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Overcoming the challenges of data scarcity in mapping marine ecosystem service potential

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ABSTRACT

Ecosystem services (ES) are a valuable way of defining the benefits derived from natural resources and are essential for balancing human exploitive uses with the preservation of natural capital. In marine ecosystems real world application of ES theory is hindered by inadequate knowledge of the distribution of communities and habitats and the ecosystem functions that they provide. Here, we present a new approach for mapping ecosystem service potential for multiple services when the details necessary for full quantification are unobtainable. By defining services from a series of principles based on current ecological understanding and linking these to marine biophysical parameters, we developed ecosystem service maps for the Hauraki Gulf, New Zealand. These maps were verified by statistical comparisons to available ecological information in well studied areas in the region. Such maps allow planners, managers and stakeholders to explicitly consider ES in ecosystem-based management (EBM) including marine spatial planning (MSP). Our approach provides a systems perspective, by emphasising connectivity between processes and locations and highlighting the potential range of trade-offs available for multi-objective management of marine systems.

1. Introduction

The obvious connection between human well-being and the state of the natural environment has not been sufficient to prevent damage and over-exploitation of natural resources and the loss of biodiversity (Butchart et al., 2010; Ehrlich and Daily, 1993, Rosenberg, 2003). Achieving environmental sustainability is an exercise in trade-offs, and its implementation in the 21st century is largely constrained to fit within the societal architectures of governance and commerce. In light of this, ecosystem services (ES) are an appealing way to define the full range of benefits derived from natural resources, allowing managers to balance short-term focused benefits for multiple users and the broader needs of resource stewardship (Arrow et al., 2012). The concept of ecosystem services is understood by both social and natural science practitioners and represents a 'common currency' for decision making. It facilitates increased accountability for natural resources and has resonated with politicians, resource managers and scientists alike (Müller and Burkhard, 2012; Turner and Daily, 2008). An impressive proliferation of ecosystem services research means it is now more conceptually robust. However, ten years since the start of the Millenium Ecosystem Assessment (2005) and fifteen years since Costanza et al. (1997) provided a global assessment of the economic values of natural capital, we have yet to fully operationalise the ecosystem service concept in management practice (Daily and Matson, 2008). Although it provides a compelling architecture, and extensive small-scale research on ecosystem functions is available, management application beyond a single habitat requires highly detailedand broadly scaled data on the distribution of biota, habitats and bio-physical characteristics.

To date, ecosystem service approaches have tended to focus on single or limited subsets of services. However, effective resource stewardship, such as ecosystem-based management (EBM), requires consideration of the full range of both benefits and cumulative impacts (McLeod and Leslie, 2009; Rosenberg and McLeod, 2005). Tools currently available for mapping ecosystem services tend to be computationally sophisticated and require significant levels of bio-physical data to underpin their operation

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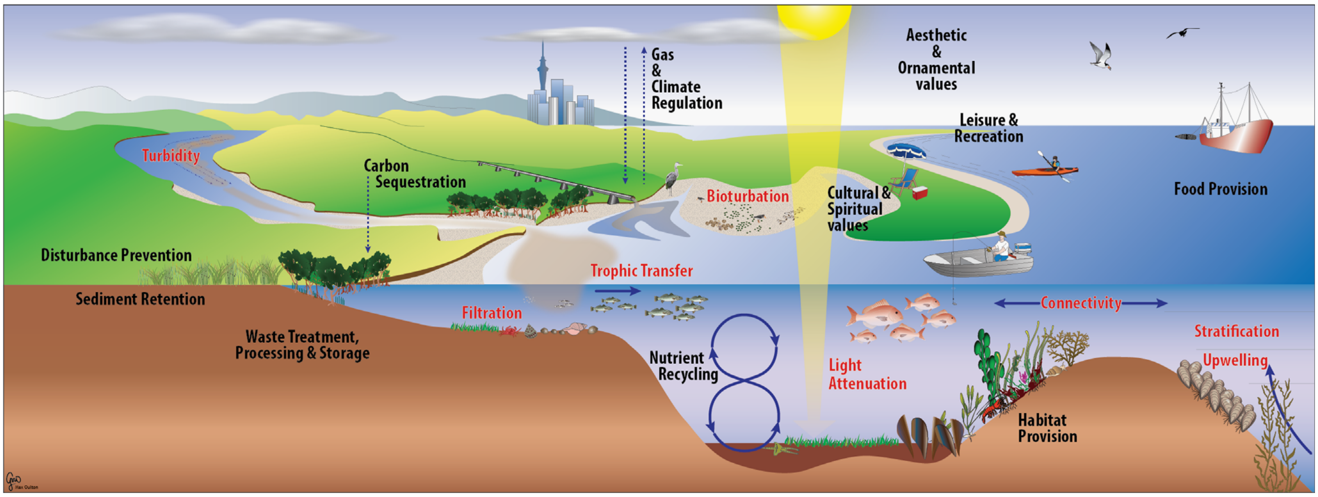

Fig. 1. A schematic, non-exhaustive illustration of ecological processes and attributes (red) and the ecosystem services (black) that can be provided by the coastal environment. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Cowling et al., 2008). These data are seldom available, especially for environments most in need of management and protection. The challenge of defining and mapping multiple ecosystem services with a scarcity of data is profound for marine ecosystems, where ecosystem boundaries are fluid, habitats are often poorly spatially defined and knowledge of ecosystem function emphasises both context dependency and complex scaling from local to global processes. While marine coastal ecosystems provide a wide range of benefits including food, renewable energy resources, waste treatment processing and opportunities for leisure and recreation (Fig. 1) (Beaumont et al., 2007, 2008; Millenium Ecosystem Assessment, 2005), there is also a growing cost of cumulative impacts of anthropogenic stressors including overfishing, urban and agricultural contaminants, habitat destruction and the effects of land-use changes (Adams, 2005; Kennish, 1997).

While effective management strategies should ideally be built around a comprehensive knowledge of environmental systems, inclusive of the distributions of species and habitats and the complexity of ecological processes, delaying management until the requisite information for complex approaches is collated is not practical. We must apply our current ecological understanding in a precautionary manner, using the best information available in conjunction with techniques that facilitate the filling of knowledge gaps. Even if we are unable to determine an exact rate of service delivery (e.g. tonnage of fish per km^2, kilograms of annual nitrogen removal for an embayment), we need techniques that can begin to indicate where ecosystem service levels will be relatively higher and lower. To fill this need, we developed a process for mapping ecosystem service potential built on a foundation of ecological principles and validated by available ecological data. We illustrate this approach for the Hauraki Gulf, New Zealand, using it to highlight the potential variation in service delivery from estuaries to the shelf-break. The Hauraki Gulf's catchment ranges from highly urbanized (Auckland City, 1.5 million residents) to intensively farmed landscapes. The Gulf covers 13,900 km^2 and supports commercial and recreational fisheries and aquaculture (Hauraki Gulf Marine Park Act, 2000). The Gulf is New Zealand's most highly valued and well-used marine area and is a hotspot for marine and natural heritage tourism (Rawlings-Way et al., 2012). We demonstrate our approach for supporting, regulating and provisioning services (see Millenium Ecosystem Assessment, 2005), specifically biogenic habitat structure, nutrient recycling and ecosystem productivity. Biogenic habitat structure is a vital supporting service, furnishing habitat and predation refugia for many species, including early juvenile stages of exploited populations. The nutrient recycling service focuses on the remineralization of organic matter and the subsequent conversion and exchange of inorganic nutrients within and between pelagic and benthic habitats. Nutrient recycling can be important for fuelling primary productivity and determining the oxidative–reductive balance and suitability of habitats for flora and biota (Sundbäck et al., 2003). Ecosystem productivity is an integrated representation of production reflecting the ability of a system to both generate and support marine flora and fauna across trophic levels; the focus is more comprehensive than simply primary production or the productivity of an exploited fish species.

2. Material and methods

The approach we present here harnesses our understanding of ecological processes, and we demonstrate how we moved from 'principles' of ecosystem functioning (biophysical and functional axioms) to creating ecosystem service maps (Fig. 2). The principles we used are based on the earlier work of Townsend et al. (2011), with our map development utilising the inherently spatial nature of the principles in combination with a scoring structure (determining how a principle affects a service) and basic, widely available data, to depict differences in service potential.

Ecological principles explicitly define a key element of how we expect an ecological system to operate (when the system is not already badly degraded) (Table 1). While there may be exceptions, the principles highlight information that is generally accepted as true. For example, regarding the production of food in the marine environment we would start with primary production (PP) and apply the following basic principles: (a) sunlight is needed to drive PP, (b) clear water supports more productivity than turbid water, (c) deeper water attenuates more light than shallow water, and (d) benthic PP is greater than water column PP in shallow systems. Using the principles, we start to gain a better understanding of conditions that lead to increases or decreases in service potential generation. Principles cover a broad and comprehensive range of ecological processes and, in identifying principles, we recommend an open and inclusive process involving a wide range of expertise.[1]

[1] Principles reviewed at expert workshop held on May 23rd 2012, Auckland, NZ. Attended by 24 key scholars from a range of organisations including academia, research institutes, NGOs, and scientists from national government departments and regional government departments.