Marine Policy 38 (2013) 80–89

Contents lists available at SciVerse ScienceDirect

Marine Policy

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

Evaluating tradeoffs among ecosystem services to inform marine spatial planning

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ARTICLE INFO

Article history:
Received 25 July 2011
Received in revised form
13 February 2012
Accepted 17 May 2012
Available online 22 June 2012

Keywords:
Economics
Ecosystem-based management
Ecosystem services
Efficiency frontier
Marine spatial planning
Tradeoff analysis

ABSTRACT

A central challenge for natural resource management is developing rigorous yet practical approaches for balancing the costs and benefits of diverse human uses of ecosystems. Economic theory has a long history of evaluating tradeoffs in returns from different assets to identify optimal investment strategies. There has been recent progress applying this framework to the delivery of ecosystem services in land use planning. However, despite growing national and international interest in marine spatial planning, there is a lack of parallel frameworks in the marine realm. This paper reviews an ecosystem service tradeoff analysis framework and provides a more comprehensive synthesis for how it can be applied to marine spatial planning and marine ecosystem-based management. A tradeoff analysis approach can reveal inferior management options, demonstrate the benefits of comprehensive planning for multiple, interacting services over managing single services, and identify 'compatible' services that provide win–win management options.

1. Introduction

Given the scope and magnitude of the environmental challenges facing natural resource management, there is an increasing demand for more holistic, ecosystem-based approaches to management [1–4]. Ecosystem-based management (EBM) is a place-based approach that aims to achieve the long-term ecosystem health and functioning that in turn provide the ecosystem services on which people rely [4–8]. Marine spatial planning (MSP) is one type of planning process that offers a promising opportunity for more integrated management and has been gaining political momentum throughout the world [9,10]. MSP identifies which areas of the ocean are appropriate for different uses or activities in order to reduce conflicts and achieve ecological, economic and social objectives [11]. One central challenge for translating EBM and MSP tenets from concept to practice is developing rigorous and straightforward approaches for balancing diverse human uses of ecosystems [12]. This paper highlights tools from economic theory and multi-objective decision making for evaluating tradeoffs in the delivery of ecosystem services, with particular emphasis on how such an approach could transform ocean management.

Ecosystem services range from tangible to intangible (e.g., food production versus aesthetic value) and provide natural capital that is essential to human welfare [13]. The Millennium Ecosystem Assessment [1] brought ecosystem service concepts to the forefront, developing four widely used service categories: provisioning (e.g., of seafood, timber), regulating (e.g., of climate, floods, water quality), supporting (of other services, e.g., pollination for food production, nutrient cycling), and cultural (e.g., recreation, spiritual value). MSP attempts to allocate space to the full range of services provided by the oceans, presenting a significant challenge to natural resource managers. Services frequently are not independent of one another, but instead exhibit complex interactions that generate tradeoffs in the delivery of one service relative to the delivery of others [14–17]. In some cases, two services may be mutually exclusive in space (e.g., wave energy buoys may preclude commercial fishing and vice versa), while in other cases the tradeoff is less severe (e.g., fishing and recreational activities can often occur in the same locations, but

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0308-597X/$ - see front matter
http://dx.doi.org/10.1016/j.marpol.2012.05.022

fishing impacts might have a negative effect on some types of recreation). Because not all interacting services can be maximized simultaneously, society must make decisions about their relative preferences for different services, and, consequently, how this affects management decisions [15,18–20]. Managers make these types of decisions on a regular basis, but often do so without the explicit consideration of these tradeoffs [21].

Balancing the delivery of a range of services is particularly critical for coastal and ocean ecosystems, which face growing human populations, increasing associated impacts, and declining ecosystem services [22–24]. Marine systems offer a challenging and interesting opportunity for implementing MSP and specifically for examining tradeoffs among services. For one, service valuation in marine settings is complicated given the general absence of property rights and the related fact that many key services are not traded in markets (e.g., recreation, wildlife viewing, protection from shoreline erosion). Furthermore, the primary market service from the oceans – fisheries – often lacks property rights, has inappropriate incentives and frequently ineffective governance, and is managed using limited-quality stock assessments, which together promote unsustainable fishing [25,26]. Management in the oceans also tends to be fragmented, with limited governance or institutional frameworks for spatial management and coordinated management across sectors [27,28]. Lastly, marine systems host numerous emerging uses, such as wave energy and offshore aquaculture. These emerging uses will contribute to crowding among efforts to maximize the delivery of particular services, posing an ideal prospect for more integrated planning prior to their development. Such planning demands an explicit analysis of tradeoffs among services under different management scenarios.

The economics discipline has developed a rich “production theory” which concerns how firms optimally trade-off between different inputs to production [29]. This is similar to portfolio theory, which analyzes the tradeoff between variance (i.e., risk) and return of a collection of assets, whether financial stocks or fish stocks, so as to maximize return for a given level of risk [30–32]. In parallel, there is a long history within decision theory, including multi-criteria and multi-objective analyses, of developing tools for decision-making where there are numerous and often competing objectives [33]. Multi-criteria analysis has been applied to numerous marine applications [34–37] and there has been recent progress applying these ideas to managing ecosystem services [20,38–41]. However, there is not a synthesis of how tradeoff analysis can used in an EBM or MSP approach. This paper (1) highlights one framework for analyzing tradeoffs, including reviewing the types of tradeoffs possible in an ecosystem services context and examining how this framework can guide EBM and (2) provides demonstrations of how ecosystem service tradeoff analysis can be applied to MSP using two stylized examples based on data.

2. Conceptual framework for ecosystem service tradeoff analysis

Production theory, a branch of microeconomics that deals with the production (as opposed to the consumption) side of the economy, was developed to examine marketed commodities [42]. While not a perfect parallel, this approach can also be applied to the production of ecosystem services, marketed or otherwise [43]. The guiding principle when applied to EBM is to ensure the sustainable and efficient delivery of multiple interacting services. The challenge in meeting this goal is that providing ecosystem services is “costly” in the sense that actions taken to deliver one service may inhibit or divert scarce resources away from actions that could have been taken to deliver other services. For example, if one is using marine reserves to provide the ecosystem service of biodiversity preservation, the possible provision of fishery yield is reduced as a second service. The cost of lost provisions from one service due to the use of another service depends on the strength and nature of their interaction. Not all services produce ‘costs’ to other services and this framework allows one to identify ‘compatible’ services as well. In short, the following analytical approach supports more informed management decisions about real and perceived tradeoffs among ecosystem services.

Production theory considers how different inputs produce different levels of outputs, typically expressed as production functions. When applied to ecosystem services, production functions are models that translate the structure and functioning of ecosystems into the provision of ecosystem services [40,44,45]. A production function approach has been used to value non-market ecosystem services that can be considered as inputs into the production of goods or services with market value (e.g., seagrass habitat as nursery grounds is an input into fisheries) [43,46], but also applies to ecosystem services that are not readily connected to a marketed output. Importantly, there may be many potential ecosystem service outcomes that can arise from a given set of inputs. This provides a basis for examining which outcomes are optimal in terms of providing the combination of services that are important to society.

In cases with a small number of services or objectives, ecosystem service outcomes can be analyzed graphically to evaluate tradeoffs. In an EBM context, this involves some quantification of the ecosystem services produced across a broad range of potential management actions or spatial plans (e.g., all possible MPA siting options, all possible harvest regulations, etc.). This can be conducted using empirical data, quantitative models or conceptual models, depending on data and model availability, and ideally considers as many sets of management actions as possible. In such an analysis, the axes of the graph correspond with levels of ecosystem services and each point corresponds with the outcomes from a given set of management actions that are known or estimated to produce amounts of each service. After plotting all (or a large subset of) possible management options, the constraint envelope, or outer bound of all the points, is the “efficiency frontier” comprised of Pareto-efficient options, whereby one service cannot be further increased without a cost in terms of the other service (Box 1). This “ecosystem services” frontier depicts management options that provide for the optimal delivery of the two or more services [37,47,48]. Points interior to the frontier are suboptimal—at least one service could be increased, at no cost to other services.

Although this approach may seem simplistic, it provides two critical insights that can be used to guide EBM. First, the position of a point relative to the frontier can suggest improvements to current management practices. Regardless of the shape of the frontier or social preferences for specific services, all sets of management actions interior to the frontier represent suboptimal decisions. These are situations where an EBM approach can lead to societal benefits at no extra cost, and commonly a gain, for both services. Such knowledge therefore has the potential to eliminate some conflicts among user groups, as it allows clearly inferior management decisions to be objectively eliminated. Of particular interest are situations in which management options that are all interior to the frontier are being debated. In such cases of “false tradeoffs”, these options may be unnecessarily pitted against each other, and tradeoff analysis could illustrate that additional management options exist that simultaneously remove the perceived tradeoff and produce a win–win outcome.

Second, the relationship between or among services also indicates whether coordinated management across services is necessary. In other words, the shape of the frontier can inform what the optimal management solution(s) is likely to be, narrowing the scope of potential policy options. Examining pairwise