Changes in Ecosystem Service Values and Their Driving Forces in the Guangxi Beibu Gulf Coastal Region (Postprint)

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Abstract

Mastering the spatiotemporal variation patterns of ecosystem structure and function is an important prerequisite for scientific ecosystem management, and how to measure the degree of human alteration of natural resources and ecosystems while meeting human needs is a noteworthy issue in current research. With the rise of the Beibu Gulf Economic Zone, the contradiction between regional economic development and ecological protection has become increasingly prominent, with phenomena such as seawater intrusion, vegetation degradation, and land desertification intensifying, posing a serious threat to the sustainable supply of ecosystem services. Based on time-series remote sensing data, this study analyzes the spatiotemporal evolution of ecosystems in the coastal areas of the Beibu Gulf, evaluates the spatiotemporal variation patterns of ecosystem service values and their driving factors, providing a scientific basis for regional ecosystem management. The study reveals: From 1999 to 2014, the punctate and discrete expansion of urban areas led to a significant increase in urban ecosystem area and intensified fragmentation; environmental deterioration caused devastating damage to wetland ecosystems, with mangroves continuously disappearing and fragmentation increasing; the area of forest ecosystems composed of woodlands and orchards increased, while cultivated land area sharply decreased. In terms of ecosystem composition, forest ecosystem services had the highest value, accounting for approximately 50% of the total value in the study area, and showed an increasing trend; in terms of ecosystem service composition, except for the values of food production, gas regulation, and nutrient cycling maintenance, which decreased, the values of other types of ecosystem services all showed an increasing trend. Driving force analysis indicates that the comprehensive urbanization rate is an important driving factor affecting the changes in ecosystem service values in the coastal areas of the Beibu Gulf, demonstrating that regional ecosystem services are closely related to socio-economic development,

and that reasonable regulation of economic structure can effectively enhance regional ecosystem service values.

Full Text

Preamble

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Evolution and Driving Force Analysis of Ecosystem Service Values in Guangxi Beibu Gulf Coastal Areas, China

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Abstract

Understanding the spatiotemporal variation patterns of ecosystem structure and function is a critical prerequisite for scientific ecosystem management. How to measure the degree of human alteration of natural resources and ecosystems while meeting human needs represents a noteworthy research question. With the rise of the Beibu Gulf Economic Zone, conflicts between regional economic development and ecological protection have become increasingly prominent, exacerbating vegetation degradation and land desertification and posing a serious threat to the sustainable supply of ecosystem services.

This study analyzed the spatiotemporal evolution of ecosystems in the Beibu Gulf coastal region and evaluated the patterns and driving factors of ecosystem service value changes from 1999 to 2014. Discrete urban expansion significantly increased urban ecosystem area and intensified fragmentation. Environmental deterioration caused devastating damage to wetland ecosystems, with continuous mangrove loss and increased fragmentation. The forest ecosystem composed of woodland and orchard increased in area, while cropland area decreased sharply. Based on time-series remote sensing data, we provide a scientific foundation for regional ecosystem management.

Among ecosystem components, forest ecosystem service value was highest, accounting for approximately 50% of the total study area value and showing an increasing trend. Within ecosystem service categories, all service values increased except for food production, gas regulation, and nutrient cycling values, which decreased. Driving force analysis indicated that the comprehensive urbanization rate is a key factor affecting ecosystem service value changes in the

Beibu Gulf coastal region, demonstrating that regional ecosystem services are closely related to socioeconomic development. Rational regulation of economic structure can effectively enhance regional ecosystem service values.

Keywords: ecosystem service value (ESV); value equivalent factor; landscape spatial pattern; driving mechanism; Guangxi Beibu Gulf

Introduction

Under the influence of intense human activities, significant changes have occurred in global climate, regional environments, and ecosystem patterns, with the importance of ecosystem service functions becoming increasingly prominent. Regional structural characteristics are key indicators reflecting ecosystem status, and the quantitative assessment and comparison of different ecosystem functions to determine benefits for humanity represent current research hotspots.

Common assessment methods include the contingent valuation method, shadow project method, market opportunity method, and asset value method. The ecosystem service value assessment method based on expert knowledge, proposed by Xie Gaodi et al., offers advantages of simplicity, minimal data requirements, high comparability, and comprehensive evaluation, making it widely used by researchers for regional ecosystem service value assessment.

In 2008, China designated the Guangxi Beibu Gulf Economic Zone as an important international regional economic cooperation zone, greatly promoting western China development, ASEAN-oriented opening and cooperation, and Guangxi' s socioeconomic development. The coastal zone, as a land-sea interaction area with frequent human activity, represents an environmentally sensitive and ecologically vulnerable region. Rapid economic growth and urbanization, coupled with rapid population growth and excessive resource consumption, have intensified environmental pollution, vegetation degradation, and land desertification, posing serious threats to ecosystem management in the Beibu Gulf Economic Zone. However, research on ecosystem structure and function evolution in the Beibu Gulf coastal region remains limited, and the relationship between rapid economic development and dramatic regional ecosystem structural changes remains unclear.

Assessing ecosystem service functions and analyzing their evolution characteristics and driving forces in the Beibu Gulf Economic Zone' s coastal areas is crucial for regional ecological construction and sustainable development. To understand ecosystem structure and function changes in the Guangxi Beibu Gulf coastal region, this study used Landsat remote sensing data to obtain land use/cover distribution maps for 1999, 2006, and 2014. We employed an improved per-unit-area value equivalent method to estimate ecosystem service values across different periods, analyzed spatiotemporal evolution characteristics of ecosystem service values, and revealed the main driving forces behind these changes. The findings provide a scientific basis for rational land resource

allocation, ecological environmental protection, and ecotourism development in the Beibu Gulf coastal region.

1. Study Area Overview

The Guangxi Beibu Gulf coastal region borders the South China Sea, extending from the Ximi River estuary in the east (adjacent to Guangdong Province) to the Beilun River in the west (bordering Vietnam). Located south of the Tropic of Cancer in a low-latitude tropical monsoon climate zone, the region is influenced by maritime monsoons with abundant rainfall throughout the year. The terrain slopes from high in the west to low in the east, tilting from land toward the ocean, with fragmented coastal topography.

The region currently features industry and tertiary sector dominance, transitioning from traditional industries to new manufacturing and modern services, particularly rapid growth in tourism services. From 1999 to 2014, tourist numbers grew from 7.5024 million to 29.819 million, while tourism revenue increased from 4.301 billion to 105.878 billion yuan.

This study selected five coastal districts and counties with strategic economic positions and coastal location advantages: Hepu County (Beihai City), Qinnan District (Qinzhou City), Port District, Fangcheng District, and Dongxing City (Fangchenggang City), covering a total area of 8,840 km².

[Figure 1: see original paper] Study area location map

2. Data Sources and Processing

Landsat satellite imagery from 1999, 2006, and 2014 served as primary data sources, supplemented by land use status maps, forest inventory data, transportation network maps, and DEM (Digital Elevation Model). High-quality images from non-growing seasons were selected.

Based on study area characteristics and the "Land Use Status Classification Standard" (GB/T 21010-2007), we classified land use into six ecosystem types: cropland, forestland, orchard, aquaculture & mangrove, water bodies, bare land, and built-up land. Supervised classification combined with manual visual correction was performed using remote sensing software. Accuracy verification showed classification accuracies of 85.63%, 85.27%, and 89.96% for the three periods, meeting research requirements.

3. Ecosystem Service Value Assessment

Following the Millennium Ecosystem Assessment framework, which defines ecosystem services as benefits people obtain from ecosystems, we quantified ecosystem service functions by merging land use types into six ecosystem categories. Based on Xie Gaodi et al.' s latest research results, we assessed

ecosystem service values in the Beibu Gulf coastal region, dividing them into four categories: supply, regulation, support, and cultural services.

The standard equivalent factor value was set at 2,340.65 yuan/hm²/year. Table 1 shows the per-unit-area ecosystem service value equivalents for each ecosystem type.

Ecosystem service equivalent value per unit area

4. Driving Indicator System

Ecosystem service value evolution is driven by both natural environmental and human factors. Over short time periods, human factors dominate. Following relevant studies, we collected demographic, economic, and tourism indicators at the county/district level for 1999, 2006, and 2014. While some data had missing items, this did not affect subsequent analysis.

Index system of ecosystem service value change driving forces

5. Results

5.1 Total Ecosystem Area Changes

Cropland and forest were the dominant ecosystems in the study area, with cropland area decreasing sharply while woodland and orchard areas changed significantly. In 1999, cropland area reached 3,678.80 km², but by 2014 had decreased to 2,636.67 km²—a reduction of 1,042.13 km² (-28.33%). Orchard area showed the most significant increase, reaching 1,915.22 km² by 2014.

The landscape matrix changed over time: cropland served as the matrix in 1999, while orchard became the dominant landscape matrix by 2014. Built-up land showed the highest change rate, increasing by 473.33 km² (310.66%) from 1999 to 2014, indicating rapid urban expansion. Mangrove area decreased most severely, with 83.74% lost, demonstrating devastating environmental impacts on wetland ecosystems. Bare land area continuously decreased, indicating ecological restoration progress.

Area changes of different ecosystem types in the study area from 1999 to 2014

5.2 Ecosystem Spatial Distribution and Pattern Changes

Although total ecosystem amounts changed dramatically from 1999 to 2014, spatial distribution characteristics remained relatively stable. Forestland was mainly distributed in the western region, cropland in the eastern region, and water bodies in the southern region, with orchards interspersed throughout. Significant differences existed among counties: Haicheng District represented typical urban ecosystem landscapes with built-up area increasing from 58.82 km² in 1999 to 241.08 km² in 2014 (63.26% of district area). Yinhai District

and Tieshan Port District represented typical agricultural ecosystem landscapes where cropland and orchard were the main landscape bases.

Dongxing City and Fangcheng District represented typical agroforestry mosaic landscapes, with forestland area largest, followed by orchard and cropland. Ecological engineering projects converted orchards and cropland on high-altitude steep slopes to forestland.

Landscape pattern indices were used to analyze ecosystem pattern changes. Patch Density (PD) describes fragmentation degree. Built-up land PD continuously increased, indicating increasingly severe fragmentation from explosive urban expansion. Cropland and forestland PD first increased then decreased, showing cropland patches decreased sporadically while forestland patches grew sporadically. Orchard PD was highest but continuously decreased, indicating orchards changed in patches, with new patches forming larger patches and reducing fragmentation.

The Interspersion and Juxtaposition Index (IJI) reflects landscape dispersion and adjacency. Mangrove IJI showed similar trends to orchard—initially dispersed, then more concentrated as area decreased. Forestland IJI showed sustained increase, indicating increasing dispersion as forest area grew.

Changes in PD of different ecosystem types from 1999 to 2014
Changes in IJI of different ecosystem types from 1999 to 2014

At the landscape level, we selected five indices: Patch Density (PD), Contagion Index (CONTAG), Patch Cohesion Index (COHESION), Landscape Shape Index (LSI), and Shannon' s Diversity Index (SHDI). PD first increased then decreased, indicating landscape fragmentation initially increased then decreased under human influence. LSI first increased then stabilized, suggesting landscape shapes became simpler through land development and utilization. CONTAG first decreased then increased, while COHESION showed small variation, indicating human activities changed ecosystem types and patch sizes but overall landscape cohesion remained stable. SHDI first increased then remained unchanged, showing ecosystems became more evenly distributed during urban development.

Landscape index analysis of landscape level in study area

5.3 Total Ecosystem Service Value Changes

Total ecosystem service value in the Beibu Gulf coastal region increased throughout the study period, reaching 5.40×10 yuan in 2014. Forest ecosystem service value was highest, accounting for over 50% of total value and showing sustained growth. Water bodies also had relatively high total service value (4.83×10 yuan), continuously increasing despite small area. Cropland ecosystem service value continuously decreased, from 4.87×10 yuan to 3.49×10 yuan (-24.95%). Although cropland area was large, its ecosystem service value was relatively

small, while water bodies, despite minimal area, contributed substantial service value, indicating their critical importance.

Ecosystem service value changes of different ecosystems in study area from 1999 to 2014

5.4 Inter-category Service Value Changes

From 1999 to 2014, all service types increased except food production, gas regulation, and nutrient cycling values. From the supply service perspective, food production value decreased while raw material production and water supply values increased as cropland ecosystems transitioned to forest ecosystems. Hydrological regulation value was highest among regulation services, while environmental purification was lowest.

From the support service perspective, biodiversity and soil conservation values were relatively large, while nutrient cycling value was small and continuously decreasing. Cultural service consisted only of aesthetic landscape value, which first increased then decreased, with unreasonable development after 2006 reducing cultural service functions.

Ecosystem service value changes of different service types in study area from 1999 to 2014

5.5 Per-unit-area Ecosystem Service Value Analysis

Significant differences existed among counties in area and ecosystem composition. We classified counties into two categories based on average ecosystem service level: high-level counties represented by Dongxing City, and low-level counties represented by Haicheng District. Dongxing City had the highest per-unit-area ecosystem service value, which continuously increased. In low-level counties, Haicheng District had the smallest per-unit-area value, continuously decreasing. Tieshan Port District and Yinhai District, typical agricultural landscape counties, showed small fluctuations in per-unit-area service value.

[Figure 3: see original paper] Per-unit-area ecosystem service value of each county for years 1999, 2006, and 2014

5.6 Spatial Pattern of Ecosystem Service Value Changes

Analyzing total ecosystem service value changes in 1km×1km grids revealed that value-increasing areas were mainly distributed in the western study region, while decreasing areas were scattered around Haicheng District. From 1999-2006, increasing areas primarily occurred in Hepu County where cropland converted to orchard, stimulated by high-economic-value fruits. Decreasing areas concentrated in urban development zones. From 2006-2014, continuous cropland in Hepu County and Qinnan District maintained value increases, while urban expansion in Port District showed decreasing trends.

[Figure 4: see original paper] Ecosystem service value change of 1km×1km grids from 1999 to 2014

6. Driving Forces of Ecosystem Service Value Changes

Correlation analysis between ecosystem service values and driving indicators from 1999-2014, followed by stepwise regression after removing low-correlation factors, revealed that the comprehensive urbanization rate was the dominant driving factor affecting ecosystem service value changes in the Beibu Gulf coastal region. As a population structure indicator equal to the proportion of urban population to total population, the comprehensive urbanization rate reflects regional economic structure through regression models, demonstrating that ecosystem services are closely related to socioeconomic development.

Supply service value had only one regression equation with population density as the independent variable. Other ecosystem service values each had two regression equations, with comprehensive urbanization rate as the final independent variable. Population structure changes lead to regional economic and ecological structure changes, ultimately affecting ecosystem service functions. Population density reflects population distribution patterns that may influence ecosystem quantity, aggregation, fragmentation, and spatial distribution characteristics, thereby altering regional ecosystem supply functions.

Per capita net income of farmers was the second most important driving factor for total ecosystem service value and cultural service value, describing living standards. Higher incomes increase cultural service demands, thereby enhancing cultural service value and total ecosystem service value. GDP was the second most important driver for regulation service value, while forestry output value was second for support service value, highlighting the importance of forest ecosystems in providing support services.

Ecosystem service value regression models of each service in the study area

7. Discussion

The improved equivalent factor method, though static, requires minimal data and is particularly suitable for regional-scale ecosystem service value assessment. It effectively reflects regional spatiotemporal dynamics and meets research needs for analyzing ecosystem service value changes in the Beibu Gulf coastal region. Although water bodies cover a small area in the study region, their total ecosystem service value ranks second only to forest ecosystems. This reflects the significantly enhanced water ecosystem service value equivalents in Xie Gaodi et al.' s latest research, particularly for water supply and hydrological regulation.

However, whether water ecosystem service values are overestimated requires further investigation. While paddy fields consume substantial water during grain production, water allocation mechanisms and consumption processes at regional

scales remain unclear, potentially leading to underestimation of cropland ecosystem water supply values.

Ecosystem service function spatial distribution shows significant variation. Haicheng District, a typical urban ecosystem, had the smallest per-unit-area service value, yet this differed little from typical agricultural landscapes like Tieshan Port District and Yinhai District. These agricultural counties primarily use paddy fields, whose water consumption makes water supply values negative, reducing average ecosystem service levels.

Urban expansion continuously increased built-up land area and total ecosystem service value. However, among various ecosystem service values, only forest and water body service values increased, while others decreased. Cropland ecosystem service value decreased most significantly. The overall increase in total ecosystem service value likely benefited from cropland conversion to orchard and forestland through ecological engineering projects such as returning cropland to forest, effectively transforming the region' s ecosystem from cropland-dominated to forest-dominated.

Ecosystem service value directly reflects ecosystem service functions. This study used the improved equivalent factor method to assess service values, with value changes effectively reflecting functional evolution in the Beibu Gulf coastal region. While qualitative studies typically describe trends through simple analysis, quantitative studies use mathematical methods to identify causes and relationships. Our data came from government departments, and we used correlation and principal component analysis to remove collinear and unrelated indicators before conducting stepwise regression on key indicators. All models and parameters reached significant levels.

Although model accuracy was high, regional condition limitations restrict statistical model applicability. Policies related to environmental protection and ecological restoration are difficult to quantify but undoubtedly key factors driving regional economic development. Scientific quantification of ecosystem service values and trade-off analysis of ecosystem service demands will provide bases for landscape regulation scheme development, promote ecotourism, and achieve coordinated ecological-economic development—representing future research priorities for the Beibu Gulf coastal region.

8. Conclusion

Understanding spatiotemporal variation patterns of ecosystem structure and function is essential for scientific ecosystem management. This study analyzed ecosystem pattern dynamics from 1999-2014 in the Beibu Gulf coastal region and examined spatiotemporal evolution characteristics and driving mechanisms of ecosystem service values.

(1) From 1999-2014, discrete urban expansion increased urban ecosystem area by 473.33 km² with intensified fragmentation. Environmental destruc-

tion caused devastating damage to wetland ecosystems, with continuous mangrove loss (decreasing by 83.74%) and increased fragmentation. Orchard area first increased then decreased, while woodland grew sporadically. Cropland area decreased sharply by 1,042.13 km² (-28.33%), with fragmentation first increasing then decreasing, indicating sporadic patch reduction.

(2) Total ecosystem service value continuously increased, reaching 5.40×10 yuan in 2014. Forest ecosystem service value was highest, accounting for approximately 50% of total value and showing an increasing trend. Among ecosystem service categories, all values increased except food production, gas regulation, and nutrient cycling values, which decreased.

(3) Although ecosystem types showed significant spatial distribution differences, average ecosystem service levels differed little between Haicheng District (urban ecosystem-dominated) and Tieshan Port District/Yinhai District (cropland ecosystem-dominated). However, counties dominated by forest ecosystems showed significantly different average service levels compared with agroforestry ecosystem-dominated counties.

(4) Driving force analysis indicated that the comprehensive urbanization rate is a crucial factor influencing ecosystem service value changes in the Beibu Gulf coastal region, demonstrating coupled ecosystem service value and socioeconomic development. Scientific quantification of regional ecosystem service value evolution driving mechanisms remains a future research priority.

References

[1] China major terrestrial ecosystem service functions and ecological security. Earth Science Progress, 2009, 24(6): 571-576.
[2] Wong C P, Jiang B, Kinzig A P, Lee K N, Ouyang Z Y. Linking ecosystem characteristics to final ecosystem services for public policy. Ecology Letters, 2015, 18(1): 108-118.
[3] Fisher B, Turner R K, Morling P. Defining and classifying ecosystem services for decision making. Ecological Economics, 2009, 68(3): 643-653.
[4] Hou Y, Li B, Müller F, Chen W P. Ecosystem services of human-dominated watersheds and land use influences: a case study from the Dianchi Lake watershed in China. Environmental Monitoring and Assessment, 2016, 188(11): 652.
[5] Kunyu Mountain Nature Reserve ecosystem service function value assessment. Acta Ecologica Sinica, 2009, 29(1): 523-531.
[6] Conditional value assessment of ecosystem maintenance in Changdao Nature Reserve. Acta Ecologica Sinica, 2014, 34(1): 82-87.
[7] Qinghai Lake wetland ecosystem service value assessment. Chinese Journal of Applied Ecology, 2015, 26(10): 3137-3144.
[8] Egooh B, Reyers B, Rouget M, Richardson D M, Le Maitre D C, van

Jaarsveld A S. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment, 2008, 127(1/2): 135-140.
[9] Zhang J Y, Ma K M, Fu B J. Wetland loss under the impact of agricultural development in the Sanjiang Plain, NE China. Environmental Monitoring & Assessment, 2010, 166(1/4): 139-148.
[10] An expert knowledge-based ecosystem service valuation method. Journal of Natural Resources, 2008, 23(5): 911-919.
[11] Spatiotemporal variation characteristics of ecosystem service value in Wuhan Urban Agglomeration. Chinese Journal of Applied Ecology, 2014, 25(3): 883-891.
[12] Nearshore ecosystem risk assessment of Guangxi Beibu Gulf. Chinese Journal of Applied Ecology, 2011, 22(11): 2977-2986.
[13] Northern Beibu Gulf ecosystem structure and function: zooplankton spatial niche and differentiation. Acta Ecologica Sinica, 2014, 34(13): 3635-3649.
[14] WTP calculation and asymmetry in environmental value assessment: a case study of coastal ecological environmental protection in Guangxi Beibu Gulf Economic Zone. Acta Ecologica Sinica, 2015, 35(9): 2870-2879.
[15] Spatiotemporal distribution characteristics of nutrients in Guangxi Beibu Gulf waters from 1990-2011. Ecology and Environmental Sciences, 2015, 24(9): 1493-1498.
[16] Zheng Q, Zhang R J, Wang Y H, Pan X H, Tang J H, Zhang G. Occurrence and distribution of antibiotics in the Beibu Gulf, China: impacts of river discharge and aquaculture activities. Marine Environmental Research, 2012, 78: 26-33.
[17] Improved ecosystem service valuation method based on per-unit-area value equivalent factors. Journal of Natural Resources, 2015, 30(8): 1243-1254.
[18] Forest change monitoring based on time series statistical characteristics. Remote Sensing Technology and Application, 2015, 19(4): 657-668.
[19] Holzkämper A, Lausch A, Seppelt R. Optimizing landscape configuration to enhance habitat suitability for species with contrasting habitat requirements. Ecological Modelling, 2006, 198(3/4): 277-292.
[20] Villamagna A M, Angermeier P L, Bennett E M. Capacity, pressure, demand, and flow: a conceptual framework for analyzing ecosystem service provision and delivery. Ecological Complexity, 2013, 15: 114-121.
[21] Ecosystem service function value evaluation of agricultural ecosystems under specialized tea cultivation: a case study of Anxi County, Fujian Province. Acta Ecologica Sinica, 2017, 37(10): 3311-3326.
[22] Wang S X, Wu B, Yang P N. Assessing the changes in land use and ecosystem services in an oasis agricultural region of Yanqi Basin, Northwest China. Environmental Monitoring and Assessment, 2014, 186(12): 8343-8357.
[23] Li T H, Li W K, Qian Z H. Variations in ecosystem service value in response to land use changes in Shenzhen. Ecological Economics, 2010, 69(7): 1427-1435.
[24] Pattern analysis in landscape ecology: dilemmas and future. Acta Ecologica Sinica, 2008, 28(11): 5521-5531.
[25] Selection of urban forest landscape pattern indices based on simulated

landscapes. Chinese Journal of Applied Ecology, 2009, 20(5): 1125-1131.
[26] Huang C B, Zhou Z X, Wang D, Dian Y Y. Monitoring forest dynamics with multi-scale and time series imagery. Environmental Monitoring and Assessment, 2016, 188(5): 273-273.
[27] Weng B S, Yan D H, Bao S J. Relationship between landscape spatial gradient patterns and environmental factors in Haihe River Basin. Acta Ecologica Sinica, 2011, 31(7): 1925-1935.
[28] Assessment of Taihu ecosystem service function value changes in recent ten years. Acta Ecologica Sinica, 2015, 35(7): 2255-2264.
[29] Ecosystem service value evolution and driving forces in the Three Gorges Reservoir Area from 1990-2011. Acta Ecologica Sinica, 2014, 34(20): 5962-5973.
[30] Impact of climate change on rice irrigation water requirements in Songnen Plain. Chinese Journal of Applied Ecology, 2015, 26(1): 260-268.
[31] Carpenter S R, Mooney H A, Agard J, Capistrano D, DeFries R S, Díaz S, Dietz T, Duraiappah A K, Oten-Yeboah A, Pereira H M, Perrings C, Reid W V, Sarukhan J, Scholes R J, Whyte A. Science for managing ecosystem services: beyond the millennium ecosystem assessment. Proceedings of the National Academy of Sciences of the United States of America, 2009, 106(5): 1305-1312.
[32] White C, Halpern B S, Kappel C V. Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. Proceedings of the National Academy of Sciences of the United States of America, 2012, 109(12): 4696-4701.

Note: Figure translations are in progress. See original paper for figures.