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The mechanics of blue growth: Management of oceanic natural resource use with multiple, interacting sectors

Dane H. Klinger[a,1,*], Anne Maria Eikeset[b], Brynhildur Davíðsdóttir[c], Anna-Marie Winter[b], James R. Watson[d,e]

[a] Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544, USA
[b] Centre for Ecological and Evolutionary Synthesis, University of Oslo, N-0316 Oslo, Norway
[c] Environment and Natural Resources, Department of Economics, University of Iceland, Reykjavik, Iceland
[d] The Royal Swedish Academy of Sciences, Global Economic Dynamics and the Biosphere Program, 10405 Stockholm, Sweden
[e] Oregon State University, College of Earth, Ocean and Atmospheric Sciences, OR 97331, USA

ABSTRACT

Integrated management of multiple economic sectors is a central tenet of blue growth and socially optimal use of ocean-based natural resources, but the mechanisms of implementation remain poorly understood. In this review, we explore the challenges and opportunities of multi-sector management. We describe the roles of key existing sectors (fisheries, transportation, and offshore hydrocarbon) and emerging sectors (aquaculture, tourism, and seabed mining) and the likely synergistic and antagonistic inter-sector interactions. We then review methods to help characterize and quantify interactions and decision-support tools to help managers balance and optimize around interactions.

1. Introduction

The ocean is a rich source of both renewable and nonrenewable natural resources, which have provided numerous economic, social, and cultural benefits throughout history and afford great opportunities for future provision of benefits [1,2]. These benefits are often realized through economic sectors, of which the overall number and total activity has increased over the last 50 years [3]. Growth in ocean-based economic sectors has come from improved access to, utilization of, and production efficiency from oceanic natural resources [4,5]. At the same time, use of oceanic resources has led to conflicts between sectors (e.g. tourism vs. offshore hydrocarbon extraction), at different levels of organization (e.g. between individuals, groups, and nations), at multiple spatial scales (e.g. in local waterways, regional seas, or global oceans), and across time (e.g. between current and future uses). Continued economic growth from the oceans is likely to lead to more cross-sector conflicts and the potential for environmental destruction, sub-optimal natural resource use, and other socially undesirable outcomes [6].

The history of modern ocean governance and management has been one of increasing complexity, with managers traditionally focusing on individual economic sectors and moving towards integrated systems with multi-sector coordination [7]. Recently, there has been a push for ecosystem-based management (EBM) of coasts and oceans [8]. EBM is a framework through which management efforts are structured around a single place or ecosystem, with the health and productivity of that ecosystem or group of ecosystems as the nucleus of management. The activity of economic sectors and other human uses are regulated to balance their impacts on the health of ecosystems [9–11]. While current management is largely fragmented, with most sectors managed by individual laws, agencies, or regulatory regimes [12,13], there are calls for integrated, cross-sectoral management approaches to achieve EBM [e.g. 14,15].

Cross-sector management is complicated by the dynamic nature of the ocean, which is constantly changing over a range of spatial and temporal scales [e.g. 16]. Climate change and natural variability are directly modifying the ocean through increased sea surface temperatures, higher acidity, and changes to other attributes of physical and chemical oceanography. These changes can lead to melting sea ice, sea level rise, and altered ecosystems (e.g. changes in species abundance and biodiversity) that ultimately affect the ability of humans to derive benefits from the ocean, with both positive and negative impacts on human access to resources and benefits [17]. In addition to acknowledging linkages between sectors, management must be dynamic and adaptive, allowing single sector and multi-sector management

* Corresponding author.
E-mail address: dhklinger@stanford.edu (D.H. Klinger).
1 Current Address: Center on Food Security and the Environment, Stanford University, Stanford, CA 94305, USA.

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frameworks to respond in near real time to changing environmental, economic, and social conditions [18].

Reflecting these challenges, the concept of blue growth as a "long term strategy to support sustainable growth in the marine and maritime sectors as a whole" was recently adopted by the European Commission [19]. The concept has been increasingly used as a strategy for achieving both sustainable marine resource use and economic expansion around the globe [20]. But the initial visioning reports addressing the concept do not detail how to operationalize blue growth [21,22]. A critical, but little studied, component of attaining the goals of blue growth is a multi-sector approach to management, including identifying and optimizing cross-sector interactions [21]. A key obstacle to multi-sector management is a lack of information on how sectors interact with each other and how changes in one sector affect the incentives and actions of others. Here, we review cross-sector interactions within the ocean economy and the decision support tools that are available to help manage these interactions.

2. Economic sectors

There is a diversity of economic sectors involved in the ocean economy, and classification of sectors varies by country and region [23–25]. An economic enterprise is considered to be an ocean-based economic sector if it exhibits one or more of three characteristics–being physically located in the ocean, using ocean resources as an input to production, or directly outputting goods or services to the ocean [23]. This review does not include the multitude of possible sectors and subsectors due to space limitations. Instead, to highlight the challenges and opportunities presented by inter-sector interactions, we review several key sectors that are recognized as focal areas for blue growth: aquaculture, wind and wave power, seabed mining, and tourism, as well as several traditional ocean sectors: fisheries, transport, and offshore hydrocarbons (Table 1). The inputs to each sector, including the required ocean resources, are compared (Table 2), as these are often sources of interactions between sectors. Costs that are frequently external to the market price of the sector's products (i.e. not reflected in the market price) are also listed, as these can often be used to determine the nature of non-neutral interactions between sectors.

2.1. Blue growth sectors

Aquaculture, wind and wave power, seabed mining, and tourism are recognized as emerging economic sectors and blue growth focal areas by the European Union [22]. Coastal and offshore aquaculture involves the farming of aquatic organisms (including plants, shellfish, and finfish) in coastal waters and the open ocean. The majority of farmed seafood is currently produced on land [26], but coastal and offshore aquaculture production are likely to increase as technology improves and the cost of farming on land increases [27]. Costs that are often external to aquaculture include: pollution of water by feces, uneaten feed, and chemicals; destruction of local habitats to build aquaculture infrastructure or by pollution; transmission of diseases and parasites to wild flora and fauna; and escaped farmed organisms that can compete or interbreed with wild organisms [27,28].

Wind and wave power are ocean-based renewable energy production sectors. Offshore wind farms use turbines to generate electricity from wind [29] and wave energy operations use a range of techniques to convert wave energy into electricity [30]. Offshore wind accounted for a quarter of the EU's wind power in 2015, and the sector is expected to expand rapidly, especially in Chinese waters [31], as technology improves to move wind farms farther offshore [32]. Wave energy converters can be located at the surface, in the water column, or on the seafloor and can surge, heave, pitch, or oscillate to convert wave energy [30,33]. Wave energy production is expected to increase dramatically by 2050, but it will likely remain a smaller player relative to offshore wind [34].

The environmental impacts of offshore wind and wave power are often external to the market price of energy. The environmental impacts of offshore windfarms occur mostly during construction of the platform and at highly local scales thereafter. Further, platforms can act as a fish aggregating device, while noise and electromagnetic fields can deter marine mammals [35]. Turbines can cause disturbances for or mortality to local and migratory birds [35]. The negative environmental impacts of wave energy that are often not included in the price include disturbance or harm to nearby ecosystems through noise, vibrations, electromagnetism, biofouling, sedimentation, disruption of animal migrations, and functioning as an artificial habitat or fish aggregating device [36].

Seabed mining involves extraction of minerals from the ocean floor [37]. Increased demand for metals and rare-earth elements and technological developments have improved the economic viability of mining the deep seabed [38]. Mining has been proposed on abyssal plains, on seamounts, and near hydrothermal vents [39]. Most seabed mining is currently focused on near-shore, shallow water areas, but technology is improving to allow experimental deep seabed mining operations in the near future [38]. The environmental costs that are

Table 1
Classification of primary ocean economic sectors as either extractive or non-extractive and reliant on living or non-living resources [based on 23,24]. Shaded sectors are included in this review and sectors recognized as blue growth focal areas by the European Union are starred (*).

Extractive	Living marine resources	Fisheries
		Aquaculture*
	Non-living marine resources	Offshore hydrocarbons
		Wind and wave power*
		Seabed mining*
		Salt
		Water
Non-extractive	Living marine resources	Tourism and recreation*
	Non-living marine resources	Transportation
		Construction
		Ship and boat building
	Both	Public administration
		Education and R&D*
		Others