Ecological Economics 71 (2011) 131–139

Contents lists available at SciVerse ScienceDirect

Ecological Economics

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

Analysis

Ecosystem services in agriculture: Determining suitability for provision by collective management

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ARTICLE INFO

Article history:
Received 18 February 2011
Accepted 22 August 2011
Available online 22 September 2011

Keywords:
Ecosystem services
Collective management
Agricultural ecosystems
Pollination services
Carbon sequestration
Nature recreation

ABSTRACT

Agricultural ecosystems provide many ecosystem services (ES) which are essential to human health and well-being. In turn, some ES affect agricultural productivity. Managing agricultural lands to provide more ES and higher quality ES may be essential for the long-term sustainability of agricultural ecosystems. Most agricultural lands, however, are managed for the short-term production of food, fiber, and fuel, often at the expense of other ES. Proposed solutions to the underprovision of ES often involve government regulation or market incentives. A growing number of scholars, however, recognize the potential for a third approach —cooperative solutions. One important element in determining if an ES is a suitable candidate for cooperative solutions is its resource characteristics. Accordingly, this paper: 1.) provides a framework for determining an ES's suitability for collective management based on its resource characteristics, 2.) provides an in-depth analysis of three agricultural-based ES to show how the framework differentiates between ES and 3.) uses the framework to analyze fourteen agricultural-based ES for their suitability for collective management. Ten out of the fourteen ES analyzed may be well suited (e.g. pollination), suited (e.g. flood control), or moderately suited (e.g. nature recreation) for collective management under current incentive systems in agricultural ecosystems.

1. Introduction

Agricultural ecosystems comprise about half of global land that is not desert, tundra, rock, or boreal, which makes farmers the chief managers of the most productive lands on Earth (Tillman et al., 2002). How farmers manage this land greatly impacts human health and well-being, the land's future productivity, neighboring ecosystems such as wetlands and forest, and the sustainability of the world food supply (Foley et al., 2005; Horrigan et al., 2002). Despite this importance, most farmers face strong incentives to manage their land for the short-term production of food, fiber, or fuel. The long-term health of agricultural ecosystems, however, as well as their ability to sustain food production and to provide society with diverse benefits, requires that farmers expand their management focus to include the provision of ecosystem services (ES) (Goldman et al., 2007; MEA, 2005). In fact, some scholars argue that one of the greatest needs in agriculture, if not the greatest, is the provision of non-production related ES such as water purification and climate regulation (e.g. Antle and Capalbo, 2002).

Most scholars agree that increasing the provision of ES in agricultural ecosystems will not be easy (e.g. Goldman et al., 2007). Robertson and Swinton (2005) called it "a grand challenge for agriculture," while Lant et al. (2008) coined the underprovision of ES "The Tragedy of Ecosystem Services" in honor of Hardin (1968). Like Hardin, Lant et al. (2008) proposed that the solution to the tragedy is government control or privatization. In fact, most proposed solutions to the underprovision of ES in agricultural ecosystems involve the common government or market approaches to provision of a public good (see Bräuer et al., 2006; Kroeger and Casey, 2007; Swinton et al., 2007 for an overview of government and market solutions).

A growing number of scholars, however, recognize the potential of a third major approach—cooperative solutions where landowners work together to provide ES (e.g. Sarker et al., 2008). Proponents of this approach often point to the spatial scale-mismatch between ES and agriculture as justification for its necessity (e.g. Goldman et al., 2007). In other words, the spatial scale of management in agricultural ecosystems (e.g. a 500 acre farm) often does not match the spatial scale of ecosystem processes necessary to provide ES (e.g. a tri-county watershed), making cooperation necessary (Cumming et al., 2006; Pelosi et al., 2010). Like market and government solutions, cooperative solutions involve costs and benefits that must be carefully examined to determine the most efficient, politically feasible, and socially feasible way to achieve a desired level of ES provision. One important step in this process is to determine which ES may be candidates for provision through cooperative solutions and which may not.

Previous studies involving cooperative solutions for ES provision in agriculture have focused on 1.) a natural habitat type within agricultural landscapes, such as wetlands, that may be provided or

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doi:10.1016/j.ecolecon.2011.08.016

restored using collective action and that, in turn, may provide a variety of ES (e.g. Hodge and McNally, 2000), 2.) a single ES, such as water quality, which may be provided through collective management in certain situations (e.g. Sarker et al., 2008) or 3.) the need for landowners to cooperate to achieve landscape level benefits in providing ES (e.g. Goldman et al., 2007). Additionally, Ayer (1997) proposed that collective action may solve many agriculture-related environmental problems and discussed some factors which may make collective action a success or a failure in certain situations. No study, however, has analyzed ES for characteristics which may make some ES better suited than others for collective management. In fact, most previous studies make no or few distinctions between individual ES when discussing cooperative solutions for the provision of ES in agricultural ecosystems (e.g. Heal et al., 2001).

Resource characteristics are one of four key factors that influence the costs and benefits of the collective management of a natural resource, along with community characteristics, institutional characteristics and organizational characteristics (Lubell, 2004; Lubell et al., 2002; Ostrom, 1990, 2001). Important resource characteristics may include the size of the resource stock, whether the stock is stationary or moving (e.g. a lake vs. a stream), the predictability of the resource flows (e.g. fish growth), or what type of benefit users may obtain from the resource (e.g. income or recreation) (Ostrom, 2001). Resource characteristics affect the likelihood that collective management will be undertaken and the likelihood that undertaking will be successful (Ostrom, 1990). The resource characteristics of an ES, therefore, may be important in determining whether or not it is a suitable candidate for provision by collective management.

Accordingly, my paper will: 1.) Provide a framework for determining an ES's suitability for provision by collective management based on its resource characteristics, 2.) Provide an in-depth analysis of three agricultural-based ES to show how the framework differentiates between ES and 3.) Use the framework to analyze eleven other agricultural-based ES for their suitability for provision by collective management. This paper, however, will not provide a comparative analysis of government solutions, market solutions, and cooperative solutions for the provision of ES in agricultural ecosystems.

2. Background

2.1. Ecosystem Services

Ecosystems may be viewed as a form of natural capital which provides flows of vital goods and services to humans (e.g. Daily, 1997). These goods and services are called ecosystem services (ES) and are often defined as the "benefits people obtain either directly or indirectly from ecosystems (MEA, 2005)." Many ES are critical to human survival (e.g. climate regulation and water cycling), while others contribute to our well-being (e.g. nature recreation and esthetic landscapes) (Kremen, 2005).

Dale and Polasky (2007) identified three critical ways in which ES interact with agriculture. First, agricultural ecosystems provide many ES, including production services such as food and fiber; regulating services such as soil retention and pest control; supportive services such as nutrient cycling and water filtration; and cultural services such as spiritual well-being and rural lifestyles (see Table 1). Second, agriculture requires many ES as inputs to production, especially soil fertility, pollination and pest control (Zhang et al., 2007). Third, agriculture affects the quality and quantity of ES which other ecosystems, such as forests and estuaries, can provide (Dale and Polasky, 2007). If the effects on other ecosystems are negative, they are called "disservices" of agriculture and often lay on the opposite end of a continuum from some important ES (Table 1). For example, if a farmer practices conservation tillage, his land may provide the vital ES of soil retention. If, however, a farmer uses conventional tillage practices on sloped land, his land may provide the opposing disservice of soil erosion, plus the resulting environmental degradation caused by stream sedimentation, loss of soil fertility, and the chemical contamination of water (Dale and Polasky, 2007).

Table 1
Selected ecosystem services (ES) and disservices (ED) from agriculture.

ES type	ES from agriculture	ES used as inputs	ED from agriculture
Regulating services	Soil retention	Soil retention	Soil erosion
	Pollination	Pollination	Competition for pollination
	Pest control	Pest Control	Pest outbreaks
	Water purification		Nutrient run-off Pesticide run-off
	Habitat provision		Habitat loss
	Atmospheric regulation		Greenhouse gas emissions
	Flood control		Flooding
	Seed dispersal		Loss of seed dispersal
Supporting services	Soil structure	Soil structure	Soil compaction
	Soil fertility	Soil fertility	Soil fertility loss
	Biodiversity	Genetic biodiversity	Biodiversity loss
	Water cycling	Soil moisture	Soil moisture loss Competition for water from other ecosystems
	Nutrient cycling	Soil nutrients	Eutrophication of rivers, estuaries, and lakes
Cultural services	Esthetic landscape		Loss of esthetic value
	Recreation		Loss of recreation value
	Spiritual well-being		Loss of well-being
	Rural lifestyles		Loss of rural culture and lifestyles
Production services	Food		
	Fuel		
	Fiber		

Sources: Zhang et al., 2007; Tillman et al., 2002; Swinton et al., 2007; Dale and Polasky, 2007; Barrios, 2007; Millennium Ecosystem Assessment, 2005.

As a result of these three ways in which agriculture interacts with ES—the ability to provide ES, the requirement of ES as inputs, and the ability to affect neighboring ecosystems' provision of ES—managing agricultural lands to provide more ES and higher quality ES has the potential to greatly increase the sustainability of agricultural ecosystems, to increase the sustainability of neighboring ecosystems, and to decrease the environmental damage which may accompany intensive agriculture (MEA, 2005; Tillman et al., 2002). Most scholars agree, however, that increasing ES provision in agricultural ecosystems will likely require society to change the incentive structure that farmers face (e.g. Swinton et al., 2007).

2.2. Incentive Structures in Agricultural Ecosystems

Incentive structures in most agricultural ecosystems encourage farmers to manage their land for the short-term production of food, fiber, or fuel, often at the expense of other ES (Swinton et al., 2007; Tillman et al., 2002). For example, most farmers manage their land for the provision of production-related ES, such as wheat (*Triticum* spp.), because these services are private goods; the farmer enjoys most of the benefits of production (e.g. income from the crop) but does not pay all of the costs (e.g. loss of income in a downstream community due to eutrophication of fisheries). Likewise, farmers disfavor the provision of cultural, supportive, or regulating ES, such as water purification, because the farmers pay all (or most) of the costs of provision (e.g. leaving land out of production next to a stream) but only enjoy a portion of the benefits (e.g. better bird watching on the farm). In some cases, farmers pay all of the costs of provision but receive no benefits because their efforts have no discernable effect on the ES (e.g. one farmer's effort to improve water quality in a large lake) or because the ES is appropriated by other users (e.g. flood control for downstream communities).

Incentive structures where the provider pays all or most of the provision costs but only receives a portion of the benefits are associated with public or quasi-public goods, which are how most scholars classify

ES (e.g. Swinton et al., 2007). This incentive structure leads to an underprovision of ES because of the free-riding problem—a problem which is often solved by government or market solutions (e.g. Kroeger and Casey, 2007). In the case of agricultural-based ES, these solutions are designed to increase provision by changing the incentive structure that farmers face. This may mean 1.) increasing the cost of not providing an ES (e.g. assessing a fine if a farmer fails to create a buffer zone along a stream corridor) or 2.) increasing the benefit of ES provision (e.g. creating a mechanism for farmers to receive price premiums on products that are produced in conjunction with ES).

The goal of most government and market solutions is to entice enough farmers to manage their land for the provision of nonproduction-related ES so that a socially-desired quantity of ES is achieved. One potential problem with these approaches, however, is that they often ignore the fact that many ES require landscape level management to provide optimal benefits (Goldman et al., 2007). In other words, individual incentive approaches ignore the potentially large and important incentive of a collective benefit which only may be achieved if most of the farmers in the region cooperate in their management effort.

2.3. The Collective Benefit of Collective Management

Ostrom (1990) argues that collective management is a viable, yet commonly-overlooked, third solution to the underprovision of a natural resource. Collective management often involves a group of citizens who jointly manage a community-owned property, such as a group of herdsmen who manage a common pasture. It may also involve a group of citizens who jointly manage individually-owned properties, however, such as members of a neighborhood association who jointly make and follow rules regarding noise levels in order to better enjoy their neighborhood.

When people work together they often achieve a collective benefit that could not be achieved by the group members' individual efforts. In the collective management of a natural resource, most participants hope to achieve the collective benefit of a stable resource base, although other collective benefits may also be achieved. For example, an inshore fishery in Alanya, Turkey was threatened by hostilities, harvest uncertainty, and lost productivity because fishers were fighting over the most productive fishing spots (Berkes, 1986). In response, members of the local fishing cooperative devised a set of rules which assigned fishing spots on a daily basis, giving each fisher an equal chance to fish highly productive spots and less productive spots. This collective management regime, enforced by the fishers themselves, created a more productive fishery since better spacing of the fishers optimized production at each site. In addition, fishers no longer wasted resources searching for or fighting over sites, plus they achieved more harmonious relationships within their community. Each of these benefits represents a collective benefit that could not have been achieved by the fisher's individual efforts. These collective benefits were only achieved because the fishers worked together to devise and enforce a set of rules for managing the local fishery (Ostrom, 1990).

In the collective management of an ES, participants may hope to achieve the collective benefit of enhanced ES provision, environmental damage mitigation or the prevention of future regulations (e.g. Lubell, 2004). For example, Ayer (1997) describes cotton (*Gossypium* spp.) farmers in Arizona who collectively managed for pest control by practicing collective integrated pest management (IPM)—a management system that requires monitoring pest populations and only applying pesticides when a certain threshold is reached. After devising and enforcing a set of collective IPM rules, these farmers achieved fewer pest outbreaks, drastically reduced input costs, and fewer confrontations with neighboring communities regarding water and air quality issues—benefits that were only achieved when most of the cotton farmers in a region worked together to enhance the ES of pest control (Ayer, 1997).

3. Framework

Ayer's (1997) example of collective IPM illustrates collective management's potential to provide a higher quantity and quality of the ES, pest control, along with other important benefits. To determine which other ES may be candidates for provision through collective management, society needs a way to assess ES for collective management suitability. Accordingly, I have developed a framework for analyzing agricultural-based ES for resource characteristics which could enhance or detract from collective provision.

To develop this framework, I reviewed collective action theory and empirical research for key elements that make collective action or collective management more likely to happen or to succeed. These key elements include the potential for positive net benefits, a low heterogeneity of participants, opportunities for face-to-face communication, a low number of participants, social linkages between participants, and information about participants' past actions (Olson, 1965; Ostrom, 1990, 2001, 2009). Next, I used these key elements to identify six characteristics of ES that may affect their suitability for collective management. These characteristics are:

1.) Potential for enhancement of ES quality or quantity by landscape level management.
2.) Potential for direct private benefits (i.e. the ES is important to the provider).
3.) Potential for indirect private benefits (i.e. the ES is important to other potential appropriators).
4.) Potential to bundle ES with the provision of other ES.
5.) Number of participants needed to provide or enhance ES (i.e. how much well-managed land is required to provide the ES).
6.) Heterogeneity of participants needed to provide or enhance ES.

After identifying these six characteristics, I devised a classification system to assess whether an ES possesses the characteristics in a high, moderate, or low quantity. In addition, I developed a ranking system based on these classifications to assess the overall suitability of an ES for provision through collective management. In the following sections, I provide an in-depth discussion of the characteristics along with a justification of my classification system.

3.1. Potential to Enhance ES Quality or Quantity through Landscape Level Management

Collective action theory predicts that people will only act collectively to provide benefits which are enhanced or increased through cooperation. In other words, if a benefit can be provided adequately through individual effort, then it will not be provided collectively (Olson, 1965).

Farm-level management of some ES, such as soil fertility, may provide society with enough benefits to make landscape level management unnecessary or undesirable. For these ES, how one farmer manages his land usually does not affect ES provision on another farmer's land. Most ES, however, require landscape level management to provide optimal benefits (Heal et al., 2001; Tscharntke et al., 2005). These ES may require management over a large area, a specific landscape configuration or both (Goldman et al., 2007). For example, pest control services depend on species richness and abundance of pest predator species, which in turn depend on the quantity, quality and landscape configuration of breeding, resting and foraging habitat (Dale and Polasky, 2007). Thus, a typical Midwestern farmer with a 550 acre farm (Archer et al., 2002) may not be able to set-aside enough habitat to support a population of pest predators and still grow crops, but the habitat provision efforts of many farmers working together could support multiple predator populations and in turn, enhance pest control in the region.

In my framework, I classify an ES as having a high potential for enhancement through landscape level management if the quantity, quality and stability of the ES depend on a specific configuration of management activities over a land region larger than a single farm. In other words, I classify an ES as "high" if the management activities of a farmer's neighbors greatly affect the farmer's ability to provide the ES (e.g. flood control), and I classify it as "low" if the management activities of a farmer's neighbors have little effect on a farmer's ability to provide the ES (e.g. soil fertility) (see Table 2). ES that are classified as "high" are most suitable for provision through collective management although some that are classified as "moderate" (e.g. soil retention) may also be suitable in some situations (White and Runge, 1994).

3.2. Potential for Direct Private Benefits for the ES Provider

Collective action theory and empirical research show that if participants believe they will gain more from collective action than participation will cost, then they will participate (e.g. Loehman and Dinar, 1994; Olson, 1965). Although net benefits depend on each provider's unique situation and, therefore, cannot be easily determined, it is likely that ES with a high potential to supply direct private benefits to the provider are more likely to supply a net benefit than those with a low potential. Direct private benefits may include: 1.) direct economic benefits, such as increased crop yields due to increased soil fertility and 2.) direct social or cultural benefits, such as increased wildlife viewing due to habitat provision.

Some ES are inputs to agriculture (e.g. pollination) and can be produced jointly with goods such as wheat (Wossink and Swinton, 2007). These ES supply the provider with the direct economic benefits of lower input costs and increased crop yields, and are more likely to be provided than other ES (Wossink and Swinton, 2007). In contrast, other ES supply little direct economic benefit to the provider (e.g. flood control) although the same ES may provide substantial economic benefits to other appropriators (e.g. down-stream municipalities). Additionally, ES vary greatly in the social and cultural benefits they provide, especially since the value of these benefits is subjective and personal (e.g. the value placed on seeing a new bird species differs greatly from one farmer to the next).

In my framework, I classify ES which are inputs to agriculture as having a "high" potential to supply direct private benefits to providers (e.g. soil fertility) (see Table 2). I classify an ES as "moderate" if it has a small potential for economic benefits but a high potential for cultural or social benefits (e.g. nature recreation), and I classify an ES as "low" if it is only valuable to the provider in the same measure it is valuable to all members of society (e.g. carbon sequestration). ES that are classified as "high" are most suitable for provision through collective management, although those that are classified as "low" or "moderate" may also be suitable if the ES has a potential to supply indirect benefits to the provider.

3.3. Potential for Indirect Private Benefits for ES Providers

If an ES is important to other appropriators besides the provider, then the provider may receive an indirect private benefit. Indirect benefits may include payments for the provision of flood control to downstream communities, hunting leases for access to private land with wildlife habitat or avoidance of threatened regulations due to water purification services (Hoffman, 2008; Knoche and Lupi, 2007; Salzman et al., 2001). Indirect benefits increase the total benefits available to ES providers, which in turn increase the net benefits for providers and the likelihood the ES will be provided through collective action (Olson, 1965).

In my framework, I classify ES which have a high economic importance to appropriators other than the providers as having a "high" potential for indirect private benefits (e.g. flood control) (Table 2). I classify an ES as "moderate" if it has a high cultural or social, but low economic, importance, to other appropriators (e.g. nature recreation). I classify all other ES as "low" (e.g. soil fertility). ES that are classified as "high" are most suitable for provision through collective management, although those that are classified as "low" or "moderate" may also be suitable if the ES has a high potential for direct benefits.

3.4. Potential to bundle the ES with provision of another ES

Many ES are so interrelated that it is hard to distinguish one from the other or to define them (Dale and Polasky, 2007; Swinton et al., 2007). For example, soil retention, soil structure and soil fertility are interrelated in complex ways and could be lumped together in one ES called soil services. Likewise, soil fertility is already a conglomeration of many ES, including dung burial, habitat for microorganisms, nutrient cycling, soil aeration, and soil moisture (Barrios, 2007;

Table 2
Analysis of agricultural-based ecosystem services (ES) for their suitability for provision through collective management by using a classification framework based on the characteristics of the ES that may enhance collective action.

Ecosystem service	Potential for landscape level enhancement	Direct benefit potential for ES providers	Importance to other potential appropriators	Potential to bundle with other ES[a]	Number of providers needed to enhance ES	Heterogeneity of providers needed to enhance ES	Suitability for collective management
Pollination	High	High	Moderate/low	Pest control, habitat	Low	Low/moderate	Highly suited
Pest control	High	High	Moderate	Pollination, habitat	Low	Low/Moderate	Highly suited
Flood control	High	Low[b]	High	Habitat, soil-related ES	Moderate/high	High	Suited
Water purification	High	Low/moderate[b]	High	Soil-related ES, most other ES	High[c]	High	Suited
Recreation	High	Moderate	Moderate	Habitat	Moderate	Moderate	Moderately suited
Biodiversity	High	Low	Moderate	Habitat recreation	High	High	Moderately suited
Habitat provision (mega fauna)	High	Low	Moderate	Recreation	Moderate	Moderate	Moderately suited
Esthetic landscapes	Moderate/high	Moderate	Moderate		Moderate	Low/moderate	Moderately suited
Habitat provision (other spp.)	Moderate/low	Low	Low		Low/moderate	Low/moderate	Not suited
Soil retention	Moderate/low	High	Moderate/high	All soil-related ES	Low/moderate	Low/moderate	Moderately to not suited
Soil fertility	Low	High	Low	All soil-related ES	Low	Low	Not suited
Soil structure	Low	High	Low	All soil-related ES	Low	Low	Not suited
Carbon sequestration	Low	Moderate	Moderate	All soil-related ES	Low	Low	Not suited

Highlighted classifications represent the characteristic that corresponds to the greatest suitability for provision through collective management.
[a] This column includes ES that are also provided at high levels in agricultural ecosystems when the main ES is provided at high level.
[b] Provider of this ES is often not the appropriator.
[c] ES may be provided by individual land owners, yet the good associated with this ES requires a high level of participation in a potentially large geographical region (e.g. water quality is the good associated with water purification).

Swinton et al., 2007). Because of the interrelatedness of ES, it is hard to manage for one without enhancing the provision of another. For example, leaving a buffer zone along stream corridors to enhance water quality also enhances pollination, pest control, nature recreation, habitat provision, biodiversity and all soil-related ES.

Bundling the provision of one ES with other ES could increase the likelihood that collective management will be undertaken or succeed because it increases potential group benefits. For example, if farmers know that participating in collective IPM will enhance pollination as well as pest control, then they may be more likely to participate. Likewise, if a group forms to provide one ES, then it may be able to increase its collective benefits with few additional costs by providing a second ES.

Because all ES have the potential to be bundled with provision of other ES, I do not use the classifications of high, medium or low for this characteristic in my framework. Instead, I list other ES that are often provided at a high level when the main ES is provided at a high level (Table 2). For example, if a farmers' cooperative provides a high level of biodiversity, then it most likely provides a high level of habitat as well. Likewise, if a group of citizens provides high water quality through watershed protection, then they usually provide flood control, too (Salzman et al., 2001).

3.5. Number of Participants Needed to Provide or to Enhance the ES

Collective action theory predicts that small groups may be more effective for collective action because 1.) they face lower transaction costs (e.g. fewer people must agree) (Olson, 1965), 2.) individual participants are more likely to see the effect of their own contribution and to consider it valuable (Olson, 1965) and 3.) face-to-face communication among participants is more likely (Ostrom, 2009).

Although small groups may be desirable, in the case of natural resource management a moderate size group may be needed to provide enough resources (e.g. land) to achieve a collective benefit (Agrawal, 2000). As discussed in Section 3.2, many ES are enhanced by landscape level management. They differ greatly, however, in the land area required. For example, pest control is considered a local service (Kremen, 2005) and may be enhanced by a small number of farmers (perhaps as few as 10–25, depending on farm size) who own farms in close proximity. Although a larger number of participants over a greater area may increase pest control (by decreasing the odds of regional pest outbreaks), cooperative benefits are possible with a relatively small number of participants. On the other hand, some ES require a larger land area (and, thus, most likely a larger number of participants) to provide enhanced cooperative benefits. For example, the service of flood control is considered a regional service (Kremen, 2005) and may depend on the cooperative efforts of landowners in a tri-county (or tri-state) watershed (Salzman et al., 2001).

In my framework, I classify local ES (those that may be enhanced by a group of less than 25 farmers) as "low," those that may be enhanced by the collective efforts of up to about 100 participants as "moderate," and regional or global ES (those that require hundreds, perhaps thousands of participants) as "high" (Table 2). ES that possess a relatively low participation requirement may be easier to provide through collective management (e.g. habitat) than those with a high participation requirement (e.g. water quality).

3.6. Heterogeneity of Participants Needed to Provide or to Enhance the ES

Collective action scholars disagree whether heterogeneity increases or decreases the likelihood of successful collective action. Olson (1965) argues that when a few individuals have a much stronger interest in a collective good than the rest of the group it has a greater chance of being supplied. Most scholars, however, argue that heterogeneity decreases the ability of participants to cooperate and increases transaction costs (e.g. Johnson and Libecap, 1982). Heal et al. (2001) claim that "the larger the number of political entities required to make a decision, the greater the costs of collective action and, therefore, the less likely action will be taken." In other words, ES which require large, diverse land areas for their provision, and therefore involve a diverse group of political actors, will be harder to provide through collective management.

Heterogeneity is also hard to define in the context of collective management of agricultural ecosystems. The least heterogeneous group might include farmers that live in the same township and grow the same crop. A more heterogeneous group may include all the wheat farmers, dairy farmers, and orchardists within the township. However, this group could also be defined as homogenous, since each member is a farmer from the same geographical area. Furthermore, groups that include only farmers may benefit from the high social capital that often exists in rural communities (Onyx and Bullen, 2000) Numerous social links between participants, knowledge of participants' past actions (e.g. previous experience with collective action like growers' cooperatives) and other aspects of social capital, such as trust, are important in determining if collective action will be successful (Ostrom, 1990; Pretty, 2003).

In the case of ES, a relatively homogenous group could supply some ES, while others may require cooperation between people of diverse backgrounds. For example, a group of farmers could supply pest control for their own appropriation, but it may take a diverse group of people (e.g. farmers, developers, suburban land-owners and factory owners) to supply water quality (Hoffman, 2008).

In my framework, I classify an ES as requiring a "low" heterogeneity of participants if the ES can be provided by a group of farmers from a relatively small geographic area (Table 2). I classify an ES as requiring a "high" heterogeneity of participants if diverse groups of people (such as farmers and factory owners) over a large area are needed for provision (Table 2). ES that require "low" heterogeneity of participants (e.g. esthetic landscapes) may be more suitable for collective management than ES that require a "high" heterogeneity of participants (e.g. biodiversity).

3.7. Overall Suitability Rankings

By using my classification system for the six resource characteristics, I developed a ranking system that summarizes the overall suitability of an ES for provision through collective management (Table 2). The ranking categories range from "highly suited" to "not suited" and are based on the following hierarchical ordering of the resource characteristics.

1.) Potential for enhancement of the ES by landscape level management.
2.) Potential for direct and/or indirect private benefits for ES providers.
3.) Potential to bundle ES with the provision of other ES.
4.) Number and heterogeneity of participants needed to provide or enhance ES.

The potential for enhancement through landscape level management is first in the hierarchical orderings because according to collective action theory, the potential to supply a collective benefit is a necessary but not sufficient condition for collective action success (Olson, 1965). Second in the orderings, the collective benefit should include a net benefit to participants (i.e. potential for direct private benefits, potential for indirect private benefits and, to a lesser extent, the ability to bundle provision of ES with another ES) (Loehman and Dinar, 1994; Olson, 1965). Finally, the transaction costs that arise through a high participant number and participant heterogeneity may be overcome by high net benefits (Hoffman, 2008), so these characteristics are ordered last.

To receive the ranking "highly suited" for provision through collective management, an ES must have 1.) a high potential for landscape level management, 2.) a high potential for either a direct or indirect private benefit, 3.) the potential to be bundled with another ES, and 4.) a low or moderate number and heterogeneity of participants needed. To receive the ranking "suited" the ES must meet the same requirements above except it may require a high number or high heterogeneity of participants. To receive the ranking "moderately suited," the ES must have

1.) a high or moderate potential for enhancement through landscape-level management, 2.) at least a moderate potential for either a direct or indirect private benefit, 3.) the potential to bundle with another ES and 4.) a low or moderate number and heterogeneity of participants. To receive the ranking "poorly suited," the ES must have 1.) a moderate potential for landscape level enhancement, 2.) at least a moderate potential for either direct or indirect benefits 3.) no bundling potential and 4.) at least one moderate or low classification for number or heterogeneity of participants (i.e. one may be high). All other ES receive the ranking, "not suited," including all ES that have a low potential for landscape level enhancement.

4. Application of the Framework

After developing my framework, I used it to analyze 14 agricultural-based ES to assess for their suitability for provision through collective management. In the following section, I provide an in-depth analysis of three ES to show how the framework differentiates between the ES in determining suitability. Afterwards, I summarize my results for the remaining eleven ES.

4.1. Pollination Services Background

In the United States, almost 90 crop species rely on pollination by the non-native honeybee (*Apis mellifera*). Native bees also provide valuable pollination services, as do other pollinating insects, birds and bats (Gallai et al., 2009). Recent trends in agricultural intensification, habitat loss and pesticide use, however, have depleted wild pollinator and commercial honeybee populations (Johansen, 1977; Kremen et al., 2002; Steffan-Dewenter et al., 2002). Additional factors such as disease, colony collapse disorder, malnutrition, mite infestation, Africanization, and the elimination of honey subsidies have also contributed to the decline in bee colonies—a decline many scholars call "the pollination crisis" (Nabhan and Buchmann, 1997; VanEngelsdorp et al., 2009).

Pollination services may be promoted by interspersing cropland with patches of native or semi-native habitat, providing season-long floral resources (e.g. planting wildflowers that bloom after crops), and reducing or eliminating pesticide application (Brosi et al., 2007; Fussell and Corbet, 1992; Kearns et al., 1998; Parker et al., 1987). For example, Kremen et al. (2002) found that native bee communities could provide full pollination services for watermelon (*Citrullus lanatus*), a crop with heavy pollination requirements, on organic farms located near natural habitat. All other farms (i.e. farms that used pesticides or were not located near native habitat) required commercial pollination services to sustain desirable yields (Kremen et al., 2002).

4.2. Analysis of Pollination Services for Collective Management Suitability

4.2.1. Potential for Enhancement of Pollination Services by Landscape Level Management—High

Many scholars believe landscape level management is important, if not essential, for the provision of pollination services (e.g. Goldman et al., 2007). For example, a bee population may require one large patch of habitat or many small patches arranged in an optimal configuration over a larger landscape. A typical Midwestern farmer (farm size 550 acres) most likely will not be able to set aside enough land to support the population and still produce crops. If many farmers, however, work together to set aside a few habitat patches each in an optimal configuration, then larger, healthier, and more diverse populations of pollinators may be supported, increasing the quantity, quality and stability of pollination services in the region.

4.2.2. Potential for Direct Private Benefits for Pollination Service Providers—High

Pollination is a required input to production for many crops. Thus, providers may benefit directly by: 1.) an increased effectiveness of commercial pollination, 2.) a reduced need for or an elimination of commercial pollination, 3.) increased yields, 4.) stable pollination during times of reduced commercial or hobby bee-keeping and 5.) pollination of gardens and orchards kept for home production (Kremen, 2005; Kremen et al., 2002; Nabhan and Buchmann, 1997).

4.2.3. Potential for Indirect Private Benefits for Pollination Service Providers—Low

Few people have an interest in pollination services besides potential providers, although people who keep bees for honey production may provide an indirect benefit to some farmers. Bee-keepers are providers (not non-providing appropriators) since they provide breeding and resting habitat for honeybees. However, they rely on other providers to supply foraging habitat so their bees may produce high-quality honey. Accordingly, it is common for bee-keepers to locate hives on a farmer's land, often in exchange for a small payment of cash or honey to the farmer, although some bee-keepers combine honey production with commercial pollination and charge the farmer a fee instead.

4.2.4. Potential to Bundle Pollination Services with the Provision of other ES—Pest Control

Pest predator populations (mostly birds and insects) may be supported by interspersing cropland with native or semi-native habitat patches and by practicing IPM (Dale and Polasky, 2007), two of the three recommended management practices for pollination services. Thus, farmers who provide a high level of pollination services should also provide a high level of pest control.

4.2.5. Number of Participants Needed to Enhance or Provide Pollination Services—Low to Moderate

Pollination services are a local service, although the land area needed to provide high quality pollination services may depend on the region, the crops, local landscape configurations, and the pollinating organisms (Kremen, 2005). In many situations, as few as 5–25 farmers/landowners working cooperatively could achieve the collective benefit of enhanced pollination services. In other situations, such as in a region intensely managed for the production of crops at the exclusion of natural habitats, greater than 25 providers may be needed.

4.2.6. Heterogeneity of Participants Needed to Enhance or Provide Pollination Services—Low to Moderate

Although pollinating organisms require landscape level management, pollination may be provided without requiring people of diverse backgrounds and needs to agree on a management plan (e.g. farmers, politicians, and developers). In many situations, a relatively homogenous group of farmers from a region could work collectively to achieve a greater benefit than they could have achieved by their individual efforts. Collective management of pollination services may be most suitable in areas where many, if not most, of the farmers require pollination (i.e. they are homogenous in their needs as well as their cultural background). In regions where farmers who need pollination are interspersed with farmers who do not, a more heterogeneous group may be required.

Pollination has a high potential for enhancement though landscape level management, a high potential for direct private benefits for providers, may be bundled with pest control, and requires a low to moderate number and heterogeneity of participants. Thus, pollination is highly suited for collective management.

4.3. Recreation Background

Recreation in agricultural ecosystems may involve consumptive uses (e.g. hunting) or non-consumptive uses (e.g. nature photography) (Knoche and Lupi, 2007; Swinton et al., 2007). Thus, to provide recreation, agricultural ecosystems must support animals and plants that people like to hunt, view, or photograph. In addition, agricultural ecosystems must provide these animals and plants in a way that creates recreational satisfaction. Satisfaction may depend on species abundance, species richness, visibility of animals or plants, places to stop and view wildlife, hunting or fishing success, low density of people, water quality, landscape esthetics, and whether or not recreation expectations were met (Decker et al., 1980; Graefe and Fedler, 1986; Hammitt et al., 1993; Stankey et al., 1973).

Accordingly, recommended management practices include practices that increase species richness, species abundance or water quality such as restoring marginal lands to their original cover (e.g. native grass) or to other perennial vegetation, establishing grassed waterways, establishing hedge rows or woody fence rows, increasing structural diversity of crops, increasing structural diversity of farmstead vegetation, delaying mowing of hay crops and headlands, and planting buffer zones in riparian areas (Bryan and Best, 1991; Camp and Best, 1993; Freemark, 1995; OECD, 1999; Stallman and Best, 1996).

4.4. Analysis of Recreation for Collective Management Suitability

4.4.1. Potential for Enhancement of Recreation by Landscape Level Management—High

Species richness, species abundance and water quality depend on the quantity and type of management activity practiced and the spatial configuration of the activity within the landscape (Goldman et al., 2007; Kremen, 2005). Thus, recreation experiences where satisfaction depends on an abundance of one species (e.g. hunting), on a high level of species richness and abundance (e.g. bird watching) or on water quality (e.g. swimming) may be enhanced by landscape level management.

4.4.2. Potential for Direct Private Benefits for Recreation Providers—Moderate

Recreation has a high potential to provide a direct cultural benefit to providers but a low potential to provide a direct economic benefit.

4.4.3. Potential for Indirect Private Benefits for Recreation Providers—Moderate

Recreation providers may achieve the indirect private benefit of hunting or fishing leases, although benefits vary with region and species of interest (Knoche and Lupi, 2007). For example, Livengood (1983) reports hunting leases in Texas of \$100–200 annually per gun, while Goodwin et al. (1993) report that hunters in Kansas are willing to pay \$31.32/year for leases. Additionally, increased crop damage by game animals may outweigh the benefits (Knoche and Lupi, 2007).

4.4.4. Potential to Bundle Recreation with the Provision of other ES—Habitat for Megafauna

To provide many satisfying recreational experiences, farmers must also provide habitat for animals such as birds and fish.

4.4.5. Number of Participants Needed to Enhance Recreation—Moderate

The land area and spatial configuration of management activities that are required to enhance the quantity or quality of recreation depend on the recreation being provided. As few as 5–20 participants may be able to enhance wildflower viewing along a country road, while hundreds of participants may be needed to provide high quality stream fishing (i.e. to provide fish habitat and high water quality).

4.4.6. Heterogeneity of Participants Needed to Enhance or Provide Recreation—Moderate

Provision of high quality recreation may require a diverse group of providers to cooperate (e.g. lake boating) or may be achieved by a relatively homogenous group of farmers (e.g. sight-seeing to view fall colors).

Recreation has a high potential for enhancement through landscape level management, but only a moderate potential for direct or indirect private benefits for providers. Thus, recreation is moderately suited for collective management.

4.5. Carbon Sequestration Background

Increases in the atmospheric abundance of CO_2 and other greenhouse gasses, have led many scientists and policy-makers to indentify strategies to mitigate climate change (Lal, 2004a). One strategy, carbon sequestration, is considered a win–win strategy that "will not solve the problem but buys us time until alternatives to fossil fuel are in effect (Lal, 2004b)." Carbon sequestration involves transferring atmospheric CO_2 into long-lived pools (e.g. forests) and storing it securely so it is not immediately re-emitted.

An important source of carbon sequestration for farmers is improving soil organic carbon (SOC) (Lal, 2004a; West and Post, 2002). This may be achieved by conservation tillage with cover crops and crop residue mulch, nutrient cycling with compost and manure, biologically efficient irrigation and other water conservation practices, rotation cropping, restoring marginal lands to their original cover or to other perennial vegetation, practicing agroforestry, and planting windbreaks and other woody vegetation around farmsteads and in hedgerows (Lal, 2004a, 2004b).

4.6. Analysis of Carbon Sequestration for Collective Management Suitability

4.6.1. Potential for Enhancement of Carbon Sequestration by Landscape Level Management—Low

Although climate regulation is a global issue, carbon sequestration may be provided by individual farmers (Lal, 2007). In other words, a farmer's management practices have little effect on a neighboring farm's SOC, except in the case of highly erodible soils where failure to retain soil on one farm may affect another farmer's ability to retain soil (White and Runge, 1994).

4.6.2. Potential for Direct Private Benefits for Providers—Moderate

Although providers of carbon sequestration only benefit from climate regulation in the same proportion as all humans, increased SOC also increases crop production (Lal, 2004a; West and Post, 2002).

4.6.3. Potential for Indirect Private Benefits for Providers—Moderate

Because mitigating climate change is important to governments, environmental groups, and other individuals, providers of carbon sequestration may have the potential to gain an indirect private benefit. Lal (2007) states that once carbon is sequestered in the soil, it can be traded like any other commodity. Thus, farmers may literally be able to "farm carbon" and sell it in a carbon market.

4.6.4. Potential to Bundle Carbon Sequestration with the Provision of other ES—All Soil-related ES

The management practices that improve SOC also provide soil fertility, soil retention, and soil structure (Lal, 2004a; West and Post, 2002).

4.6.5. Number of Participants Needed to Enhance or Provide Carbon Sequestration—Low

Carbon sequestration may be provided by individual farmers (Lal, 2007).

4.6.6. Heterogeneity of Participants Needed to Enhance or Provide Pollination Services—Low

Carbon sequestration may be provided by individual farmers (Lal, 2007).

Carbon sequestration has a low potential for enhancement by landscape level management, a necessary condition for suitability for collective management. Thus, carbon sequestration is not suited for collective management.

4.7. Analysis of Other ES for Collective Management Suitability

Results for my analysis of eleven other agricultural-based ES are summarized in Table 2. Two of the fourteen ES, pollination and pest control, are highly suited to provision through collective management. Two more, water purification and flood control, are suited to collective management, while another five (recreation, biodiversity, habitat provision for mega fauna, esthetic landscapes, and soil retention) are moderately suited. The final four ES (habitat for micro fauna, soil fertility, soil structure, and carbon sequestration) were not suited for provision through collective management because of a low potential for landscape level enhancement.

5. Discussion

In the development of my framework, I identified one resource characteristic—the potential for enhancement through landscape level management—which is essential for determining whether or not an ES may be a candidate for collective provision in agricultural ecosystems. Without this potential, a substantial collective benefit is unlikely to occur, giving farmers little or no incentive to participate in a group activity with high transaction costs (Olson, 1965). In my analysis, four of fourteen ES were not suited for collective management based on this resource characteristic alone. Thus, society must consider resource characteristics, especially the potential for enhancement through landscape level management, when choosing how to approach the ES underprovision problem.

The remaining five characteristics in my framework help differentiate between ES that are good candidates for provision through collective management and those that are marginal candidates. These characteristics are concerned with the benefits and costs of collective management and help determine the likelihood that farmers will voluntarily provide the ES through collective action. Unlike with the first characteristic, an unfavorable classification for any of these characteristics may be overcome depending on the context and regional importance of the ES. For example, White and Runge (1994) found that farmers who received a direct economic benefit were more likely to participate in collective action to control erosion in Haiti than those who did not, but this was not the only indication of who would participate. In other words, economic benefits were an important but not a necessary incentive. Likewise, in the 1990s water quality became so important in New York City that diverse citizens in the neighboring rural counties were able to overcome problems of heterogeneity, a large number of participants, and a lack of direct benefits in order to supply the city with higher water quality and themselves with the indirect benefit of escaped regulatory pressure (Hoffman, 2008; Salzman et al., 2001.)

Regional importance of the ES may in fact be one of most important factors in determining the likelihood of successful collective management. For example, Ayer (1997) reports that in years of extreme pest problems, cotton farmers in Arizona successfully managed pests by creating pest management districts that practiced collective IPM on a regional scale. When pest problems dissipated, however, interest in the districts also dissipated and many did not survive (Ayer, 1997). This example re-emphasizes an earlier point that many agricultural ecosystems are managed for short-term production gains, not long-term sustainability such as stable pest populations. It also points to an overarching problem that despite suitability for provision through collective management, few ES are being provided this way under the current incentive structures in agriculture.

Sandler (1992, p. 18) claims that "some forms of collective action come naturally, while other forms need government intervention." Likewise, many scholars propose that society needs to create more policies that provide incentives for people to cooperate in the provision of ES (e.g. Goldman et al., 2007). In fact, some scholars claim that government policies which induce cooperation may be the most cost effective way to provide ES (e.g. Hodge and McNally, 2000). In other words, the most effective approach for addressing the underprovision of ES in agricultural ecosystems may be a combination of the three major approaches—government solutions, market solutions, and cooperative solutions.

Most proposed policies that combine two or three of the major approaches are designed to induce voluntary cooperation among providers. Three examples are the 1.) agglomeration bonus which was designed to create larger patches of continuous habitat within single farms and across private boundaries (Parkhurst et al., 2002), 2.) cooperation bonus which expands on the idea of the agglomeration bonus by ensuring that the most important land for ES provision is retired (Goldman et al., 2007) and 3.) entrepreneur incentive which encourages landowners to cooperate in creating and implementing their own landscape design for ES provision (Goldman et al., 2007). A fourth proposed policy, ES districts, includes an element of coercion which Olson (1965) claims may increase the likelihood that collective action succeeds. These districts would have the legal power to manage ES by using a combination of voluntary incentives and regulations (Goldman et al., 2007; Heal et al., 2001).

This paper fills a gap in the literature by identifying which ES may be good candidates for collective management and which may not. Research is needed, however, to compare the costs and benefits of each major approach and the combined approaches to ES provision. Additionally, research is needed to determine what policies may best induce collective management of ES in agricultural ecosystems.

6. Conclusion

Although the recent trend in agricultural intensification in Western cultures has caused a decrease in the provision of ES in agricultural ecosystems (Björklund et al., 1999; Tillman et al., 2002), a third major approach to the free-rider problem – collective management – may help to reverse this problem. My analysis shows that many ES have characteristics that make them highly suited, suited, or moderately suited to provision through collective management, indicating that collective management may be a viable alternative to government or market solutions for some ES. Holling and Meffe (1996) argue that command and control is often an undesirable way to manage natural resources, claiming that command and control solutions lead to a pathology in management that decreases the quality and quantity of resources supplied. Likewise, numerous examples exist in which natural resources were seriously degraded when privatized or put under government control (e.g. Arnold and Campbell, 1986; Thomson et al., 1986). Instead of fully relying on these common solutions to the free-rider problem—privatization or government control—collective management provides an important alternative which has worked to provide stable natural resources in numerous long-term situations (Ostrom, 1990) and may also work to provide ES in agricultural ecosystems.

Acknowledgments

I thank Harvey James, Laura McCann, Tom Johnson and Joe Parcell for their helpful comments on this manuscript.

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