Biological Conservation 144 (2011) 1499–1507

Contents lists available at ScienceDirect

Biological Conservation

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

Using portfolio theory to assess tradeoffs between return from natural capital and social equity across space

Benjamin S. Halpern [a,b,*], Crow White [b], Sarah E. Lester [b], Christopher Costello [c], Steven D. Gaines [c]

[a] National Center for Ecological Analysis and Synthesis, 735 State Street, Santa Barbara, CA 93101, USA
[b] Marine Science Institute, University of California, Santa Barbara, CA 93106, USA
[c] Bren School of the Environment, University of California, Santa Barbara, CA 93106, USA

ARTICLE INFO

Article history:
Received 4 June 2010
Received in revised form 19 January 2011
Accepted 24 January 2011
Available online 21 February 2011

Keywords:
Ecosystem services
Environmental justice
Marine reserves
Fisheries
Channel Islands
Portfolio theory

ABSTRACT

Spatial variance in returns from natural resources, driven by resource dynamics and regulations, can have strong consequences for equitable delivery of value to individuals and communities. Yet resource management models implicitly weight returns equally across space, even when space is explicitly included in model dynamics and policy. Here we translate financial portfolio theory from the temporal to spatial realm and use it to quantify the inherent tradeoff between resource returns and social equity, defined as a more uniform distribution of resource value across space. We illustrate this approach with a marine case study of the Channel Islands, California, USA. Depending on the spatial distribution of resources, increasing spatial equity requires nonlinear reductions in resource returns. Realistic management options, such as effort-based fisheries regulations or marine protected areas, increase or reduce this tradeoff, respectively. We also quantify two critical advantages of portfolio approaches to management: they improve outcomes by avoiding false expectations and increase either resource return or social equity while maintaining the other.

1. Introduction

The idea of diversifying one's assets in order to manage risk (variability) and increase returns, i.e. building a portfolio of investments, has become widely understood and practiced. Yet it was not until the pioneering work of Markowitz that portfolio theory was developed and mathematically derived (Markowitz, 1952) and a decade or two later before portfolio approaches to asset management became commonplace. Portfolio theory has since revolutionized financial, insurance, and capital markets and has more recently been applied to diverse fields such as biodiversity conservation (e.g. Figge, 2004; Koellner and Schmitz, 2006; Tilman et al., 2006), psychology (Chandra and Shadel, 2006), computer science (Huberman et al., 1997), fisheries management (Baldursson and Magnusson, 1997; Edwards et al., 2004; Sanchirico et al., 2008; Schindler et al., 2010), and forestry (Crowe and Parker, 2008; Knoke, 2008), among others. The ecological examples demonstrate how portfolio theory can be applied to the management of natural capital, i.e. the goods and services provided by natural ecosystems. In all of these examples the fundamental guiding principle is that individual assets (investment stocks, insurance policies, fish stocks, species, ecosystem services, etc.) respond uniquely over time to changes in the system, and therefore one can minimize temporal variance (i.e. risk) for a given aggregate level of return by building a portfolio of assets that respond differently (i.e. have negative covariance) to these changes.

Analogous to financial capital management, resource management generally tries to maximize the sustainable delivery of goods and services derived from natural capital (i.e. assets = ecosystem services) while ensuring consistent supply of these natural resources. What is fundamentally different about resource management is that natural resources also have a spatial component of variance and covariance in their abundance and value, with resources unevenly distributed across land- or seascapes. Many resource management problems involve management measures which are spatially explicit or allocate access to resources across space, with implications for users also distributed across space. For example, spatial closures are often used to reduce fishing mortality and rebuild stocks, with the location of those closures disproportionately affecting fishermen who fished those grounds relative to fishermen who fished grounds that remain open. Although non-spatial forms of management such as uniform fisheries regulations remain common, the trend in marine resource management is towards spatially-explicit methods such as marine spatial planning.

For a large set of these management problems, there are dual objectives of (a) maximizing the total sustainable benefit to

* Corresponding author at: National Center for Ecological Analysis and Synthesis, 735 State Street, Santa Barbara, CA 93101, USA. Tel.: +1 805 892 2531; fax: +1 805 892 2510.
E-mail address: halpern@nceas.ucsb.edu (B.S. Halpern).

0006-3207/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2011.01.019

stakeholders of a given policy and (b) ensuring the equitable distribution of benefits to different stakeholder communities within the planning region. Often these goals are mandated by law. Even when they are not mandated, there are practical reasons for seeking both objectives – maximizing sustainable economic benefit and providing benefit to the greatest number of people has social value. In many cases efforts to maximize the overall value of natural resources favors locations with the highest value, yet if resources are patchy in space then resource users with the best access to high-value patches will benefit disproportionately from such a management approach (Blaustein, 2007; Jones, 2009). Spatial variance and covariance in resources consequently creates an important tradeoff for spatial management decisions (e.g. fishing regulations, use permits, etc.); one must balance the desire to achieve optimal overall value derived from natural resources with the need for spatial equity wherever governments and resource agencies have a moral or practical need to make access to and delivery of services more equitable among people and communities (Mutz et al., 2002).

Social inequity can lead to conflicts among individuals or stakeholder groups and stall or doom efforts to implement management reform. The need to address social equity in management decisions is widely recognized. The clearest examples occur when sets of people are differentially restricted from a resource, e.g. access to nature parks, or when groups of people are disproportionately hurt by permitted uses of areas, e.g. pollution from zoned industrial uses (Blaustein, 2007; Evans and Kantrowitz, 2002; Mascia and Claus, 2009). Indeed, compliance with management policies is often dependent on equitable access to resources, real or perceived (Sutinen and Kuperan, 1999). Here we demonstrate a novel approach to incorporating spatial evenness of ecosystem services into resource management decision-making; this approach explicitly accounts for social equity in cases where resource users are seeking an even distribution of resource returns across space. We focus on equity issues in which patchwork regulations modify access to resources within and among user groups in a spatially-explicit manner and offer quantitative analytical tools to assess these inequities. In particular, portfolio theory offers an efficient tool for proactively evaluating the tradeoffs between maximizing return from natural resources and maximizing equitability in access to those natural resources, providing critical guidance for management decisions.

The underlying premise of portfolio theory is that covariance among assets influences the variance of a collection of assets at any given level of return. This will be true when covariances are sufficiently large (relative to asset variances and returns) that they influence portfolio variance given a desired level of return. Here we focus on questions of resource management where human activities that derive value from the ocean (ecosystem services) are the 'assets', the value derived is the 'return', and where variance and covariance are measured spatially. Spatial covariance measures spatial access to assets by different users and is therefore important when management decisions affect multiple resources. As governments and agencies move towards ecosystem-based management and comprehensive spatial planning (Halpern et al., 2008; POC, 2003; USCOP, 2004), such cross-sector management will likely become much more common, as will tools necessary for addressing inherent tradeoffs. Accounting for spatial covariance allows resource managers to address issues of equity of access by groups using different resources simultaneously and provides a means to explicitly assess tradeoffs within and among ocean use sectors. Smaller spatial variance represents more even distribution of total resource value across space, and often comes at the cost of lower portfolio returns.

To measure the value added by a portfolio approach, its performance needs to be compared with solutions that do not use, or are unaware of, covariance. That is, comparisons need to be made to traditional, or analyst, approaches where covariance among natural resources is thought to not exist ('naïve analyst') or is known but ignored ('informed analyst'). This evaluation framework leads to two types of comparisons: (1) how does the 'naïve analyst' expect to perform relative to the actual results that occur given consideration of covariances among natural resources (portfolio approach); and (2) how does the portfolio approach perform relative to the 'informed analyst' where covariances are ignored when allocating access to natural resources? The former comparison addresses false expectations that arise when real consequences of covariance are not accounted for, while the latter comparison addresses the true value added of a portfolio approach relative to the analyst approach. Theoretically, the sign and magnitude of the covariance values influence whether the naïve analyst's expectations exceed or fall short of the informed analyst result (Supplementary Fig. 1). When covariance values are relatively large (positive or negative), portfolio solutions are expected to strongly outperform the informed analyst, because the portfolio 'investor' knows to avoid assets (natural resources, or specific locations) that covary strongly and positively and to invest in assets that covary strongly and negatively (Supplementary Fig. 1). That is, consideration of covariances helps reduce portfolio variance and achieve better returns. The magnitude of returns and variances for individual natural resources, relative to the magnitude of covariance, also will affect the degree to which the portfolio solution outperforms the informed analyst (Sanchirico et al., 2008).

We make three important contributions in this paper. First, we demonstrate the application of portfolio theory to resource management questions where spatial variance in natural capital is important. Ultimately natural resource management must consider both spatial and temporal variance simultaneously, but for clarity we focus solely on spatial variance here. We illustrate the translation of portfolio theory to spatial variance using a marine case study based on valuation estimates of several marine resources around the Channel Islands, California, USA. These estimates include two sets of ecosystem services measured in very different units, which show how portfolio theory can be applied to the spatial management of a diversity of resource types. Second, we use the case study to address several questions aimed at understanding the consequences of asset covariance that are important for the application of portfolio theory within ecosystem-based management: (1) what is the nature of the tradeoff between portfolio return and social equity, when social equity is defined by the spatial evenness in access to natural resources? (2) what are the costs of failing to account for covariance on management expectations (the naïve vs. informed analyst comparison) and on actual management outcomes (informed analyst vs. portfolio investor comparison)? and (3) how does portfolio analysis change optimal asset allocation relative to a non-portfolio (analyst) approach? Our third contribution is to explore how portfolio theory can guide establishment of spatially-explicit management and zoning plans, including fishery closure zones. We demonstrate how portfolio analyses can be used to compare management options and, importantly, how the theory can generate spatially-explicit management recommendations. We also discuss where and when management would likely benefit from the application of portfolio theory and highlight key remaining research gaps that need to be filled before portfolio management could be fully operationalized.

2. Methods

Portfolio approaches to asset management assess the tradeoff between expected risk (variance) and return, where return on the portfolio (μ_P) is the sum of total available returns on each asset