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Ecological footprint analysis on tourism carrying capacity at the Zhoushan Archipelago, China

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ABSTRACT

Tourism has been a dynamic and potential industry in China in the recent two decades. However, the rapid development of tourism has caused tremendous ecological pressure. Evaluation of tourism carrying capacity is imperative to have a comprehensive understanding of tourism's development and sustainability. Ecological footprint (EF) analysis was applied to quantitatively assess the ecological carrying capacity of tourism in the Zhoushan Municipality during the years 2010–2014, and geospatial technologies were used for regional analysis. Results showed that the tourism EF (TEF) and local EF slowly increased between 2010 and 2014. TEF accounted for a remarkable proportion over this five-year period and reached 20–30% of the regional EF. Amongst the four sub-regions, Dinghai appeared to have a relatively large deficit, whereas Shengsi presented a great ecological carrying capacity surplus, thereby revealing a remarkable local imbalance of development. Although the TEF of Zhoushan was slightly over its carrying capacity, the per capital EF of residents remained below average national and global levels. Proper planning and development of tourism at the regional level are suggested as a sound strategy for sustainable development of the Zhoushan Municipality.

KEYWORDS

Tourism; ecological footprint; demand and supply; ecological deficit and surplus; island

Introduction

Tourism is regarded as a profitable economic sector and a potential stimulus to the economy by many countries (Neto, 2003). The tourism industry worldwide contributed 7.6 trillion dollars (2014 prices), which accounted for almost 9.8% of the global GDP, and created approximately 9.1% of the employment opportunities worldwide in 2014 (World Travel & Tourism Council, 2016). The transformation and reform of China's economy in the recent two decades have allowed the domestic tourism industry to develop rapidly and become a new booming industry in the country. The national tourism revenue almost doubled every year from 1993 to 2010 (Li, Zhu, & Liu, 2016). The overall contribution of the national tourism industry in 2014 was 6.61 trillion RMB or approximately 10.39% of the total GDP. The tourism revenue of China is expected to continually increase over the next few decades (Chen & Yang, 2016; Li et al., 2016). Tourism has become one of the most dynamic and potential industries in China (Lin & Jing-Bing, 2006).

Local tourism development is primarily dependent on natural resources and its environment. The impacts of tourism activity on the environment, however, have often been detrimental (Neto, 2003). The tourism resources within the carrying capacity of the local environment should be effectively managed. Tourism carrying capacity (TCC), an important management tool of measuring tourism development and sustainability, has gradually gained widespread concern from scientists and decision-makers (McCool & Lime, 2001; Xiong, 2013).

In the early stages of TCC studies, researchers primarily focused on the maximum number of individuals of a given habitat support, without being perpetually damaged (Li & Rong, 2007; Sun & Wang, 2000). The key research questions then have developed from

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"How many is too many?" to "What are the appropriate or acceptable conditions?" (McCool & Lime, 2001). Different approaches to assessing the TCC have been proposed in previous papers. However, they showed some limitations, such as a complicated index system with subjective determination processes, in revealing the environmental sustainability of tourism activities in quantitative terms (Navarro Jurado et al., 2012; Sharma, 2016; Tang, 2015). Ecological footprint (EF) is regarded as a simple and operable indicator with intuitive and clear calculation results that can maintain comparability over time and amongst regions; it can better integrate tourism development and natural environmental protection at tourist destinations (Wackernagel et al., 1999). Tourism ecological footprint (TEF) has rapidly taken ground as a tool for assessing all aspects required to guide sustainable tourism activities (Gössling, Hansson, Hörstmeier, & Saggel, 2002; Hunter & Shaw, 2007; Martin-Cejas & Sánchez, 2010; Peeters & Schouten, 2006). EF analysis, which provides a direct measurement of natural capital, is an effective tool that attempts to evaluate the sustainability of a system from an accounting perspective (Kharrazi, Kraines, Hoang, & Yarime, 2014). This quantitative method not only adopts the same unit of biological productive area for converting different types of areas but also provides a useful approach for comparing the environmental pressure of various components of tourism. As an intuitive method for calculating and conveying the demand and supply of natural resources, the EF can also be used as a powerful educational tool to help people understand the real degree of the ecological problem (Martin-Cejas & Sánchez, 2010). EF provides global and industrial perspectives to estimate and depict the pressure upon natural resources imposed by human lifestyles. To compare the environmental impact of the different components of tourism products, visitors are provided with correct and pertinent information and then encouraged to switch their travel models.

Nevertheless, existing TEF studies often highlight the ecological balance of profits and losses and rarely reveal the degree or level of its balance of supply and demand on the basis of continuous spatial–temporal scale (Patterson, Niccolucci, & Marchettini, 2008). Research under continuous time is conducive to reflecting its change and development trend (Liu, 2014). Moreover, most studies have concentrated on single scenic spots, separating entire islands and their neighbouring or embedded tourist cities (Tsaur, Lin, & Lin, 2006). Tourist destination is an open economic system, which is not only constantly engaged in providing people with various services but also exists with the surrounding regions of material and energy exchange (Romadhon, Yulianda, Bengen, & Adrianto, 2014). In China, "county" is a basic administrative unit implementing sustainable development strategy. Accordingly, thorough evaluation of county tourism environment is practically important for the government to formulate and implement targeted policies. In addition, the visualisation of results should be improved by strengthening the combination of remote sensing and GIS technology to provide a direct and comprehensive basis for regional or subregional management (Sun et al., 2014).

One of the most famous tourist islands in China, namely, the Zhoushan Archipelago, was selected as a study site. We applied the EF concept to assess the tourism ecological environmental quality and analyse its sustainability of regional development at the county scale during the years 2010–2014. EF–geospatial technology-based approaches were applied to assess the TCC. The results may provide a scientific guide to local decision-makers for implementing sustainable tourism activities in the near future. The methods and case study may also offer important implications for other coastal cities or islands for tourism sustainability studies.

Material and methods

Study area

The Zhoushan Archipelago (29°32′–31°04′N, 121°30′–123°25′E), located in the northeast of Zhejiang Province (Figure 1), is the largest island in the East China Sea, covering a total area of 22,000 ha, of which an area of 20,800 ha is sea. This island administers two districts and two counties, namely, Dinghai District, Putuo District, Daishan County and Shengsi County (Table 1). Zhoushan is a unique port and tourist city with 1390 islands of abundant natural sights and cultural resource. This city is also known as the "Buddhist Paradise on the Sea". The gross marine production contributes two-thirds of its total GDP, and the coastal and island tourism industry contributes about a quarter. Tourism is a major industry supporting the overall development of Zhoushan. Thus, measuring the TCC of the Zhoushan Archipelago will not only serve as a good case study but also provide important scientific references for future tourism planning and sustainable development in Zhoushan.

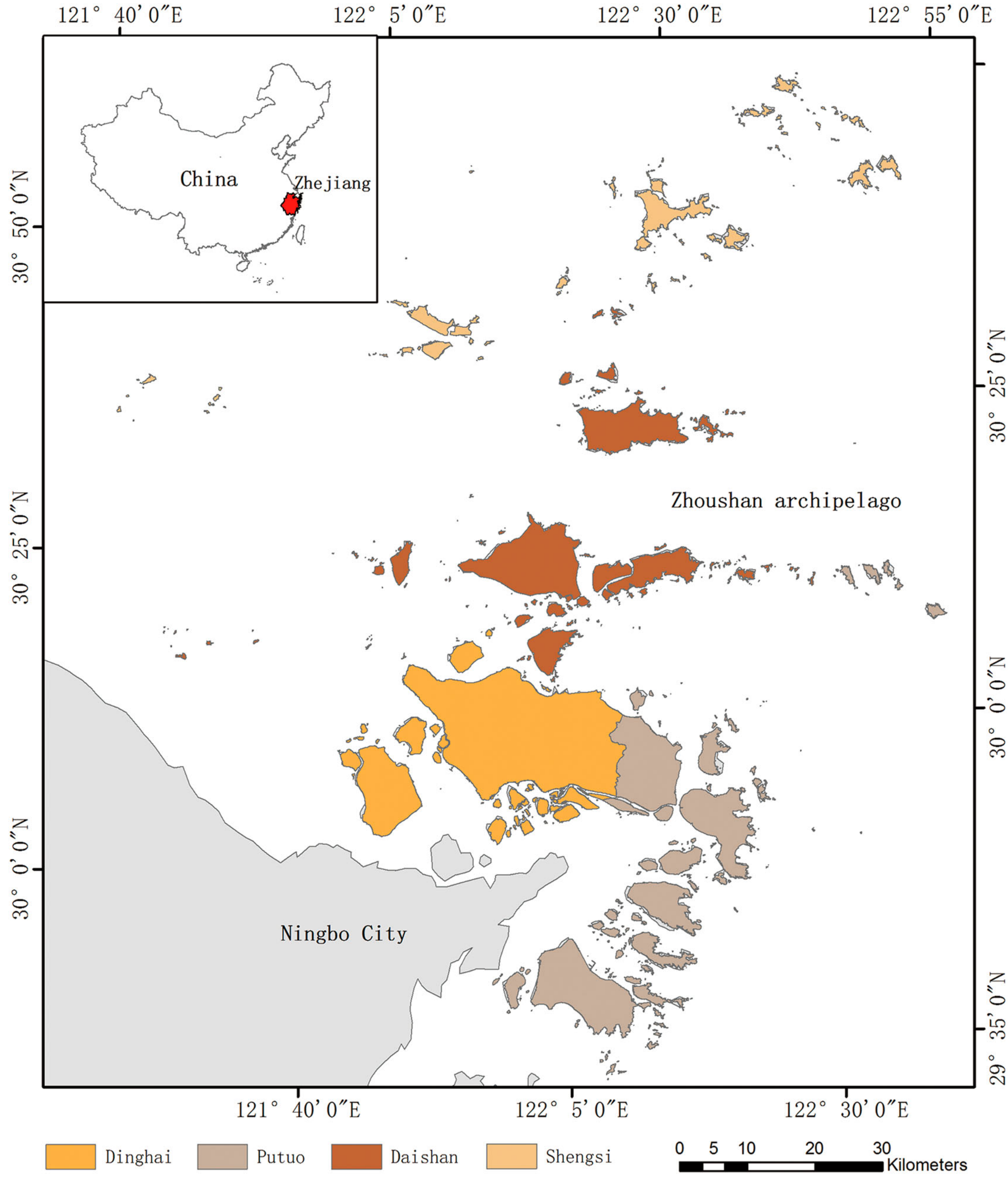

Figure 1. Study area of the Zhoushan Archipelago.

TCC assessment

Index system

The index system for TCC assessment was constructed based on the EF (Table 2). The TEF and local EF (LEF) were calculated to reveal the TCC of Zhoushan. Twenty-three specific indicators were selected to measure the EF.

EF calculation

All indicators were used to transfer the consumptions into six major types of biologically productive lands, namely, built-up land, cropland, pasture, forest land, fishing ground and fossil energy land (Wackernagel, Lewan, & Hansson, 1999). The accounts were normalised by translating each of the biologically productive

Table 1. Regional features of the Zhoushan Archipelago (2014).

District and county	Natural conditions				Social conditions		
	Study area (ha)	Land area (ha)	Tidal-flat area (ha)	Inhabited island	Population (in thousands)	GDP	Tourism revenue in billion (Yuan)
Putuo	6728	458.6	69.77	32	322.9	32.852	14.276
Dinghai	1444	568.8	37.74	23	386. 1	41.793	6.916
Daishan	5242	326.5	57.4	16	187.9	19.303	3.304
Shengsi	8824	86	21.28	16	78.0	8.014	3.580

lands from simple hectares (actual surface area) to global hectares (termed as gha) through conversion factors, namely, equivalence factors and yield factors (Lin et al., 2016; Monfreda, Wackernagel, & Deumling, 2004). The yield factors were adopted by Liu Moucheng in the study of the EFs of China to improve the reality of the calculation (Liu, 2014), and the equivalence factors were derived from the Global Footprint Network (GFN) (Lin et al., 2016), as summarised in Table 3.

The EF accounts can be classified into three parts: built-up land footprint, biological resource footprint and energy consumption footprint (Geng et al., 2014). Each land type is calculated by dividing the amount of consumption by specific coefficients of production, and the EF is the aggregated value of these area types converted into global hectares, that is,

$$EF = A_1 \times e_1 + \sum_{i=2}^{5}\left(\sum_{j=1}^{n}\frac{C_j}{P_{ij}} \times y_i \times e_i\right) + \sum_{j=1}^{n}\left(\frac{E_j}{r} \times e_6\right) \times \left(1 - \frac{1}{4}\right), \quad (1)$$

where y_i is the national yield factor for the i_{th} type of land; e_i is an equivalence factor for the i_{th} type of

Table 2. Index system of the TCC of Zhoushan.

Target	Sub-target	Index	Indicator	Unit	Data source
TCC of Zhoushan	TEF	Transportation	(B_1) Traffic land area	ha	a
			(B_2) Passenger transport volume	passenger-km	a
			(B_3) Unit energy consumption	t	d
			(B_4) Tourist usage rate	%	d
			(B_5) Self-driving travelling ratio	%	b
		Accommodation	(B_6) Number of beds		b
			(B_7) Room occupancy rate	%	b
			(B_8) Built-up land requirements per bed	ha	d
			(B_9) Energy requirements per bed	t	d
		Food	(B_{10}) Restaurant area	ha	a
			(B_{11}) Per capita food consumption	kg	a
			(B_{12}) Per capita cooking fuel consumption	t	a
			(B_{13}) Number of tourists		a
			(B_{14}) Tourist residence time	d	b
		Purchases	(B_{15}) Market area	ha	b
			(B_{16}) Sales of special local products	kg	d
		Sightseeing	(B_{17}) Area of scenic spot	ha	c
			(B_{18}) Energy consumption	t	d
	LEF	Built-up land	(B_{19}) Built-up land area	ha	c
		Food and Goods	(B_{20}) Per capita resource consumption	kg	a
			(B_{21}) Number of residents		a
		Energy	(B_{22}) Household energy consumption	t	a
			(B_{23}) Industrial energy consumption	t	a
	Bio-capacity (BC)	Biologically productive lands	(B_{24}) Area of built-up land	ha	c
			(B_{25}) Area of cropland		
			(B_{26}) Area of pasture		
			(B_{27}) Area of forest land		
			(B_{28}) Area of fishing grounds		

[a]Data from Zhoushan Statistical Yearbooks (Zhoushan Bureau of Statistics, 2010–2014).
[b]Data from investigation reports on tours (Zhoushan City Tourism Committee, 2010–2014).
[c]Data from Land Change and Update Surveying (Zhoushan Bureau of Land Resources, 2010–2014).
[d]Data from the referred or estimated data.

Table 3. Yield factor and equivalence factor.

		Cropland	Forest land	Pasture	Fishing ground	Built-up land	Fossil energy land
Yield factor	China	1.74	0.86	0.51	0.74	1.74	0
	Zhejiang	1.37	0.56	1.43	2.07	1.37	0
Equivalence factor	GFN	2.52	1.28	0.43	0.35	2.52	1.28

land; i (= 1, 2 , 3, 4, 5, 6, representing built-up land, cropland, pasture, forest land, fishing ground and fossil energy land, respectively) represents the land types; A_1 is the area of built-up land located human infrastructures; C_j is the annual total demand for the j_{th} products by humans; P_{ij} is the annual national average yield for the j_{th} product provided by the i_{th} type of land; $E_j$is the annual energy consumption of product j; and r is the energy conversion constant. A quarter of anthropogenic emissions were removed from the calculation because they were sequestered by oceans (Broadgate et al., 2013; Lee & Peng, 2014).

Different regions have great differences in natural and economic conditions, as well as in productivity structure. The national average yield (Dai, Wu, & Ouyang, 2015) and conversion factors (Table 3) derived from previous studies were applied in our analysis. In particular, the biologically productive land occupied by livestock husbandry was divided into grassland and farmland, instead of the traditional model that classified the land all into grassland, to adapt to the captive breeding and free-ranging modes for livestock husbandry of China (Dai et al., 2015). In addition, the consumption of aquatic products was divided into marine aquaculture and marine fishing. Accordingly, the current ecological environmental sustainability of Zhoushan could be reflected accurately from 2010 to 2014.

Index composition

(1) TEF

Based on its nature and characteristics, the tourist consumption is broken down into typical TEF categories of food, accommodation, transport, sightseeing, purchases and entertainment (Li & Hou, 2011; Patterson, Niccolucci, & Bastianoni, 2007). Area types are summed up to obtain the TEF value, and the system model is set up including five elements of tourism activities and described as follows:

$$\mathrm{TEF} = \mathrm{TEF}_t + \mathrm{TEF}_a + \mathrm{TEF}_f + \mathrm{TEF}_p + \mathrm{TEF}_s, \quad (2)$$

where TEF stands for the total tourism ecological footprint; TEF_t denotes the tourist transport footprint account;TEF_a denotes the tourist accommodation footprint account; TEF_f denotes the tourist food consumption footprint account; TEF_p denotes the tourist purchase footprint account; and TEF_s denotes the tourist sightseeing footprint account.

In tourist transport footprint account, the tourist arrival transport footprint was excluded to make it comparable between regional EF and bio-capacity (BC), which meant only the footprint that occurred in the islands was accounted.

(2) LEF

The LEF can be validated according to Equation (1). The LEF per capita was obtained by dividing the total LEF by the number of residents.

(3) BC

When calculating the BC, 12% of the available land should be preserved for biodiversity protection (Wackernagel et al., 1999). The BC of the region can be determined by the following formula:

$$\mathrm{BC} = \sum_{i=1}^{5} A_i \times e_i \times y_i \times (100 - 12)\%, \quad (3)$$

where A_i is the real area of the i_{th} type of land used for BC account, including built-up land, cropland, pasture, forest land and fishing grounds; and y_i is the yield factor of Zhejiang for the i_{th} type of land.

For the archipelago's characteristics, inland waters and sea area, as the biologically productive land of fishing ground, were estimated in BC calculation.

(4) TCC (sustainability)

The TEF reflects the demand for biologically productive land of all tourists. The BC of tourism represents the amount of biologically productive land that can be provided from the tourist region, and it is obtained by removing the LEF from the regional BC. The difference in the two values is used to determine whether an ecological deficit or reserve exists and can be calculated using Equation (4). If the BC exceeds the total EF, then the system is sustainable. Conversely, if the total EF exceeds the BC, an ecological deficit exists in an unsustainable system,

$$\begin{aligned}\mathrm{TCC}\ (\text{ecological deficit/surplus}) \\ = \mathrm{TEF} - (\mathrm{BC} - \mathrm{LEF}). \quad (4)\end{aligned}$$

A positive result represents ecological deficit, and a negative one represents ecological surplus.

Data collection

Primary and secondary data of the study area from 2010 to 2014 were derived from field surveys, local government agency reports and published papers and books (Table 2). In addition to these published documents, a questionnaire was administered to obtain data and information needed for the study. The questionnaire mainly included tourists' choices of sightseeing spots and special local products, as well as the tourists' utilisation rate of public transport facilities. A total of 203 tourists were interviewed by responding to the questionnaire at the major transport hubs and visitor centres of Zhoushan from June 2016 to July 2016. The conversion factors and other supplementary data were collected from published materials (Gössling et al., 2002; Wackernagel et al., 1999; Wiedmann, Barrett, & Cherrett, 2003; Xiao, Yu, Liu, & Xin, 2010).

Results

The results are presented in terms of TEF, LEF, BC and TCC (the sustainability of tourism activities).

TEF

The results of the five-year TEF of four districts (Table 4) showed that Putuo had the highest TEF, whereas Daishan had the lowest TEF from 2010 to 2014. The TEF of Putuo decreased at an average annual rate of 11.59% in former years (2010–2013) but rebounded in 2014.

Amongst the five major factors of TEF (Figure 2), the tourist purchase footprint (TEF_p) showed the greatest share of TEF and almost a similar trend to the total. In the entire Zhoushan, TEF_p showed a downward trend, but it was still the largest source and even more than a half of the TEF in the first two years (years 2010 and 2011). The lowest one was the tourism sightseeing footprint (TEF_s), and it almost never changed in the five-year period.

The contributions to TEF by the five types of lands are shown in Figure 3. Tourist demand of resources was mainly based on fossil energy land and fishing ground, and pasture was the lowest one. The fossil energy land increased yearly. The average annual growth rate of Zhoushan even reached 13.16%.

LEF

The LEF in each sub-region changed dynamically, but the growth tendency was observed from 2010 to 2014 (Table 4). The LEF of Zhoushan increased at the rate of 5.31% per year, and the average annual growth rate of LEF per capita was 5.11% (Table 5). The per capita LEF average annual growth rates of Putuo, Dinghai, Daishan and Shengsi were 5.63%, 4.58%, 5.03% and 5.44%, respectively. The LEF of Dinghai accounted for half of the total due to the impact of industry energy consumptions, and its average per capita LEF was much higher than those in the other three sub-regions.

The contribution to LEF by the five types of lands showed that the demand of the fossil energy land dominated the LEF and almost increased yearly (Figure 4). In addition to the heavy demand of fossil energy land, fishing ground was the second major

Table 4. TEF, LEF, BC and tourism BC of the Zhoushan Archipelago.

	TEF (10^4 gha)					LEF (10^4 gha)				
District and county	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Putuo	31.44	25.43	21.99	21.52	27.16	28.47	27.90	29.11	29.81	35.61
Dinghai	10.32	11.55	12.42	11.17	13.41	58.20	65.20	63.03	68.08	71.52
Daishan	2.29	4.10	3.69	3.00	3.03	14.20	13.68	13.84	17.47	16.98
Shengsi	3.62	6.45	5.06	5.18	5.13	3.92	5.10	4.93	4.89	4.78
Total	47.67	47.54	43.15	40.87	48.73	104.78	111.89	110.90	120.24	128.89
	BC (10^4 gha)					BC of tourism (10^4 gha)				
District and county	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Putuo	46.89	46.94	46.94	47.01	47.02	18.42	19.03	17.84	17.20	11.42
Dinghai	11.81	11.89	11.99	12.07	12.08	−46.39	−53.31	−51.04	−56.01	−59.44
Daishan	36.22	36.25	36.28	36.32	36.32	22.02	22.56	22.45	18.85	19.34
Shengsi	60.60	60.61	60.62	60.62	60.62	56.67	55.51	55.69	55.73	55.84
Total	155.50	155.69	155.84	156.01	156.05	50.72	43.79	44.94	35.77	27.16

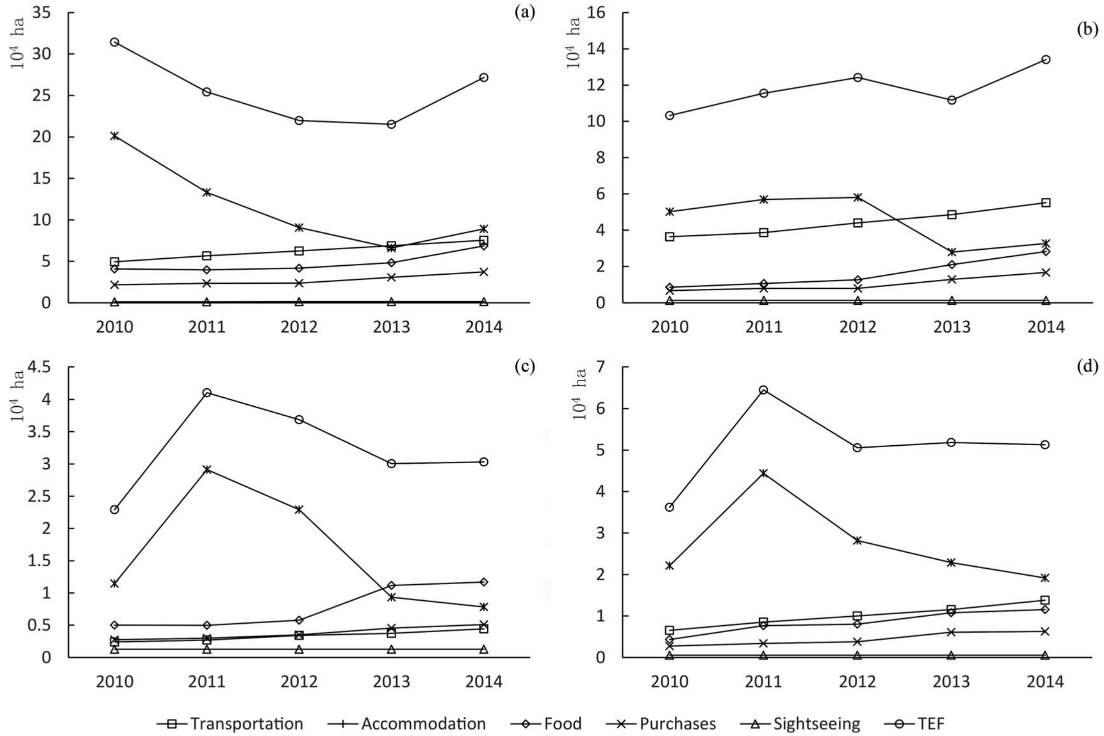

Figure 2. Annual TEF contribution of five categories from 2010 to 2014. The TEF status in Putuo, Dinghai, Daishan and Shengsi is shown in (a)–(d), respectively.

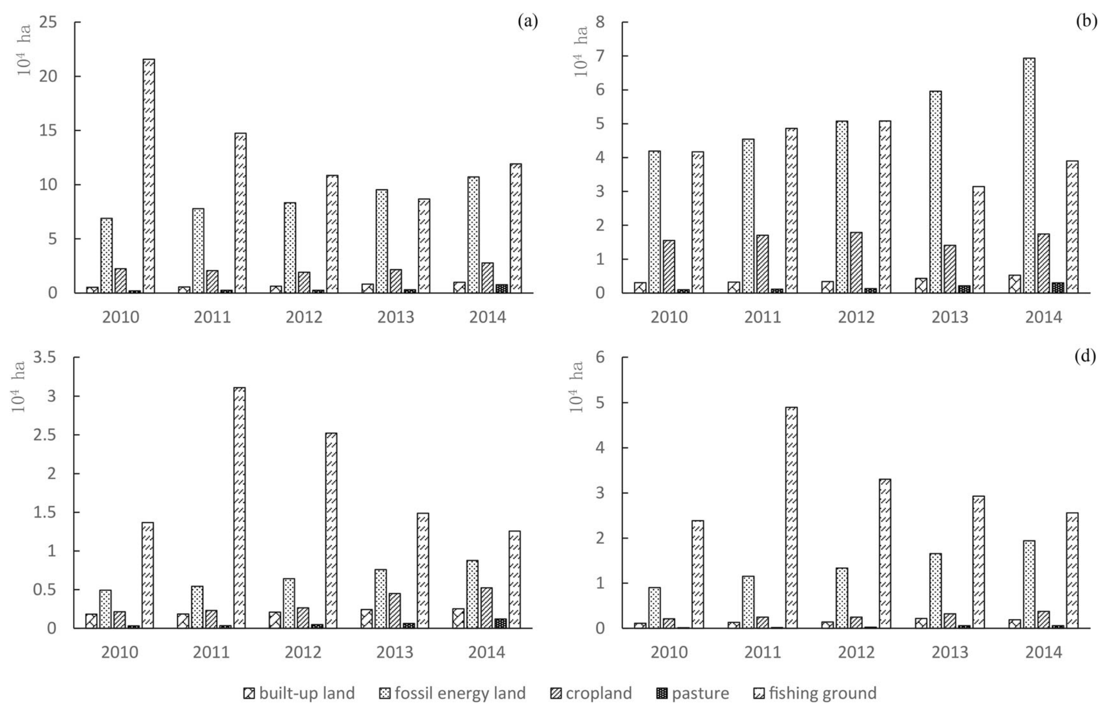

Figure 3. Annual TEF contribution of land types from 2010 to 2014. The TEF status in Putuo, Dinghai, Daishan and Shengsi is shown in (a)–(d), respectively.

Table 5. Per capita LEF of the Zhoushan Archipelago.

District and county	LEF per capita (gha·cap^{-1}·year^{-1}) 2010	2011	2012	2013	2014
Putuo	0.89	0.87	0.90	0.93	1.10
Dinghai	1.55	1.72	1.65	1.77	1.85
Daishan	0.74	0.72	0.73	0.93	0.90
Shengsi	0.50	0.65	0.62	0.63	0.61
Average	1.08	1.15	1.14	1.24	1.32

source of local demand, and it was even more than all other four land types in Shengsi. The demand of pasture was the lowest in each sub-region. The demands of built-up land, fossil energy land, cropland, pasture and fishing ground all increased at average annual rates of 2.43%, 5.81%, 3.42%, 8.51% and 5.83%, respectively.

BC

In the four sub-regions, Dinghai possessed the minimum BC. Conversely, Shengsi demonstrated its advantage because of its large sea area, which was the largest contributor of BC for fishing ground (Table 4). The BC did not fluctuate much over the years; however, the built-up land maintained a steady growth in each sub-region. The calculation results with five land types are summarised in Figure 5. In the entire Zhoushan, the BC of built-up land increased at an average rate of 2.43% per year, but the BC of forest land, cropland, pasture and fishing ground all showed a reduction at average annual rates of 0.38%, 0.87%, 0.47% and 0.02%, respectively.

TCC (sustainability)

The difference in the regional EF and BC reflects whether an ecological deficit or reserve exists.

BC of tourism

The results of the five-year BC of tourism (Table 4) showed that Shengsi possessed the greatest tourist environment BC. Negative values appeared in Dinghai, which meant that the resident demand for resources exceeded its BC. The changes in the BC of tourism in Zhoushan presented a declining trend yearly. The reduction in the BC of tourism was relatively slow between 2010 and 2012, and the average yearly declining rate was 5.87%. The declining rate then increased rapidly between 2012 and 2014 with an average yearly declining rate of 22.26%.

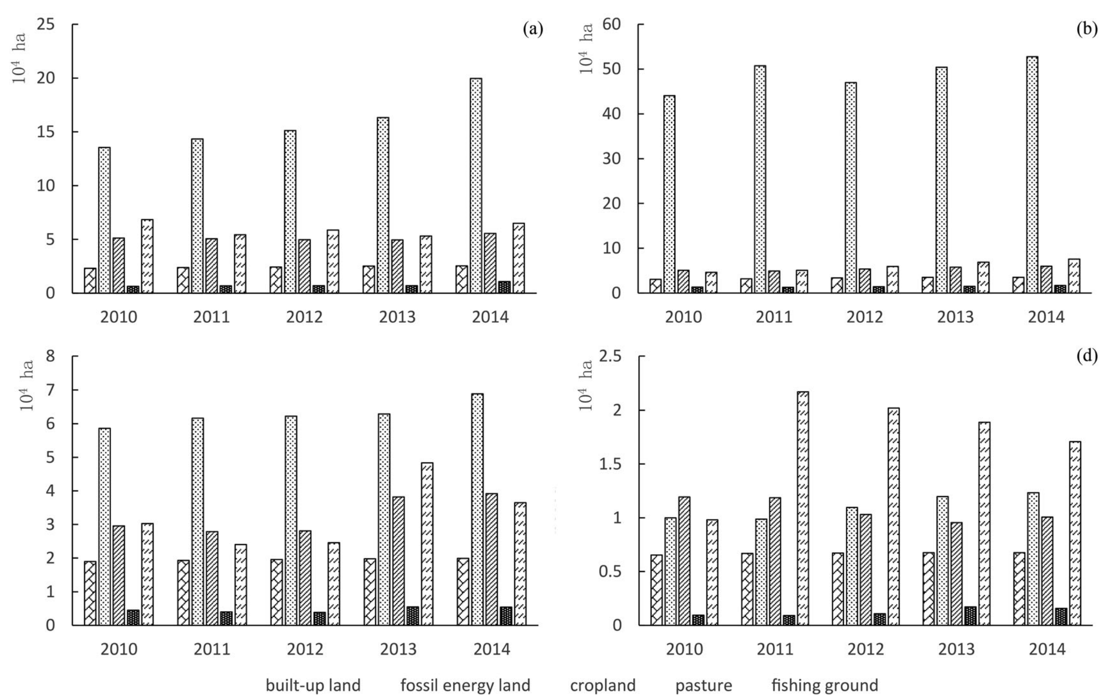

Figure 4. Annual LEF contribution of land types from 2010 to 2014. The LEF status in Putuo, Dinghai, Daishan and Shengsi is shown in (a)–(d), respectively.

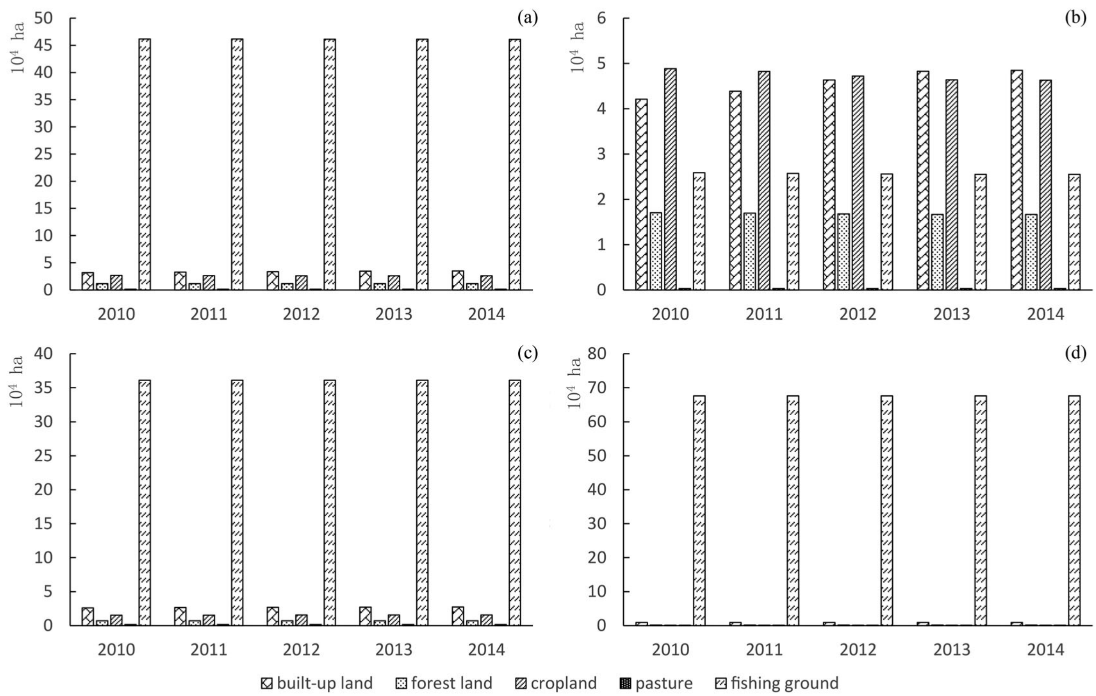

Figure 5. Annual BC from 2010 to 2014. The BC status in Putuo, Dinghai, Daishan and Shengsi is shown in (a)–(d), respectively.

Tourism ecological deficit and surplus

Under the synthetic effects of tourist and local human activities, the regional EF (including both TEF and LEF) of Zhoushan remained at the same level as the BC annually from 2010 to 2013 but exceeded clearly in 2014 (Figure 6(a)). The ecological deficit had intensively grown from 49,870 gha to 215,632 gha with an increase of 165,763 gha during 2013–2014.

The ecological deficit and surplus outcomes of each sub-region (Figure 6(b) and Table 6) showed that Daishan and Shengsi maintained the ecological surplus and sustainable development, whereas Putuo and Dinghai presented an unsustainable development, especially for Dinghai, which had an ecological deficit of more than six times as much as its BC in 2014. Moreover, various types of biologically productive land showed different degrees of ecological deficit, except for fishing ground. The ecological deficit of forest land (the demand of fossil energy land) was generally the highest, followed by cropland. The demand of forest land reached approximately 31 times as much as its BC in 2014. The changes in the TCC of each sub-region (Figure 7) indicated that the ecological environmental quality worsened as the sub-region approached the continental.

Discussion and conclusions

Tourism industry, on one hand, relies on the very ecosystem services provided by local environment, to sustain and economically profitable. On the other hand, activities associated with tourism more often than not create detrimental damages to the environment that potentially affects its ecosystem services. For sustainable development of a community or a region, it is critical to fully understand TCC, defined as the environmental capacity to sustainably provide the additional ecosystem services incurred resulting from tourism.

The research results revealed that the regional EF (including both TEF and LEF) of Zhoushan slowly increased at a rate of 4.01% each year from 1524,537 gha in 2010 to 1776,259 gha in 2014 (Table 7). An ecological deficit was observed with a rapid growth of EF in 2014 (Figure 6(a)), which indicated an unsustainable development trend in Zhoushan. We found that the consumption of meat and aquatic products in Putuo was higher in 2014 than in the other years, and the energy consumption of the industry in both Putuo and Dinghai also grew sharply. High EF and ecological deficit appeared in

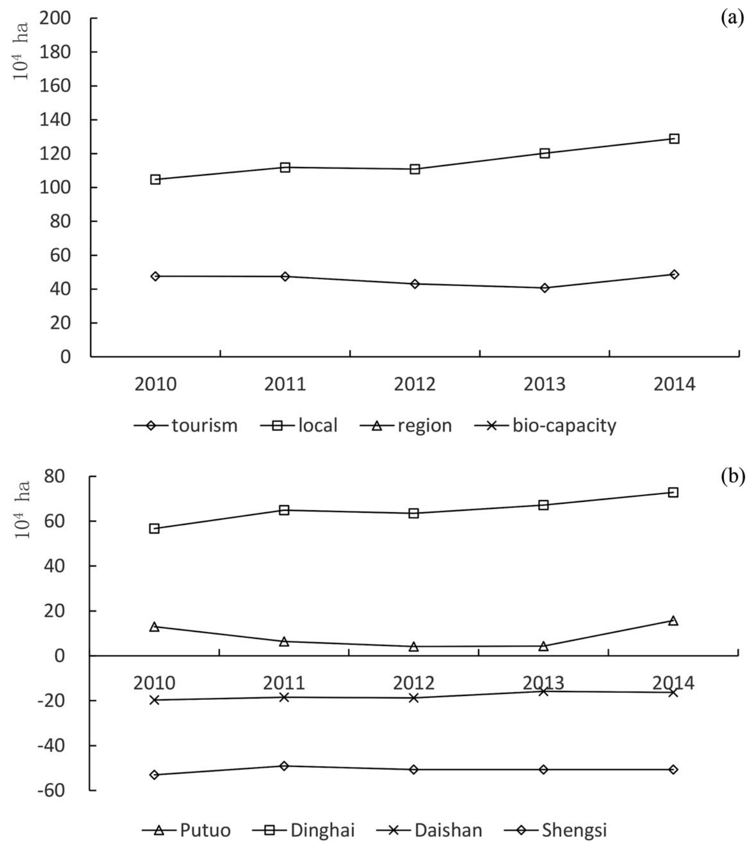

Figure 6. TCC of Zhoushan from 2010 to 2014. The annual EF and BC are shown in (a) and the annual ecological deficit and surplus outcomes of sub-regions are shown in (b).

Dinghai due to the high industry energy consumption. The development of Putuo tourism promoted local economic development but at the cost of high TEF. By contrast, Shengsi possessed a great ecological surplus because of its abundant marine resources and low population density. The dramatically different distribution of EF in sub-regions indicated that regional development was unbalanced, further suggesting that both the tourist and LEF at the regional level must be immediately relocated. For example, Shengsi, with its natural beauty, would share some responsibility for tourism, and Daishan would bear more industrial pressure because it is close to the continent and the Yang Shan Port, the

Table 6. Tourism ecological deficit and surplus of the Zhoushan Archipelago (10^4 gha).

	Putuo District					Dinghai District				
Land type	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Built-up land	−0.33	−0.33	−0.27	−0.12	0.05	−0.84	−0.87	−0.92	−0.88	−0.79
Forest land	19.28	20.97	22.31	24.71	29.51	46.55	53.58	50.37	54.69	58.01
Cropland	4.71	4.49	4.27	4.53	5.74	1.76	1.81	2.41	2.54	3.08
Pasture	0.72	0.82	0.85	0.91	1.73	1.41	1.38	1.50	1.69	1.98
Fishing ground	−17.75	−25.96	−29.40	−32.12	−27.69	6.22	7.35	8.47	7.50	8.92
	Daishan County					Shengsi County				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Built-up land	−0.53	−0.54	−0.52	−0.50	−0.49	−0.13	−0.12	−0.11	−0.03	−0.06
Forest land	5.64	5.99	6.16	6.34	7.06	1.77	2.01	2.30	2.73	3.05
Cropland	1.63	1.48	1.52	2.71	2.88	1.31	1.34	1.19	1.19	1.29
Pasture	0.32	0.27	0.27	0.45	0.50	−0.01	0.00	0.02	0.12	0.11
Fishing ground	−31.72	−30.61	−31.13	−29.79	−31.21	−64.26	−60.56	−62.30	−62.81	−63.36

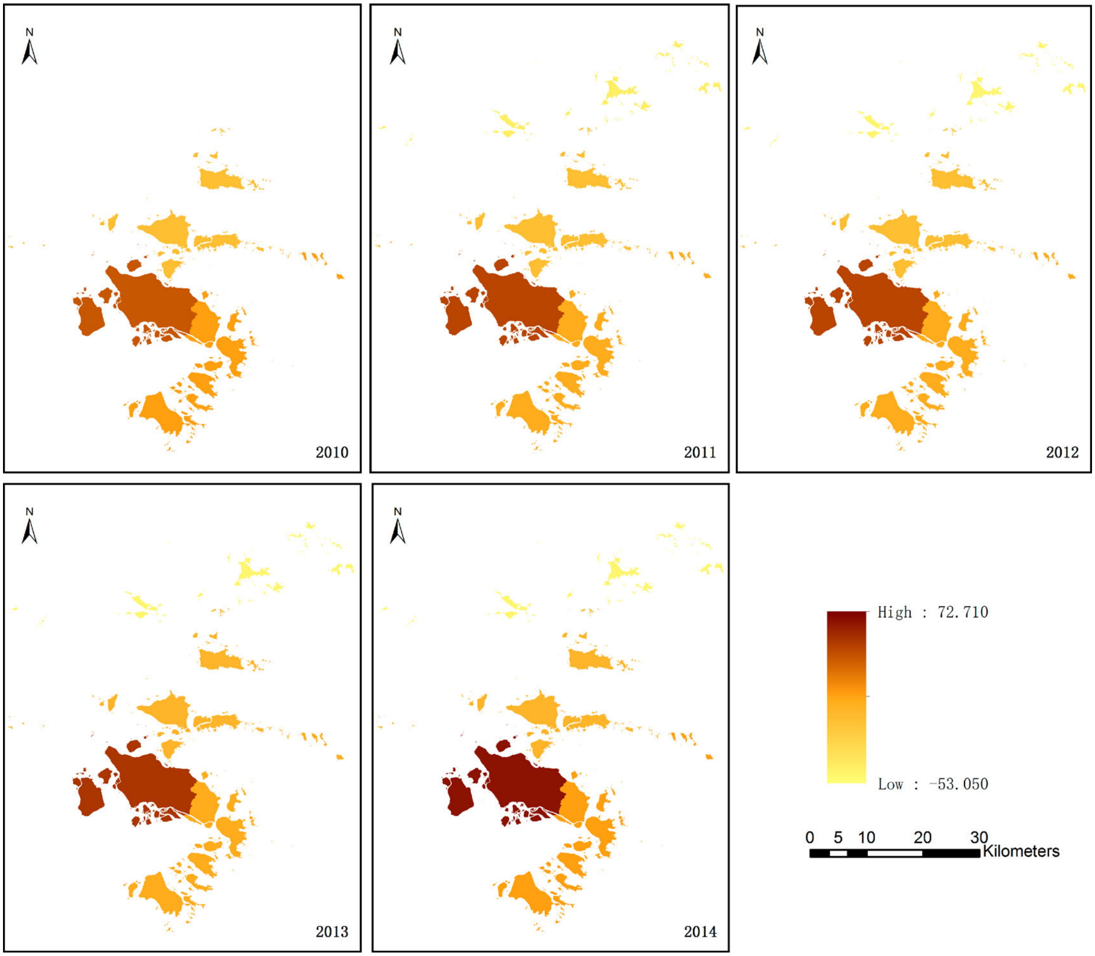

Figure 7. Annual ecological deficit and surplus of Zhoushan from 2010 to 2014. Dark colour indicates high ecological pressure.

deep water hinge harbour of Shanghai's international shipping centre. Beyond that, the sustainable exploration of ocean resources may relieve the pressure of resource, environment and living space on the land. The ecological carrying capacity might also be enhanced. A comparison of Taiwan (5.93 gha cap^{-1} in 2011) (Lee & Peng, 2014) and Hainan (2.14 gha cap^{-1} in 2004) (Fu, 2006) revealed a large development space in Zhoushan, which has a sparse population and numerous islands. Many small islands have never been exploited and utilised, and they are valuable resources for the tourism development of the original ecological landscape.

A comparison with the results based on the report of GFN in 2012 (GFN, 2016) indicated that the LEF of Zhoushan (1.1 gha per capita) was approximately two-fifths of the global footprint (2.8) and 2.3 gha lower than the average value of China (3.4). Therefore, resource utilisation by Zhoushan residents was below the national and global average levels. However, many

Table 7. Regional EF and proportion of TEF.

	Regional EF (10^4 gha)					Proportion of TEF (%)				
District and county	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Putuo	59.90	53.33	51.09	51.32	62.77	52.48	47.68	43.03	41.93	43.27
Dinghai	68.52	76.75	75.45	79.25	84.93	15.06	15.05	16.46	14.09	15.79
Daishan	16.49	17.79	17.52	20.47	20.02	13.90	23.07	21.04	14.67	15.14
Shengsi	7.54	11.55	9.98	10.07	9.91	48.04	55.83	50.66	51.48	51.75
Total	152.45	159.43	154.04	161.12	177.63	31.27	29.82	28.01	25.37	27.44

contradictions between regional development and ecological environment protection were found. EF analysis presented that the energy consumption by industry and tourist transportation played a major role in the regional EF, which accounted for more than half of the total. Although the resource consumption of per-unit GDP decreased in each sub-region, governments should continue to promote energy conservation to reduce emissions associated with industrial production and transportation. The continuous rise of built-up land footprint must also be addressed. Plans should be set in the course of developing construction to fulfil the intensive use of limited space (Zheng & Shen, 2008).

Furthermore, the results in Figure 4 showed that the residents were consuming a rising amount of food. Hence, reducing kitchen waste may reduce the food footprint (Lee & Peng, 2014), such as encouraging the "clear your plate" campaign against wasting food. Regarding the negative effects of obesity, residents should be encouraged to limit their food intake to improve the liberal diet environment (He et al., 2014; Wang, Mi, Shan, Wang, & Ge, 2007). As for tourism, for the unbalanced distribution of TEF in sub-regions (Table 4), tourists should be guided to choose diverse travel routes so that they avoid the ecological destruction caused by excessively dense tourists in some popular scenic spots. Another opportunity to reduce the environmental pressure of tourists is through the use of tour guides, who can educate their customers by interpreting and modelling environmentally appropriate behaviours (Randall & Rollins, 2009).

In comparison with other cities in Zhejiang Province, the tourist revenue of Zhoushan ranked close to the bottom, although it has grown in pace with the provincial average level in the recent 10 years (Ma et al., 2015). Its ratio of tourist revenue in GDP was also at the top of these cities (Ma et al., 2015), and the number of tourists continued to increase annually. Thus, tourism is an important part of regional economic development in Zhoushan, which also has been revealed in the overall EF accounting results. Although per capital TEF decreased from 0.022 to 0.014 gha cap^{-1}, the total TEF was high. In general, TEF accounted for a remarkable proportion over the years, and the proportion of TEF of different years reached 25–30% (Table 7). In particular, the proportion of TEF was more than 40% in Putuo and reached about half in Shengsi. However, tourism is generally identified as a highly consumptive industry, which is operating at less favourable eco-efficiency values than the world average (Gössling et al., 2005). Regulating the growth of TEF is necessary to strengthen sustainable development in Zhoushan. From the components of the TEF, except the purchase footprint without obvious rules, transportation and food consumption footprint accounts presented higher growth rate (Figure 2). This result demonstrated that tourist transport EF and food consumption EF in the near future will probably become the bulk of the total TEF of Zhoushan. Some strategies can be applied to control the impacts from these aspects, such as advocating low-carbon travel (Kahn & Morris, 2009). In addition, the falls of tourist purchase footprint suggested that additional special local products may be necessary to stimulate the consumption desire of tourists.

In conclusion, this study considered LEF and TEF to assess the status of local tourism's ecological carrying capacity. The ecological deficit and surplus outcomes showed that Zhoushan maintained a dynamic balance from 2010 to 2013 but started an unsustainable status in 2014. In terms of sub-region, Daishan and Shengsi maintained an ecological surplus, whereas Putuo and Dinghai presented an ecological deficit. The results provided ecological constraints of tourism development and scientific guidance for tourism resource allocation in Zhoushan. Fernández-Latorre, Diaz, and Olmo (2011) documented a case study of Canary Islands carried out for each island to assess tourism ecological development. However, our study analysed at the county scale with islands, which was important for the government to formulate and implement targeted policies in China. Detailed soil properties and terrain features could be further incorporated to improve the regional ecological carrying capacity assessment. With advanced geospatial tools, these tourism ecological carrying capacity assessments can be effectively applied for regional tourism development and planning.

Disclosure statement

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