

# Variation in Ecosystem Service Value in Response to Landscape Pattern Changes of Zhujiajian Island, China

G. Shen, X. Wang, D. Wang, and X. Xia

**Abstract**—Sea islands are fundamental components of marine and coastal ecosystems among the most productive in terms of services that are linked to human well-being. The landscape patterns of sea islands are undergoing considerable changes from natural successions and anthropogenic activities, which affect their ecosystem service value (ESV), ultimately resulting in ecosystem degradation. Landscape patterns for Zhujiajian Island were derived for seven periods from 1986 to 2014 using Landsat 5 TM and Landsat 8 OLI data by an unsupervised K-Means method. Based on the quantitative relationship between individual landscape type and corresponding ESV, the paper introduced two indexes: total ecosystem service value (TESV) and mean ecosystem service value (MESV). These indexes were used to interpret the ecological implications of landscape pattern changes affecting sea-island ecosystems. Although the area increased by 5%, the TESV of Zhujiajian Island continuously declined by 21% from 1986 to 2014, which suggested ineffective environmental protection and management paralleling social and economic development. The MESV declined dramatically by 25% in the study period, indicating a marked degradation of the ecosystem quality of Zhujiajian Island. The results suggest that human activities should be sustainably managed to prevent the ecosystem degradation of Zhujiajian Island.

**Index Terms**—Ecosystem service value, landscape pattern, Zhujiajian Island, variation.

## I. INTRODUCTION

Marine and coastal ecosystems are among the most productive regarding services linked to human well-being [1]. Landscape ecosystems of sea islands are undergoing considerable changes from natural successions and anthropogenic activities [2]. Landscape structure and pattern (composition, configuration, and connectivity) plays a major role in maintaining biodiversity and fresh water systems, and the provision of ecosystem services [3]-[9]. The changes of landscape structure and pattern affect ecosystem service value (ESV) by altering the material exchange and energy flow and impeding the ability of ecosystems to provide their services [1], since all ecosystem services are related to the movement of organisms and materials across landscapes [10]-[12]. The reduction of ESV caused by natural and human factors results in the ecosystem degradation [13].

Manuscript received October 26, 2016; revised May 1, 2017. This work was supported by Nation Natural Science Foundation of China under Grant No. 41576095, Zhejiang Planning project of philosophy and Social Sciences under Grant No. 12YD16YBM, and Zhejiang Provincial Natural Science Foundation under Grant No. LY15D060003.

G. Shen, X. Wang, D. Wang, and X. Xia are with State Research Center for Island Exploitation and Management, Second Institute of Oceanography, State Oceanic Administration, China (e-mail: shengang@sio.org.cn; carlinwxk@163.com; degang\_w@sio.org.cn; xiaxm@sio.org.cn).

Variations in ESV can be employed to indicate the changes of sea-island landscape ecosystems as a whole.

ESV has had an increased focus in science and environmental policy [14]. Over the last 30 years, assessments of natural resource value based on different spatial and temporal measurement scales have been performed to determine ecosystem services [15]. These assessments have developed considerably in terms of relevant theories, methods, and the breadth and depth of their applications [16]. However, there are limited studies that support the conservation and management of sea islands ecosystems.

Therefore, the paper aims to provide a simple approach to determine the transformation of sea-island ecosystems by coupling ESV with landscape pattern to: 1) obtain the long-term landscape patterns of a sea island from a Landsat series of remote sensing data; 2) calculate the total ecosystem service value (TESV) and mean ecosystem service value (MESV) based on the empirical ESV of individual landscape types; and 3) determine the transformation of sea-island ecosystems and the ecological driving forces for the conservation and management of sea islands.

## II. STUDY SITE AND DATA

### A. Study Site

The study site, Zhujiajian Island, is the fifth largest island located in the southeastern Zhoushan Archipelago (Fig. 1). Crop farming, fishing, and tourism are the main industries. It covered an area of approximately 6365.05 ha in 2014, and is located in the subtropical and maritime monsoon climate zone, with an average annual temperature of 16.1 °C and average annual precipitation of 1,186.90 mm. Zhujiajian Island is a bedrock island situated in the “Min-Zhe” uplift zone of the East China Sea. There are widespread andesitic-granitic igneous rocks of Mesozoic age, and the bedrock outcrops were uplifted during the Miocene as the Fukien-Reinan Massif. The soil in Zhujiajian Island consists of typical classes widely distributed in the Zhejiang coastal area. The lower coastal plain area consists of coastal solonchak, fluvo-aquic solonchak, gray fluvo-aquic soils, and percologenic paddy soils. The hilly upland of the island has red, red-yellow, and yellow soils from the lower to the upper zones.

The distinguishable landscape types comprise woodland, shrubs, and grass, agricultural land, construction land, water surface, and bare land. The woodland is mainly composed of *Pinus thunbergii* Parl., *P. massoniana* Lamb., *Cinnamomum camphora* (L.) Presl., *Cyclobalanopsis glauca*., *Lithocarpus glaber* (Thunb.) Nakai, *Ilex rotunda* Thunb., *Neolitsea*

*sericea* (Bl.) Koidz, *Castanopsis sclerophylla* (Lindl.) Schott., *Viburnum odoratissimum* Ker Gawl., and *Quercus fabri* Hance. Shrubs and grassland are dominated by *Ilex nitidissima* C. J. Tseng, *Rhaphiolepis umbellata* (Thunb.) Makino, *Buxus sinica* (Rehd. et Wils.) Cheng, *Loropetalum chinensis* (R. Br.) Oliv., *Rhododendron pulchrum* Sweet, *Pittosporum tobira*, *Elaeagnus pungens*, *Miscanthus floridulus* (Labill.) Warb. ex K. Schum. et Lauterb., and *M. sinensis* Anders. Agricultural land includes aquaculture and crop planting areas. Residential land, roads, and tourist facilities are classified into construction land. Rivers, ponds, and reservoirs are all regarded as water surface. Bare land consists of sandy beach, bare rock, and bare land.

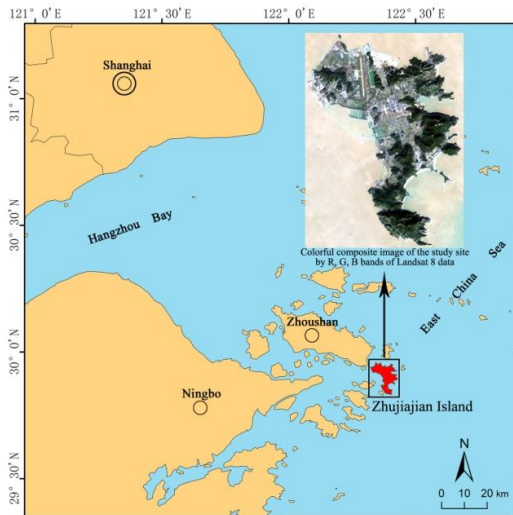


Fig. 1. Location of the study site.

### B. Data Acquisition

The Landsat series of remote sensing data were used to generate the landscape patterns of Zhujiajian Island (Table I).

TABLE I: REMOTE SENSING DATA USED IN THE STUDY

Data type	Acquisition time	Adopted bands	Spatial resolution
Landsat 5 TM	8 May 1986	1~5	
Landsat 5 TM	17 April 1990	1~5	
Landsat 5 TM	16 November 1995	1~5	
Landsat 5 TM	9 September 2000	1~5	30 meters
Landsat 5 TM	29 April 2006	1~5	
Landsat 5 TM	7 May 2009	1~5	
Landsat 8 OLI	6 December 2014	2~6	

All Landsat data were downloaded from United States Geological Survey (USGS) website. A distribution map of the forest resources of the study site for 2006 was provided by the Agriculture, Forestry, and Fisheries Rural Committee, Zhoushan. Field data were obtained via a two-week field survey in 2014, and a hand-held Trimble GeoXT global positioning system (GPS) was used to determine the location of the different landscape types.

## III. MODEL DESCRIPTION

### A. Landscape Identification and Classification

Agricultural and construction land were manually

identified by visual interpretation for all the periods. The series of Landsat data were used to classify woodland, shrubs and grassland, water surface, and bare land by an unsupervised K-Means method in the ENVI+IDL environment. A 2006 forest resource map and 2014 field survey data were employed to assist the individual landscape identification and classification for 2006 and 2014, respectively. The experience of landscape identification in 2006 and 2014 was applied to 1986, 1990, 1995, 2000, and 2009, whereas all imageries used to map the landscape patterns were Landsat series data with similar spectral characteristics and the same spatial resolution.

### B. The Assessment of Zhujiajian Island ESV

The ESV calculation comprised the ecosystem classification, functional identification of individual ecosystems, and its service value quantification. Costanza *et al.* (1997) classified the global biosphere into 16 types of ecosystems and 17 kinds of services, and estimated the total value of each ecosystem by the 'willingness-to-pay' of individuals for ecosystem services [17]. Although this method was intended for a global scale, it is being applied to a specific region considering local ecosystem management. Considerable studies have been conducted to evaluate the service value of Chinese terrestrial ecosystems, and service value coefficients of different terrestrial ecosystems have been summarized in Table II.

TABLE II: ESV PARAMETERS OF CHINESE ECOSYSTEMS

Landscape category	Ecosystem service value (RMB Yuan/ ha.yr)	References
Woodland	13667.20	Yu <i>et al.</i> , 2005
Shrub and grass	6509.40	Zhao <i>et al.</i> , 2004
Agricultural land	6114.30	Sun <i>et al.</i> , 2007
Construction land	-5372.10	Dong <i>et al.</i> , 2006
Bare land	371.40	Shi <i>et al.</i> , 2012
Water surface	40676.40	Shi <i>et al.</i> , 2012

Based on the ESV parameters in Table II, total ecosystem service value (TESV) and mean ecosystem service value (MESV) of Zhujiajian Island were obtained by Equations (1) and (2), respectively.

$$TESV = \sum_{n=1}^6 VC_n \cdot A_n \quad (1)$$

$$MESV = (\sum_{n=1}^6 VC_n \cdot A_n) / A \quad (2)$$

Here, TESV is the total ecosystem service value of Zhujiajian Island for a year (RMBYuan/yr); n represents the ecosystem type; VC is the service value coefficient of ecosystem n (RMBYuan/ha.yr);  $A_n$  is the area of ecosystem n (ha); MESV is the mean ecosystem service value of Zhujiajian Island for a year (RMBYuan/ha.yr); A is the total area of Zhujiajian Island (ha).

The ESV of individual pixels for each landscape type was obtained by multiplying the actual pixel area of landscape pattern by the ESV parameters of Chinese terrestrial ecosystem types was substituted for each landscape type, and the ESV map of Zhujiajian Island was produced.

IV. RESULTS

A. Landscape Pattern Changes in Zhujiajian Island

Fig. 2 mapped the landscape patterns of Zhujiajian Island from 1986 to 2014. From the landscape patterns of the past seven periods, there are three landscape types, namely construction, agricultural, and bare land, that changed drastically. Construction land expanded extensively from 1990 to 1995, and 2000 to 2006. The initial expansion mainly appeared in the northern and central plain area of Zhujiajian Island. The latter substantial expansion resulted from the growth of the initial expansion, and the new emergence of construction land in the seaward plain in the southeastern area. In contrast, agricultural land decreased with the increases in construction land, from 1990 to 1995, and 2000 to 2006. Two new blocks of bare land emerged at the northern and western coast of Zhujiajian Island from 2006 to 2009. Woodland underwent a “decrease-increase-decrease” process, and in contrast, shrubs and grassland underwent an “increase-decrease-increase” process. The total area of

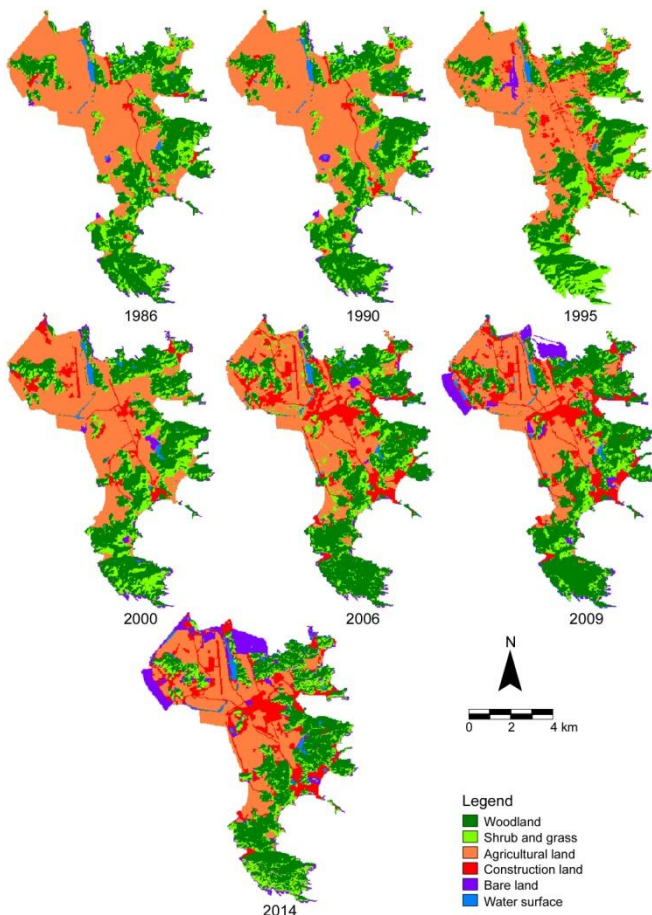


Fig. 2. Landscape patterns of Zhujiajian Island from 1986 to 2014.

These spatial changes of the landscape patterns of Zhujiajian Island have been quantitatively illustrated in Fig. 3. The area of construction land suddenly increased from 146.35 ha in 1990 to 323.91 ha in 1995 and from 348.42 ha in 2000 to 966.18 ha in 2006. Contrary to construction land, agricultural land decreased slightly from 2693.02 ha in 1990 to 2511.52 ha in 1995, and drastically from 2495.34 ha to 1839.89 ha in 2006. There was an obvious increase of bare land from 152.13 ha in 2006 to 429.45 ha in 2009. Woodland underwent a “decrease-increase-decrease” process, and in contrast, shrubs and grassland underwent an “increase-decrease-increase” process. The total area of

woodland, and shrub and grass gradually declined from 2006 after recurrent fluctuations from 1986 to 2006. Generally, the water surface area increased from 1986 to 2014.

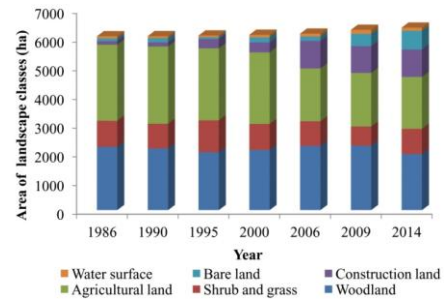


Fig. 3. Landscape classes and area of Zhujiajian Island from 1986 to 2014.

Parallel with internal landscape changes, the whole area of Zhujiajian Island expanded by 5% from 6063.92 ha to 6365.05 ha during the past 30 years (Fig. 4); 69% of this increase occurred from 2009 to 2014.

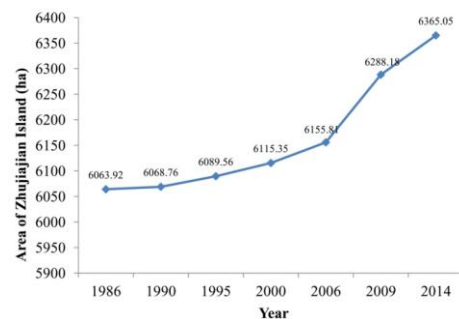


Fig. 4. Area changes of Zhujiajian Island from 1986 to 2014.

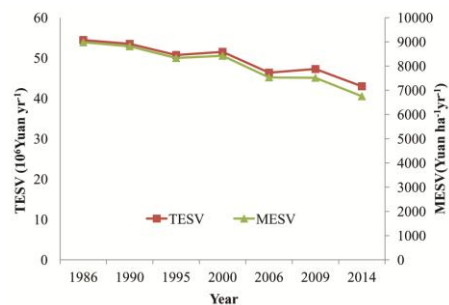


Fig. 5. TESV and MESV variation of Zhujiajian Island from 1986 to 2014.

B. Variation in TESV and MESV of Zhujiajian Island from 1986 to 2014

In 1986, Zhujiajian Island had a TESV of  $54.46 \times 10^6$  Yuan  $\text{yr}^{-1}$ . TESV declined during the following 28 years (Fig. 5) by 21% to 2014. Two marked reductions happened between 2000 and 2006, and 2009 and 2014, respectively.

Generally, variation in MESV of Zhujiajian Island showed a similar trend to TESV (Fig. 5). MESV declined by 25% from 1986 to 2014, with a reduction of 2226.50 Yuan  $\text{yr}^{-1}\text{ha}^{-1}$ . However, MESV declined more rapidly from 1995 than TESV.

Landscape patterns were transformed into ESV maps by corresponding landscape type to its ESV. Fig. 6 illustrates the spatial distribution of ESV of the study site. Variation in the ESV primarily occurred in the agricultural land and the bays embodying sand beaches.



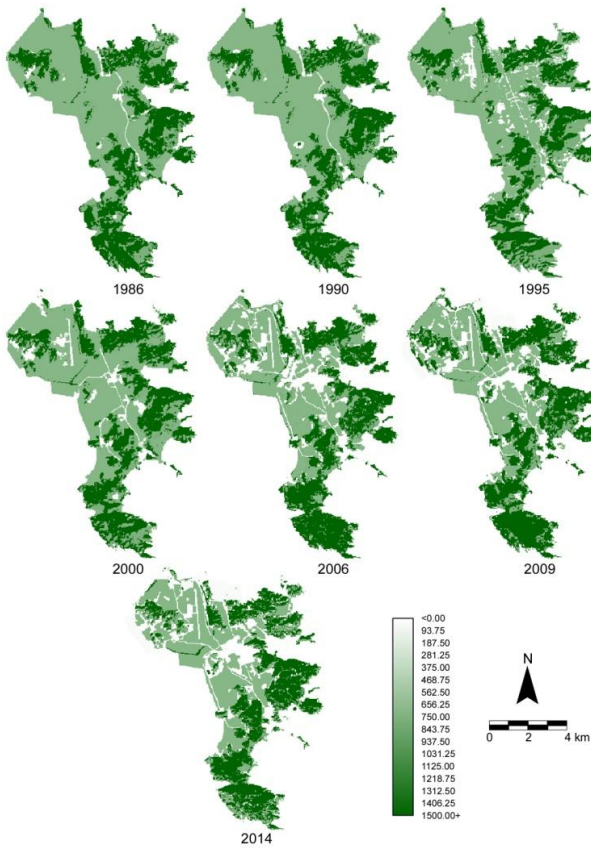


Fig. 6. ESV map of Zhujiajian Island from 1986 to 2014.

## V. DISCUSSION

### A. Drivers of Landscape Pattern Changes in Zhujiajian Island

Local social and economic policies and large engineering projects have resulted in the landscape pattern changes of Zhujiajian Island. Many residents immigrated to Zhujiajian Island from the small islands around it under the guidance of the Oshima Ken migration strategy conducted since 1993. Construction of a large number of residential houses led to the substantial increase of construction land from 1990 to 1995. Simultaneously, the Putuoshan airport project also contributed to increased construction land. Partial urban functions of Zhoushan City were transferred to Zhujiajian Island, especially leisure and travel, due to the construction of the Zhujiajian Bridge that was opened to traffic in 1999. This caused further growth of construction land from 2000 to 2006. Construction land generally occupied agricultural land, which accounted for two obvious decreases corresponding to two increases of construction land. Northern bare land was caused by sea reclamation to satisfy the increasing parking demand of the Putuo Mountain tourist attraction. Regarded as a natural refuge harbor, western bare land was also reclaimed land to be used as an international cruise ship terminal and its supporting facilities.

Physical geographic factors affected the spatial position of landscape changes in Zhujiajian Island. The majority of mountainous and coastal areas are formed by rock, and agricultural land is being utilized for construction purposes. Consequently, the most intense area of landscape changes

was located at the central region comprising agricultural land. Non-rocky coast and sandy beach resources, southeast Zhujiajian Island, were transformed to various tourism and resort facilities from previously agricultural land. The northern area is used for ferry terminals, and undertakes the tourism traffic transfer in and out of Putuoshan Island. Since the Zhoushan cross-sea bridge was open to traffic in 2009, parking demand increased from self-driven tourism resulting in reclamation for bare land in the north.

### B. Variations in ESV and the Implications of Sea-island Management

Landscape ecosystems of sea islands are dynamic systems due to anthropogenic impacts and natural successions. Monitoring and assessment of dynamic systems is challenging considering poor accessibility and difficult data acquisition. Landscape changes resulting from various ecological processes indicate the changes of sea-island ecosystems. Driving forces and some ecological processes could be deduced on the basis of past landscape change traces, and general trends of some indexes of the sea-island ecosystem could be estimated by the quantitative relationship between the whole landscape pattern and corresponding ecosystem indexes.

In this paper, the corresponding TESV of Zhujiajian Island for each period was calculated by an ESV sum of individual landscape. TESV of a sea island can be compared to the asset of a company; sea islands with higher TESV values are more valuable. Therefore, TESV could be used as a pricing basis of sea-island lease, sales, and damage compensation. More importantly, TESV could be regarded as a quantitative indicator of sea-island protection and management. TESV of Zhujiajian Island continuously declined from 1986 to 2014, although the island area increased by 5%. The variation in TESV suggested ineffective conservation and management paralleling the social and economic development of Zhujiajian Island.

To evaluate the status of sea-island ecosystems more scientifically, the paper introduced the MESV index. MESV expresses the ESV of unit area, independent of the whole area of the sea island, and can be used to determine the quality of sea-island ecosystems. In general, MESV declined dramatically by 25% over the past 28 years, with an average reduction of  $2226.50 \text{ Yuan yr}^{-1} \text{ ha}^{-1}$ . This result indicated a marked decline of the ecosystem quality of Zhujiajian Island in the past three decades. In addition, MESV was used to compare the ecosystem quality of different islands.

Water surface and woodland have the greatest ESV unit areas (Table II), and TESV and MESV depend on the area ratio of these landscape types. ESV of water surfaces (fresh water systems) reveals its significance in sea-island ecosystems. The most fundamental task of sea-island conservation is to conserve fresh water systems on what sea-island ecosystems depend for survival, followed by an enhancement of the woodland area ratio where possible. For bedrock islands like Zhujiajian Island, field road networks and greening of construction land is the priority for woodland, as the mountain is covered by thin and barren soil more suitable for shrubs and grass. Sea-island management should focus on the control of human activities based on the ecosystem capacity.

### C. ESV Mapping

Landscape pattern maps show landscape types of specific spatial locations, with little ecological significance. ESV maps converted from landscape pattern maps could directly reflect the ESV of specific locations, and convert data from qualitative to quantitative values. This conversion would make it possible to fuse the spatial information of landscape patterns into other quantitative data sets, and provide more information for the integrated assessment of sea-island ecosystems, such as suitability and priority analyses.

## VI. CONCLUSION

Landscape pattern at a certain time is the integrated outcome of instantaneous or long-term ecological processes. Landscape pattern changes only show the landscape changes of specific spatial locations; therefore it is important to determine the ecological processes and corresponding quantitative transformation behind the landscape pattern changes. Two new indexes, TESV and MESV, were developed to further interpret the ecological significance of landscape pattern changes in Zhujiajian Island. These indexes enhanced the understanding of sea islands and their economic and ecological value; allowing for the integrated assessment and management of resources through quantitative landscape mapping.

## ACKNOWLEDGMENT

We would like to thank the senior research fellow Jianyu Chen and Huaguo Zhang of Second Institute of Oceanography, State Oceanic Administration, P. R. C. for his helpful comments and constructive suggestions.

## REFERENCES

- [1] Millennium Ecosystem Assessment (MEA), *Ecosystems and Human Well-Being, Synthesis*, Washington D.C., U.S.A.: Island press, 2005.
- [2] G. Shen, and X. Xia, "Sea-landscape ecology: An integrated perspective for the conservation and management of sea islands," *Journal of coastal zone management*, vol. 19, pp. 420, March 2016.
- [3] P. Taylor, L. Fahrig, K. Henein, and G. Merriam, "Connectivity is a vital element of landscape structure," *Oikos*, vol. 68, pp. 571–573, December 1993.
- [4] B. Brosi, P. Armsworth, and G. Daily, "Optimal design of agricultural landscapes for pollination services," *Conservation letters*, vol. 1, pp. 27–36, February 2008.
- [5] F. Bianchi, N. Schellhorn, Y. Buckley, and H. Possingham, "Spatial variability in ecosystem services: simple rules for predator-mediated pest suppression," *Ecological applications*, vol. 20, pp. 2322–2333, October 2010.
- [6] K. Kozak, C. Lant, S. Shaikh, and G. Wang, "The geography of ecosystem service value: The case of the Des Plaines and Cache River wetlands, Illinois," *Applied Geography*, vol. 31, pp. 303–311, January 2011.
- [7] R. Syrbe and U. Walz, "Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics," *Ecological Indicators*, vol. 21, pp. 80–88, October 2012.
- [8] I. Palomo, B. Martin-Lopez, P. Alcorlo, and C. Montes, "Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach," *Ecosystems*, vol. 17, pp. 1202–1215, September 2014.
- [9] G. Shen, X. Xia, J. Jia, and C. Jiang, "Identifying drivers of landscape changes for ecological management of Tantoushan Island, China," *Journal of coastal conservation*, vol. 19, pp. 621–630, August 2015.
- [10] T. Tschamtko, A. Klein, A. Kruess, I. Steffan-Dewenter, and C. Thies, "Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management," *Ecology letters*, vol. 8, pp. 857–874, January 2005.

- [11] D. Le Maitre, S. Milton, C. Jarman, C. Colvin, I. Saayman, and J. Vlok, "Linking ecosystem services and water resources: landscape-scale hydrology of the Little Karoo," *Frontiers in Ecology and the Environment*, vol. 5, pp. 261–270, June 2007.
- [12] M. Mitchell, E. Bennett, and A. Gonzalez, "Agricultural landscape structure affects arthropod diversity and arthropod-derived ecosystem services," *Agriculture ecosystems & environment*, vol. 192, pp. 144–151, July 2014.
- [13] S. Carpenter, R. DeFries, T. Dietz, H. Mooney, S. Polasky, and W. Reid, "Millennium ecosystem assessment: research needs," *Science*, vol. 314, pp. 257–258, October 2006.
- [14] R. Lopes and N. Videira, "Valuing marine and coastal ecosystem services: an integrated participatory framework", *Ocean & coastal management*, vol. 84, pp. 153–162, November 2013.
- [15] J. Zhao, and K. Yang, "Valuation of ecosystem services: Characteristics, issues and prospects," *ACTA ECOLOGICA SINICA*, vol. 27, pp. 346–356, January 2007.
- [16] Y. Shi, R. Wang, J. Huang, and W. Yang, "An analysis of the spatial and temporal changes in Chinese terrestrial ecosystem services functions," *Chinese science bulletin*, vol. 57, pp. 2120–2131, June 2012.
- [17] R. C. Costanza, R. d'Arge, R. G. Groot, S. F. Farber, M. Grasso, B. Hannon *et al.*, "The value of the world's ecosystem services and natural capital," *Nature*, vol. 387, pp. 253–260, May 1997.



**Gang Shen** was born in Hubei province, China, in 1978. He received the Ph.D. degree in agricultural environment engineering from Tokyo University of Agriculture and Technology, Japan, in 2011. His major field of study is landscape ecology and sea-island conservation and management.

In 2013, he joined Second Institute of Oceanography, State Oceanic Administration, China. His current research interests include landscape changes and ecological processes of islands and coastal zones, ecosystem health and integrity of islands and coastal zones, environmental monitoring and dynamic modeling of islands and coastal zones.



**Xinkai Wang** was born in Hubei province, China, in 1986. He is a Ph.D. Candidates in structural geology from Zhejiang University, China, now. His major field of study is spatial carrying capacity of coastal zones. In 2008, he studied in Second Institute of Oceanography, State Oceanic Administration, China. His current research interests include dynamic geomorphology of coastal zones, environmental monitoring and dynamic modeling of islands and coastal zones.



**Degang Wang** was born in Shandong province, China. He received a M.S. degree in Marine Geology from Second Institute of Oceanography, State Oceanic Administration, China, in 2008. His major field of study is the development and management of sea island.

Now, he is an associate professor of State Research Centre for Island Exploitation and Management, Second Institute of Oceanography, State Oceanic Administration, China. He has been active in the area of Island development, protection and management for nearly 10 years and has been a frequent contributor to Zhejiang Ocean and Fishery Bureau. His current research involves study of ecosystem services and of land use change influence mechanism on ecosystem service values, support for the scientific development of the island in China.



**Xiaoming Xia** was born in Jiangsu province, China, in 1965. He received the Ph.D. degree in Marine Geology from Second Institute of Oceanography, State Oceanic Administration, China, in 2009. His major field of study is marine geology, and, survey and study of island & coastal zone.

He is the associate director and senior research fellow of Second Institute of Oceanography, State Oceanic Administration, China. His interests are estuary and coastal processes and effects of resource and environment, processes of island and coast and their monitoring and management.