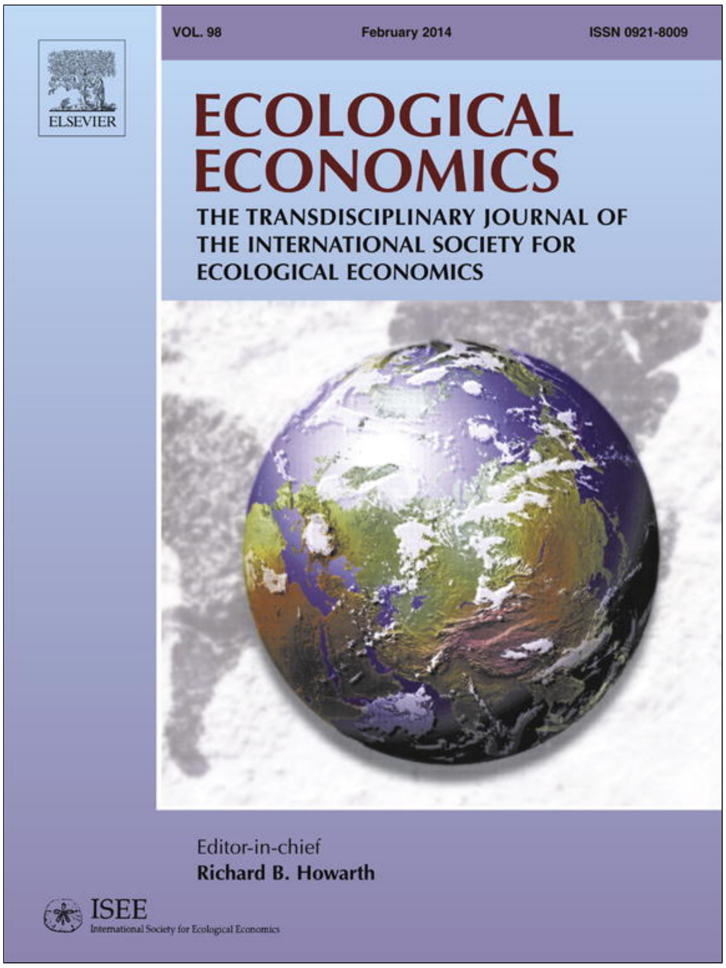
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Analysis

Ecosystem services as substitute inputs: Basic results and important implications for conservation policy☆

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ABSTRACT

In recent decades conservation advocates have often emphasized the contributions of ecosystem services to the production of other products. A demonstration of the value of ecosystems as inputs into production would motivate their conservation. Such arguments often offer the observation that ecosystem services can substitute for purchased inputs, and thus reduce costs. If this is true, however, it has another important implication: a producer who is preserving local ecosystems so as to maximize her own profit will produce less output if she further increases her reliance on ecosystem services. This may induce "leakage," by which one producer's greater reliance on ecosystem services indirectly motivates others to preserve fewer natural ecosystems. I demonstrate this result in a simple but canonical model, and calibrate my findings to a celebrated example to show they could be quantitatively significant. My results suggest another reason that appeals to ecosystem services as a motivation for conservation should be made with care. At the most basic level, they emphasize the importance of being clear about what we mean by conservation: do we want to save some diversity in many places, or nearly all indigenous diversity in a few places?

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1. Introduction

Tremendous enthusiasm has been expressed in recent years for "ecosystem services". Ecologists Daily and Matson (2008) write that there is "…a growing feeling of Renaissance in the conservation community. This flows from the promise in reaching, together with a much more diverse and powerful set of leaders than in the past, for new approaches that align economic forces with conservation." The literature on ecosystem services argues that when land use decision-makers forgo more intensive use of the landscapes under their control they preserve systems that provide a host of valuable services. These may include climate moderation, scenic views, recreational amenities, pest control, pollination, protection of biodiversity, water purification, and nutrient cycling, among others (see, e.g., Daily, 1997 for a more comprehensive and annotated list).

An ecosystem services approach to conservation has proved problematic, however. Despite the considerable enthusiasm the idea has generated, and notwithstanding recent advances in both natural science and economic valuation, evidence has not yet been marshaled that preserving habitats generally provides greater economic value than would converting them to other uses. While Kareiva and Ruffo (2009) write, "[N]ow more than ever, we need to embrace ecosystem services as a basis for conservation," they go on to lament that "we do not have enough science to back up our hypotheses....we have not proven, on the ground, that these ideas work."

Even if we do "prove, on the ground, that these ideas work," however, we would still be faced with tough questions. If these ideas do, indeed, "work," why have they not been more widely implemented? The most obvious problem involves a mismatch of scale; *local* people make land use choices that provide both local and *global* benefits. In particular, any benefits that arise from the preservation of biodiversity per se are pure public goods. The aesthetic or moral appreciation of the continued existence of the full array of life forms on the planet is not limited to those close enough to experience it directly. To the extent that compensation for global public goods is lacking, local decision makers may overexploit their resources relative to globally optimal use (Kremen et al., 2000; Naidoo and Ricketts, 2006; Pearce, 2005).

A number of contributions to the literature have emphasized the benefits local communities might realize by maintaining habitats to, for example, support pollinators (Ricketts et al., 2004), provide coastal protection (Costanza et al., 2008), or manage urban runoff (Stratus Consulting, 2009). If local people appreciate these ecosystem services, it should not be difficult or expensive to get them to maintain at least marginally more of the ecosystems than provide them: if local people are optimizing, they would, by construction, be indifferent between converting the marginal hectare of land under their control to production directly as opposed to continuing to provide the ecosystem services

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that enhance production. Thus, only small payments ought to be required to induce a little more preservation of natural ecosystems.

Moreover, local people might *not* allocate the land under their control optimally between production and the provision of ecosystem services. There might be reciprocal externalities: owners of adjacent orchards might, for example, maintain too little area to shelter native pollinators. This might occur because the pollinators one landowner protects might also service her neighbor's trees, and so the first landowner would not be compensated for sheltering the pollinators. Or it might simply be that local people do not fully understand the benefits ecosystems afford them in an increasingly developed world.[1]

Arguments that conservation might be achieved cheaply are certainly attractive to conservation advocates who often lack adequate resources to pay for large-scale land acquisition (see, e.g., Pearce, 2005, who laments the apparent unwillingness of the international community to put its money where its mouth is to pay for conservation).

Is there any catch? In this paper I suggest that there may be. My central result is a simple syllogism. If ecosystem services are substitutes for purchased inputs, and if local people preserve or restore habitat so as to provide themselves with the level of ecosystem services that maximizes their own profits, then output would *decline* if *more* land were preserved or restored to provide ecosystem services. This would then imply that the price of output would increase, and more people would be induced to enter production.

The syllogism is only as credible as are its major and minor premises. If ecosystem services and purchased inputs are *not* substitutes, the output effect I posit would be reversed. However, much of the literature on ecosystem services emphasizes that they can be substituted for inputs that would otherwise have to be purchased. I give some examples to support this assertion in the second section of the paper.

How about the minor premise, “and if local people are optimizing with respect to their own interests”? Even if local people were *not* preserving the areas of natural ecosystems they should be in order to maximize their own objectives, however, the result would hold in the neighborhood of the optimum. It begs the question of how far conservation advocates should push the argument that local people will benefit from increased conservation (see also footnote one above).

What difference would it make if, in relying more on ecosystem services, output were to decline? The problem is that if an appreciation of the contributions of ecosystem services induces each farmer who increases her reliance on them to reduce her output, pressure will grow elsewhere to expand production. This, in turn will motivate clearing new land and a consequent reduction in ecosystem services provided elsewhere. In short, if ecosystem services are substitutes for purchased inputs, greater reliance on ecosystem services may induce “leakage” or “slippage” by which increased conservation in one area results in more extensive use of land in production elsewhere (for an analogous case, see Wu, 2000 for a study of leakage under the Conservation Reserve Program).[2]

Now let me lay out the intuition underlying the result. It may, on first inspection, seem counterintuitive that if greater reliance on ecosystem services would help producers, they would produce *less* if they relied on ecosystem services *more*. The key is that ecosystem services can help producers either by enhancing the productivity of the other inputs they employ, or by allowing them to economize on their purchases of those other inputs. If the latter effect dominates, the cost savings from substituting to less expensive inputs could exceed the value of production lost when the purchased inputs are displaced. The producer's profits could go up even as her production goes down.

Natural systems provide local land owners with ecosystem services such as pollination, pest control, and flood and erosion protection. These are valuable to a landowner to the extent that they contribute to her profits. Enhancing the provision of such services will have different implications for conservation, however, depending on whether the ecosystem services in question are *substitutes for*, or *complements to*, the other inputs she purchases. Many of the ecosystem services we often hear about are substitutes, rather than complements. If a farmer maintains more land to shelter pollinators, she can substitute native pollinators for the rental of commercial bees. If she keeps more land fallow she can substitute natural regeneration of soil fertility for the purchase of commercial fertilizers. If a developer maintains part of a new housing development in wetlands rather than building on every square meter of a parcel he can substitute natural flood control and water purification processes for “gray infrastructure” of concrete and steel.

Consider a landowner who is optimizing her intensity of land use with respect to her own interests. This means she is indifferent between using land a little more intensively — say, cutting down the marginal hectare of forest to plant crops — and preserving it to provide pollinator habitat, flood protection, or other services. Now if an ecosystem service such as pollination by native insects is a substitute for a purchased input such as renting a colony of honey bees, the landowner who maintains a little more area in forest will obviate the need to rent the marginal colony of bees. She saves the rental cost of the bee colony, *but if she were indifferent to clearing another hectare of land, she must be forgoing an equal value of crop produced*. So, if she preserves the extra hectare of forest her output must decline even though her earnings do not.

If our hypothetical landowner/farmer's output declines it means less food is produced. That means that the price of food will increase, and that has two implications for conservation. First, it will mean that farming will be more profitable to anyone who wishes to take it up, and so land is likely to be used more intensively elsewhere. Second, the choice of where to set the balance between preserving land to provide ecosystem services and purchasing inputs to substitute for such services depends on relative prices of inputs and outputs. If one farmer relies more on ecosystem services the process of supply contraction and price increase I have just described will generate incentives for other farmers *not* to emulate her decision.

So, the argument I have just summarized suggests that, in addition to determining exactly what incentives the values of ecosystem services provide to landowners, we must also consider how incentivizing landowners to conserve more will actually affect conservation policy. We must consider the effects of one landowner's preservation choices on the incentives facing others.

The remainder of this paper is divided into several sections. In the next section I discuss a couple of examples in which ecosystem services may be substitutes for purchased inputs and their implications for conservation policy. Following that I develop a canonical model of production with ecosystem services. One often encounters references to “ecological production functions” in the ecosystem services literature (see, e.g., National Research Council, NRC of the National Academy of Sciences, 2006; Polasky, 2008). There could, of course, be any number of different production processes relating different purchased inputs and different ecological attributes to different outputs. There should, however, be underlying commonalities that allow us to develop principles of ecological production, just as we have a theory of industrial

[1] I offer these observations for the sake of argument. There is a large literature (see, e. g., Ostrom, 1990, or Baland and Platteau, 1996) noting that local people do, in fact, often solve problems of reciprocal externality. Moreover, a local landowner might take with a grain of salt a conservation advocate's suggestion that the landowner would be better served by choices that also happen to be in the conservation advocate's interest.

[2] There is an extensive literature dealing with related issues. Economists have long appreciated that landscapes are productive assets capable of performing a number of functions and producing multiple output (see, e. g., OECD, 2001; Abler, 2004; though see also Vincent and Binkley, 1993, who argue that separating production and conservation activities in specialized areas may be more efficient in some landscapes). While there are certainly instances in which the interests of commercial production and conservation may be aligned, such “win–win” outcomes are typically limited to a range of the production vs. conservation space. As in my analysis, some other authors have noted that the nature of the interaction between natural and purchased inputs — whether they are complements or substitutes — may have important implications for conservation policy (see, generally, Wossink and Swinton 2007, and in the specific context of tradable permit markets, Heberling, Garcia, and Thurston, 2010), although I am not aware of any previous demonstration of the results I emphasize here.

production from which we derive formulations for factor prices, derived demands, etc., in the production of goods more generally. I use this canonical model to perform some simple comparative static exercises. I consider how the quantity of output might vary in the vicinity of a landowner's privately optimal choice of land preservation.

I show that if ecosystem services and purchased inputs are substitutes greater reliance on the former will result in a reduction of output. The general model provides no indication of the empirical importance of such effects, however. So, in the fourth section of the paper I revisit an example discussed in the second section. I calibrate a model with data from an area of the U.S. state of Virginia, where a well-known organic farm employs an ecosystem services approach to production. The model is very simple and admittedly restrictive. It shows that the effects I identify *could* be quantitatively significant. Regrettably, this falls far short of a general demonstration that such effects *are* of great practical importance. Inasmuch as the concerns I raise here have received relatively little attention in the literature to date, however, my results do point to the need for more careful empirical research.

The observations I offer in this paper underscore an overarching question: What do we mean by "conservation?" Is our objective to preserve a smattering of natural diversity over large swathes of the landscape, or to preserve more isolated areas in which indigenous diversity is nearly completely retained? Different people can and do disagree, but I return to this question in a concluding section and emphasize that it is our conservation objectives that will ultimately determine the strategies we determine are most effective in achieving them.

2. Two Examples

In this section I consider two examples that document the substitution of ecosystem services for purchased inputs. Many of the services attributed to ecosystems often have to do with farming. In her 1997 edited volume *Nature's Services*, Gretchen Daily identifies among ecosystem services "generation and renewal of soil and soil fertility; pollination of crops and natural vegetation; control of…agricultural pests; dispersal of seeds and translocation of nutrients". Other services in the list, such as flood control and moderation of temperature and wind might also benefit farms.

Polyface Farm in the western part of Virginia and its proprietor, Joel Salatin, feature prominently in Michael Pollan's best-selling book *the Omnivore's Dilemma* (2006). Less than 20% of land in the farm is devoted directly to production, the rest being retained in forest. This conserved land moderates temperature and wind, protects plants and animals, promotes soil regeneration, shelters small predators that eat agricultural pests while acting as a buffer between farm animals and the larger predators that might otherwise threaten them, regulates the flow of water, and facilitates its retention (Pollan, 2006, pp. 222 – 225). Mr. Salatin's 220 hectare farm differs markedly from those of his neighbors. Mr. Salatin does not purchase any chemical pesticides, manufactured fertilizers, or feed from other sources (Pollan, 2006; Salatin, nd). His neighbors in Augusta County, Virginia, devote almost half of their total production expenses to such purchases (United States Department of Agriculture, USDA, 2007). While Mr. Salatin preserves more than four-fifths of his land in forest (Pollan, 2006), less than one fifth of the other roughly 115,000 hectares designated as farmland in Augusta County is forested (United States Department of Agriculture, USDA, 2007). In short, then, Polyface Farm relies on ecosystem services as substitutes for the inputs its neighboring competitors purchase.

Flood control and water purification are other examples of ecosystem services. Land developers "produce" residential and commercial communities by combining purchased inputs with natural features of the landscape. Some authors have suggested that it would be cost-effective to employ "green infrastructure" in urban areas (see, e.g., Stratus Consulting, 2009; Odefey et al., 2012). Additional planting or retention of trees, rain gardens, wetlands, and other more "natural" landscape features could be used instead of pipes, tunnels, pumping plants, and other components of the "gray infrastructure" that have traditionally been relied upon to manage urban stormwater. In addition to preventing flooding, it has been suggested that "green infrastructure" would reduce costs of heating and cooling. While green infrastructure might also make the communities adopting it more attractive places to live, much of the literature promoting its adoption stresses the cost savings made possible by substituting it for alternative stormwater treatment and heating and cooling approaches (Odefey et al., 2012; Stratus Consulting, 2009).

The argument that ecosystem services are valuable often rests on the assertion that they are substitutes for — in contrast to complements to — purchased inputs. These two examples document this case. Let us see in the next section what the assumption of substitutability implies.

3. Properties of the Ecological Production Function

In this section I define a canonical ecological production function and investigate its properties. A production function relates quantities of inputs to quantity(ies) of output(s). For simplicity I will confine attention to a single output, and write

$$q = f(x, S, A) \tag{1}$$

where q is the quantity of output, x the quantity of purchased inputs, S the quantity of ecosystem services provided, and A the area of land used directly in production.

The distinguishing characteristic of an *ecological* production function is that output depends in part on the services provided by remnant natural ecosystems. Remnant natural ecosystems are maintained to the extent that alternative land uses are forgone. In agriculture, for example, some land may be withheld from production to serve as hedgerows, windbreaks, habitat for pollinators and wild animals that prey on pests, or natural cover and wetlands that may recharge groundwater and mitigate flooding. We might interpret some common practices as variants on this theme of intensity of use. Letting land lie fallow for a period while soil regains fertility is a substitute for the addition of fertilizers. The proportion of land lying fallow at any time might be a measure of the amount of "conservation" being practiced. The length of periods of rotation in plantation forestry might be interpreted as a measure of the intensity of land use. Similarly, agro-forestry, in which perennial crops are adopted in favor of annuals, or interspersed between annuals, might be regarded as a situation in which a lower intensity of land use is adopted in favor of providing more ecosystem services.

Residential development might also be interpreted as a choice between more intensive use and a greater reliance on ecosystem services. Conserved natural areas might provide services such as scenic and recreational amenities, flood and storm protection, groundwater recharge, and the like. The intensity of land use might be measured by the proportion of an area retained in vegetative cover as opposed to covered in impermeable surface.

Other examples might be developed with industrial facilities, retail space, etc. Note that nothing I have said precludes production that may be constrained by regulation. Farmers may, for example be restricted in the amount of pesticide overspray or fertilizer runoff they generate (see Heberling et al., 2010 for an interesting analysis of the latter that raises similar issues to those I consider here). Residential developers may have to meet standards for stormwater retention. The question then arises whether regulatory requirements might be met at lower cost by substituting "green infrastructure" for alternative control measures.

There is an inescapable tradeoff between using land directly in production and retaining some areas to provide ecosystem services. I will express this tradeoff simply as

$$S = \phi\left(\bar{A} - A\right) \tag{2}$$

where $\bar{A}$ is the size of parcel held by a land use decision maker, A is the amount of that parcel she uses directly in production, and ϕ is a parameter that measures the productivity of preserved land in providing ecosystem services.

The amount of ecosystem services generated declines with the amount of land, A, that is cultivated, devoted to structures, etc. While it will be expositionally convenient to refer to S as defined by (2) as the "quantity of ecosystem services", this may be something of a misnomer, as the ecosystem services of interest may be *a function of S*, rather than being identical to S. Expressions (1) and (2) do not necessarily imply that any physical measure of ecological production varies linearly with the amount of land withheld from production. For example, we could suppose that the capacity of natural ecosystems to filter out nutrients is a declining exponential function (as in Mayer et al., 2007), or that the diversity of species in an area of size $\bar{A} - A$ is described by power function (as in MacArthur and Wilson, 1967). The important consideration is, rather, that A enters into the production function both directly and indirectly through S, and that the production function is well-behaved in terms of the usual convexity requirements for interior solutions.[3]

Let r be the price of inputs, and normalize the price of output to one. A landowner's profit will be

$$\pi = f(x, S, A) - rx \tag{3}$$

Profit is maximized by purchasing inputs until

$$f_x \leq r \tag{4}$$

and increasing the intensity of land use until

$$f_A - \varphi f_S \geq 0 \tag{5}$$

where subscripts denote partial derivatives; $f_x = \partial f/\partial x$, etc. Note that the first-order conditions (4) and (5) may be inequalities. It might be optimal for some purposes to employ no purchased inputs, while in other cases it might be optimal to maximize the intensity with which land is employed. I will focus, however, on interior solutions, i.e., instances in which (4) and (5) are equalities.

3.1. Conditions for Substitution

As I have noted above, much of the ecosystem services literature presumes that ecosystem services are substitutes for purchased inputs: producers can save money by using land less intensively and relying more on "natural" inputs. Let us define "substitutes" in the conventional way: ecosystem services are substitutes for purchased inputs if, when the price of purchased inputs goes up, more land will be conserved to provide ecosystem services. In the notation I have introduced above, S is a substitute for x if $dS/dr > 0$. Since the amount of land conserved and the amount used directly in production must sum to the amount of land available, $\bar{A}$, and we are measuring the amount of ecosystem services by the amount of land conserved, $dS/dr = -dA/dr$.

Suppose the first-order conditions (4) and (5) hold as equalities, and differentiate each totally with respect to r. Then

$$f_{xx}\frac{dx}{dr} - (\varphi f_{xS} - f_{xA})\frac{dA}{dr} = 1 \tag{6}$$

and

$$(f_{xA} - \varphi f_{xS})\frac{dx}{dr} + \left(\varphi^2 f_{SS} - 2\varphi f_{SA} + f_{AA}\right)\frac{dA}{dr} = 0 \tag{7}$$

Using (6) to eliminate dx/dr from (7),

$$\frac{dA}{dr} = \frac{\varphi f_{xS} - f_{xA}}{f_{xx}(\varphi^2 f_{SS} - 2\varphi f_{SA} + f_{AA}) - (\varphi f_{xS} - f_{xA})^2} \tag{8}$$

The denominator of (8) is positive by satisfaction of the second-order conditions for profit maximization. Purchased inputs are complements with land employed directly in production, and, thus, substitutes for ecosystem services, then, if the numerator of (8) is negative.

3.2. Input Use and Production When Land Use Changes

The ecosystem services literature often focuses on the question of whether land might provide more value if used at lower intensity. Consider what would happen if a landowner who is already allocating her land optimally increased her reliance on ecosystem services by restoring a little more native habitat.

We are particularly interested in what would happen to purchased inputs, x, and total output, q, if land were used less intensively. So differentiate the production relationship totally with respect to A to find

$$dq/dA = f_x\, dx/dA - \varphi f_S + f_A \tag{9}$$

Let us assume that the choice of land intensity is close to that which maximizes profit in the *status quo*, so that expression (5) is satisfied, and concentrate on the first term on the right-hand side of (9). We can find dx/dA by totally differentiating (4) with respect to A:

$$f_{xx}\frac{dx}{dA} - \varphi f_{xS} + f_{xA} = 0 \tag{10}$$

or

$$\frac{dx}{dA} = \frac{\varphi f_{xS} - f_{xA}}{f_{xx}} \tag{11}$$

The second-order condition for profit maximization requires $f_{xx} < 0$. Comparing (11) and (8), $dx/dA > 0$ if and only if ecosystem services are substitutes for purchased inputs.

Suppose land is allocated between conservation and production so as to maximize profits *ab initio* (i.e., so that $\phi f_S = f_A$). Then using (11) in (9), if ecosystem services and purchased inputs are substitutes,

$$dq/dA = f_x \frac{\varphi f_{xS} - f_{xA}}{f_{xx}} > 0. \tag{12}$$

Production *increases* if *less* land is preserved to provide ecosystem services (i.e., if A becomes larger), so production must *decline* when *more* land is conserved to provide ecosystem services.

Let me take a moment to note the implication of (12). I am taking a micro-level view here. *One producer*, if she were to devote more of her land to the provision of ecosystem services and less to production, would produce less even if her profits were not reduced on the margin. This would imply, however, that market price would increase. I have normalized the price of output to one, and so the relative price of purchased inputs, r, would decline. From (8), then, other producers would have a *reduced* incentive to emulate the producer who has reduced her intensity of land use.

Consider the conservation policy implications of this finding. If producers who were *already* optimizing with respect to their own individual or community interests responded to exhortations to rely more on ecosystem services, they would reduce their aggregate production, with the consequent effects I have just discussed. As (12) is a strict inequality, this result will also hold in the neighborhood of such an optimal allocation. This means conservation advocates would be well advised to understand the circumstances of producers whose behavior they hope to change. If the producers are already optimizing, these

[3] If the production function were not well-behaved, the optimal allocation of land would likely involve conservation areas being separated from those in which production takes place (see Vincent and Binkley, 1993).

effects will follow. If they are not already optimizing, the effects may arise as producers approach their locally optimal allocation.

I might demonstrate that this point has not been taken fully onboard by conservation advocates with an anecdote. At a recent seminar the speaker described "the farm of the future" — an enterprise in which a substantial amount of land now devoted to producing crops for sale would instead be devoted to generating ecosystem services. When he was finished, a hand shot up in the audience. "And what," the questioner asked, "are the people of the future going to eat?"

It seems reasonable to suppose that the answer would involve some combination of less food, different food, or food grown in different locations than those in which land is now cultivated. To the extent that the last possibility obtains, promoting conservation in one area could result in more degradation elsewhere. The point that such "leakage" (or, as it is sometimes called, "slippage") is a concern — both conceptually and empirically — has been raised in the related context of agricultural conservation programs that involve land retirement (see, e.g., Wu, 2000), but the parallel concerns that may arise under an ecosystem services approach to conservation have not been as fully explored.

4. An Illustrative Example: A Stylized Depiction of Farming in Augusta County, Virginia

Recall Polyface Farm in the western portion of the state of Virginia. Its proprietor, Joel Salatin, has adopted an ecosystem services based approach to farming, in which he leaves large areas of his land in forest rather than plowing and planting it, and relies on this forest area for fertilization, water retention, protection from weather, pest control, and other services. To the best of my knowledge, there is no publicly available production data on his proprietary enterprise.

There is, however, extensive data for Augusta County, Virginia, in which Polyface Farm is located. In this section I assume a specific functional form for the production function and illustrate the potential magnitudes of some of the effects I have described above.

4.1. A Tractable Specification

Consider the constant returns to scale production function,

$$q = \sqrt{xS} - \gamma xS/A \tag{13}$$

where the variables are as defined above and γ is a positive constant. This production function is very simple and restrictive. I most certainly do not mean to claim that the results I obtain here are general, or that the exercise that follows represents a careful approach to empirical estimation. By the same token, however, I would argue that the production relationship given in (13) is not implausible, nor even particularly unusual. Thus I would argue that the results below constitute a compelling argument that the concerns I highlight cannot be dismissed lightly as artifacts of an unreasonable specification.[4]

As the price of output is normalized to one, the profit objective is

$$\pi = \sqrt{xS} - \gamma xS/A - rx \tag{14}$$

The first-order conditions for profit maximization are, with respect to x,

$$\frac{1}{2}\sqrt{S/x} - \gamma S/A - r = 0 \tag{15}$$

and with respect to A,

$$-\frac{\varphi}{2}\sqrt{x/S} + \gamma x\frac{\varphi\bar{A}}{A^2} = 0 \tag{16}$$

It can be verified that the second-order conditions for optimization are satisfied when the first-order conditions, (15) and (16), hold.

Solving (15) for x,

$$x = \frac{S}{4(\gamma S/A + r)^2} \tag{17}$$

Substituting (17) in the first-order condition with respect to A and using the definition $S = \phi(\bar{A} - A)$ yields, after some rearrangement and simplification,

$$A = \frac{\bar{A}}{1 + \sqrt{r/\gamma\varphi}} \tag{18}$$

Let me digress for a moment to note that (18) illustrates something that some might find paradoxical: the amount of land devoted directly to production increases in the effectiveness with which preserved land generates ecosystem services, as measured by the parameter ϕ. Put in colloquial terms, if a little ecosystem services go a long way, there is no need to set aside enough land to provide a lot of such services.

In this production function ecosystem services and purchased inputs are substitutes: when the price of purchased inputs, r, goes up, the use of land in production declines, meaning that land preservation must increase. Let us now confirm that this also implies that output declines when the amount of land conserved increases relative to the profit-maximizing level. Multiplying (15) by x,

$$\frac{1}{2}\sqrt{xS} - \gamma xS/A - rx = \pi - \frac{1}{2}\sqrt{xS} = 0 \tag{19}$$

Differentiating (19) totally with respect to A and evaluating the expression when both A and x are chosen to maximize profit, we find that

$$S\frac{dx}{dA} = \varphi x \tag{20}$$

or noting that $S = \phi(\bar{A} - A)$ and rearranging,

$$\frac{dx/x}{dA/A} = \frac{A}{\bar{A} - A} \tag{21}$$

Heuristically, when most land is used in production, there must be heavy reliance on purchased inputs. Consequently, if still more land were to be devoted to production, many more inputs would need to be purchased in order to compensate for the loss of ecosystem services. As a matter of conservation policy we are more interested in the opposite thought experiment: what happens if land is removed from production and instead preserved for the provision of ecosystem services? Again, if there is heavy reliance on purchased inputs to begin with, then the marginal rate of technical substitution of ecosystem services for purchased inputs will be high, and there will be a large reduction of purchased inputs.

[4] To give some idea as to the generality of expression (13), we might regard (13) as a special instance of the production function.

$$f(x,S,A) = x^{\alpha}S^{1-\alpha} - \gamma\left(x^{\alpha}S^{1-\alpha}\right)^2/A$$

where $\alpha = ½$. It can be shown (details available upon request) that the result used for calibration, expression (21) below is a sort of mid-way point, with stronger (weaker) results obtaining if $\alpha < (>)$ ½.

The effect of a change in land use on output will be

$$\frac{dq}{dA} = \frac{\partial q}{\partial x}\frac{dx}{dA} \tag{22}$$

From the first-order condition for profit-maximizing input use, $\partial q/\partial x = r$ (recall that the price of output is normalized to one), and so

$$\frac{dq/q}{dA/A} = \frac{rx}{q}\frac{A}{\bar{A}-A} \tag{23}$$

It is easy to see that drastic reductions in output might result if there were a relatively high reliance on purchased inputs in the *status quo*.

4.2. Calibration

While one would not want to attempt serious empirical analysis on the basis of so simple a model, it may be useful just to consider what expression (23) would imply if we calibrated it with available data. Let me do one such exercise. I emphasize again that this exercise is only intended to be illustrative. The data that will be relevant for our purposes are summarized in Table 1.

Recall that Polyface Farm is located in Augusta County, Virginia. At around 220 hectares, Mr. Salatin's farm accounts for only about one-fifth of 1% of the roughly 116,000 hectares of land in farms in Augusta County. Of this total, some 44,000 hectares were planted in crops and 50,000 hectares were designated as pastureland. Less than 16% of farmland in the county is in the forest. The value of products sold from Augusta County farms came to about \$195 million. Farm production expenses totaled about \$166 million. From these I subtract \$13 million payments for land, either through rental or interest payments, since I want to distinguish payments for variable inputs from the returns to land.

Using these numbers in expression (23) to derive the elasticity of farm output with respect to land devoted to production we have

$$\frac{dq/q}{dA/A} = \frac{\$153\text{ million}}{\$195\text{ million}}\bullet\frac{98,000\text{ hectares}}{18,000\text{ hectares}} = 4.3 \tag{24}$$

According to this calculation, if Mr. Salatin's neighbors were presently near the allocation of land at which they are maximizing their profits and they were to move toward emulating him by taking 1% of the land they now cultivate or use as pasture out of production so that it might provide greater ecosystem services, their output would decline by 4.3%.[5]

[5] Of course this begs the question of whether Mr. Salatin's neighbors are maximizing their profits. Would they be doing much better for themselves if they were to emulate Mr. Salatin? We simply do not have enough information to know. I would, however, note two things. The first is to say that it seems presumptuous for non-farmers with little knowledge of farm practices in Augusta County to assert that farmers there are not, in general, optimizing, either individually or collectively. The second is to note that Mr. Salatin appears to occupy a niche that could not likely bear much competition. He charges several thousand dollars for his frequent speaking engagement; Polyface Farms markets farm tours, T-shirts, DVDs, and other products, as well as Mr. Salatin's seven published books (Salatin, n. d.). These income sources would likely be significantly diminished if enough people bought his book *You Can Farm: The Entrepreneur's Guide to Start and Succeed in a Farming Enterprise* and emulated his model. Mr. Salatin probably receives some scarcity rents because his farm is an anomaly. I might also note that in an earlier version of this paper I calibrated a model in which I assumed that ecosystem services and purchased inputs were perfect substitutes. In that model farmers would switch from relying solely on the former to relying solely on the latter, or vice-versa, depending on relative prices; in equilibrium, producers would be indifferent between a "conventional" and an "ecosystem service based" approach. While I did not feel that the perfect-substitutes specification was very reasonable, and subsequently dropped it, one nice implication of the analysis was that it showed how farmers like Mr. Salatin and his neighbors could co-exist while following very different strategies. When calibrated to the data, however, that model also showed that a farmer who decided to switch from current practices to emulate Mr. Salatin would also dramatically cut her production.

Table 1
Selected agricultural statistics for Augusta County, Virginia.

A. Allocation of farmland (thousands of hectares), 2007	
Total land in farms	116
Of which:	
Total cropland	44
Permanent pastureland	50
Total woodland	18
Other (structures, feedlots, ponds, roads, etc.)	4
B. Revenue and expenses (millions of dollars), 2007	
Market value of agricultural products sold	195
Total farm production expenses	166
Less land rental payments and interest on real estate loans	(13)
Farm production expenses net of land payments	153

Source of all figures: United States Department of Agriculture (USDA) (2007)

I cannot overemphasize that it would be silly to put too much faith in such a simple model, and especially in such a simple model calibrated to such coarse aggregate data. By the same token, though, it is dangerous to ignore the general implications of such an analysis. Augusta County, Virginia, is a largely rural area. Less than half of the area of the county is designated as farmland. In Augusta County, as elsewhere in the world, the likely consequence of a reduction in production from existing farms would be the expansion of farming into new lands. The reader may very well object that we cannot know the impact of such "leakage" without much more careful study. That is exactly my point. We should be careful about extolling the conservation benefits of relying more on ecosystem services until we know more about the broader effects of such an approach.

5. Conclusions and a Final Example

In this paper I have raised a concern with "leakage": the propensity for reliance on ecosystem services in one venue to increase pressures for more intensive land use elsewhere. If, as is often assumed, the services provided by natural ecosystems are substitutes for purchased inputs in production, and if producers are making land use decisions so as to approximately maximize their profits in the *status quo*, then heavier reliance on ecosystem services will result in a reduction in output. This reduction in output will translate into an increase in prices, greater pressure to produce more elsewhere, and reduced incentives for other producers to emulate the decision to rely more heavily on ecosystem services in production.

The reader may have a number of reservations about the analysis I have presented. Chief among these concerns may be that I have adopted a very micro-level focus. If producers were to follow exhortations to rely more on ecosystem services, how much effect would this have on conservation policy? My answer is "It all depends on effects that are beyond the purview of my very limited model." While this may seem quite obvious, it does beg questions that have not been clearly answered in the conservation literature.

In *Alice in Wonderland* Alice and the Cheshire Cat have a memorable exchange after Alice asks the cat which road she should take. The cat then asks Alice where she wants to go. When she expresses indifference, the cat replies "Then it doesn't matter which way you go". Even those of us who feel some sympathy with the underlying motivations of authors writing on ecosystem services may experience growing exasperation with work in that genre. Where is it that advocates want to go? There are certainly divided opinions among conservation experts as to what constitutes "conservation". John Terborgh (1999) seeks to maintain expanses of natural habitat extensive and "wild" enough as to preserve top-level predators; others would apparently be content with more numerous, smaller, and generally less "wild" reserves (see, e.g., Daily and Ellison, 2002, or Kareiva et al., 2012).

Perhaps the objectives of conservation are a matter of taste. Be that as it may, however, it does seem incumbent on those suggesting strategies for achieving conservation to be explicit about their goals and clear about the ways in which the measures they suggest are intended to achieve them. Let me conclude with an example. Peter Kareiva has been a frequent, albeit occasionally a constructively critical, commentator on the literature on ecosystem services (see, e.g., Tallis and Kareiva, 2005; Kareiva and Ruffo, 2009; Kareiva, 2009). Kareiva et al. (2012) begin a very controversial paper by noting that "By its own measures, conservation is failing…There are so few wild tigers that they will be lost forever if current trends continue. Simply put, we are losing more special places and species than we're saving."

The author's prescription is that

> Instead of pursuing the protection of biodiversity for biodiversity's sake, a new conservation should seek to enhance those natural systems that benefit the widest number of people, especially the poor. Instead of trying to restore remote iconic landscapes to pre-European conditions, conservation will measure its achievement in large part by its relevance to people, including city dwellers. Nature could be a garden — not a carefully manicured and rigid one, but a tangle of species and wildness amidst lands used for food production, mineral extraction, and urban life.

This vision of "a tangle of species and wildness amidst lands used for food production, mineral extraction, and urban life" suggests a puzzling paradox. At the beginning of their article the authors lament the decline of the wild tiger. Yet India has conducted a sort of long-term experiment with a "tangle of species and wildness amidst lands used for food production". According to colonial records about 800 people a year were killed by tigers in the first decade of the 20th century (*Statistical abstract relating to British India, Statistical Abstract, 1915*). Fifty or more may still be killed every year in the Sundarbans region of India and Bangladesh (British Broadcasting Company, BBC, 2009). Of course, the tigers have not fared well either, as evidenced by the fact that their numbers continue to decline.

This would appear to be an instance in which at least *one* of the goals of *some* conservationists — *in situ* preservation of top predators — cannot be achieved by integrating remnant bits of natural habitat with economic activities that are purported to benefit from proximity to such areas. This does not necessarily mean that *other* goals could not be achieved in part by expanding reliance on ecosystem services, though again, it could mean that the achievement of some goals in some places might increase pressure on other habitats in other places. These observations all serve to underscore the simple message of this paper. Even if one can make the economic case that an expansion of reliance on ecosystem services will conserve more land in some places, it is still not entirely clear that greater reliance on ecosystem services would advance broader conservation goals. It is, admittedly, frustrating that available data and scientific understanding do not allow us to be more specific about the magnitude of the concerns I have raised. By the same token, however, the fact that these magnitudes are so uncertain argues for giving these issues greater thought when considering the implications of an ecosystem services approach to conservation policy.

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