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Nouveauté or Cliché? Assessment on island ecological vulnerability to Tourism: Application to Zhoushan, China

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ABSTRACT

In comparison with coastal zones, islands are even more vulnerable to anthropogenic disturbance, especially to tourism and tourism-induced activities. Despite a great number of studies on either island tourism or island vulnerability reviewed in this paper, knowledge and practice of the impact from tourism upon island ecological vulnerability (IEV) still needs to be expanded. In this contribution, the IEV of four administrative regions in Zhoushan, China is assessed between 2012 and 2017 based on an "exposure (E)-sensitivity (S)-adaptive capacity (A)" framework and by means of coupling coordination degree modeling (CCDM) for determination of the overall development level of E-S-A subsystems in each region. The assessment results show that: (1) An index system consisting of 1 objective, 3 sub-objectives, 7 elements, and 20 indicators can be established and tested to reflect the IEV to tourism; (2) As the most attractive tourist destinations, Shengsi and Putuo inevitably have the highest IEV values; (3) Dinghai's moderate low level of IEV comes as a surprise, due to its direct connectivity to its neighboring coastal city of Ningbo; (4) The more balanced the coupling coordination degree (CCD) values among E-S-A subsystems are, the higher the IEV values in the four tourist destinations of Zhoushan. In conclusion, tourism can be a double-edged sword for islands, the overall benefits of which outweigh the negative impacts upon island ecological conditions.

1. Introduction

Anthropogenic disturbance associated with climate change is considered to be an increasing menace to global coastal zones (Bigano et al., 2008; Nguyen et al., 2016). In comparison with large amounts of well-documented and profound studies on climate-induced impacts on coastal zones, inclusive of temperature rise (Preston et al., 2008), sea-level rise (Abuodha and Woodroffe, 2010; Nicholls and Cazenave, 2010; Torresan et al., 2008), and natural hazards (Mahendra et al., 2011; Saxena et al., 2013; Gallina et al., 2016; Sahoo and Bhaskaran, 2018), academic research on anthropogenic disturbance in this area thus far has yielded less significant results. Nevertheless, anthropogenic factors, such as urbanization (Li et al., 2018, 2017, 2016), population agglomeration (Adger and Vincent, 2005; Neumann et al., 2015) and tourism (Hall, 2001; Davenport and Davenport, 2006; Moreno and Becken, 2009), have been detrimental to the coastal inhabitants, the impact of which is exacerbated by climate change due to intensive aggregated human activity. This phenomenon has attracted academic interests in indicator-based vulnerability assessment of anthropogenic impacts on coastal zones seen from social, economic, ecological and geological angles (Mclaughlin et al., 2002; Mclaughlin and Cooper, 2010; Yoo et al., 2011, 2014).

Among the above-mentioned anthropogenic disturbance, tourism is prerequisite to coastal zone development. For this reason, it has also received substantial recognition from many international agencies who have conducted assessments and utilized corresponding results as standards for setting institutional priorities. For example, the Intergovernmental Panel on Climate Change (IPCC) has strengthened the position of tourism in its Fifth Assessment Report (IPCC, 2014), particularly with respect to the recognition of transboundary impacts, adaptation, vulnerability, and mitigation (Scott et al., 2015). As an indispensable part of coastal zones, islands have been effective incubators and testing grounds for the sound extrapolation of coastal tourism in recent years. In comparison with coastal zones, islands are

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even more vulnerable to anthropogenic disturbance, especially tourism and tourism-induced activities. With respect to tourism, island destinations around the world are stuck in an age-old dilemma. On the one hand, insular factors, such as exoticism, aestheticism and diversity of natural habitats, have long been the major contributors that have never failed to allure the tourists. Consequently, tourism has furnished island communities and its inhabitants with significant economic benefits (Fabinyi, 2008; Abecasis et al., 2013). On the other hand, tourism-induced negative impacts have simultaneously made islands more susceptible to environmental, societal and cultural perturbations due to islands' limited area, vulnerability to ecological change, and economic dependence (Benitez-Capistros et al., 2014; Chi et al., 2017).

1.1. The importance of island tourism

In the context of island tourism, proof of the significant academic interest is the existence of numerous scientific works published in this specific field. Literature reviews of island tourism by many researchers (Lim and Cooper, 2009; Parra-López and Martínez-González, 2018) indicate that sustainable development of island tourism in the last decade goes hand in hand with determinant analysis and vulnerability assessment of ecological systems. Firstly, in terms of determinant analysis, several sets of socio-economic-environmental indicator indices have been established to guide and strengthen sustainable island tourism. Reddy (2008) analyzed the "bottom-up" sustainable tourism rapid indicator framework, aiming to ameliorate the ways of moving tourism practices towards sustainable tourism in the less-developed Andaman and Nicobar Islands of India. Yang et al. (2016) identified social and economic factors as endogenous determinants of change in Dachangshan Island of Northeast China. Moghal and O'Connell (2018) examined the multiple stressors influencing vulnerability in a small island tourism-destination community in Barbados. Secondly, tourism is supposed to impose negative effects on a certain range of insular ecological systems to accommodate tourists flocking to islands and upholding a high profile in the global tourist industry. The idea of socio-ecological systems has only recently been employed in examining island tourism relations, especially in the Chinese insular context, including Liuqiu Island (Chen et al., 2017a) and Zhoushan Archipelago (Chen et al., 2017b; Gu, 2017). Thirdly, islands are inherently regarded as vulnerable to external disturbance, and therefore a bunch of studies have investigated the level of vulnerability of islands to tourism. Economic vulnerability of Small Island Developing States (SIDS) has long been emphasized in the field of political economy (Scheyvens and Momsen, 2008). In the vulnerability assessment of Asian islands to tourism from both ecological and spatial viewpoints, innovative methods and vulnerability assessment systems were adopted, such as the choice experiment method (Chen, 2019), the Small Islands Vulnerability Index (Kurniawan et al., 2016) and the Sustainable Ecotourism Indicator System (Ng et al., 2017), to evaluate their vulnerability status.

1.2. The evolution of the study on island vulnerability assessment

Innate insular qualities, such as remoteness, limited resources, high economic dependency and susceptibility to climate change and natural disasters, have aggravated island vulnerability to both climatic hazards and anthropogenic disturbance. The twenty first century has even witnessed an increasing research interest in island vulnerability assessment. The scientific literature (Appendix A) provides an appropriate and representative, though not exhaustive, coverage of global island vulnerability assessments since 2000, in which a systematic method/index/framework and the corresponding indicators have been utilized to quantify island vulnerability.

It should be pointed out that studies on island vulnerability assessment in the new century are intimately connected to the following three dimensions. Firstly, socio-economic-environmental dimensions have been the top priority for authors, accounting for nearly 70% of the articles listed in Appendix A. In relation to the social dimension of island vulnerability, the literature emphasizes the integral role that institutions and governance play in determining island system's ability to adapt to climate change and natural disasters (Briguglio et al., 2009; Farhan and Lim, 2013; Birk, 2014; Sjöstedt and Povitkina, 2017). Other literature focuses on a wide variety of social issues, mainly demography (Barrientos, 2010; Martins et al. 2012; Duvat et al., 2017; Jackson et al., 2017), private sector resources (Becken et al., 2014; Fakhruddin et al., 2015), and housing (Boruff and Cutter, 2007). The economic dimension is always discussed in conjunction with environmental issues in the listed literature. The authors highlight the interaction between economic factors and environmental indicators (Guillaumont, 2010; Julca and Paddison, 2010; McCubbin et al., 2015) in the context of island vulnerability, while literature solely on economics focuses on island's economic vulnerability to climate change and natural disasters (Adrianto and Matsuda, 2002, 2004). Secondly, the topographic vulnerability of islands is extensively analyzed with a selection of islands in Asia (Al-Jeneid et al., 2008; Sahana et al., 2019), North America (Maio et al., 2012), and SIDS (Turvey, 2007), in which geographical information systems integrated with remote sensing and geo-processing approaches are widely employed to gauge topographic and geographic changes. Thirdly, more recently, ecological indexes have emerged to quantify island vulnerability to anthropogenic disturbance based on IPCC's typology (McCarthy et al., 2001) suggesting that vulnerability can be characterized as a function of three components: exposure, sensitivity, and adaptive capacity. As the number of island studies on ecological vulnerability assessment is expanding, Chinese scholars who contribute to it are at the vanguard, engaging in the "Exposure-Sensitivity-Adaptive capacity" (E-S-A) framework. Chi et al. (2017) applied this E-S-A framework to establish a composite index system consisting of demographic, topographic, economic, and ecological indicators and to analyze island vulnerability to human activity in Miaodao Archipelago of China. Xie et al. (2019) further explored IEV to urbanization in the Zhoushan Archipelago and set a threshold of tourists in Zhujiajian Island of Zhoushan. Sun et al. (2019) assessed the IEV of eighteen towns and townships in Chongming Island and analyzed the overlap between IEV distribution and eco-urbanization projects in Chongming.

1.3. The research gap and our contribution

Despite the intensive studies into island tourism and island vulnerability reviewed above, knowledge and practice of the impact from tourism upon island ecological vulnerability still needs to be expanded. On the one hand, although the negative impacts associated with island tourism have apparently haunted policy-makers and the tourism industry for years, tourism, among other industries, has been more sustainable as it brings tangible benefits for island communities (Kaltenborn et al., 2012), helps protect nature and environment on islands and revitalizes the insular economy through seasonal and restorative use of the local labor force and local resources (Nicely and Palakurthi, 2012; Sharpley and Ussi, 2014). On the other hand, island vulnerability to climate change and natural disasters has been the focus of study in the literature, while few studies, however, have addressed island vulnerability to anthropogenic disturbance. What appears to be missing is an island ecological vulnerability-oriented research with a focus on anthropogenic disturbance, especially tourism. This paper aims to fill this gap.

It attempts to assess the extent to which island ecological vulnerability is affected by tourism. Thus, the contribution of this paper is three-fold. Firstly, it reviews literature on island vulnerability since 2000 in order to fathom the research gap. Secondly, based on our previous research article (Sun et al., 2019), an IEV assessment model to tourism is established to gauge the impact of tourism on island vulnerability. Thirdly, it provides both qualitative and quantitative results for policy-makers to leverage resources across financial, ecological, environmental, industrial departments in the future planning of tourism in island areas.

The remainder of this paper will proceed as follows: Section 2 presents a general geographic, demographic, and tourism development of our study area, Zhoushan of China. Section 3 introduces our conceptual framework, research materials and methods. It elucidates the methodological approach to IPCC's vulnerability assessment, in which the E-S-A framework is embedded and an indicator system of IEV model is also constructed. Section 4 analyzes the results derived from the E-S-A framework and the distributional ecological vulnerability of Zhoushan. Section 5 discusses some fundamental issues behind the technocratic approach and data analysis. Section 6 concludes and highlights the major findings and research limitations.

2. Study area

Zhoushan (29°32′–31°04′N and 121°30′–123°25′E) is a prefecture-level city in northeastern Zhejiang Province in eastern China. It consists of an archipelago of islands at the southern mouth of Hangzhou Bay, off Ningbo, and is always praised to be the "backyard garden" of the Yangtze River Delta. Covering a total administrative area of 22,200 km^2, Zhoushan includes 20,800 km^2 of marine territory, but only 1459 km^2 of land area. It administrates 2 districts (Dinghai and Putuo) and 2 counties (Daishan and Shengsi) (Fig. 1), with Dinghai District as its administrative center and largest settlement, and hosts a resident population of 971,500 and a population density of 666 persons/km^2 at the end of 2017 (Table 1).

With reference to this study, three aspects are critical for the choice of Zhoushan as a destination case study: (1) the area comprises four administrative island districts or counties, which are considered to be vulnerable to human activities, particularly tourism-related ones; (2) tourism is a major economic driver for the whole region; and (3) despite mega cross-sea bridge projects linking Zhoushan with mainland Ningbo of Zhejiang Province, perceptions concerning the region still refer to the notion of the specific qualities associated with islands.

In July 2011, Zhoushan was selected as Zhoushan Archipelago New Area, approved by the State Council of China's Central Government as the fourth state-level new area (following Pudong of Shanghai, Binhai of Tianjin, and Liangjiang of Chongqing) and the first New Area with a marine economy theme. Both marine tourism and an ecological island are highlighted in this New Area development project. Transportation in Zhoushan has been improved significantly in the last decade, especially after the opening of Zhoushan Trans-Oceanic Bridges in 2009, an indispensable component of the Yongzhou Expressway (numbered G9211 in the National Trunk Highway System), which consists of five consecutive bridges connecting Zhoushan to Zhenhai District of Ningbo in mainland China. These five bridges are Jintang Bridge, Xihoumen Bridge, Taoyaomen Bridge, Xiangjiaomen Bridge and Zhujiajian Strait Bridge (Fig. 2). In the far North of Zhoushan, Donghai Bridge, another mega cross-sea bridge, connects the offshore Yangshan Deep-Water Port in Yangshan Town of Zhoushan's Shengsi County with mainland Shanghai's Pudong New Area. Albeit named after Mt. Putuo, Zhoushan Putuoshan Airport is located on Zhujiajian Island.

Traditionally Zhoushan had been heavily dependent on the primary industry, especially fishing. Nowadays with the development of the secondary and tertiary industries, Zhoushan's economic base has been largely diversified and tourism has grown to be one of the major contributors to local economic output. Zhoushan is surrounded by a coastline of 2444 km and has an abundance of marine resources and places of interest, landscape forms and tourism resources. It is famous for two national level key scenic areas (Mount Putuo and the Shengsi Islands) and two provincial level key scenic areas (Taohua Island and Daishan) (see Fig. 2). Overall, the tourism sector has contributed to 12% of Gross Domestic Product (GDP) for Zhoushan. From 2012 to

Table 1
Land area, population, and population density in districts/counties of Zhoushan (2017).

Region	Land area (sq.km)	Year-end resident population	Population density (persons/sq.km)
Total	1459	971,500	666
Dinghai District	574	394,000	686
Putuo District	462	319,300	691
Daishan County	326	181,900	558
Shengsi County	97	76,200	785

Source: Zhoushan Statistical Bureau (2018).

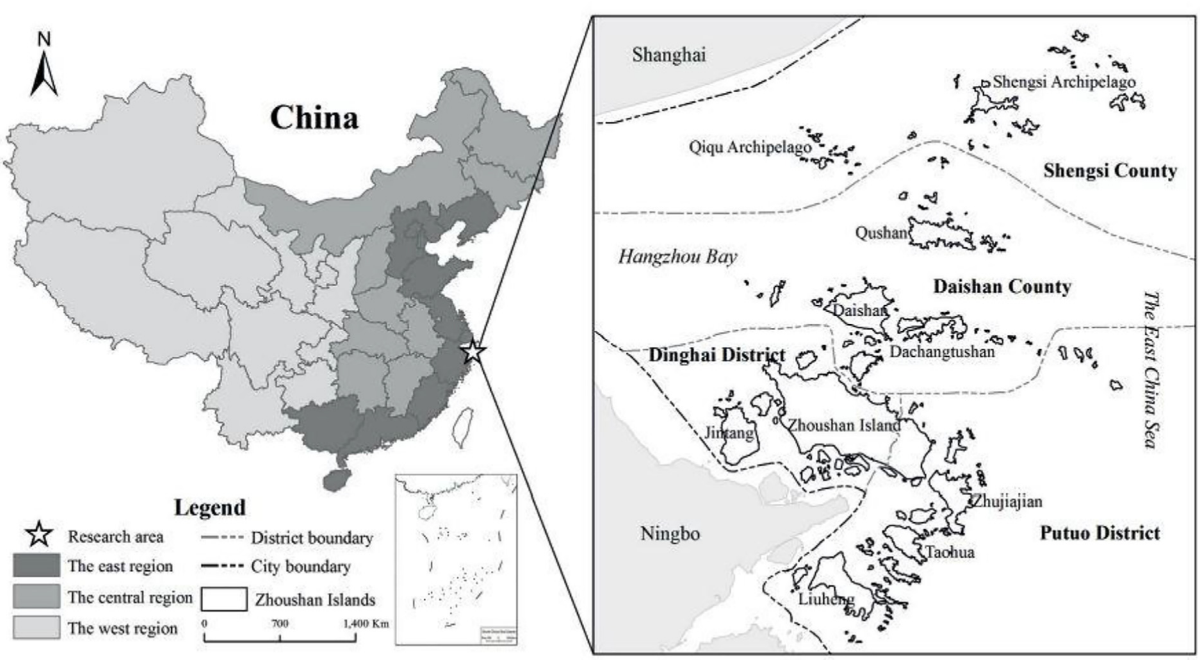


Fig. 1. Geographic location of the Zhoushan.
Source: Qiu et al., 2017

Fig. 2. Zhoushan's Trans-Oceanic Bridges and major places of interests. Source: Google Maps and Zhoushan Tourist Committee (2018).

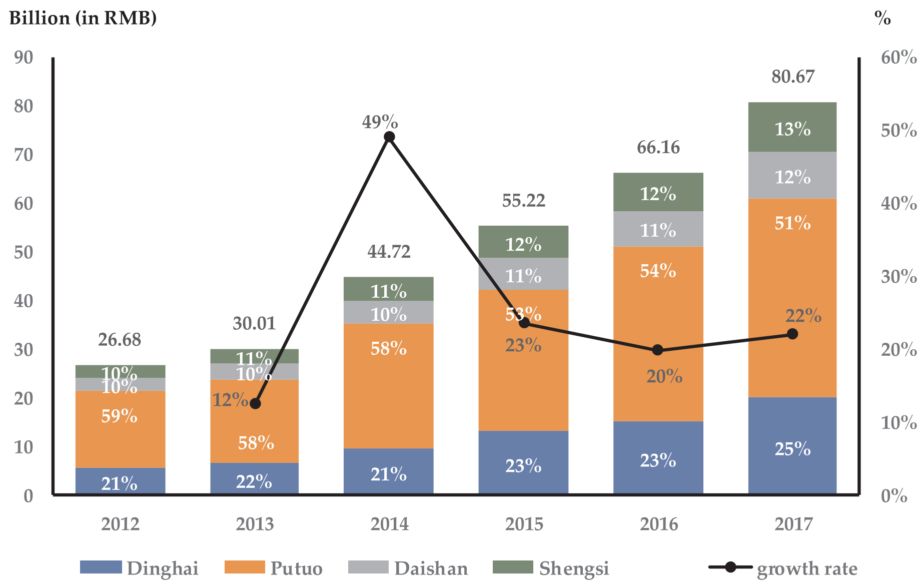


Fig. 3. Zhoushan's tourism income contributed by four administrative regions from 2012 to 2017. .
Source:Zhoushan Statistical Bureau (2018)

2017, the number of tourists increased by a startling 98.7% from 27,710,200 to 55,071,600, while revenue from tourism even tripled from RMB 26.68 billion to RMB 80.67 billion (see Fig. 3).

3. Conceptual framework, materials and methods

3.1. Conceptual framework

Since IPCC's climate change vulnerability assessment, in which the E-S-A framework is embedded, has been practically modified and applied to researching ecological vulnerability in China's site-specific islands (Chi et al., 2017; Xie et al., 2019; Sun et al., 2019), the present paper continues to utilize the E-S-A framework as a follow-up study to our previous work on ecological vulnerability of China's islands to anthropogenic disturbance (Sun et al., 2019). Consequently, we hold a firm belief in the reasons why the E-S-A framework was adopted and follow the same assumptions as we proposed in our previous work.

In the present paper, island tourism mainly refers to the tourist population shift from the mainland (both domestic and foreign) to island destinations, and the tourism income incurred in a collection of activities, services and industries which deliver a travel experience and other hospitality services provided for individuals or groups traveling to island destinations. Thus, assessing the IEV to tourism demands a clear conceptual framework (Fig. 4) in which various indicators can be identified and quantified to reflect the status quo of island vulnerability.

3.2. Methods

The application of the conceptual framework for an assessment of ecological vulnerability to tourism in an island area requires the establishment of an indicator system that reflects both ecological indicators and island tourism statistics. In comparison with our previous work in Chongming Island (Sun et al., 2019), an indicator system comprising 1 objective, 3 sub-objective, 7 elements, and 20 indicators is constructed for the case study of Zhoushan (Table 2). The ultimate value of IEV for each district or county is derived from Eqs. (1) and (2):

$$\textit{Potential impact} = E + S \tag{1}$$

where E and S are the values of objective index-Exposure and Sensitivity,

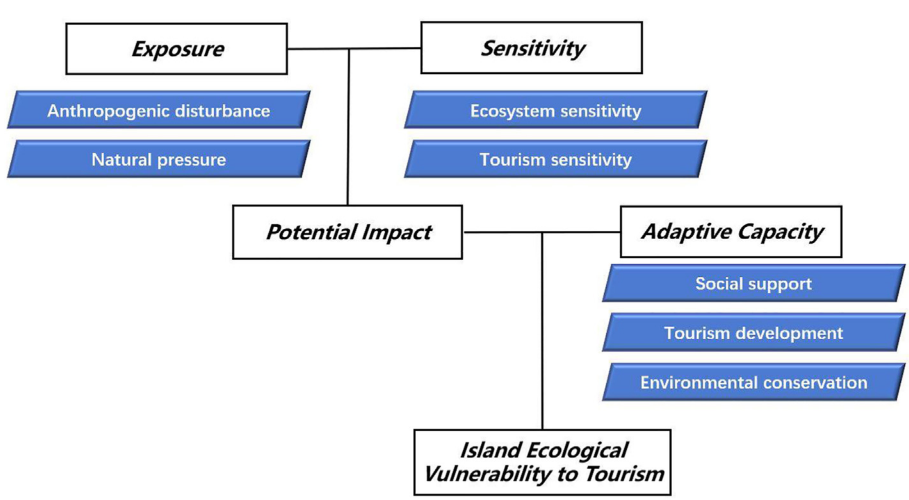


Fig. 4. Conceptual framework of island ecological vulnerability.

Table 2
Indicator system of IEV model for Zhoushan.

Objective layer		Element layer	Indicator layer/type
IEV	Exposure	B1 Anthropogenic disturbance	C1 Population density (+)
			C2 Energy consumption per unit of GDP (+)
			C3 Road density (+)
			C4 Industrial gaseous waste discharge (+)
			C5 Industrial solid waste discharge (+)
			C6 Industrial wastewater discharge (+)
		B2 Natural pressure	C7 Disaster influence (+)
			C8 Island area change rate (+)
	Sensitivity	B3 Ecosystem sensitivity	C9 Sea water quality (−)
		B4 Demographic sensitivity	C10 Tourist density (+)
			C11 Ratio of tourists to locals (+)
			C12 Ratio of peak month tourists to low month tourists (+)
	Adaptive Capacity	B5 Social support	C13 Expected investment ratio of tourism key construction project (+)
			C14 Number of medical beds per 100 inhabitants (+)
			C15 Proportion of tertiary industries (+)
		B6 Tourism development	C16 Tourism income (+)
			C17 Tourism income growth rate (+)
			C18 Tourism contribution to GDP (+)
		B7 Environmental conservation	C19 Forest coverage (+)
			C20 Urban green coverage (+)

Note: The indicators can be divided into positive indicators (+) and negative indicators (−) according to their properties. The greater the positive indicators are, the better the results are, while the negative indicators denote the opposite.

$$IEV = \frac{Potential\ impact}{1 + A} \tag{2}$$

where *IEV* and *A* are the values of island ecological vulnerability (IEV) and objective index—Adaptive Capacity respectively.

3.2.1. Indicator selection

Exposure includes two elements: Anthropogenic disturbance and Natural pressure. Anthropogenic disturbance is composed of Local population density, Energy consumption per unit of GDP, Road density, and Industrial waste discharge, which are extensively used in ecosystem assessment. Disaster influence and Island area change rate denotes Natural pressure.

Sensitivity is deduced from Ecosystem sensitivity and Tourism sensitivity. Sea water quality signifies Ecosystem sensitivity, while Tourism sensitivity is composed of Tourist density, Ratio of tourists to locals, and Ratio of peak month tourists to low month tourists. These tourism indicators are emphasized in a bunch of sustainable tourism development studies (Reddy, 2008; Blancas et al., 2010; Banos-González et al., 2015).

Adaptive capacity refers to the ability of social, tourist and environmental elements to deal with the impact of island tourism. Expected investment ratio of tourism key construction project, Number of medical beds per 100 inhabitants, and Proportion of tertiary industries are selected to signify social support; Tourism income, Tourism income growth rate, and Tourism contribution to GDP are highlighted to reflect Tourism development; Forest coverage and Urban green coverage are chosen to denote Environmental conservation.

3.2.2. Data acquisition

Data sources mainly include Zhoushan Statistical Yearbook (2018); Statistical Yearbook of Dinghai District (2018), Putuo District (2018), Daishan County (2018) and Shengsi County (2018); and Zhoushan Tourist Committee (2018). Data are collected for the years 2012–2017 to reflect the temporal evolutions and impact of tourism on island vulnerability.

This paper takes the data of year 2011 as the base when calculating the change rate of each variable. Before processing the raw data, we utilize the entropy weight method and related equations developed in our previous work (Sun et al., 2019) to standardize the indicators.

Disaster influence is the maximum precipitation and the maximum wind speed during the trajectories of the typhoon *Haikui*, which tracked to the south of Zhoushan on August 8th 2012 (Fig. 5a), and the typhoon *Chan-hom*, which tracked across Zhoushan on July 11th 2015 (Fig. 5b). The typhoon's trajectory is derived from the typhoon track forecast system (http://typhoon.zjwater.gov.cn/default.aspx). The precipitation and wind speed data are obtained from the authors' personal communication with authorities at the Zhoushan Meteorological Bureau. The ultimate value of Disaster influence is derived from Eq. (3), which is developed by Zhu et al. (2017):

$$\mathrm{I} = 0.78\mathrm{x} + 0.43\mathrm{y} \tag{3}$$

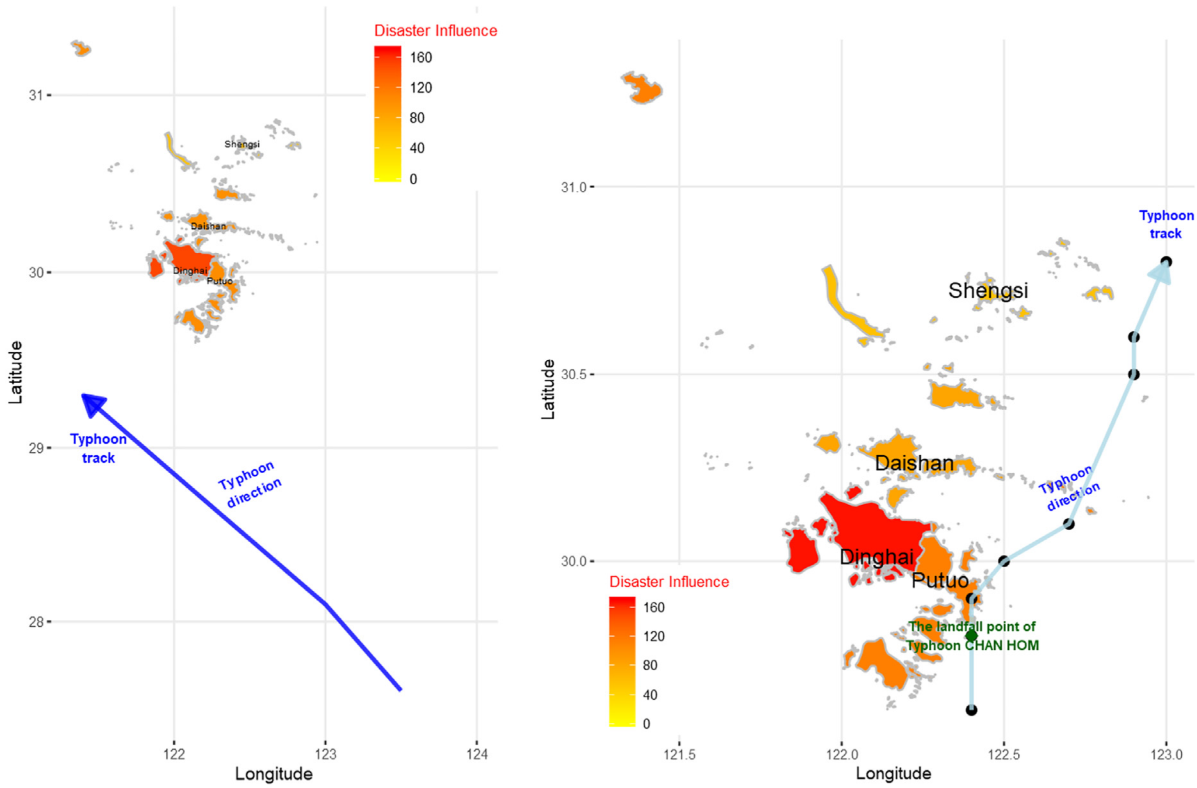
where I is the comprehensive index of typhoon precipitation and wind speed; x and y are the standardized maximum precipitation and the maximum wind speed, respectively.

4. Results

After clarifying the conceptual framework for assessing Zhoushan's ecological vulnerability to tourism, presenting the geographic, demographic, and tourism development of Zhoushan, and; thus, depicting detailed methods of indicator collection and data acquisition, we now analyze the assessment results of Zhoushan from 2012 to 2017 in a temporal evolution.

4.1. Ecological exposure

Fig. 6 summarizes the standardized values of ecological exposure for each district or county in Zhoushan from 2012 to 2017, which reflects the temporal evolution of their ecological exposure. As observed in Fig. 6, Typhoon *Haikui* of 2012 and *Chan-hom* of 2015 severely aggravated the ecological exposure in Dinghai, elevating the latter's exposure degree from a moderate level in 2013, 2014, 2016 and 2017 to a high level in 2012 and 2015. As the seat of Zhoushan municipal government and the most populous region, Dinghai usually bears much of the brunt for high anthropogenic disturbance, especially in the indicators of Energy consumption per unit of GDP and Industrial waste discharge. It is surprising that, as the most popular region for tourism, Putuo maintained a moderate low to moderate level of exposure throughout the observation years, due largely to its low Industrial gaseous waste and solid waste discharge. Nevertheless, it is worth noting that since 2014 the amounts of Industrial gaseous waste, solid waste and wastewater discharge in Putuo have surpassed those of its counterpart in Dinghai, which became a group of negative impact indicators on Putuo's exposure degree in the following observation years.



(a) Typhoon *Haikui*'s trajectory and influence. (b) Typhoon *Chan-hom's* trajectory and influence.

Fig. 5. Disaster influence.

Cradled in the arms of Dinghai, Daishan sits in a geographically secure location, which to a certain extent helps explain why it has maintained low levels of exposure degree during the observation years. As an emerging tourist destination, Shengsi has been incurred moderate high to high levels of exposure degree. On the one hand, despite a small local population, it possesses the heaviest population density among Zhoushan throughout 2012 to 2017. On the other hand, intensive land reclamation has increased the Island area change rate in Shengsi, dramatically exacerbating its exposure levels.

4.2. Ecological sensitivity

As shown in Fig. 7, the sensitivity of the four regions in Zhoushan demonstrates a significant differences, with high levels for Putuo, moderate high levels for Shengsi, and low levels for Dinghai and Daishan. Since Sea water quality was practically constant in our study, Tourism sensitivity determined the overall sensitivity degree. As the most famous tourist attraction in Zhoushan, Putuo's Tourist density has increased 92.5% from 36,883 persons/km^2 in 2012 to 70,996 persons/km^2 in 2017, with an average annual growth rate of 18.5%. Its Ratio of tourists to locals has also skyrocketed 95.7% from 52.5 in 2012 to 102.7 in 2017, with an even greater average annual growth rate of 19.1%. Putuo's top position on these two indicators made it much more sensitive to tourism. Shengsi's Tourist density and Ratio of tourists to locals have been ranked second in Zhoushan in the period 2012–2017, while its Ratio of peak month tourists to low month tourists has topped the list during the observation years, both of which have contributed to its moderate high level of ecological sensitivity.

As a compound element consisting of Tourist density, Ratio of tourists to locals, and Ratio of peak month tourists to low month tourists, Tourism sensitivity in our framework has undoubtedly had a tremendous effect on potential impact of ecological vulnerability. Fig. 8 presents the single-value of the Tourism sensitivity index for each region in Zhoushan in the time frame 2012–2017. The low level of tourism sensitivity in Dinghai and Daishan predetermined its corresponding potential impact.

4.3. Potential impact

The combination of ecological exposure and sensitivity defines the degree of potential impact. Fig. 9 presents the potential impact of each region in Zhoushan on the aggregate of ecological exposure and sensitivity. It may come as a surprise that Shengsi topped the list of potential impact with moderate high levels to high levels in 2013, 2014, 2016 and 2017, due largely to its great Island area change rate and moderate high level of Tourism sensitivity. Putuo only topped the list with moderate high and high levels in the year 2012 and 2015 respectively, when Typhoon *Haikui* and *Chan-hom* struck Zhoushan and inflicted much greater Disaster influence in Putuo than in Shengsi. Regardless of Disaster influence, Shengsi has taken the lead in the aggregate of ecological exposure and sensitivity during the observation years. In comparison, the degree of potential impact in Dinghai and Daishan has been moderate low to low level, with a large deviation from that of Putuo and Shengsi in its single value.

4.4. Adaptive capacity

A higher adaptive capacity signifies a higher resilience to counteract potential impact, thus leading to a lower ecological vulnerability. Fig. 10 presents the adaptive capacity of the four regions in Zhoushan, demonstrating obvious differences, with an annual moderate high level in Dinghai (0.73) and Putuo (0.7), an annual moderate low level in Shengsi (0.4), and an annual low level in Daishan (0.08). In single value of Adaptive capacity, Dinghai and Putuo topped the list alternately, with Dinghai coming out on top in 2012, 2013, and 2015, and Putuo in 2014, 2016 and 2017. Given that Social support and Environmental

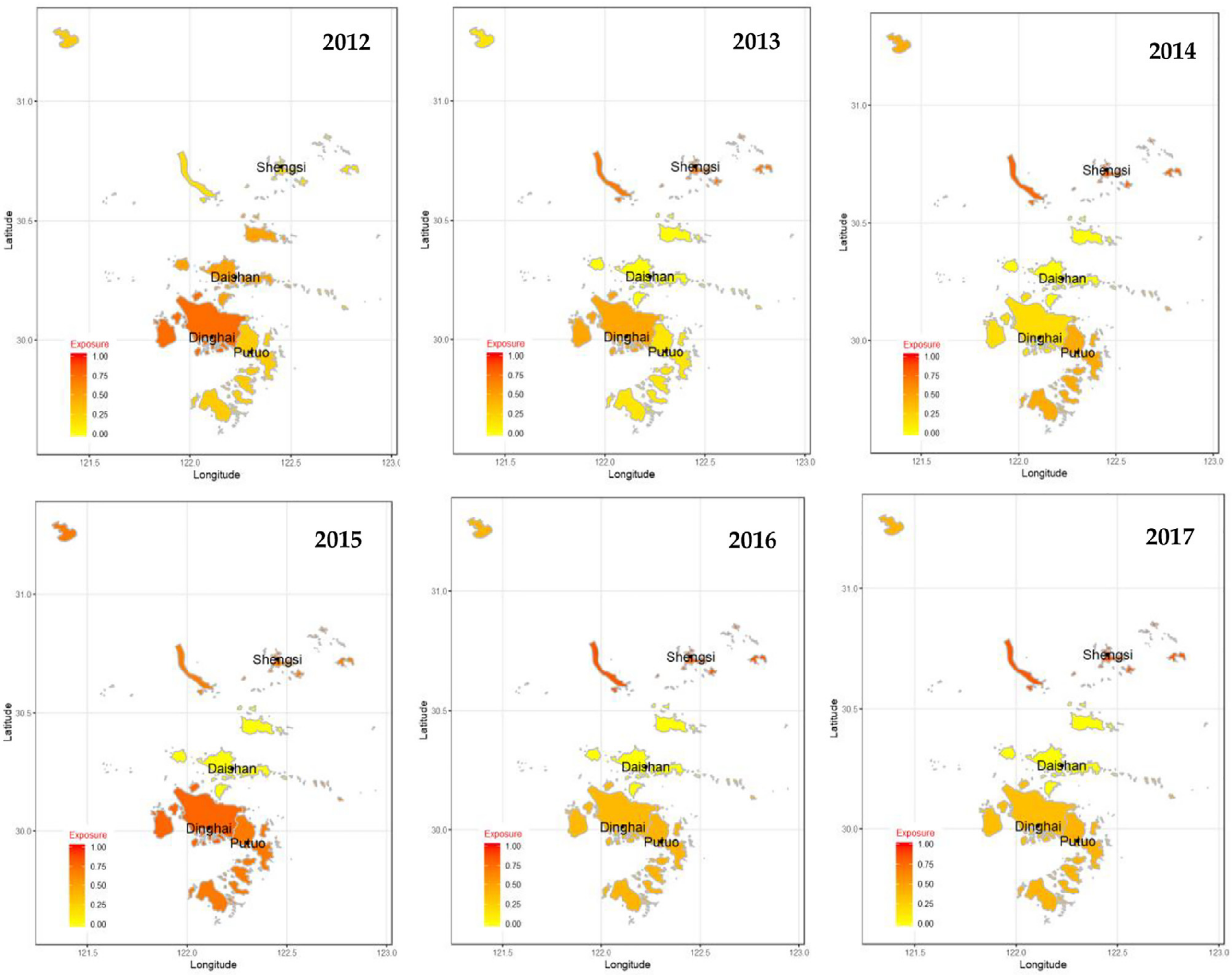


Fig. 6. Ecological exposure of Zhoushan in the period 2012–2017.

conservation fluctuated narrowly during the observation years, Tourism defined Adaptive capacity to a large extent. Putuo's revenue from tourism has increased by 126.2% from RMB 15 billion in 2012 to RMB 33.9 billion in 2017, with an average annual growth rate of 25.2%, significantly enhancing its adaptive capacity. As the seat of Zhoushan, Dinghai received the largest proportion of investment in tourism key construction projects, performing more headquarters function to provide tourism service and accommodate tourists than tourism function to attract tourists.

Fig. 11 presents the single-value for Tourism development for each region in Zhoushan in the period 2012–2017. Since 2013, Shengsi has surpassed Dinghai in the performance of Tourism development and sustained a compelling momentum in the following observation years. In comparison with Dinghai, Putuo and Shengsi, Daishan's overall Tourism development seems almost negligible.

4.5. Composite IEV of Zhoushan in the period 2012–2017

The assessment results of IEV in Zhoushan are shown in Fig. 12: 1) the most vulnerable regions in Zhoushan are Shengsi and Putuo; 2) Dinghai has the third highest vulnerability index; 3) Daishan is relatively resilient compared with the other regions. Shengsi topped the composite IEV in Zhoushan, with an annual average value of 1.03 (moderate high), followed by Putuo with 0.83 (medium), Dinghai with 0.31 (moderate low), and Daishan with 0.21 (low). The IEV of Putuo and Dinghai reached their respective summit in 2015, probably induced by Disaster influence, Typhoon *Chan-hom*, which, exerted less ecological impact on Daishan and Shengsi. The IEV of Daishan has been at a low level range during the observation years. The IEV of Shengsi has been on the rise and reached its peak in 2017 (Fig. 13).

It is surprising that Shengsi was the most vulnerable region in Zhoushan, though its sheer remoteness should have allowed it to be virtually immune to anthropogenic disturbance, especially tourism. As a fledgling and burgeoning tourist destination in Zhoushan, Shengsi has maintained a moderate high level of ecological vulnerability to tourism in the years 2012–2017, which may be explicated as follows. Firstly, its high local population density and intensive land reclamation have seriously exacerbated its exposure. Secondly, its sensitivity has been greatly elevated by its second largest Tourist density (annual average of 43,083 persons/km^2) and Ratio of tourists to locals (annual average of 534 times), as well as even the largest Ratio of peak month tourists to low month tourists (annual average of 105 times). Thirdly, this region has a moderate low level of adaptive capacity to neutralize its moderate high level of potential impact.

4.6. Coupling relationship of E-S-A in Zhoushan in the period 2012–2017

Currently, coupling coordination degree modeling (CCDM) is extensively used to assess the coordination of a few coupling systems (Li et al., 2012; He et al., 2017; Liu et al., 2018; Fan et al., 2019). However, CCDM is rarely applied to three and multi-subsystems coupling. This section evaluates the coordinated development degree among the triple

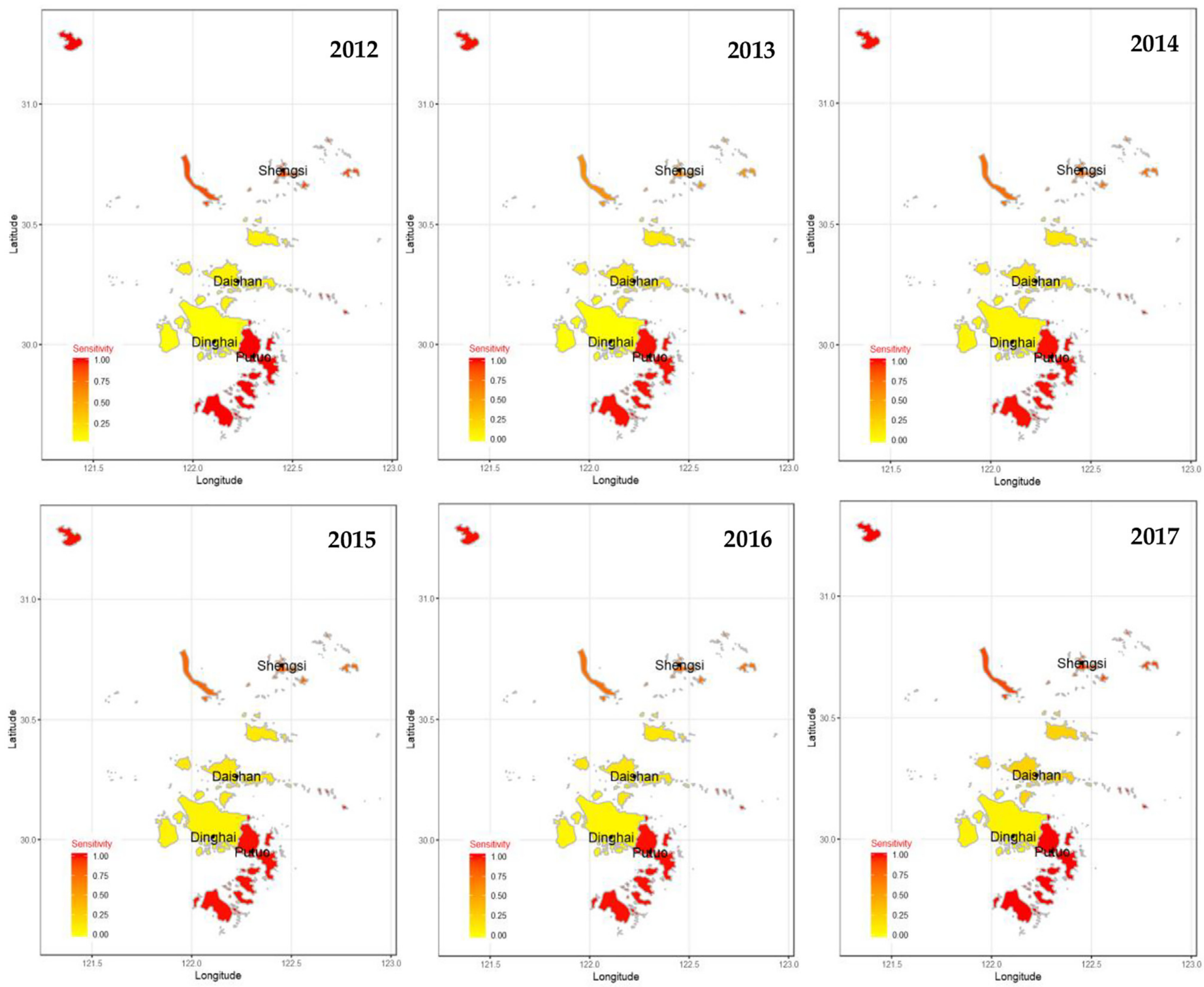


Fig. 7. Ecological sensitivity of Zhoushan in the period 2012–2017.

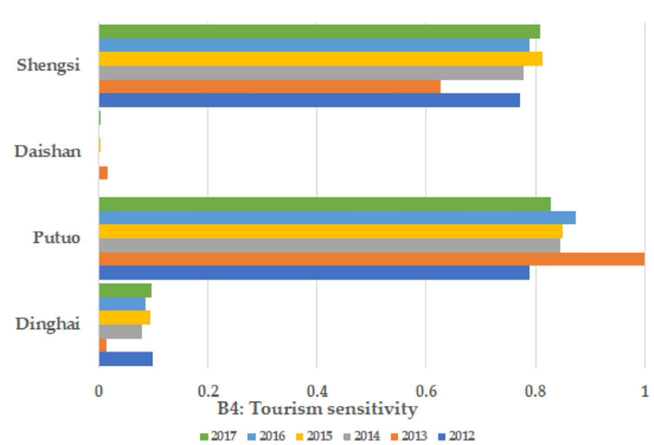


Fig. 8. Tourism sensitivity of Zhoushan in the period 2012–2017.

Exposure-Sensitivity-Adaptive capacity subsystems through CCDM. Based on previous studies conducted by Sun and Cui (2018) and Xing et al. (2019), the CCDM in our study is given in the following formula:

$$C = \left\{ \frac{E \times S \times A}{\left[\frac{E+S+A}{3} \right]^3} \right\}^{\frac{1}{3}}, D = \sqrt{C \times T} \ and \ T = \alpha E + \beta S + \gamma A \quad (4)$$

where C is the coupling degree, whilst E, S and A are the comprehensive levels of Exposure, Sensitivity and Adaptive capacity subsystems, respectively. D is the coupling coordination degree (CCD) and T reflects the overall development level of E-S-A subsystems. α, β and γ represent the contribution of each subsystem. This study assumes that each subsystem is equally important to the coordinated development of the E-S-A subsystems. Thus, $\alpha = \beta = \gamma = \frac{1}{3}$. According to the value of CCD, the coordinated development level of E-S-A subsystems is divided into six classes. The division of development stages is shown in Table 3.

As revealed in Fig. 14, the CCD among *E-S-A* subsystems in the four regions of Zhoushan showed different change trends in the period 2012–2017. The CCD values were all below 0.7. The coordinated development among E-S-A subsystems for Shengsi was at the level of moderately balanced development after 2012 and that of Putuo was at the level of barely balanced development except for 2015. The coordinated developments among E-S-A subsystems of Dinghai were at the level of barely unbalanced development except for 2013 and 2014. Daishan only reached the level of barely balanced development in 2012 and remained 0 in the following five years.

The above results show that the more balanced the CCD values are, the higher the IEV values in the four tourist destinations of Zhoushan (Fig. 15). The average CCD annual values in the four regions are 0.5964 (Shengsi), 0.5181 (Putuo), 0.2751 (Dinghai), and 0.0904 (Daishan) respectively, the ranking of which corresponds with that of IEV in Fig. 13. Shengsi's moderately balanced development and Putuo's barely

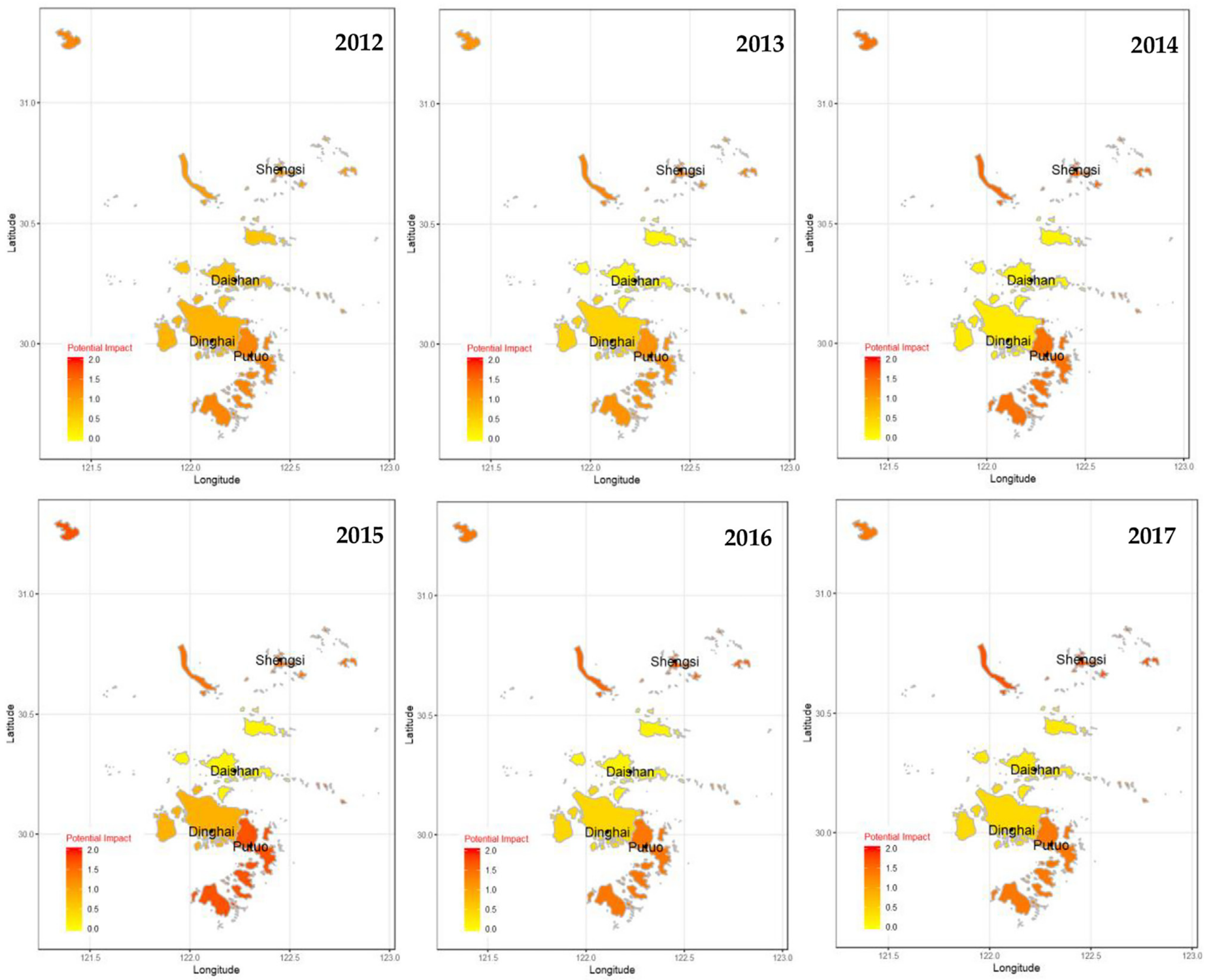


Fig. 9. Ecological potential impact of Zhoushan in the period 2012–2017.

balanced development signify that intensified tourism development in island areas has significantly elevated its IEV values, aggravating its vulnerability to tourism. Daishan's seriously unbalanced development indicates that it has considerable potential for becoming the next booming island tourist destination in Zhoushan. Dinghai's moderately unbalanced development parallels its position in providing headquarters resources for tourism development in the other three islands.

5. Discussion

5.1. Policy implications

By means of radial graphs (Fig. 16), we discerned possible implications for each region to help local government develop appropriate environmental and tourism policies. Shengsi, the most vulnerable region in Zhoushan, has a high level of exposure degree, exacerbated by its high population density and intensive land reclamation. Concurrently, a moderate high level of ecological sensitivity incurred by high tourist density and a higher ratio of tourists to locals contributes to its highest potential impact among the four regions. Besides, a moderate low level of capacity to adapt to the potential negative impacts further elevates its composite IEV. To mitigate the ecological vulnerability in Shengsi, environmental policy should prioritize undergoing ecological restoration measures and preserving biodiversity, while tourism policy should focus on promoting tourism in the shoulder season (roughly April through mid-June and September through October) to manage spatiotemporal separation of tourists by shunting peak season tourists, an optimal scheme long echoed by Chinese scholars (Du et al., 2016; Yao et al., 2016; Hu et al., 2018).

Putuo, the second most vulnerable region in Zhoushan, has a medium level of exposure degree, but a high level of sensitivity degree induced mainly by high sensitivity to tourism. Its top position in tourist density and ratio of tourists to locals makes it extremely sensitive to tourism. Owing to its moderate high level of adaptive capacity neutralizing its high potential impact, Putuo ranked second to Shengsi in the IEV value. For Putuo, environmental policy should include enhancing pollution monitoring and accelerating the construction of an ecological civilization demonstration zone (a prominent ecological project established and supervised by China's Ministry of Ecology and Environment). Tourism policy should give priority to capping tourists' numbers in peak months (Xie et al., 2019) as well as upgrading local tourism industry by providing high quality travel service experience, including raising tourist travel cost and decreasing tourist density.

Dinghai has a moderate low level of IEV with a moderate low level of potential impact and a moderate high level of adaptive capacity. The major menace to its exposure is always derived from industrial waste discharge and disaster influence, while its sensitivity to tourism is unexpectedly low. As the seat of Zhoushan government, Dinghai has received the most favorable social support in adaptive capacity, which has partially offset the negative impacts from anthropogenic

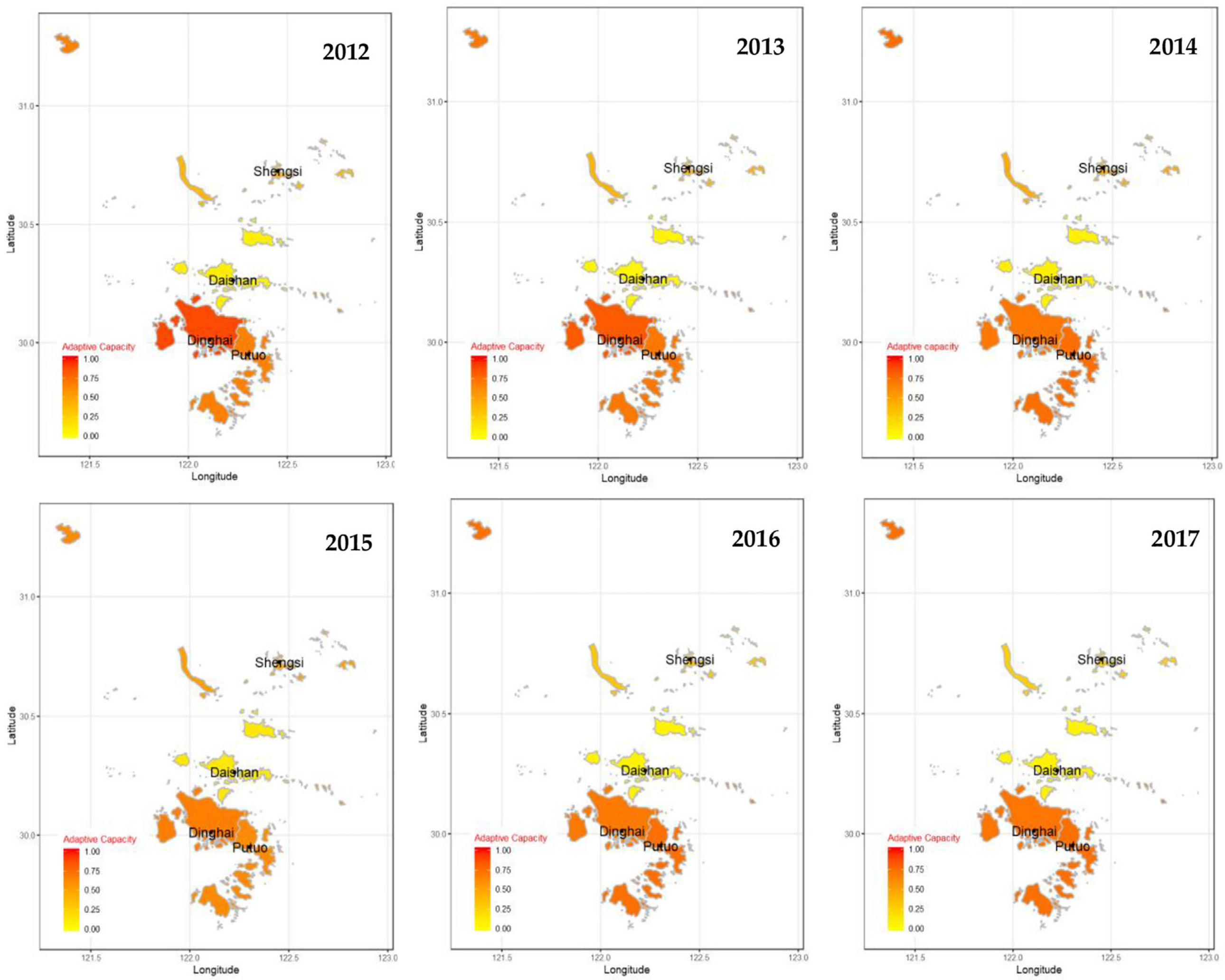


Fig. 10. Ecological adaptive capacity of Zhoushan in the period 2012–2017.

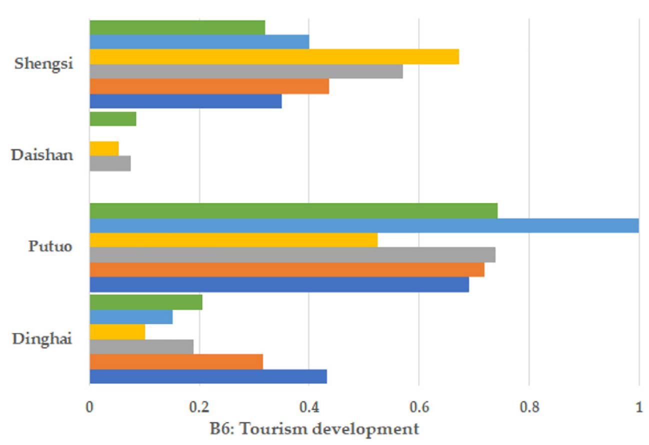


Fig. 11. Tourism development of Zhoushan in the period 2012–2017.

disturbance and natural pressure. Given the circumstances, environmental policy should highlight the construction of environmental infrastructure such as wastewater treatment plants and renewable energy plants, and the implementation of stricter pollution control regulations. Tourism policy should serve to accentuate its function as headquarters to provide tourism services and accommodate tourists, and a fast train connection to neighboring metropolises.

Daishan is least vulnerable among the four regions in Zhoushan by virtue of its low level of compound ecological potential impact. Since its ratio of peak month tourists to low month tourists has fluctuated slightly throughout the observation years, only its environmental monitoring needs to be enhanced consistently. Diverse portfolios of tourist products should be moderately encouraged to increase the income of local communities.

5.2. Trade-offs of island tourism among E-S-A subsystems

The research results have shown that there is much space for improvement in the coordinated development of E-S-A subsystems to island tourism in these four regions in Zhoushan. On the whole, the coordinated development levels of E-S-A subsystems to island tourism were moderately low and apparently diverse in the four regions. Shengsi had the highest CCD value in most observation years but its annual value was still below 0.6. Notwithstanding the low annual values, CCD levels in Shengsi and Putuo were significantly higher than those in Dinghai and Daishan. The result indicated that the impact of island tourism on IEV was heterogeneous.

To some extent, this heterogeneity triggers a trade-off between the tourism development in adaptive capacity subsystem and the tourism sensitivity in sensitivity subsystem. On the one hand, tourism development has strengthened the local economy, especially in Shengsi and Putuo, raising their respective adaptive capacity to tourism and offsetting partial negative potential impact from ecological exposure and

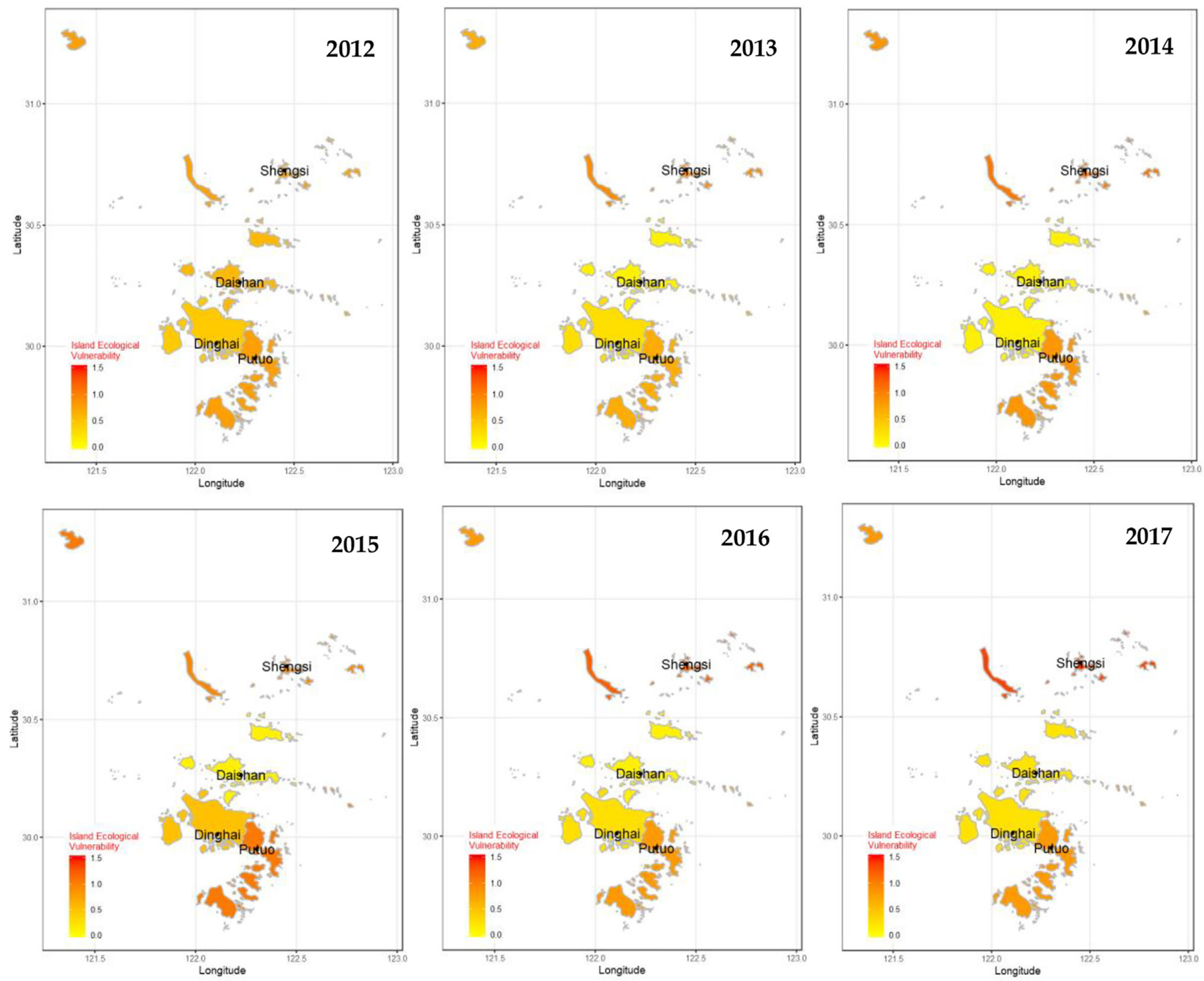


Fig. 12. Composite island ecological vulnerability assessment of Zhoushan in the period 2012–2017.

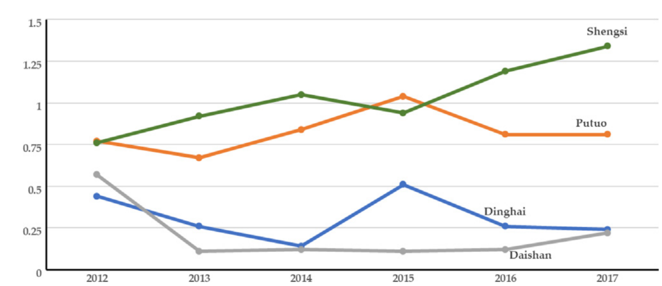


Fig. 13. Composite IEV evolution of Zhoushan in the period 2012–2017.

sensitivity. On the other hand, tourists flocking to destinations have also elevated local tourist density and ratio of tourists to locals, aggravating local tourism sensitivity and anthropogenic disturbance. It is rather tricky to get the best of both worlds: tourism-oriented income and contribution to local GDP, and tourism-induced ecological sensitivity and environmental deterioration. Through trade-off analysis, policy-makers need to acknowledge the more efficient subsystem in E-S-A and decide which of the subsystem indicators should be prioritized. It is commonly believed that the enhancement of social support and environmental conservation should be a more direct option for policy-makers to mitigate the composite IEV values. Besides, a tripartite set of consistent top-down national-provincial-local plans in China's circumstance could secure a more desirable blueprint for island ecological sustainability (Ma et al., 2018).

5.3. The overlap between CCD and IEV temporal evolution

We claim that the CCDM can generate results that are both significant and meaningful for Zhoushan's future tourism development. As a pilot and pioneering island city in China, it is imperative for Zhoushan to explore the coupling relationship among E-S-A subsystems, and the key factors influencing future sustainable and healthy tourism. To a large extent, the result of CCD in our study period overlaps with the composite IEV temporal evolution, especially for Shengsi and Putuo

Table 3
Division of the development stages of E-S-A subsystems.

Value of D	$0 \le D < 0.15$	$0.15 \le D < 0.3$	$0.3 \le D < 0.4$	$0.4 \le D < 0.55$	$0.55 \le D < 0.75$	$0.75 \le D < 1$
Development stages	Seriously unbalanced	Moderately unbalanced	Barely unbalanced	Barely balanced	Moderately balanced	Favorably balanced

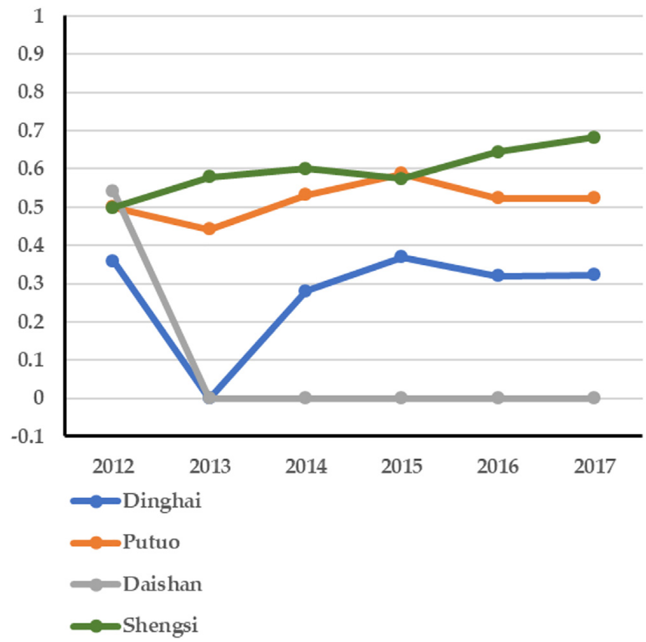


Fig. 14. Coupling coordination degree of E-S-A subsystems in the four regions in the period 2012–2017.

(see Figs. 13 and 14). The results reveal that Zhoushan's tourism development during this period has exerted constant and enormous pressure on its ecological vulnerability. The more coordinated the CCD values among E-S-A subsystems are, the higher the IEV values in the four tourist destinations of Zhoushan.

The policy-makers in the tourism industry of Zhoushan appear not to be in a quandary over whether to promote island tourism or not in Zhoushan. Although Zhoushan's burgeoning tourism industry during the study period brings with it a number of negative ecological impacts that affect both the quality of life for local inhabitants and the quality of tourism for inbound tourists, Zhoushan has unflinchingly pursued a growth into path for tourism industry and compatibilized its tourism development with National New Area project. Improved transportation connectivity to neighboring coastal city Ningbo has greatly fueled its accessibility for both domestic and international tourists. Nevertheless, the ecological and environmental issues remain firmly entrenched in the discourse on islands where tourism has become prominent (Banos-González et al., 2015; Qiu et al., 2017).

6. Conclusions

Ecological vulnerability, which provides a direct measurement of exposure, sensitivity, and adaptive capacity, is an effective and innovative tool that attempts to assess the vulnerability of a system from an ecological perspective. In recent years, island ecological vulnerability (IEV) has rapidly taken ground as a tool for estimating and

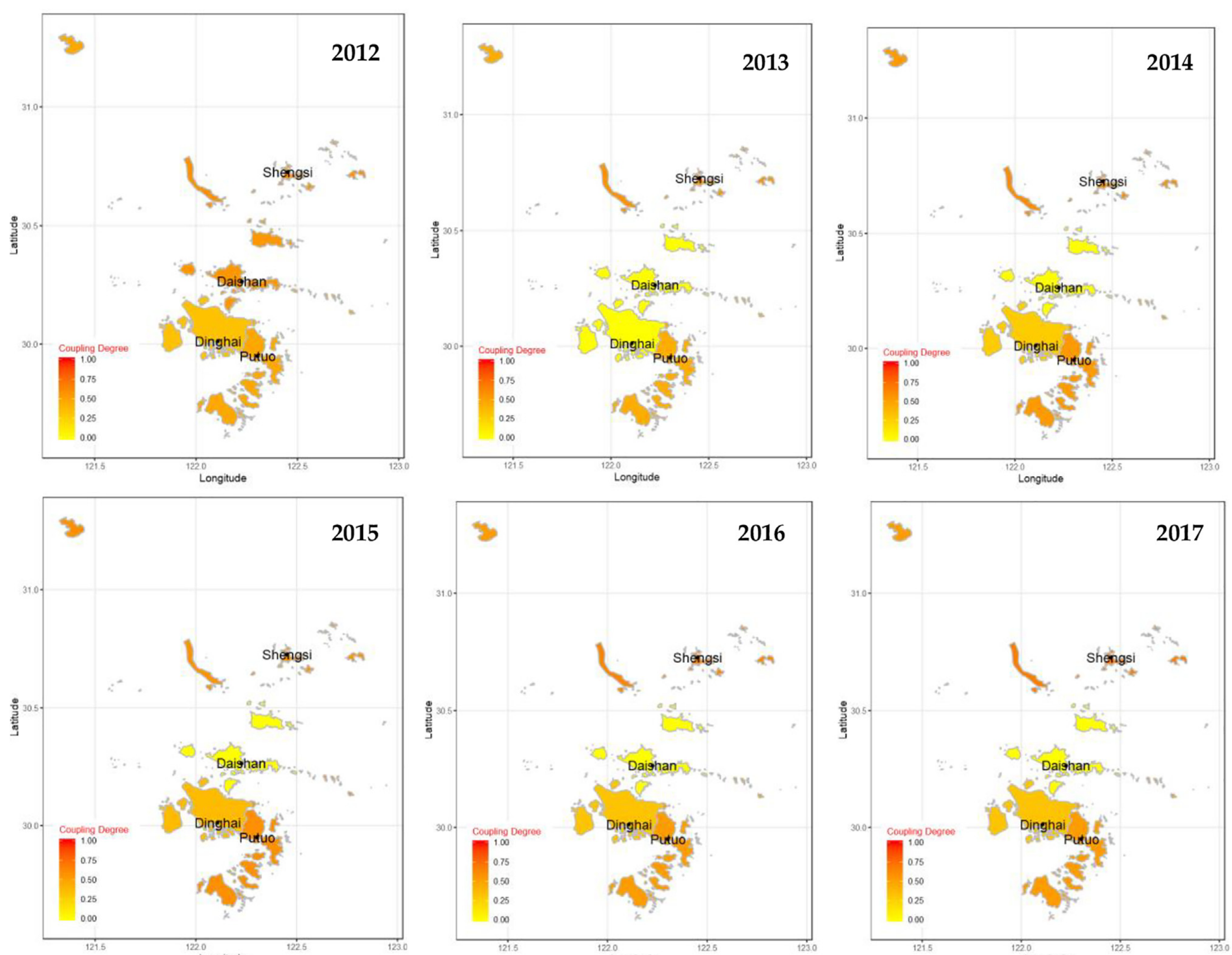


Fig. 15. Coupling coordination development of E-S-A subsystems in Zhoushan in the period 2012–2017.

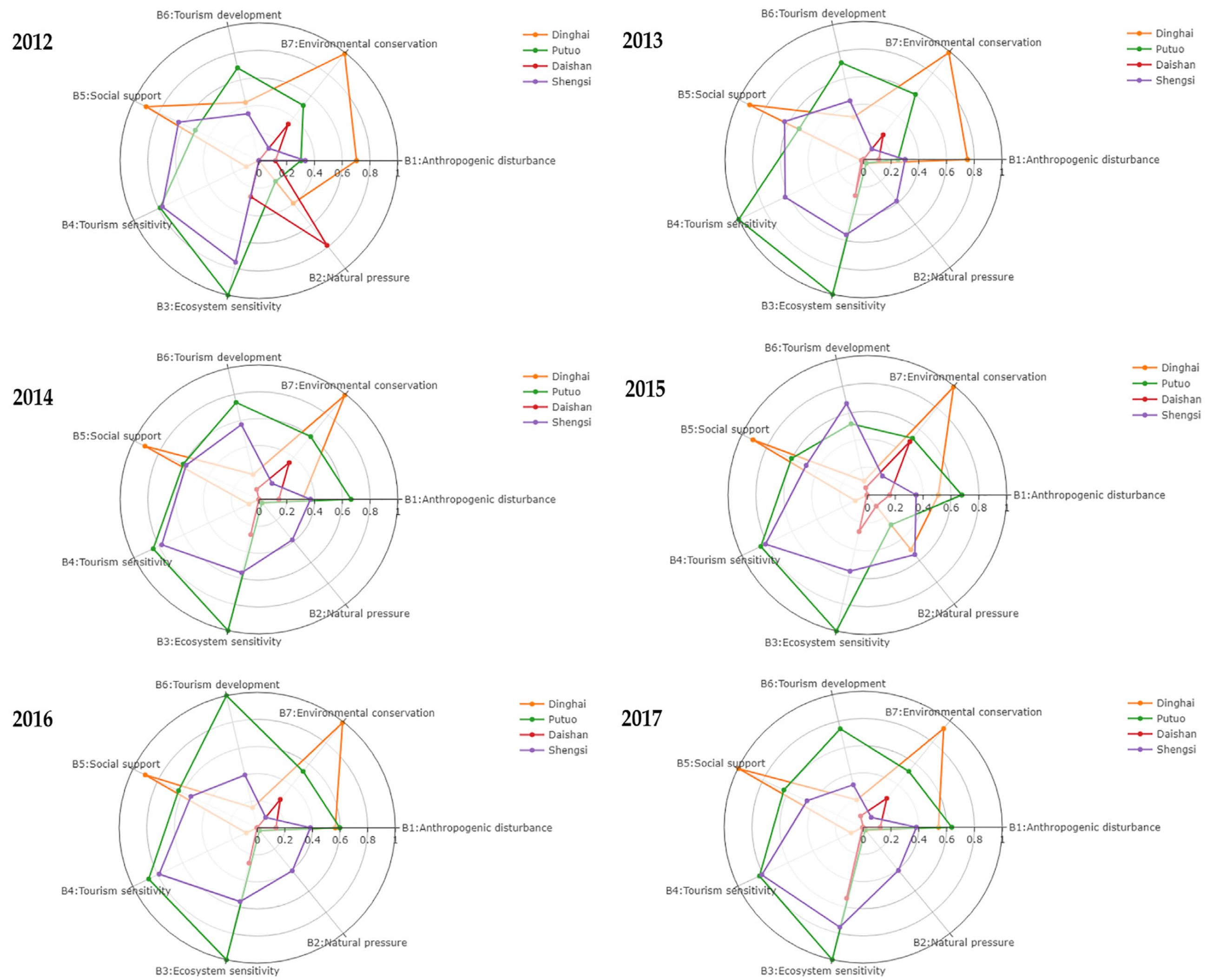


Fig. 16. Radial graphs of Element layer for each region in Zhoushan in the period 2012–2017.

depicting the pressure upon island ecological conditions imposed by anthropogenic disturbance, including urbanization (Sun et al., 2019) and tourist activities (Xie et al., 2019). In our study, IEV can better integrate the analysis of tourism development and its ecological impacts. Our study contributes to the growing literature that attempts to identify island vulnerability by collecting and analyzing data from an island city in China through an adapted E-S-A vulnerability framework, which, consisting of 1 objective, 3 sub-objectives, 7 elements, and 20 indicators, is established and tested on the IEV of Zhoushan's four administrative island regions to tourism.

The assessment results in Zhoushan indicate that, on the whole, the four administrative island regions present distinctive levels of ecological vulnerability to tourism during the observation years, due largely to their respective geographic locations and insular functions. Our major findings are that: (1) As the most attractive tourist destinations, Shengsi and Putuo inevitably have the highest IEV values. (2) Dinghai's moderate low level of IEV comes as a surprise, due to its direct connectivity to its neighboring coastal city of Ningbo. Dinghai hosts more headquarter functions than actual tourism functions. (3) The more balanced the CCD values among E-S-A subsystems are, the higher the IEV values in the four tourist destinations of Zhoushan. Tourism appears a double-edged sword for islands, overall benefits of which outweigh the negative impacts upon island ecological conditions in our case study.

As contribution to the island vulnerability assessment, a dynamic model of the ecological vulnerability of Zhoushan has been elaborated and calibrated for 2012–2017 period. Nevertheless, this model presents some limitations. Since it has been developed employing a context-specific approach, this model should be cautiously applied to the IEV assessment for other worldwide islands with fixed links to the mainland, such as Prince Edward Island of Canada linked by the Confederation Bridge with mainland, and Bahrain Island linked by the King Fahd Causeway with the Saudi Arabian mainland. However, the need for problem-specific perspectives to deal with practical complexity of socio-ecological systems is certainly encouraged (Jin et al., 2009; Marín et al., 2012). Another limitation resides in the lack of a quantitative analysis of locally organized tourism activities and a qualitative analysis of tourists' behaviors, which are unequivocal priorities in future research on the interactive relations between island ecological vulnerability and sustainable tourism development.

CRediT authorship contribution statement

Xin Ma: Conceptualization, Methodology, Writing - original draft. **Martin de Jong:** Writing - review & editing, Formal analysis. **Baiqing Sun:** Supervision, Funding acquisition. **Xin Bao:** Data curation, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Summary of global island vulnerability assessments since 2000.

Authors	Method/index/framework	Geographical applications	Dimensions	Indicators	Driving factors
Adrianto and Matsuda (2002)	Economic Vulnerability Index	Small Islands; Amami Island, Japan	Economics	Gross Island Products	Sea-level rise (SLR), natural disaster
Adrianto and Matsuda (2004)	Composite economicvulnerabilityindex	Small islands	Economics	Economic exposure, economic remoteness, economic impact	Environmental,natural disasters
Al-Jeneid et al. (2008)	Topographic Vulnerability Index	Small Islands States; Kingdom of Bahrain	Topography	Surface elevation, slope, landcover	SLR
Barrientos (2010)	Social Vulnerability	Small Island States; Grenada	Social and economic	Demography, economic size, economic openness	Natural disaster, Economy changes
Becken et al. (2014)	Tourism disaster vulnerability framework	Caribbean and Pacific Islands, the Maldives	social, economic, political, and environmental	Coastal tourism, coastal product, private sector resources, and coastal ecosystems	Natural disaster
Birk (2014)	Sustainable livelihoods framework	Solomon Islands	Socio-economic stressors	Economic potential, infrastructure, governance	Climate change and SLR
Boruff and Cutter (2007)	Environmental vulnerability framework	SIDS; Saint Vincent and Barbados	Social and economic	Population, housing, employment, land use	Natural hazard
Briguglio et al. (2009)	Economic Vulnerability and Resilience	SIDS	Economics, Governance, and Social	Economic openness, macroeconomic stability, good political governance, and social development	The characteristics of small island
Chi et al. (2017)	Island Ecological Vulnerability (IEV) Evaluation Model	China; Miaodao Archipelago	Ecological Vulnerability; exposure, sensitivity, adaptive capacity	Population density, GDP per capita, steep region proportion, sea water quality	Human activities
Duvat et al. (2017)	Trajectories of exposure and vulnerability	Pacific Islands	Natural and anthropogenic	Geopolitical, demographic, socio-economic, environmental	Climate-related environmental changes
Fakhruddin et al. (2015)	Infrastructure Vulnerability Model	Samoa Islands	Social	Infrastructure damage, service capacity	Climate change
Farhan and Lim (2012)	Coastal Vulnerability Index (CVI)	Small Islands; Seribu Islands, Indonesia	Environment	Land use, coastline changes, island remoteness, coral reef changes, pollutant areas, geological condition	Urban pressures, pollutants
Farhan and Lim (2013)	Integrated Coastal Zone Management	Small Islands; Seribu Islands, Indonesia	Governance	Indonesian Constitutions, Government regulation	Complex systems of administration
Fattal et al. (2010)	Global Vulnerability Index	France; Noirmoutier Island	Environmental, socioeconomic	Heritage, infrastructure, human activities, oil spill management	Anthropogenic disturbance; oil spill pollution
Gowrie (2003)	Environmental vulnerability index	Island of Tobago	Environmental risk and degradation	Anthropogenic, meteorological, biological, geological	Geographical dispersion, natural hazards
Gravelle and Mimura (2008)	Digital Elevation Model	Fiji Islands; Viti Levu	Design water level	Maximum tidal, effect of SLR, storm surge	SLR
Guillaumont (2010)	Economic Vulnerability Index	SIDS	Economics andenvironment	Instability channels to growth, human capital	Natural or external shocks
Holding et al. (2016)	SIDS Groundwater Systems Assessment	Global; SIDS	Groundwater	Recharge volume, change in recharge, protection regulations	Climate change
Huebner (2012)	Semi-structured Online Questionnaire	South Pacific Small Islands	Environmental, Infrastructural damages, Social	SLR, destruction of coral reefs, emigration, disease outbreaks	Climate change
Jackson et al. (2017)	Methods for the Improvement of Vulnerability in Europe	Vanuatu; Emae Island	Social, economic, physical, cultural environmental, institutional	Population growth, water security, economic impact, infrastructure, ecosystem services,	Natural hazard
Julca and Paddison (2010)	Environmental vulnerability	SIDS	Economics andenvironment	Economic vulnerability, international migration and the recreation of vulnerabilities	Natural hazard, climate change
Kura et al. (2015)	DRASTIC and GALDIT models	Malaysia; Kapas Island	Groundwater	Net recharge, aquifer media, topography, Impact of vadose zone	Anthropogenic pollution and seawater intrusion
Maio et al. (2012)	Coastal hazard vulnerability framework	USA; Rainsford Island	Topographic	Surface elevation, slope, landcover	SLR and coastal flooding
Martins et al. (2012)	Multicriteria Analysis	Portugal; São Miguel Island, Azores,	Social	Demography, socioeconomic, built environment, seismic hazard exposure	Natural hazard; seismic risk
McCubbin et al. (2015)	Semi-structured interview	SIDS; Tuvalu	Economic, social, environmental	Economy, food, water, overcrowding, cyclones	Climate change
Moghal and O'Connell (2018)	Community-Based Vulnerability Assessments	SIDS; Barbados	Economic, social, environmental	Economic recession, mitigation response, biodiversity	Both climatic stressors and non-climatic stressors

Sahana et al. (2019)	CVI	India; Sundarban Biosphere Reserve	Topographic	Elevation, coastal slope, coastal shoreline change, mean tidal range	Natural hazard
Sarris et al. (2010)	Total Seismic Vulnerability Index	Greece; Chania City, Crete Island	Seismic	Construction year, construction materials, geology, morphology	Natural hazard
Scandurra et al. (2018)	Composite Vulnerability Index	SIDS	Social, environmental, remoteness, economic,	Population density, CO2 emissions, internet users, import value index	Climate change
Schmutter et al. (2017)	Socio-economic Vulnerability Index	SIDS	Socio-economic	Population changed, ecosystems shift, reduction of fisheries and aquaculture	Ocean acidification
Sjöstedt and Povitkina (2017)	Institutional Vulnerability	SIDS	Governance	Democracy, GDP per capita, government effectiveness	Natural disaster
Sun et al. (2019)	IEV Assessment Model	China; Chongming Island	Ecological Vulnerability; exposure, sensitivity, adaptive capacity	Arable land proportion, urban green coverage, energy consumption	Anthropogenic disturbance; urbanization
Taramelli et al. (2015)	Source-Pathway-Receptor-Consequence (SPRC)	Caribbean; Cayman Islands	Critical facilities	Structural and architectural feature	Natural hazard
Turvey (2007)	Composite Vulnerability Index	SIDS	Geographic	Coastal, peripherality, urbanization, natural disasters	Climate change
Xie et al. (2019)	IEV Assessment Model	China; Zhoushan Archipelago	Ecological Vulnerability; exposure, sensitivity, adaptive capacity	Natural pressure, ecosystem productivity, social support condition	Anthropogenic disturbance

References

Abecasis, R.C., Longnecker, N., Schmidt, L., Clifton, J., 2013. Marine conservation in remote small island settings: factors influencing marine protected area establishment in the Azores. Mar. Pol. 40, 1–9. https://doi.org/10.1016/j.marpol.2012.12.032.

Abuodha, P., Woodroffe, C.D., 2010. Assessing vulnerability to sea-level rise using a coastal sensitivity index: a case study from southeast Australia. J. Coast. Conserv. 14, 189–205. http://www.jstor.org/stable/40928191.

Adger, W.N., Vincent, K., 2005. Uncertainty in adaptive capacity. C. R. Geosci. 337, 399–410. https://doi.org/10.1016/j.crte.2004.11.004.

Adrianto, L., Matsuda, Y., 2002. Developing economic vulnerability indices of environmental disasters in small island regions. Environ. Impact Assess. Rev. 22 (4), 393–414. https://doi.org/10.1016/s0195-9255(02)00012-4.

Adrianto, L., Matsuda, Y., 2004. Study on assessing economic vulnerability of small island regions. Environ. Dev. Sustain. 6 (3), 317–336. https://doi.org/10.1023/b:envi.0000029902.39214.d0.

Al-Jeneid, S., Bahnassy, M., Nasr, S., Raey, M.E., 2008. Vulnerability assessment and adaptation to the impacts of sea level rise on the Kingdom of Bahrain. Mitig. Adapt. Strateg. Glob. Chang. 13 (1), 87–104. https://doi.org/10.1007/s11027-007-9083-8.

Banos-González, I., Martínez-Fernández, J., Esteve-Selma, M.Á., 2015. Dynamic integration of sustainability indicators in insular socio-ecological systems. Ecol. Model. 306, 130–144. https://doi.org/10.1016/j.ecolmodel.2014.08.014.

Barrientos, A., 2010. Vulnerability and social protection in small island states: the case of Brenada. Soc. Econ. Stud. 59 (1 & 2), 3–30. http://www.jstor.org/stable/27866610.

Becken, S., Mahon, R., Rennie, H.G., Shakeela, A., 2014. The tourism disaster vulnerability framework: an application to tourism in small island destinations. Nat. Hazards 71 (1), 955–972. https://doi.org/10.1007/s11069-013-0946-x.

Benitez-Capistros, F., Hugé, J., Koedam, N., 2014. Environmental impacts on the Galapagos Islands: identification of interactions, perceptions and steps ahead. Ecol. Indic. 38, 113–123. https://doi.org/10.1016/j.ecolind.2013.10.019.

Bigano, A., Bosello, F., Roson, R., Tol, R.S.J., 2008. Economy-wide impacts of climate change: a joint analysis for sea level rise and tourism. Mitig. Adapt. Strateg. Glob. Change 13, 765–791. https://doi.org/10.1007/s11027-007-9139-9.

Birk, T., 2014. Assessing vulnerability to climate change and socioeconomic stressors in the Reef Islands group, Solomon Islands. Geogr. Tidsskr. 114 (1), 59–75. https://doi.org/10.1080/00167223.2013.878228.

Blancas, F.J., González, M., Lozano-Oyola, M., Pérez, F., 2010. The assessment of sustainable tourism: application to Spanish coastal destinations. Ecol. Indic. 10 (2), 484–492. https://doi.org/10.1016/j.ecolind.2009.08.001.

Boruff, B.J., Cutter, S.L., 2007. The environmental vulnerability of caribbean island nations. Geogr. Rev. 97 (1), 24–45. https://doi.org/10.1111/j.1931-0846.2007.tb00278.x.

Briguglio, L., Cordina, G., Farrugia, N., Vella, S., 2009. Economic vulnerability and resilience: concepts and measurements. Oxford Dev. Stud. 37 (3), 229–247. https://doi.org/10.1080/13600810903089893.

Chen, H.S., 2019. Establishment and application of an evaluation model for Orchid Island sustainable tourism development. Int. J. Environ. Res. Public Health 16 (5), 755. https://doi.org/10.3390/ijerph16050755.

Chen, H.S., Liu, W.Y., Hsieh, C.M., 2017a. Integrating ecosystem services and eco-security to assess sustainable development in Liuqiu Island. Sustainability 9 (6), 1002. https://doi.org/10.3390/su9061002.

Chen, J.D., Ye, G.Q., Jing, C.W., Wu, J.P., Ma, P.P., 2017b. Ecological footprint analysis on tourism carrying capacity at the Zhoushan Archipelago, China. Asia Pac. J. Tour. Res. 22, 1049–1062. https://doi.org/10.1080/10941665.2017.1364276.

Chi, Y., Shi, H., Wang, Y., Guo, Z., Wang, E., 2017. Evaluation on island ecological vulnerability and its spatial heterogeneity. Mar. Pollut. Bull. 125, 216–241. https://doi.org/10.1016/j.marpolbul.2017.08.028.

Daishan County Government, 2018. Daishan Statistical Yearbook. 2018. http://www.daishan.gov.cn/col/col1326547/index.html (accessed 10 June 2019).

Dinghai District Government, 2018. Dinghai Statistical Yearbook. http://www.dinghai.gov.cn/col/col1489733/index.html (accessed 10 June 2019).

Davenport, J., Davenport, J.L., 2006. The impact of tourism and personal leisure transport on coastal environments: a review. Estuar. Coast. Shelf Sci. 67 (1–2), 280–292. https://doi.org/10.1016/j.ecss.2005.11.026.

Du, S., Guo, C., Jin, M., 2016. Agent-based simulation on tourists' congestion control during peak travel period using Logit model. Chaos Solitons Fractals 89, 187–194. https://doi.org/10.1016/j.chaos.2015.10.025.

Duvat, V.K.E., Magnan, A.K., Wise, R.M., Hay, J.E., Fazey, I., Hinkel, J., Ballu, V., 2017. Trajectories of exposure and vulnerability of small islands to climate change. Wiley Interdiscip. Rev. Clim. Chang. 8 (6), e478. https://doi.org/10.1002/wcc.478.

Fabinyi, M., 2008. Dive tourism, fishing and marine protected areas in the Calamianes Islands, Philippines. Mar. Pol. 32 (6), 898–904. https://doi.org/10.1016/j.marpol.2008.01.004.

Fakhruddin, S.H.M., Babel, M.S., Kawasaki, A., 2015. Assessing the vulnerability of infrastructure to climate change on the Islands of Samoa. Nat. Hazards Earth Syst. Sci. 15 (6), 1343–1356. https://doi.org/10.5194/nhess-15-1343-2015.

Fan, Y., Fang, C., Zhang, Q., 2019. Coupling coordinated development between social economy and ecological environment in Chinese provincial capital cities-assessment and policy implications. J. Clean. Prod. 229, 289–298. https://doi.org/10.1016/j.jclepro.2019.05.027.

Farhan, A.R., Lim, S., 2012. Vulnerability assessment of ecological conditions in Seribu Islands, Indonesia. Ocean Coastal Manage. 65, 1–14. https://doi.org/10.1016/j.ocecoaman.2012.04.015.

Farhan, A.R., Lim, S., 2013. Improving vulnerability assessment towards Integrated Coastal Zone Management (ICZM): a case study of small islands in Indonesia. J. Coast. Conserv. 17 (3), 351–367. https://doi.org/10.1007/s11852-013-0269-9.

Fattal, P., Maanan, M., Tillier, I., Rollo, N., Robin, M., Pottier, P., 2010. Coastal vulnerability to oil spill pollution: the case of Noirmoutier Island (France). J. Coast. Res. 265, 879–887. https://doi.org/10.2112/08-1159.1.

Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., Marcomini, A., 2016. A review of multi-risk methodologies for natural hazards: consequences and challenges for a climate change impact assessment. J. Environ. Manage. 168, 123–132. https://doi.org/10.1016/j.jenvman.2015.11.011.

Gowrie, M.N., 2003. Environmental Vulnerability Index for the Island of Tobago, West Indies. Conserv. Ecol. 7 (2), 11. https://www.jstor.org/stable/26271947.

Gravelle, G., Mimura, N., 2008. Vulnerability assessment of sea-level rise in Viti Levu, Fiji Islands. Sustain. Sci. 3 (2), 171–180. https://doi.org/10.1007/s11625-008-0052-2.

Gu, Y.Q., 2017. Research on ecological compensation in island tourism destination based on PES – the Zhoushan Archipelago new area as an example. J. Environ. Prot. Ecol. 18, 1765–1771.

Guillaumont, P., 2010. Assessing the economic vulnerability of Small Island Developing States and the least developed countries. J. Dev. Stud. 46 (5), 828–854. https://doi.org/10.1080/00220381003623814.

Hall, C.M., 2001. Trends in ocean and coastal tourism: the end of the last frontier? Ocean Coastal Manage. 44 (9–10), 601–618. https://doi.org/10.1016/s0964-5691(01)00071-0.

He, J., Wang, S., Liu, Y., Ma, H., Liu, Q., 2017. Examining the relationship between urbanization and the eco-environment using a coupling analysis: case study of Shanghai, China. Ecol. Indic. 77, 185–193. https://doi.org/10.1016/j.ecolind.2017.01.017.

Holding, S., Allen, D.M., Foster, S., Hsieh, A., Larocque, I., Klassen, J., Van Pelt, S.C., 2016. Groundwater vulnerability on small islands. Nat. Clim. Chang. 6 (12), 1100–1103. https://doi.org/10.1038/nclimate3128.

Hu, T., Jin, M., Lei, X., Liao, Z., Ge, P., 2018. Tourists initial optimal shunt scheme using multi-objective genetic algorithm. Wirel. Pers. Commun. 102 (4), 3517–3527. https://doi.org/10.1007/s11277-018-5388-z.

Huebner, A., 2012. Public perceptions of destination vulnerability to climate change and implications for long-haul travel decisions to small island states. J. Sustain. Tour. 20 (7), 939–951. https://doi.org/10.1080/09669582.2012.667107.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 151–153.

Jackson, G., McNamara, K., Witt, B., 2017. A framework for disaster vulnerability in a small island in the Southwest Pacific: a case study of Emae Island, Vanuatu. Int. J. Disaster Risk Sci. 8 (4), 358–373. https://doi.org/10.1007/s13753-017-0145-6.

Jin, W., Xu, L., Yang, Z., 2009. Modeling a policy making framework for urban sustainability: incorporating system dynamics into the ecological footprint. Ecol. Econ. 68 (12), 2938–2949. https://doi.org/10.1016/j.ecolecon.2009.06.010.

Julca, A., Paddison, O., 2010. Vulnerabilities and migration in Small Island Developing States in the context of climate change. Nat. Hazards 55 (3), 717–728. https://doi.org/10.1007/s11069-009-9384-1.

Kaltenborn, B.P., Thomassen, J., Linnell, J.D.C., 2012. Island futures-Does a participatory scenario process capture the common view of local residents? Futures 44 (4), 328–337. https://doi.org/10.1016/j.futures.2011.11.001.

Kura, N.U., Ramli, M.F., Ibrahim, S., Sulaiman, W.N.A., Aris, A.Z., Tanko, A.I., Zaudi, M.A., 2015. Assessment of groundwater vulnerability to anthropogenic pollution and seawater intrusion in a small tropical island using index-based methods. Environ. Sci. Pollut. Res. 22 (2), 1512–1533. https://doi.org/10.1007/s11356-014-3444-0.

Kurniawan, F., Adrianto, L., Bengen, D.G., Prasetyo, L.B., 2016. Vulnerability assessment of small islands to tourism: The case of the Marine Tourism Park of the Gili Matra Islands, Indonesia. Glob. Ecol. Conserv. 6, 308–326. https://doi.org/10.1016/j.gecco.2016.04.001.

Li, Y., Kappas, M., Li, Y., 2018. Exploring the coastal urban resilience and transformation of coupled human-environment systems. J. Clean. Prod. 195, 1505–1511. https://doi.org/10.1016/j.jclepro.2017.10.227.

Li, Y., Li, Y., Zhou, Y., Shi, Y., Zhu, X., 2012. Investigation of a coupling model of coordination between urbanization and the environment. J. Environ. Manage. 98, 127–133. https://doi.org/10.1016/j.jenvman.2011.12.025.

Li, Y., Qiu, J., Zhao, B., Pavao-Zuckerman, M., Bruns, A., Qureshi, S., Li, Y., 2017. Quantifying urban ecological governance: a suite of indices characterizes the ecological planning implications of rapid coastal urbanization. Ecol. Indic. 72, 225–233. https://doi.org/10.1016/j.ecolind.2016.08.021.

Li, Y., Zhang, X., Zhao, X., Ma, S., Cao, H., Cao, J., 2016. Assessing spatial vulnerability from rapid urbanization to inform coastal urban regional planning. Ocean Coastal Manage. 123, 53–65. https://doi.org/10.1016/j.ocecoaman.2016.01.010.

Lim, C.C., Cooper, C., 2009. Beyond sustainability: optimising island tourism development. Int. J. Tour. Res. 11 (1), 89–103. https://doi.org/10.1002/jtr.688.

Liu, W., Jiao, F., Ren, L., Xu, X., Wang, J., Wang, X., 2018. Coupling coordination relationship between urbanization and atmospheric environment security in Jinan City. J. Clean. Prod. 204, 1–11. https://doi.org/10.1016/j.jclepro.2018.08.244.

Ma, X., de Jong, M., den Hartog, H., 2018. Assessing the implementation of the Chongming Eco Island policy: What a broad planning framework can tell more than technocratic indicator systems. J. Clean. Prod. 172, 872–886. https://doi.org/10.1016/j.jclepro.2017.10.133.

Mahendra, R.S., Mohanty, P.C., Bisoyi, H., Kumar, T.S., Nayak, S., 2011. Assessment and management of coastal multi-hazard vulnerability along the Cuddalore-Villupuram, east coast of India using geospatial techniques. Ocean Coastal Manage. 54 (4), 302–311. https://doi.org/10.1016/j.ocecoaman.2010.12.008.

Maio, C.V., Gontz, A.M., Tenenbaum, D.E., Berkland, E.P., 2012. Coastal hazard vulnerability assessment of sensitive historical sites on Rainsford Island, Boston Harbor, Massachusetts. J. Coast. Res. 278, 20–33. https://doi.org/10.2112/jcoastres-d-10-00104.1.

Marín, V.H., Rodríguez, L.C., Niemeyer, H.M., 2012. A socio-ecological model of the Opuntia scrublands in the Peruvian Andes. Ecol. Model. 227, 136–146. https://doi.org/10.1016/j.ecolmodel.2011.12.010.

Martins, V.N., Silva, D.S., Cabral, P., 2012. Social vulnerability assessment to seismic risk using multicriteria analysis: the case study of Vila Franca do Campo (São Miguel Island, Azores, Portugal). Nat. Hazards 62 (2), 385–404. https://doi.org/10.1007/s11069-012-0084-x.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S., 2001. In: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge, UK, pp. 4–8.

McCubbin, S., Smit, B., Pearce, T., 2015. Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. Glob. Environ. Change-Human Policy Dimens. 30, 43–55. https://doi.org/10.1016/j.gloenvcha.2014.10.007.

Mclaughlin, S., Cooper, J.A.G., 2010. A multi-scale coastal vulnerability index: a tool for coastal managers? Environ. Hazards 9, 233–248. https://doi.org/10.3763/ehaz.2010.0052.

Mclaughlin, S., Mckenna, J., Cooper, J.A.G., 2002. Socio-economic data in coastal vulnerability indices: constraints and opportunities. J. Coast. Res. 36, 487–497. https://doi.org/10.2112/1551-5036-36.sp1.487.

Moghal, Z., O'Connell, E., 2018. Multiple stressors impacting a small island tourism destination-community: a nested vulnerability assessment of Oistins, Barbados. Tour. Manag. Perspect. 26, 78–88. https://doi.org/10.1016/j.tmp.2018.03.004.

Moreno, A., Becken, S., 2009. A climate change vulnerability assessment methodology for coastal tourism. J. Sustain. Tour. 17 (4), 473–488. https://doi.org/10.1080/09669580802651681.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J., 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding – a global assessment. PLoS One 10, e0118571. https://doi.org/10.1371/journal.pone.0118571.

Ng, S.I., Chia, K.W., Ho, J.A., Ramachandran, S., 2017. Seeking tourism sustainability – a case study of Tioman Island, Malaysia. Tourism Manage. 58, 101–107. https://doi.org/10.1016/j.tourman.2016.10.007.

Nguyen, T.T.X., Bonetti, J., Rogers, K., Woodroffe, C.D., 2016. Indicator-based assessment of climate-change impacts on coasts: a review of concepts, methodological approaches and vulnerability indices. Ocean Coast. Manag. 123, 18–43. https://doi.org/10.1016/j.ocecoaman.2015.11.022.

Nicely, A., Palakurthi, R., 2012. Navigating through tourism options: an island perspective. Int. J. Cult. Tourism Hospit. Res. 6 (2), 133–144. https://doi.org/10.1108/17506181211233063.

Nicholls, R.J., Cazenave, A., 2010. Sea-level rise and its impact on coastal zones. Science 328 (5985), 1517–1520. https://doi.org/10.1126/science.1185782.

Parra-López, E., Martínez-González, J.A., 2018. Tourism research on island destinations: a review. Tour. Rev. 73 (2), 133–155. https://doi.org/10.1108/tr-03-2017-0039.

Preston, B.L., Smith, T.F., Brooke, C., et al., 2008. Mapping Climate Change Vulnerability in the Sydney Coastal Councils Group. Report prepared for the Sydney. Coastal Councils Group.

Putuo District Government, 2018. Putuo Statistical Yearbook. http://www.putuo.gov.cn/col/col1423470/index.html (accessed 10 June 2019).

Qiu, S., Yue, W., Zhang, H., Qi, J., 2017. Island ecosystem services value, land-use change, and the National New Area Policy in Zhoushan Archipelago, China. Isl. Stud. J. 12 (2), 177–198. https://doi.org/10.24043/isj.20.

Reddy, M.V., 2008. Sustainable tourism rapid indicators for less-developed islands: an economic perspective. Int. J. Tour. Res. 10 (6), 557–576. https://doi.org/10.1002/jtr.700.

Sahana, M., Hong, H., Ahmed, R., Patel, P.P., Bhakat, P., Sajjad, H., 2019. Assessing coastal island vulnerability in the Sundarban Biosphere Reserve, India, using geospatial technology. Environ. Earth Sci. 78 (10). https://doi.org/10.1007/s12665-019-8293-1.

Sahoo, B., Bhaskaran, P.K., 2018. Multi-hazard risk assessment of coastal vulnerability from tropical cyclones – a GIS based approach for the Odisha coast. J. Environ. Manage. 206, 1166–1178. https://doi.org/10.1016/j.jenvman.2017.10.075.

Sarris, A., Loupasakis, C., Soupios, P., Trigkas, V., Vallianatos, F., 2010. Earthquake vulnerability and seismic risk assessment of urban areas in high seismic regions: application to Chania City, Crete Island, Greece. Nat. Hazards 54 (2), 395–412. https://doi.org/10.1007/s11069-009-9475-z.

Saxena, S., Geethalakshmi, V., Lakshmanan, A., 2013. Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India—a case study. Weather Clim. Extremes 2, 48–57. https://doi.org/10.1016/j.wace.2013.10.001.

Scandurra, G., Romano, A.A., Ronghi, M., Carfora, A., 2018. On the vulnerability of Small Island Developing States: a dynamic analysis. Ecol. Indic. 84, 382–392. https://doi.org/10.1016/j.ecolind.2017.09.016.

Scheyvens, R., Momsen, J., 2008. Tourism in small island states: from vulnerability to strengths. J. Sustain. Tour. 16 (5), 491–510. https://doi.org/10.1080/09669580802159586.

Schmutter, K., Nash, M., Dovey, L., 2017. Ocean acidification: assessing the vulnerability of socioeconomic systems in Small Island Developing States. Reg. Environ. Change 17 (4), 973–987. https://doi.org/10.1007/s10113-016-0949-8.

Scott, D., Hall, C.M., Gössling, S., 2015. A review of the IPCC fifth assessment and implications for tourism sector climate resilience and decarbonization. J. Sustain. Tour. 1–23. https://doi.org/10.1080/09669582.2015.1062021.

Sharpley, R., Ussi, M., 2014. Tourism and Governance in Small Island Developing States (SIDS): the case of Zanzibar. Int. J. Tour. Res. 16 (1), 87–96. https://doi.org/10.1002/jtr.1904.

Shengsi County Government, 2018. Shengsi Statistical Yearbook. http://www.shengsi.gov.cn/col/col1354801/index.html (accessed 10 June 2019).

Sjöstedt, M., Povitkina, M., 2017. Vulnerability of small island developing states to natural disasters. J. Environ. Dev. 26 (1), 82–105. https://doi.org/10.1177/1070496516682339.

Sun, B.Q., Ma, X., de Jong, M., Bao, X., 2019. Assessment on island ecological vulnerability to urbanization: a tale of Chongming Island China. Sustainability 11 (9), 2536. https://doi.org/10.3390/su11092536.

Sun, Y., Cui, Y., 2018. Evaluating the coordinated development of economic, social and environmental benefits of urban public transportation infrastructure: case study of four Chinese autonomous municipalities. Transp. Policy 66, 116–126. https://doi.org/10.1016/j.tranpol.2018.02.006.

Taramelli, A., Valentini, E., Sterlacchini, S., 2015. A GIS-based approach for hurricane hazard and vulnerability assessment in the Cayman Islands. Ocean Coastal Manage. 108, 116–130. https://doi.org/10.1016/j.ocecoaman.2014.07.021.

Turvey, R., 2007. Vulnerability assessment of developing countries: the case of Small Island Developing States. Dev. Policy Rev. 25 (2), 243–264. https://doi.org/10.1111/j.1467-7679.2007.00368.x.

Torresan, S., Critto, A., Valle, M.D., Harvey, N., Marcomini, A., 2008. Assessing coastal vulnerability to climate change: comparing segmentation at global and regional scales. Sustain. Sci. 3, 45–65. https://doi.org/10.1007/s11625-008-0045-1.

Xie, Z., Li, X., Jiang, D., Lin, S., Yang, B., Chen, S., 2019. Threshold of island anthropogenic disturbance based on ecological vulnerability assessment—a case study of Zhujiajian Island. Ocean Coastal Manage. 167, 127–136. https://doi.org/10.1016/j.ocecoaman.2018.10.014.

Xing, L., Xue, M., Hu, M., 2019. Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: case of Wuhan City in China. J. Environ. Manage. 230, 474–487. https://doi.org/10.1016/j.jenvman.2018.09.065.

Yang, J., Ge, Y., Ge, Q., Xi, J., Li, X., 2016. Determinants of island tourism development: the example of Dachangshan Island. Tourism Manage. 55, 261–271. https://doi.org/10.1016/j.tourman.2016.03.001.

Yao, L., Ma, R., Liao, Z., Du, S., Jin, M., Ren, P., 2016. Optimization and simulation of tourist shunt scheme: a case of Jiuzhai Valley. Chaos Solitons Fractals 89, 455–464.

https://doi.org/10.1016/j.chaos.2016.02.018.

Yoo, G., Hwang, J.H., Choi, C., 2011. Development and application of a methodology for vulnerability assessment of climate change in coastal cities. Ocean Coast. Manag. 54, 524–534. https://doi.org/10.1016/j.ocecoaman.2011.04.001.

Yoo, G., Kim, A.R., Hadi, S., 2014. A methodology to assess environmental vulnerability in a coastal city: Application to Jakarta, Indonesia. Ocean Coast. Manag. 102, 169–177. https://doi.org/10.1016/j.ocecoaman.2014.09.018.

Zhoushan Statistical Bureau, 2018. Zhoushan Statistical Yearbook (2002–2018). http://zstj.zhoushan.gov.cn/col/col1559852/index.html (accessed 10 June 2019).

Zhoushan Tourist Committee, 2018. Destinations. http://zstour.zhoushan.gov.cn/col/col1563478/index.html (accessed 10 June 2019).

Zhu, J., Lu, Y., Li, G.P., Ren, F.M., 2017. Risk assessment of typhoon disasters in Fujian Province of each county. J. Catastrophol. 32, 204–209. https://doi.org/10.3969/j.issn.1000-811X.2017.03.034. (In Chinese).