporting services, which are processes for maintaining system viability. Inter-linkages between ecosystems and urban systems can be considered the other three ecosystem services which support the physiological requirements of urban systems (see Fig. 2).

3.3. Emergy evaluation of the ecosystem services

Emergy synthesis is a method of environmental accounting where the cumulative energy necessary to produce the observed components of the studied system is accounted for (Odum, 1988; Campbell and Brown, 2012). Ecosystem services can be defined as any benefit to humanity derived from the environment; however, this research only considers ecosystem services that exist external to existing markets (Jiang et al., 2007; Jacobs et al., 2015). After linking ecosystem services

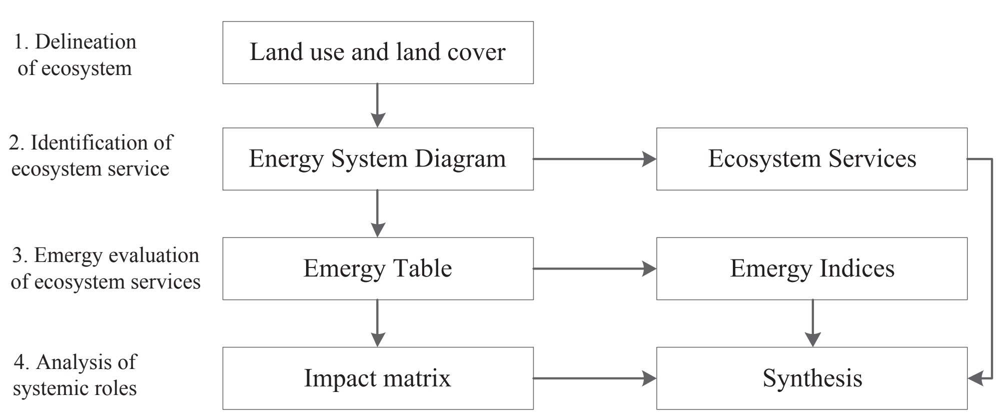

Fig.2. Framework of ecosystem valuation.

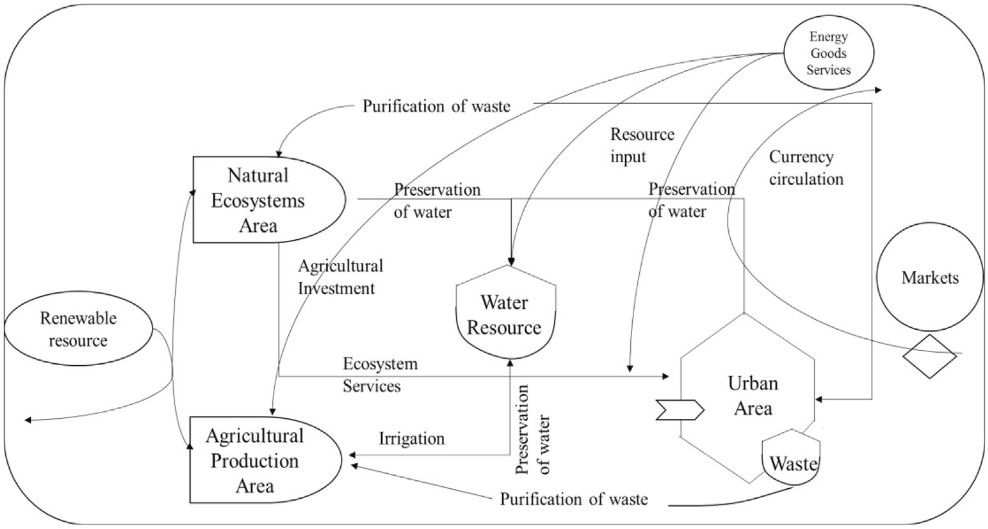

Fig. 3. Ecological economic system of Chongming Island.

with forest, agricultural and wetland ecosystem according to the varied land use types, an emergy analysis system diagram was drawn (see Fig. 3).

After drawing a system diagram, an emergy evaluation table can be developed to quantify the energy content or mass of the identified flows. The energy content or mass can then be multiplied by its solar transformity or specific emergy to obtain its emergy in solar emjoules (sej). By converting all energy flows and physical resources to solar emergy, these values can be used for direct numerical comparison and summing (Huang et al., 2011).

Environmental accounting (emergy synthesis) was developed in order to provide valuation external to the economy and adherent to the fundamental laws of thermodynamics (Odum, 1996). The emergy method accounts for all types of energy, from the environment and humanity, of all forms, used both directly and indirectly, to produce a product or service (Brown and Bardi, 2001). This allows for the differences in "quality", or ability to do work, of said products or services to be realized and compared (Table 1). This system of valuation allows the connections between nature's production of ecosystem services and people's consumption of them to be quantified in the same physical unit and translated into financial terms (Chen and Chen, 2011; Campbell and Tilley, 2014).

In this study, we use the general method developed by Campbell and Brown (2012) to determine emergy value of an ecosystem service, firstly, we diagram the target component of the ecosystems where the material and energy flows associated with the ES are evident using the energy systems language. Then determine the steady state conditions for model calibration under natural conditions in Chongming Island and under typical suburban development using data found in the literature. We simulate the model and determine the difference in biophysical flows. At last, we apply appropriate transformities (sej/J), either calculated or from the literature, to these values to obtain the emergy value. The 15.83×10^{24} sej/yr global renewable emergy baseline was used (Odum et al., 2000). The general equation for determining the emergy value is as follows.

$$Emergy = (Biophysical\ value, J) \times (Transformity, sej/J)$$

The emergy value of the ecosystem services was determined to be the difference between the emergy flow in a natural system and the most likely alternative land-use, calculated as

$$Ecosystem\ service = (Emergy\ flow\ in\ the\ natural\ ecosystem, sej) - (Emergy\ flow\ in\ the\ most\ likely\ alternative\ land-use, sej)$$

3.4. Impact matrix

Impact matrix methodology is contained in the sensitivity model (SM), a widely applied biophysical approach that was presented by Vester and von Hesler (1980). The impact matrix can reveal linkages between system components (Vester, 1988; Wiek and Binder, 2005). Each component defines a row and a column in the impact matrix. The assessments in a single row indicate the flows from component 1 to the other components; whereas the assessments in a single column indicate the flows from other components to component 1 (see Table 2). In this paper, the components including agriculture-soil nutrient, agriculture-biomass, agriculture-soil water, forest-soil nutrient, forest-biomass, forest-soil water, water resource-upstream, water resource-groundwater and urban system.

The sums of all flows to all other components (sum of rows = active sum) indicate the ability of an individual component to influence all other components in the system. The sum of inflows from other components (sum of columns = passive sum) is a corresponding value for the passiveness of the component due to changes in other components in the system. The total sum (active sum + passive sum) represents how strongly the component is interlinked with the system; the higher the total sum (TS) of flows to and from the component, the more critical it

Table 1
Relevant terminology and definitions.

Term	Definition
Emergy	The available energy of one kind that is used up in transformations directly and indirectly to make a product or service
Solar emjoule (sej)	The unit of emergy, a solar equivalent joule. Solar is the most diffuse energy, thus the logical base unit
Transformity	The cumulative available energy (emergy) used to create one unit of matter, available energy, information, etc.
Renewable emergy baseline	This is the quantity of renewable emergy input to the earth in a certain given year, consisting of solar, deep heat and tides, and used to determine transformities of global renewable flows like rain and wind. We use 15.83E24 sej/yr as the global renewable emergy baseline.

Table 2
Impact matrix showing interaction between components.

From ↓ to →	Component 1	Component 2	Component 3	…	Active-sum(AS)
Component 1					
Component 2					
Component 3					
…					
Passive-sum (PS)					
Total Sum (AS + PS)					
Quotient (AS/PS)					

Note: adapted from Vester (2012).

is to the system. The quotient (Q) is calculated by dividing the active sum (AS) by the passive sum (PS) for each component, revealing whether its character is more active or reactive. If Q is > 1, the component has an active role in the system; if it is < 1, that the component is strongly influenced by other components.

4. Results

4.1. Ecosystem service assessment of each subsystem

Based on land use and land cover maps, this study identified six major ecosystems that generate ecosystem services for urban areas. The major ecosystems include forest, agricultural areas and wetland. The agricultural system includes crop lands, orchards, and aquaculture. The wetland ecosystem includes fresh and tidal water that can provide various ecosystem services for urban areas. Table 3 summarizes the services that each of these ecosystems might provide.

We evaluate the emergy of tidal wetland, agricultural, forest and freshwater ecosystems on Chongming Island in 2012. Results show that the tidal wetland ecosystem contributed the most service to Chongming Island, accounting for 45.2% of the ecosystem service, followed by the agricultural ecosystem, which accounted for 34.5% and the freshwater wetland ecosystem, which accounted for 6.3% (Fig. 4).

Water supply, flood storage and aquatic product supply were the main emergy outflows of the wetland ecosystem, accounted for 51.1%, 17.6% and 25.2% respectively. Food supply was the main emergy outflow of cropland ecosystem and accounts for 58% of the total. Organic matter production and water retention were the main emergy outflows provided by the forest ecosystem, accounting for 33.6% and 30.0%, respectively (Fig. 5). Based on the systematic emergy dynamic

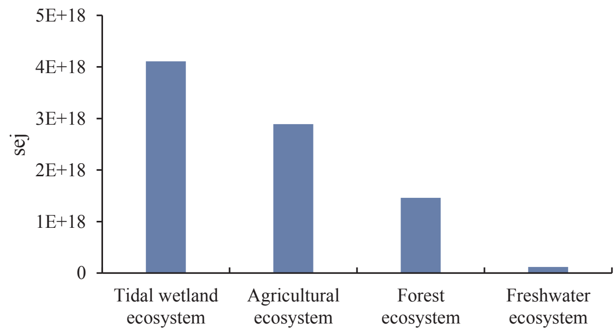

Fig. 4. Emergy-based ecosystem of each subsystem in 2012.

analysis, the wetland and forest ecosystem have played more significant roles in water supply and retention while the cropland ecosystems have occupied a less important position in food supply from 2002 to 2012.

We found that organic production, carbon fixation and oxygen release have trended lower with decreased, compared with 2002, the decrease was 11.3% and 8.1%, respectively. However, because of the increase in precipitation in 2012, the emergy of water conservation showed an increasing trend of 11%. Meanwhile, the values of food supply and soil conservation' emergy showed a slow downward trend (Fig. 6).

4.2. Emergy evaluation of the ecosystem services on Chongming Island

Table 4 describes the results of our emergy synthesis for evaluating ecosystems services. The results of the emergy synthesis of forest ecosystem in 2012 was shown in Table 4. In this subsystem, renewable energies consist of the sun, wind and rain, among which Rain chemical (6.36 E20 sej/yr) is the major source of renewable emergy. The outflow energy includes surface runoff (3.07 E20 sej/yr), ground water discharge (5.45 E20 sej/yr), and soil loss (4.84 E18 sej/yr). Ground water discharge is generated by water infiltration (6.44 E20 sej/yr), which has the highest emergy value of all internal processes.

Renewable energy sources include the sun, wind and rain. The size of agricultural fields determines the amount of renewable energies used by the agricultural production area. To enhance crop production, human-subsidized production systems must use energy and materials (e.g., fertilizer, irrigation water, and labor). One of the major ecosystem services offered by agricultural production areas is food provision. As large volumes of irrigated water are required to maintain aquaculture and crops, the water infiltration to the soil can eventually be used to recharge ground water or to form surface runoff.

Table 3
Links among ecosystem types and ecosystem services identified for Chongming Island.

Services	Ecosystem					
	Forest area	Agricultural area			Wetland area	
		Cropland	Orchard	Aquaculture	Freshwater	Tidal
Provisioning Services						
Food		•	•	•		
Fresh water	•				•	
Regulating services						
Water regulation	•				•	•
Erosion regulation	•	•	•	•		•
Water purification and water treatment						•
Cultural services						
Recreation and ecotourism	•	•	•	•	•	•
Supporting services						
Primary production	•		•	•		
Nutrient cycling	•	•				

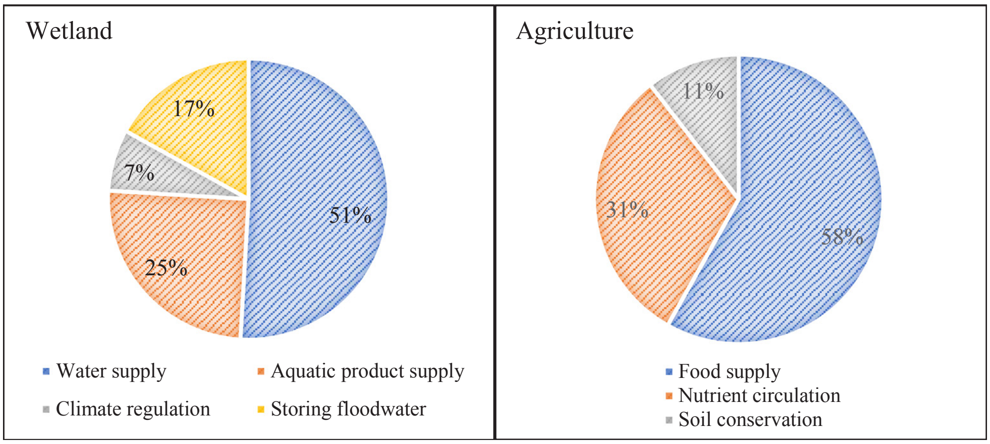

Fig. 5. Emergy of the wetland and agricultural ecosystem service.

The emergy value of flows for each of the agricultural production ecosystems in the study region was shown in Table 5. Cropland requires more fertilizer than other agricultural production ecosystems, including more N (5.92 E12 sej/yr), P (7.81 E15 sej/yr) and K (8.52 E14 sej/yr). Meanwhile, the emergy value of good and service is the highest (5.78 E20 sej/yr). The aquaculture areas provide excellent opportunities for recreation, such as fishing, in the study region. The emergy value of recreation services is 6.39 E20 sej/yr in the study region.

Upstream channels receive not only inflows from ground water but also surface runoff. In addition to the public water supply and hydroelectricity generation, the impoundment of reservoirs can be used for irrigation. In addition to surface runoff and upstream flows, waste water from nearby urban areas also flows into downstream channels. Many smaller ponds in downstream areas can store water to irrigate farmland and can also be used for fish production.

The flows of energy, internal process and outflows were used to calculate emergy values of water resources for 2012. The emergy value of reservoir inflows accounts for 4.77 E20 sej/yr, while ground water discharge from upstream watersheds is approximately 5.45 E20 sej/yr. The energy values of the water supply and hydroelectricity are 1.89 E21 sej/yr and 3.03 E20 sej/yr, respectively. Both make a large contribution to the emergy of the water resources (Table 6).

4.3. Impact matrix for identifying the systemic roles of the ecosystems

Impact matrix of ecosystem services are shown in Table 7, assessments in each row indicate how one component influences other components; whereas assessments in each column indicate the influence of other components. The components with a high active sum (AS) include upstream rivers, soil nutrients and crop biomass of the agricultural production areas, and soil water in the forest ecosystems. The upstream rivers, crop biomass and soil water in the forest ecosystems also have high passive sums (PS), leading to the highest value for a total sum (TS = AS + PS), indicating the critical influence of these components in the entire system.

The forest ecosystem can conserve water resources by storing excess runoff and discharging ground water to surface water. The soil water component thus provides a regulating service on water flow and plays a critical role in the entire system. The soil nutrients in the forest ecosystem are an active component because they support biomass

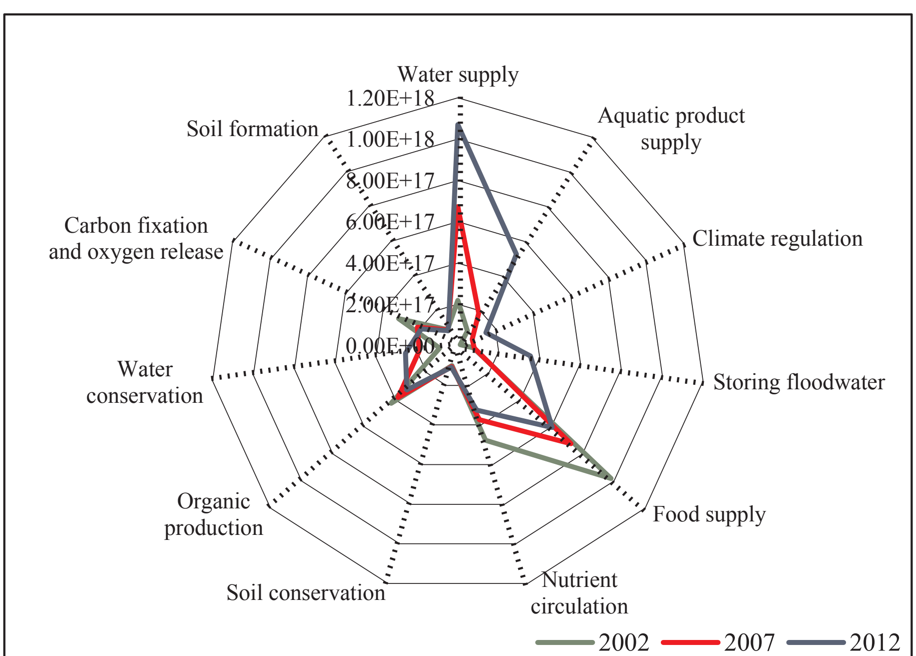

Fig. 6. Emergy-based ecosystem services of each subsystem during 2002–2012.

Table 4
Emergy evaluation of the forest ecosystem in 2012.

Items	Raw data (unit/yr)	Transformity (sej/unit)	Source	Solar emergy (sej/yr)
Inflow energy				
Sun	8.97E+18	1	Odum (1996)	8.97E+18
Wind	3.02E+17	1496	Odum et al. (2000)	4.51E+20
Rain (geopotential)	1.07E+13	10,488	Odum (1996)	1.12E+17
Rain (chemical)	3.49E+16	18,200		6.36E+20
Rain (chemical-absorbed)	1.07E+16	18,200		1.94E+20
Internal processes				
NPP, total live biomass	1.08EE+16	18,020		1.94E+20
Litterfall	1.04E+16	18,619		1.94E+20
Infiltration	2.32E+16	27,764		6.44E+20
Outflow energy				
Surface runoff	1.11E+16	27,764		3.07E+20
Ground water discharge	1.96E+16	27,764		5.45E+20
Soil loss	6.54E+13	74,000		4.84E+18

Table 5
Emergy evaluation of the agricultural production in 2012.

Items	Cropland (sej/yr)	Orchard (sej/yr)	Aquaculture (sej/yr)	Total (sej/yr)
Inflow energy				
Sun	5.99E+17	1.40E+17	1.17E+17	8.56E+17
Wind	3.02E+19	7.07E+18	5.89E+18	2.29E+16
Rain (geopotential)	4.69E+15	1.10E+15	4.58E+14	6.25E+15
Rain (chemical)	4.35E+19	9.96E+18	8.30E+18	6.18E+19
Rain (chemical-absorbed)	1.22E+19	3.05E+18	2.39E+18	1.76E+19
Goods and services	1.30E+20	2.16E+19	4.26E+20	5.78E+20
Fertilizer				
N	4.03E+15	1.89E+15	–	5.92E+12
P	5.51E+15	2.30E+15	–	7.81E+15
K	5.67E+14	2.85E+14	–	8.52E+14
Irrigation	1.05E+17	2.47E+16	2.48E+18	2.61E+18
Outflow energy				
Surface runoff	4.10E+19	9.61E+18	–	5.06E+19
Soil loss	1.55E+18	3.64E+17	–	3.80E+18
Production	1.24E+20	4.40E+19	5.46E+19	2.23E+20
Recreation	1.73E+20	3.16E+19	4.34E+20	6.39E+20

Table 6
Emergy evaluation of water resources in 2012.

Items	Raw data (unit/yr)	Transformity (sej/unit)	Source	Solar emergy (sej/yr)
Inflow energy				
Ground water	1.96E+16	27,764	Huang (2011)	5.45E+20
Runoff (upstream)	1.11E+16	27,764		3.07E+20
Soil loss (upstream)	6.54E+13	74,000		4.84E+18
Waste water	4.37E+12	676,409		2.95E+18
Goods and services	9.76E+07	1.87E+12		1.82E+20
Tourist	3.01E+07	1.87E+12		5.63E+19
Internal process				
Reservoir inflows	1.75E+16	27,764		4.77E+20
Upstream flow	8.93E+10	48,459		4.33E+15
Outflow energy				
Hydroelectricity	2.47E+15	123,000		3.03E+20
Water supply	9.74E+15	194,108		1.89E+21
Recreation				
Fish production	1.29E+10	2.00E+06		2.59E+16
Irrigation	5.16E+15	48,459		2.51E+20
River	9.14E+05	48,459		4.43E+10

production. The high active sum and passive sum values of the agricultural production system components reveal the critical role they play in the provision of ecosystem services.

By calculating the activeness and passiveness of each ecosystem component, and placing them into a system grid we can examine the importance of each component within the system (Fig. 7). The horizontal and vertical lines represent the arithmetic sum of passiveness and activeness, respectively. Dividing the system into four sectors (active, passive, critical and indifferent) to demonstrate the specific significance of each component.

Results revealed that the upstream waters provide surface water and hydroelectricity, which is considered the most critical components and have an active role in the entire ecosystem, the downstream portion of the water resources tends to receive runoff and discharge from other system and consequently its role is less than that of upstream components. And for the soil water in the forest ecosystem that provides a

Table 7
Impact matrix of ecosystem services in 2012.

From ↓ to →	Forest ecosystem			Agricultural ecosystem			Water Resource			Urban system	Active sum (AS)
	Soil water	Soil nutrient	Biomass	Soil water	Soil nutrient	Biomass	Upstream	Down stream	Groundwater		
Renewable Energies	6.21E+20			1.98E+20							
Forest ecosystem											
Soil water							8.14E+20		5.99E+20		1.413E+20
Soil nutrient			1.67E+20				4.14E+18				1.711E+20
Biomass		2.13E+14								0.00E+00	2.13E+14
Agricultural ecosystem											
Soil water								1.87E+20	1.02E+20		2.89E+20
Soil nutrient						1.43E+21		6.82E+20			2.112E+21
Biomass										1.52E+21	1.52E+21
Water Resource											
Upstream				2.15E+20				7.50E+20		2.18E+21	3.145E+21
Down stream											
Groundwater				3.19E+18							3.19E+18
Urban system					1.89E+18	5.16E+20	2.17E+20	2.17E+09			7.349E+20
Passive sum (PS)	6.21E+20	2.13E+14	1.67E+20	4.16E+20	1.89E+18	1.95E+21	1.04E+21	1.62E+21	7.01E+20	3.70E+21	
Total sum (TS)	2.03E+20	1.71E+20	1.67E+20	7.05E+20	2.11E+21	3.47E+21	4.18E+21	1.62E+21	7.04E+20	4.43E+21	
Quotient (AS/PS)	2.28E	803474.178	1.27545E−06	0.69439487	1117.4632	0.781089	3.03823674	0	0.004550642	0.198618919	

regulating service on water flow and plays a critical role in the entire ecosystem. The soil nutrients in the forest ecosystem are an active component because they support biomass production. The highest passive sum value is the urban system reveal that urban system is easily affected by other components, is a major consumer of ecosystem services and sinks. The high active and passive sum values of agricultural system reveal the important roles they play in the provision of ecosystem services.

5. Conclusions and discussion

This study presents an approach for evaluating ecosystem services that fulfills the systemic and biophysical requirements of an appropriate assessment. The results based on the emergy synthesis indicate that the tidal wetland ecosystem contributes the most service to Chongming Island, accounting for 45.2% ES emergy in 2012. The wetland and forest ecosystems played more significant roles in water supply and retention while the cropland ecosystem had a less important role in food supply from 2002 to 2012. The major consequence of land cover change was the decreased provision of ecosystem services from agricultural production areas. The results of our matrix analyses reveal that water resources in upstream watersheds, soil water in forest and agricultural ecosystems play the most critical roles in providing ecosystem on Chongming Island. The urban ecosystem is easily affected by other components, has gradually transformed from a positive to a passive participant in the role of supplier and user for ecosystem services.

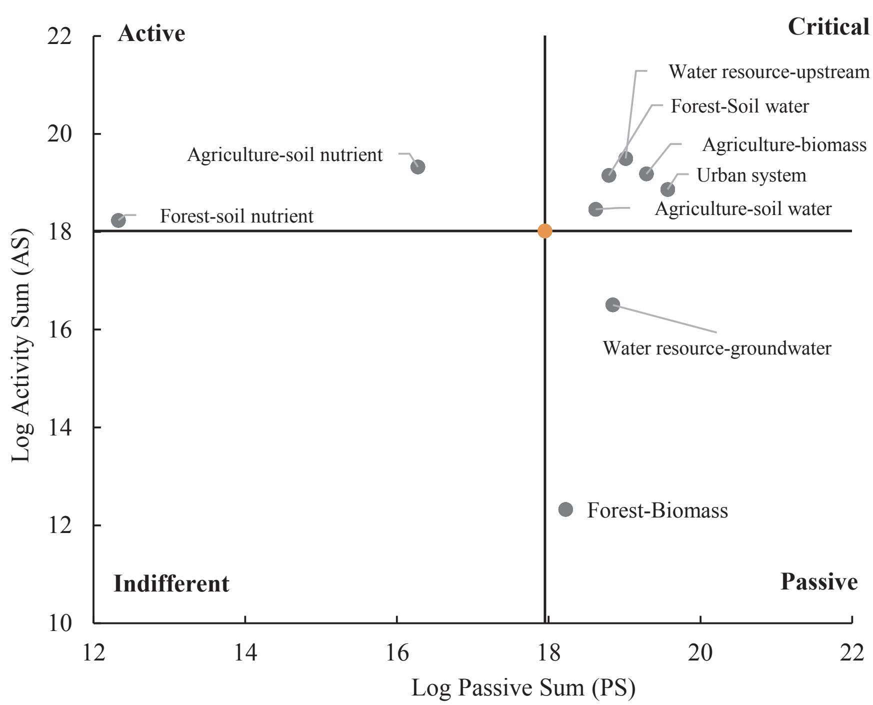

Fig. 7. System grids showing systemic role of ecosystem services in Chongming Island.

Some ecosystems change in urban areas result from activities related to the citizen use of ecosystem services, such as food and water, however, most ecosystem changes in pre-urban areas are the indirect effect of land use and land cover changes (Li et al., 2007; Alberti, 2010). For Chongming Island, industrial transformation has resulted in land use and land cover change, high cost of urban land and rapid accumulation of capital have led to increased investment, focus on the short-returns of developers was the cause of the loss in ES function and environmental degradation at the same time, the rapid development of highway and expressway corridors resulted in the loss and degradation of prime agricultural lands and subsequent environmental impacts, such as water pollution. Competition for land in the process of urban expansion, the promotion of the regional industrial structure adjusting strategy and the influences of imported production on local markets all have played a role in land use and land cover change and the energy flow in the market.

The healthy and sustainable development of a city or region needs a variety of services provided by the surrounding ecosystem. Folke et al. (1997) reported that the 29 largest cities of Baltic Europe appropriate for their resource consumption and waste assimilation an area of forest, agricultural, marine, and wetland ecosystems that is at least 565–1130 times larger than the area of the cities themselves. The results were consistent with the conclusion of this study, urban systems are easily affected by other components, is a major consumer of ecosystem services and sinks. Elmqvist et al. (2015) revealed that the ecological restoration and rehabilitation of ecosystems such as wetland and forest ecosystem, may not only be ecologically and socially desirable, but also play more significant economically roles in city system, which was consistent with the conclusion of our research. What's more, the systemic role of agricultural production areas in providing ecosystem services is becoming less critical, and these issues need urgent attention. In rapidly transforming landscapes such as the urban area in Chongming Island, planning for a more efficient urban agglomeration is an important strategy for urban planning to create a sustainable and environmentally future.

Therefore, land planners should reinforce the effective spatial plan for controlling urban growth, an adequate spatial plan should visualize future landscape changes and model ecosystem responses. And the current non-urban land use control system for rural areas should have a guiding plan to ensure consistent standards for regulating sprawl, and environmental degradation. The designation of long-term natural and agricultural production areas, combined with policies to encourage increased urban density and limit growth in more rural areas, is urgently needed. Without these long-term plans, the traffic land and residential and industrial land will increase rapidly, thus lead to the decrease of farmland and the resulting loss of ecosystem services in peri-urban areas. On the other hand, the total area of wetlands in Chongming Island reduces. Large lakes are smaller and small lakes are being disappeared. The main reason for the decrease of wetland area is that the biological diversity, purification of water body, water conservation and other ecosystem services are going down the surrounding lake. Therefore, land planners should strengthen wetland management and restore the ecosystem function of wetland ecosystem.

A final note about this paper is that we did not analyze the cultural services, which may underestimate the value of the ecosystem service and its impact of the urban system. Furthermore, because the lack of official data of partial indicators of Chongming Island, we converted the data from Shanghai based on the transfer coefficient, this may also bring errors to the estimated results. Even so, the implications of biophysical valuation of ES for district's spatial planning need to address it now.

Conflicts of interest

The authors declare no conflicts of interests.

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