Ecological Economics 100 (2014) 63–73

Contents lists available at ScienceDirect

Ecological Economics

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

Methodological and Ideological Options

Firm-level ecosystem service valuation using mechanistic biogeochemical modeling and functional substitutability

Stephen D. Comello [a,*], Gabriel Maltais-Landry [c], Benedict R. Schwegler [b], Michael D. Lepech [b]

[a] *Graduate School of Business, Stanford University, Stanford, CA 94305, USA*
[b] *Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA*
[c] *Department of Biology, Stanford University, Stanford, CA 94305, USA*

ARTICLE INFO

Article history:
Received 14 October 2012
Received in revised form 20 October 2013
Accepted 17 January 2014
Available online 18 February 2014

Keywords:
Ecosystem service valuation
Functional substitutability
Estuary
Sustainability
Biogeochemical model

ABSTRACT

Increasingly, private firms are focusing on environmental sustainability. However, such entities continue to experience difficulty in operationalizing sustainable practices in management decisions. For firms that own natural ecosystems, part of the difficulty stems from their inability to balance the environmental value of conserving these ecosystems against potential profits that could be captured through their development. To overcome this, we present a new comparative framework for natural and engineered systems, which allows for a rigorous valuation of ecosystem services based on functional equivalence with engineered systems. This framework allows for the opportunity of such value to be represented within international accounting standards, thus aligning biological ecosystem service valuation with current, rigorous, accepted accounting norms. Looking specifically at the removal of phosphorus via wetland, we characterize an ecosystem service using a mass-balance mechanistic biogeochemical model. We then simulate the ecosystem performance under various loading conditions to determine the limit state for which the wetland can perform the service of phosphorus removal in the long-term. Finally, using functional substitutability, we apply an appropriately scaled price of the engineered equivalent system to determine a market-based value of the ecosystem service. As a demonstration, we apply this methodology to an estuary located in Southern California.

1. Introduction

Increasingly, private firms are focusing on environmental sustainability. This can be explained by a number of factors including stakeholder pressure, cost of compliance, and increased competition (Ditlev-simonsen and Midttun, 2011; Lamberton, 2005; Schaltegger and Burritt, 2000). While sustainability has been at least a peripheral subject of strategic significance to corporate decision-makers for almost 20 years (Gray, 1994; Howard-grenville et al., 2008; McWilliams and Siegel, 2001), private firms continue to experience challenges with operationalizing sustainability efforts, monetizing the outcomes, and leveraging improved sustainability performance in the market (Bell and Morse, 2008; Davidson, 2010; Peloza, 2009). To be clear, a firm would ultimately achieve environmental sustainability if all its operations occurred within the ecological limit states of the relevant receiving/interacting natural environmental systems. Ecological limit states define thresholds, which if surpassed, cause a regime change altering the stocks and flows of natural resources. The quantity, quality, and accessibility of such stocks and flows are ultimately reflected in economic terms, most notably by changing cost structures of existing goods and services.

A continuing challenge is the inability of firms to comprehensively understand the connection between their actions and subsequent ecological impacts, coupled with an inability to consider firm-caused ecological impacts within existing operational decision-making (Comello et al., 2012).

Having an understanding of firm decisions that promote enhanced value derived from owned natural ecosystems and an accepted method to represent this value, firms are positioned to make decisions that implicitly consider natural ecosystem stewardship. In this light, the degree to which a firm's operations are sustainable will become more scientifically grounded and reflect a truer indication of the long-term viability of the firm and the natural ecosystems it owns.

Previously, we have proposed a framework for direct consideration of a firm's environmental impacts using ecosystem service valuation to capitalize the relationship between the firm and the natural environment. Long-term viability of a firm is defined in terms of its ability to provide value that is ultimately measured in terms of profit (or a metric of social value if concerned with non-profit firms). The profit motive still remains the primary argument for the preservation of ecosystem services. The intent of valuating ecosystem services is to provide information to meet this goal. The lack of such quantified information exposes the firms to negative risks that could impair the long-term viability of the firm,

* Corresponding author at: Stanford Graduate School of Business, Stanford University, 655 Knight Way, Stanford, CA 94305, USA.
E-mail addresses: scomello@stanford.edu (S.D. Comello), gmaltais@stanford.edu (G. Maltais-Landry), ben.schwegler@stanford.edu (B.R. Schwegler), mlepech@stanford.edu (M.D. Lepech).

0921-8009/$ – see front matter
http://dx.doi.org/10.1016/j.ecolecon.2014.01.014

since such risks were not fully considered in strategic and operational decisions.

The approach allows firms the potential to value ecosystem services performed on firm-owned lands as an asset on the balance sheet. Having this value – derived from an understanding the ecological processes (e.g. energy and material stocks and flows) necessary for the proper functioning of the ecosystem to maintain value – enables the firm to manage and inform rationally-based decisions regarding firm-owned ecosystems in similar fashion to other physical assets. It is stressed that the goal of the framework is to position firms to implicitly consider natural ecosystem stewardship, so as to align firm goals with environmental sustainability under the auspices of established business decision norms. Specific decisions better informed through the employment of the framework can include risk management strategies linked to environmental policy/liability, operations continuity/resilience strategies related to climate change and/or natural disasters, cost-benefit assessments of management practices to maintain/enhance ecosystem function in the context of firm operations and sale of benefits derived from ecosystem services (and/or knowledge of value of damages to ecosystem services due to trespass) to other private or public entities. On this last point, entities external to the firm (e.g. public, private or non-profit organizations, etc.) may find it in their best interest to pay for well-functioning ecosystem services provided by the firm. An example of this is if an external entity produces low-strength nutrient runoff upstream of the firm that owns a wetland. The external entity would be willing to pay for treatment services provided by the wetland so long as it is the least costly option available and the effluent does not permanently impair the ecosystem service. A rigorous basis for valuation and ecosystem functioning would be imperative in determining fair price and conditions of service.

The framework, described in detail by Comello et al. (2012), consists of five stages and five tools shown in Fig. 1.

The concept of "functional substitutability" is central to the operationalization of this framework. Based on general economic substitutability (Freeman, 2003), functional substitutability asserts that a minimum value can be calculated for services provided by natural ecosystems when they can be shown to be "identical" for services provided by an engineered system constructed equivalently for that service. For example, the service of phosphorus (P) removal from effluents can be accomplished by either a wetland ecosystem or a municipal wastewater treatment plant (WWTP). This perspective – in-line with neoclassical environmental economics – offers an additive approach to ecosystem services by valuing each individual functional component of an ecosystem that leads to a benefit, rather than valuing a pre-defined list of benefits assumed in a less detailed ecosystem assessment (Johnston and Russell, 2011).

The notion of "identical" provision of services is possible by strict operational definitions of the functions that provide the service (Comello et al., 2012). Such operational definitions are possible through application of rigorous ecosystem boundaries. The subsystems which drive the process – the functions – are characterized in terms of individual contributions and interactions within the greater system. In this sense, boundary definition and system description/characterization follow from a "systems thinking" approach commonly applied in systems engineering, systems ecology, exergy analysis, and industrial ecology (Bejan et al., 1996; Graedel and Allenby, 2003; Odum, 1983). This reductionist analytical approach enables ecological systems to be described using engineering tools and concepts and allows for rational comparison between the value of identical services provided by ecological and engineered systems. This enables decision-makers to weigh trade-offs in value of individual assets – either ecological, engineered or a hybrid – within their asset portfolio using a common currency metric.

A major challenge to implementation of firm-level ecosystem service valuation is a lack of models that can characterize and predict the behavior of a natural ecosystem subjected to external forcing or loading caused by a firm's activities. Further, the data required to calibrate and populate would need to be collected from field-level studies.

This paper presents a methodology to characterize and predict the behavior of an ecosystem service, and the ability to attach a market-based price to this change in service. The methodology uses the widely-accepted accounting concept of "marking-to-model", in which a combination of a descriptive model and market-based data are used to determine the economic value of an asset for which no direct market(s) exists. The proposition that such a methodology can be extended to ecosystem services is based on the premise that functional substitutability enables a direct functional comparison between engineered and natural systems based on the products created. Given this comparison, the engineered system provides a basis for market-based observables that can be translated into a valuation of the equivalent ecological system. Marking-to-model also leverages the concept of fair value assessment, one which is meant to enable investors to assess the amounts, timing, and uncertainty of future cash flows from an investment in a firm's shares or debt securities (FASB, 2008). Part of the appeal of fair market valuation is its attempt to increase the "decision usefulness" of financial information for a (limited) number of stakeholders, namely analysts, investors, and shareholders (Elad, 2007).

The goal of this work is to demonstrate the use of a comprehensive biogeochemical model – coupled with functional substitutability – to operationalize firm-level ecosystem service valuation thereby enabling the potential for ecosystem services to be added to the firm's balance sheet. Doing so would represent ecosystem service value in a way most recognizable to existing firm operation decision-making norms. To

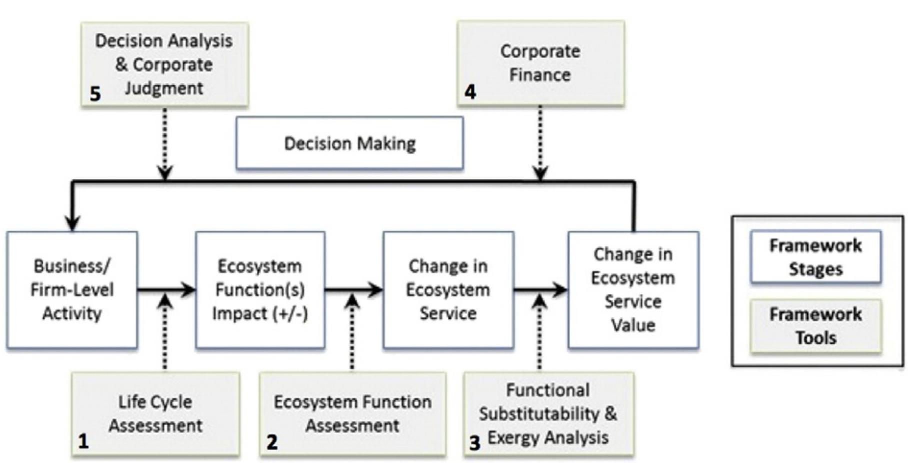

Fig. 1. Firm-level ecosystem service valuation framework.