



## Analysis

## Simple-but-sound methods for estimating the value of changes in biodiversity for biological pest control in agriculture

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## ARTICLE INFO

## Article history:

Received 8 October 2014

Received in revised form 17 October 2015

Accepted 20 October 2015

Available online 11 November 2015

## Keywords:

Species richness

Functional diversity

Ecosystem services

Economic valuation

Natural enemy

Sustainable agriculture

## ABSTRACT

Recent meta-analyses indicate that an increase in the number of natural enemy species raises the overall effectiveness of biological control of insect pests in agricultural settings. Although economic valuations of biological pest control in agriculture show an impressive cost savings from this ecosystem service, no direct estimate of the value of biodiversity for biological control has been attempted. We apply a basic microeconomic model for estimating the value of changes in the richness of arthropod natural enemies or in functional diversity for biological pest control for two sample crops using experimental results reported in the ecological literature. Market-based outcomes were driven by changes in crop yields associated with experimental reductions in natural enemy species richness, and modified by supply shifts and price elasticities. We show how our simple model differs from common approaches used in the ecological literature, and explain why this alternative model more accurately estimates societal well-being for consumers and producers participating in these crop markets. We conclude by discussing the additional research and data needed to make economic valuation of ecosystem services in agricultural settings more feasible, rigorous, and realistic in the future.

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## 1. Introduction

Biological pest control relies on the conservation of natural enemies of insect pests in agroecosystems and is necessary for sustainable crop production (Crowder and Jabbour, 2014; Power, 2010; Rusch et al., 2010). However, the value of marginal changes in the species richness or functional diversity of natural enemy communities in agricultural fields has not been estimated directly, in part because of data gaps linking enemy diversity to crop yields and production costs. We used published results from small-scale field experiments in Kentucky (Snyder and Wise, 2001) to generate some estimates of the values that marginal changes in biodiversity of natural enemies might represent for society in the markets for squash and cucumber in Georgia and South Carolina. In the process of generating those estimates, we demonstrate a key framework from basic microeconomics that natural scientists can apply themselves to calculate value estimates with available data, and explain the limitations of some common techniques used by non-economists in ecosystem service valuation efforts.

The overall value of natural pest control in the U.S. is very large, accounting for savings of \$4.5 billion annually, according to calculations by Losey and Vaughan (2006). Zhang and Swinton (2012) estimated

that the value of biological control of a single pest in soybean production for four Midwestern states in 2005 was over \$80 M. Although these studies did not focus on biodiversity, evidence suggests that a diverse assemblage of natural enemies provides better pest control services in agriculture overall (Woodcock et al., 2014), and protects against loss of these services as climate change proceeds (Crowder and Harwood, 2014) because they tend to suffer fewer functional deficits than depauperate communities with low species richness (fewer species). A functional deficit can occur when an important natural enemy species, group of functionally similar enemy species, or species that provides complementary mortality is absent from the assemblage (Cardinale et al., 2003; Letourneau et al., 2009; Snyder et al., 2008; Tylianakis and Romo, 2010). With mounting evidence of the overuse of pesticides (Pimentel and Peshin, 2014), increasing demand for alternative agricultural production methods (Dimitri and Greene, 2002), and legislation that encourages sustainable management practices (Roubos et al., 2014), it is increasingly important to understand the value of biodiversity or functional diversity conservation for biological control. Yet, the issue of how natural enemy diversity relates to biological control is still under intensive investigation (Crowder and Jabbour, 2014), since some natural enemies of pests feed on or otherwise interfere with each other (Duffy et al., 2007; Finke and Denno, 2005; Holt and Polis, 1997; Ives et al., 2005; Rosenheim, 2007). Predation of one natural enemy species by another usually hampers biological control but can

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stabilize a pest population or improve biological control under certain conditions (Ong and Vandermeer, 2014). Also, ecological studies on natural enemy diversity often lack critical information needed for economic analyses, such as benefits measured in terms of yield advantages or changes in on-farm revenue (as noted by Cardinale et al., 2012; Chaplin-Kramer et al., 2011). Therefore, to our knowledge, this is the first economic valuation of changes in natural enemy diversity for biological control in agricultural systems.

Using meta-analysis to combine a wide array of studies showing positive, neutral, and negative effects of an increase in enemy species richness on prey suppression, Letourneau et al. (2009) showed that, on average, doubling enemy species richness resulted in a large, statistically significant, negative effect on the abundance of herbivores, including pest species. In addition, the magnitude of the change in enemy species richness predicted the strength of its effect on herbivores (Letourneau et al., 2009). Furthermore, Griffin et al. (2013) found that enemy species richness had positive effects on the suppression of an herbivore species compared with the effect of an average predator species alone. Predator richness did not have effects above and beyond that of the most effective single predator—stressing the importance of superior enemy species. Nevertheless, both meta-analyses indicated that there is a positive impact of natural enemy richness on the strength of biological control of prey. However, meta-analyses of the ecology literature cannot measure how much an additional natural enemy species is worth for biological control services. Such value estimates would reveal and quantify the hidden costs to society associated with agricultural practices that cause beneficial species to become locally absent or present in such low abundances that they are unable to carry out their role in agroecosystems.

In this paper, we demonstrate how changes in producer and consumer surplus in agricultural markets could result from changes in natural enemy species richness associated with commercial crops by using data from manipulative field experiments (Snyder and Wise, 2001). In their experiments, Snyder and Wise (2001) compared crop yields in plots that were accessible to all enemy species (high enemy species richness and functional diversity) to plots manipulated to have either medium or low enemy species richness and functional diversity. Their data imply that naturally occurring enemy species associated with crop pests provide valuable ecosystem services, even just in the markets for two specialty crops. However, their results showed that the values are not a simple increasing function of the number of species of natural enemies, but rather depend on how the enemy species functioned in different assemblages of the crop-pest-enemy community. Their case study called into question a common practice in ecology and resource economics of measuring biodiversity in terms of numbers of species with little attention to how species may interact under different conditions.

Our approach estimates the values, positive or negative, of non-marginal changes in diversity of natural enemies, filling a gap between generalized attempts to quantify the total value of natural pest control nationwide (Losey and Vaughan, 2006) and structural bioeconomic models of crop-production decision making and outcomes used in small scale studies of the value of natural biocontrol (Zhang and Swinton, 2012), optimal spatial configuration of habitat for natural enemies in agricultural landscapes (Zhang et al., 2010), and how landscape-level crop mix affects natural enemy habitat and thereby pest control costs in cellulose biomass production (Skevas et al., 2014). The latter approach makes fewer simplifying assumptions and accounts for optimal changes in farmer behavior in response to hypothetical changes in the environment; however, it has significant data demands and is a large modeling project in its own right. Many researchers in ecology and entomology do not have easy access to economists with whom they can collaborate, have limited data, and would like to be able to at least generate approximate ecosystem service values from the limited data that are at hand. The approach presented here is useful for generating approximate economic value estimates that avoid some huge

pitfalls, and can identify whether or not to pursue further efforts to generate the data needed for a more complex analysis.

First, we demonstrate a simple methodology grounded in economic theory for estimating changes in social well-being as a result of biodiversity changes associated with biological control of pests in agricultural environments. Second, we show how our methods avoid some common errors and produce more realistic estimates of economic outcomes than one of the approaches currently used in some ecological papers. Third, we challenge ecologists to include parameters in their research that link biodiversity with production outcomes and management costs to improve and expand the economic valuation of biodiversity and ecosystem services.

## 2. Overview of Valuation Methodology

A change in the diversity of natural enemies to agricultural pests could have multiple effects. It could alter the cost of producing a given amount of crop, and thus change the economic surplus in the market. It could also have effects on things like human health, populations of other animal species, and water quality by reducing the amount of pesticide that is used in farming. This paper focuses on measuring the value of the first of these changes.

To demonstrate the economic surplus approach to valuation of discrete shifts in the costs of crop production, we use a stylized graphical demonstration in a single market (Fig. 1). The vertical axis represents marginal cost and price for supply, and marginal willingness to pay and price for demand. The horizontal axis represents quantity of the crop produced and sold in the market to be studied. The marginal cost (MC) curve for the industry describes the cost of producing one more unit of output given that farmers are choosing production methods to minimize the total costs of production. MC tends to be upward sloping because as aggregate industry output increases the crop is being grown on lands that are increasingly less well suited for this kind of crop so input costs may be higher and yields may be lower in that range of production. In a competitive market, the industry supply curve is given by the industry's aggregate MC curve. If the industry supply curve is very steep we say it is inelastic, and production will not respond much to changes in price. Demand curves (showing the quantity of a good purchased for a given price) tend to be downward sloping, as the incremental benefit consumers receive from purchasing more of any one product tends to be declining. However, if the market one is studying is a regional subset of a national or international market, the demand curve is likely to be very flat; if, for example, the price of broccoli in California starts to go up, wholesale buyers can in part turn to suppliers in other states and other countries.

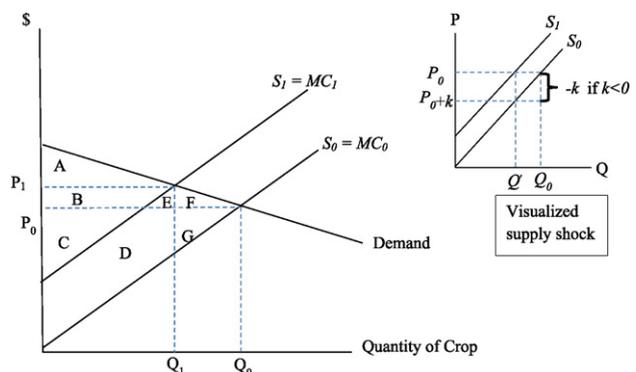


Fig. 1. Framework for calculating change in welfare from supply shock<sup>a</sup>. <sup>a</sup>The marginal costs of production increase from scenario 0 to scenario 1 due to a shock of  $k < 0$  (shown in the inset graph).

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