Science of the Total Environment 615 (2018) 572–580

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A methodological framework for coastal development assessment: A case study of Fujian Province, China

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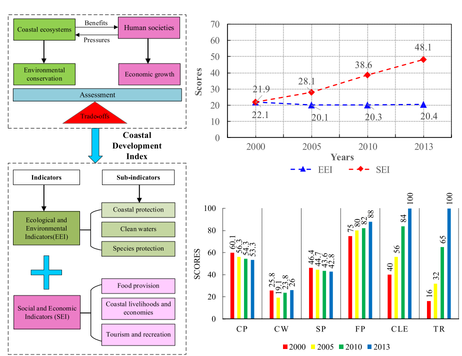
HIGHLIGHTS

- We develop an index to assess the sustainability of coastal development.
- Formulas directly calculate indicators without a normalizing procedure.
- The approach helps identify strategies to limit unsustainable coastal development.
- The approach helps integrate coastal development and conservation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 April 2017
Received in revised form 28 September 2017
Accepted 28 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Coastal development index (CDI)
Ocean health index (OHI)
Environmental conservation
Economic growth
Ecologically sustainable development

ABSTRACT

Decision-makers often have to make trade-offs between economic growth and environmental conservation when developing and managing coastal environments. Coastal development and management need to be subject to rigorous assessments to determine if they are sustainable over time. We propose a methodological framework — the Coastal Development Index (CDI) for the assessment of the changes in sustainability of coastal development over time. CDI is a modified version of the Ocean Health Index (OHI) but with two new indicators — ecological and environmental indicators (EEI), and social and economic indicators (SEI), both of which comprise three sub-indicators (coastal protection, clean waters and species protection for EEI, and food provision, coastal livelihoods and economies and tourism and recreation for SEI). The six sub-indicators represent key aspects of coastal development and the level of exploitation of natural resources that have previously been missing in other conceptual frameworks. We demonstrate the value of CDI with a detailed case study of Fujian Province in China, 2000–2013. The scores of CDI decreased from 1.01 in 2000 to 0.42 in 2013 suggesting that the Fujian coastal zone has experienced unsustainable development in that time. Meanwhile, the scores of EEI decreased from 22.1 to 20.4 while the scores of SEI increased from 21.9 to 48.1 suggesting that environmental values have been eroded by economic growth. Analysis of the scores of sub-indicators reveals a need to integrate economic growth and social development with environmental conservation on Fujian coastal management. Our case study highlights the potential value of the CDI for improving the ecological sustainability of coastal zone management and development practices.

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https://doi.org/10.1016/j.scitotenv.2017.09.309
0048-9697/

1. Introduction

Over 2 billion people worldwide live near coasts. Coastal environments benefit humans by providing access to seafood, facilitating trade, and providing employment (Halpern et al., 2008; He et al., 2014). Numerous human activities (e.g., fishing, coastal reclamation, port transportation, and tourism) place heavy pressure on coastal ecosystems (Lotze et al., 2006; Mora et al., 2011; Perry et al., 2011), making coastal environments vulnerable to threats such as habitat loss, pollution, eutrophication, and loss of species (Bellwood et al., 2011; Crain et al., 2009; Dolan and Walker, 2006). Managing these threats is a substantial challenge for decision-makers who have to take into account the trade-offs between environmental conservation and economic growth. To meet this challenge, targeted scientifically-based strategies and planning is required to manage coastal environments in an ecologically sustainable manner (Celliers et al., 2013; Wigand et al., 2015; Wongthong and Harvey, 2014). In this context, ecologically sustainable coastal development entails generating economic benefits while improving, or at least maintaining, the health of coastal ecosystems including preventing erosion, habitat degradation, and species loss (Bartelmus, 2002; Basiago, 1998; Harding, 2005).

Rigorous assessment of the changes in coastal development over time is a key step for judging whether coastal management strategies and policies are sustainable or whether they need to be modified and improved. Various conceptual frameworks have been developed to assess the sustainability of coastal developments at multiple temporal and spatial scales. An important original framework is the Pressure–State–Response (PSR) framework, which was conceived to assess the cause–effect relationships between human activities and environmental responses through multiple indicators (Bowen and Riley, 2003; Carr et al., 2007; OECD, 1993). Users of PSR aim to identify the underlying reasons for the anthropogenic pressure on natural environments. They also want to quantify the influence on human well-being resulting from the changes in the condition of the environment. The Drivers — Pressures — State — Impacts — Responses (DPSIR) framework was amended to better address these issues (EEA, 1999). Other indicator frameworks were then developed as updated versions of DPSIR to assess various aspects of sustainable development in coastal zones around the world (Chowdhury et al., 2015; Cui et al., 2015; Vethaak et al., 2017). Despite a number of case studies confirming the usefulness of PSR, DPSIR, as well as other indicator frameworks for assessing the sustainable development of coastal zone (Bidone and Lacerda, 2004; Palmer et al., 2011; Yu et al., 2010), some key knowledge gaps remain. First, these frameworks (PSR, DPSIR, and other indicator frameworks) are not able to analyze the specific problems of coastal development. This is because the indicators in these frameworks have limitations such as those associated with the integration of multiple sub-indicators in a single composite category, such as the pressures of human activities on the environment, the state of the environment and natural resources (Huang et al., 2011; Yuan et al., 2014). Second, distinguishing cause–effect relationships between indicators and appropriately categorizing them within these frameworks is difficult; they can even be marked discrepancies in indicator classification between experts (e.g., the EEA, 1999) (Bell, 2012; Gari et al., 2015). As an example, urbanization was identified as a driver in the framework used by Zaldívar et al. (2008), but Lin et al. (2007) classified it as pressure variable in their work. Third, the results of these frameworks are not sufficiently accurate to provide a rigorous assessment of the development of coastal zones. As these frameworks contain multiple indicators with various units, normalizing the raw data on indicators to create dimensionless values within given bounds (such as [0–1]) is an essential step to facilitate reasonable assessment. However, this is challenging because the units for, and orders of magnitude of, indicators differ greatly within one category. For instance, the unit of fishery production is a "tonne" while the unit of reclamation area is "ha" (Lin et al., 2007). In this way, converting the raw data via normalization methods would produce inaccurate results. To tackle the problems outlined above, a new set of tools and indicators is required to facilitate better assessment of the sustainability of coastal development.

In this paper, we propose a new methodological framework— the Coastal Development Index (CDI) to directly assess how the sustainability of coastal developments is changing over time. Using a detailed case study of Fujian Province, China, we demonstrate that the CDI can not only help assess the changes in the sustainability of coastal development but also help identify strategies and policies to limit unsustainable development. The CDI builds on the Ocean Health Index (OHI) (Halpern et al., 2012) but adds two new indicators of critical importance in the context of assessing coastal development (see Table 1). One addition is ecological and environmental indicators (EEI) that encompass three sub-indicators that focus on pressures in terms of habitat degradation, coastal pollution and species diversity loss caused by human activities on coastal ecosystem. A further addition to the CDI is social and economic indicators (SEI) that consist of three sub-indicators, which concentrate on benefits in terms of food provision, employment and economy from marine industries, and recreation that humans derive from coastal ecosystems. The six sub-indicators—coastal protection (CP), clean waters (CW), and species protection (SP) in the EEI and food provision (FP), coastal livelihoods and economies (CLE), and tourism and recreation (TR) in the SEI represent key aspects of coastal development and levels of exploitation of natural resources. With this new framework, the CDI offers a powerful tool for assessing the changes in the sustainability of coastal development.

2. Materials and methods

2.1. Study area

Fujian Province is located in the southeast of China and is adjacent to the South China Sea, facing Taiwan across the Taiwan Strait. It is an economic hub of "China's 21st Century Maritime Silk Road" (Lo, 2015). In this case study, we focus on the coastal area of Fujian Province: from north to south, Ningde, Fuzhou, Putian, Quanzhou, Xiamen, Zhangzhou, and the offshore sea (Fig. 1). The size of the study area is 7.8×10^4 km^2, including a terrestrial area of 5.6×10^4 km^2 (the entire area of the coastal cities in Fujian Province) and an offshore ocean area of 2.2×10^4 km^2 (in accordance with the *Marine Functional Zoning in Fujian Province* (2011 − 2020)).

Fujian Province has experienced rapid economic growth, especially in marine industries since economic reforms in China were initiated in 1978. According to the *China Marine Statistical Yearbook* (2014), the gross value of marine industrial output of Fujian Province reached 502.8 billion yuan (80 billion US dollars) in 2013, which is nearly five times the value in 2000. The Fujian coast is an important natural habitat for wetland species. As a fast-developing marine province in China, large-scale coastal reclamation has occurred in many coastal habitats (e.g., mangrove forest, mudflat), resulting in the reduction in waterbird

Table 1
Coastal Development Index (CDI) framework.

	Indicators	Sub-indicators	Components
Coastal Development Index (CDI)	Ecological and Environmental Indicators (EEI)	Coastal Protection (CP)	
		Clean Waters (CW)	
		Species Protection (SP)	Nature reserves Species diversity
	Social and Economic Indicators (SEI)	Food Provision (FP)	Fisheries Mariculture
		Coastal Livelihoods and Economies (CLE)	Coastal livelihoods Coastal economies
		Tourism and Recreation (TR)	