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A global ocean observing system framework for sustainable development

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ABSTRACT

Sustainable development depends on maintaining ecosystem services which are concentrated in coastal marine and estuarine ecosystems. Analyses of the science needed to manage human uses of ecosystem services have concentrated on terrestrial ecosystems. Our focus is on the provision of multidisciplinary data needed to inform adaptive, ecosystem-based approaches (EBAs) for maintaining coastal ecosystem services based on comparative ecosystem analyses. Key indicators of pressures on coastal ecosystems, ecosystem states and the impacts of changes in states on services are identified for monitoring and analysis at a global coastal network of sentinel sites nested in the ocean-climate observing system. Biodiversity is targeted as the "master" indicator because of its importance to a broad spectrum of services. Ultimately, successful implementation of EBAs will depend on establishing integrated, holistic approaches to ocean governance that oversee the development of integrated, operational ocean observing systems based on the data and information requirements specified by a broad spectrum of stakeholders for sustainable development. Sustained engagement of such a spectrum of stakeholders on a global scale is not feasible. The global coastal network will need to be customized locally and regionally based on priorities established by stakeholders in their respective regions. The E.U. Marine Strategy Framework Directive and the U.S. Recommendations of the Interagency Ocean Policy Task Force are important examples of emerging regional scale approaches. The effectiveness of these policies will depend on the co-evolution of ocean policy and the observing system under the auspices of integrated ocean governance.

1. Introduction

With its emphasis on ecosystem services valued by society and the recognition that they are the foundation of sustainable development and human wellbeing [1,2], the Millennium Ecosystem Assessment [3] has played an important role in helping to guide the formulation and implementation of environmental policies nationally and internationally. The MA, and subsequent analyses of the science needed to manage human uses of ecosystem services for sustainability [4], have focused for the most part on terrestrial ecosystems largely because people live on land and more data are available for these ecosystems than those of the coastal and global oceans [5,6]. Our focus is on coastal marine and estuarine ecosystems (hereafter referred to as "coastal ecosystems") and the development of an operational global ocean observing system that provides data on coastal ecosystems needed to sustain ecosystem services in the face of human expansion and global climate change. As used here, an "operational" observing system serves quality controlled data and data-products in forms and at rates needed by policy makers and those engaged in the conservation of ecosystem services and the management or regulation of human uses of these services (henceforth referred to as the "practitioners").

Maintaining healthy coastal ecosystems (from coastal watersheds to the coastal ocean) is critical to sustainable development. Over 40% of the world's human population lives within 100 km of the coastline; eleven of the world's fifteen largest cities are located here; and the number of people living in the coastal zone is

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expected to double by 2050 [7,8]. To a great extent, these demographics reflect the exceptionally high concentration of services provided by coastal ecosystems [9–14]. Over the last 150 years, coastal ecosystems worldwide have experienced rapid changes driven by human expansion and global climate change [15–23]. These drivers of change converge on coastal ecosystems, exacerbate the impacts of natural hazards on human wellbeing [24], and jeopardize the provision of coastal ecosystem services globally [1,9,10,25–27].

Since the 1960s, concerns over the impacts of these drivers of change have led to a large and growing body of ocean policies, laws and international agreements [28] aimed at enabling sustainable development. A common theme of these agreements is the importance of ecosystem-based approaches (EBAs) to managing human uses of ecosystem services and adapting to the impacts of climate change, i.e., sustaining and restoring ecosystem services while enabling socio-economic development and addressing the tradeoffs among sustaining services and managing uses [27,29–34].

Successful implementation of EBAs remains an elusive goal for two main reasons [1,28,29,35]: (1) the scarcity of sustained observations of ecosystem dynamics across the land–sea interface (landscape to seascape) that enable rapid detection and timely anticipation of changes in coastal ecosystem dynamics and the provision of ecosystem services and (2) the lack of adequate systems of governance. Both challenges are addressed here by identifying a provisional set of core chemical and biological indicators that should be used to guide the establishment of a global network of regional ocean observing systems for coastal ecosystems and by highlighting the need for new holistic and integrated approaches to ocean governance that oversee and facilitate sustained feedbacks between the formulation and implementation of ocean policies and the establishment of coastal and ocean observing systems.

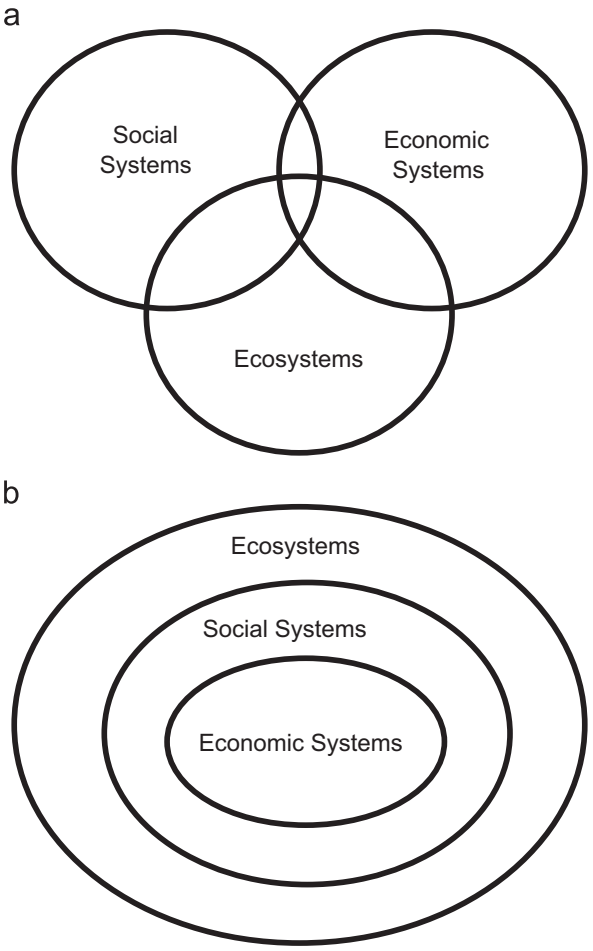

Fig. 1. Relationships among social systems, economic systems and ecosystems: (a) The conventional approach and (b) the ecosystem-based approach.

2. Informing ecosystem-based approaches for sustainable development

2.1. Sustainable development and ecosystem services

Sustainable development has been defined in many different ways [35], the most widely used being "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [36]. This broad concept of sustainable development has been broken down into three dimensions: economic development, social development and environmental sustainability [37]. For the most part, existing national strategies for sustainable development treat these as interactive but not necessarily interdependent objectives (Fig. 1a). However, as discussed above, sustainable development requires EBAs that consider socio-economic development (e.g., human uses of ecosystem services) in the context of ecosystem dynamics [38,39]. In this construct, economic activity occurs within a network of social relationships, both of which are constrained by ecological parameters (Fig. 1b). Thus, effective EBAs for managing human uses of ecosystem services have the potential to provide cost-effective opportunities for addressing the multiple (often conflicting) goals of socio-economic development and environmental sustainability in a synergistic manner [40].

Although ecosystem services are the foundation of sustainable socio-economic development, the marine ecosystem services that are systematically monitored for adaptive EBAs are very limited [27]. For the most part, services and the ecosystems states upon which they depend (Table 1), are not monitored, reported or analyzed on time and space scales required for proactive EBAs to manage human uses of services for sustainability [3,4,16]. The few that are monitored routinely are useful for retrospective analyses of trends and causal relationships (e.g., water quality parameters and fish landings), but not for timely, proactive decision-making.

2.2. Integrated ecosystem assessments

Effective EBAs depend on the routine and frequent provision of reliable integrated ecosystem assessments (IEAs). An IEA is a formal synthesis and quantitative analysis of multidisciplinary data on changes in ecosystem dynamics and the impacts of these changes on ecosystem services [41–44]. They are (1) stakeholder-driven, science-based, multidisciplinary, data-driven processes that target geographically defined ecosystems with the goal of sustaining services by maintaining the structure and function of ecosystems upon which services depend; (2) decision-support tools that use data and models to document current ecosystem states and changes in states on ecosystem services, anticipate future states, and assess ecological and socio-economic tradeoffs between sustaining and using ecosystem services; and (3) *learning by doing* processes that rely on frequent evaluations of performance against objectives as well as advances in science and technology [45].

The parties to the 2002 World Summit on Sustainable Development recognized the importance of repeated IEAs and called for a regular process under the United Nations for global reporting and assessment of the state of the marine environment (current and foreseeable). In 2005, the UN General Assembly endorsed this recommendation and called for global reporting and assessments