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FEATURE

Enhancing ecosystem services: Designing for multifunctionality

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It is increasingly recognized that ecosystem services provide a foundation for the well-being of individuals and society (MEA 2005). Land managers typically strive to enhance particularly desirable services. For example, farmers plant crops and manage the soil and hydrologic conditions to favor crop production. In agricultural regions such as the US Corn Belt, exceptionally high agricultural production has been achieved, but at the expense of other ecosystem services, including abundant wildlife and clean water. In the past, land managers were unaware of these tradeoffs or simply considered them less important in favor of a collective mindset to maximize agricultural production. More recently, however, there has been rising demand for a broader range of ecosystem services coupled with documented degradation of landscape capabilities to provide them. Concern over these circumstances has grown among policymakers, scientists, and conservationists (MEA 2005), and there is now a general recognition that we must be more deliberate in managing our agricultural landscapes for multiple ecosystem services (Brandt and Vejre 2004; Foley et al. 2005; Palmer et al. 2004; Secchi et al. 2008). How should conservation planners go about this task? What methods are available to guide them toward this goal? In this paper, we present a conceptual framework and discussion of some approaches to conservation planning that may help to move this endeavor forward.

The Millennium Ecosystem Assessment (MEA) program produced a conceptual framework that is useful for guiding how landscapes might be managed for multiple ecosystem services (figure 1). According to the MEA concept, ecosystem services are ecological functions that provide human benefits such as food and shelter and they consist of numerous interrelated biotic and abiotic processes (MEA 2003). This concept can be expanded by noting that while ecosystems are naturally multifunctional, they provide more or less of the services that people want within limits determined by landscape structure. Through modifications to landscape structure, however, land managers can rebalance ecosystem services in favor of those that are particularly desirable. To favor agricultural production, for example, structural modifications are typically made to vegetation type and genetic pool (crop variety and weed control), chemical pools (fertilizer), and hydrologic routing (drainage and irrigation). Landscape design, from this perspective, is a systematic method for deciding how landscape structure should be modified to favor those ecosystem services that we want or need to enhance (Selman 2009).

Enhancing multifunctionality to provide multiple ecosystem services has become particularly important for agricultural landscapes (Jordan and Warner 2010). Historically, the structure of these landscapes has been modified mainly to enhance crop production, but successes toward that goal created other problems. Conservation focused initially on controlling erosion of the soil resource that supports the agricultural production service. Now, however, conservationists additionally seek to enhance water quality, increase wildlife populations, and sequester carbon, among other ecosystem services, and to provide them in a sustainable manner. Since crop production for food and monetary benefits remains a primary service from agricultural landscapes, landscape modification for bolstering other ecosystem services must be accomplished efficiently, at low cost, and with minimum loss of crop production.

CONSERVATION PRACTICES

Enhancement of ecosystem services from agricultural landscapes in the United States is frequently accomplished by using methods developed and promoted by the USDA Natural Resources Conservation Service (NRCS). The building blocks of the USDA NRCS methods are conservation practices, each having specific design criteria for the purpose of solving a single or limited set of problems. For

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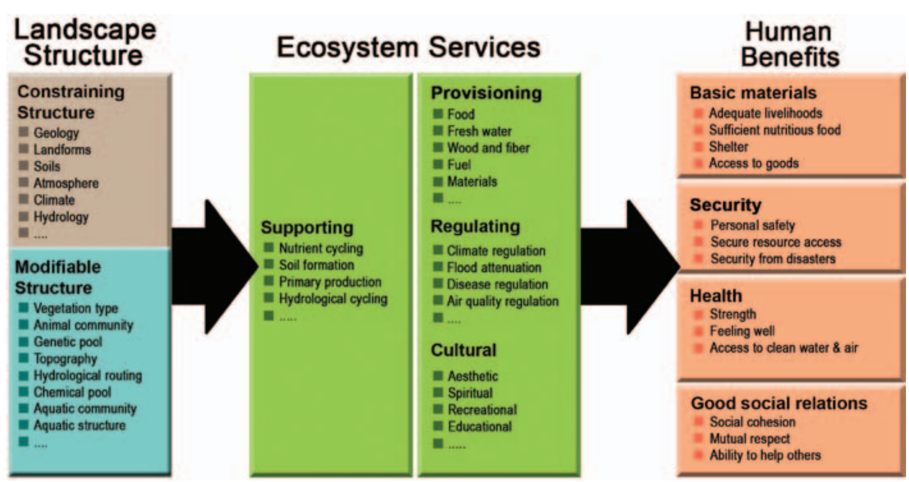
Figure 1

Linkage between landscape structure, ecosystem services, and human benefits. Adapted from Millennium Ecosystem Assessment (MEA 2005).



example, a Contour Buffer Strip practice (code 332) is designed to increase infiltration, reduce transport of sediment, and reduce sheet and rill erosion (USDA NRCS 2011a). To apply practices, a conservationist identifies a problem that exists on a site and then determines a practice or suite of practices that can adequately mitigate it. This approach has worked very well over past decades to reduce soil erosion while sustaining high levels of agricultural production.

As conservationists strive to bolster additional ecosystem services, however, some limitations of the USDA NRCS methods begin to emerge. First, individual conservation practices have restricted flexibility to be designed to optimize multiple ecosystem services. Typically, each practice is restricted to a few stated purposes, a narrow range of acceptable design, and may be limited to application on only certain land uses. Design adjustments may be considered for enhancing certain additional services, but only to the extent that they do not diminish effectiveness for the stated purposes. Adjustments are not allowed for other ecosystem services that a practice may be capable of providing that are beyond the range of requirements for the stated purposes and considerations. Each of these rules is intended to standardize the design and application of a practice to ensure acceptable performance and accounting for the stated purposes. On the other hand, they limit optimization of the design of a practice, which may diminish performance for a stated purpose, in order to deliver a broader range of desired ecosystem services. As a consequence, in order to deliver multiple benefits, two or more practices may need to be installed in separate locations, which may reduce crop acreage unacceptably, instead of a single, optimal, and less area-demanding practice in one location.

Second, not every ecosystem service has an USDA NRCS practice designed specifically for providing that service. For example, vegetative conservation practices (i.e., practices that involve establishment and management of vegetation) are designed primarily, if not exclusively, to control erosion, manage water, produce marketable products, and provide wildlife habitat, while other services that they could also provide, such as air quality, aesthetics, recreation, and restoration of natural ecological patterns and processes are often not considered. A practice design cannot be intentionally adjusted for a service that is not specifically listed as a purpose or consideration of the practice.

Third, conservation practices do not contain design criteria for providing landscape-scale ecosystem services. Creating landscape structures like corridors for enhancing populations of certain wildlife species may work only if connectivity is created across large distances that may include multiple farms or entire watersheds or even regions. Practices, however, are typically planned and designed for individual sites or farm fields. Whole-farm conservation planning and design are infrequently done. Consequently, success in creating larger-scale landscape structures like corridors is achieved mainly through unsystematic installation on multiple sites until an appropriate scale of connectivity is achieved. While USDA NRCS does provide procedures for landscape-level planning that would help chart critical locations for individual installations across landscapes, including Area-Wide Planning (USDA NRCS 2011b) and National Planning Procedures (USDA NRCS 2011c), they are rarely used.

Fourth, the process of selecting and designing USDA NRCS practices has become complex. There are currently 159 conservation practices, including 38 vegetative practices that are applicable to crop land (USDA NRCS 2011a); although, for any one state the number of approved practices may be smaller. Many practices have overlapping purposes and similarities in their design criteria. These commonalities can lead to confusion in the process of selecting the most efficient practice or suite of practices for enhancing multiple ecological services.

Fifth, despite the comprehensiveness of conservation practices, new purposes (or ecosystem services) continue to emerge that are not addressed by existing practices. In response, new conservation practices are developed for addressing the new purposes. However, adding new practices to the current system of 159 practices will exacerbate complexity of the system.

IMPROVING THE USE OF CONSERVATION PRACTICES

The use of USDA NRCS practices for enhancing ecosystem services could be improved in three ways. First, practice purposes and considerations could be broadened to allow greater range of design adjustments for multiple benefits, even if they diminish the primary purpose(s). Although current standards maintain the distinct identity of each practice and ensure a base level of performance, they also limit the flexibility for designing simultaneously for additional benefits. Finding efficient compromises among design criteria for different ecosystem services would be a fundamental part of designing a practice for multiple ecosystem services.

Second, the USDA NRCS's National Planning Procedures (USDA NRCS 2011c), coupled with Area-Wide Planning (USDA NRCS 2011b) and Rapid Watershed Assessment (USDA NRCS 2009), should get more widespread use. These procedures identify multiple land-use concerns and goals, recognize the interconnections between individual sites and farms within larger planning units (e.g., watersheds), and assess the cumulative effects of proposed actions on the needs and issues of each scale. Properly nesting site-scale practices within a landscape context is especially important for efficiently enhancing ecosystem services that accrue with landscape-scale applications.

Third, greater use could be made of the agency's existing worksheet tools for developing conservation plans with Resource Management Systems, including Conservation Practices Physical Effects, Site-Specific Practice Effects Worksheet, Conservation Effects for Decisionmakers, and Resource Management Systems Options Worksheet. In the planning and design process, a Conservation Practices Physical Effects assessment, for example, would be used to evaluate the multiple impacts of each practice and suites of practices which would feed back into the planning process to identify opportunities for refining and improving the plan. Currently, there is no provision for using

Conservation Practices Physical Effects assessments to assist the design process.

LANDSCAPE ECOLOGICAL PLANNING AND DESIGN

Further improvement in the provision of multiple ecosystem services will require even greater flexibility for optimizing multiple ecosystem services into applications of individual practices and for placing these multifunctional practices at strategic locations and times across landscapes. Area efficiency and cost-effectiveness of practices would be enhanced by (1) designing each installation for optimum combinations of services; (2) targeting locations and emphasizing design features that produce disproportionately greater benefits and synergies; (3) avoiding locations and minimizing design features that produce conflict, cancelling effects, or negative consequences; and (4) tailoring the design from location to location depending on site capabilities and landowner preferences.

These qualities are implied goals of landscape ecological planning and design (Ahern 2006; Ndubisi 2002; Selman 2009; Steinitz 1990). The process of planning for these qualities is facilitated by understanding how landscapes are currently functioning and how a modification of landscape structure would affect ecological functioning and services provided. A change in perspective from site problem and practice to ecosystem function and service provides an easier framework for assessing and integrating multiple ecosystem services and scales. For example, it becomes easier to visualize how a grassed waterway that is designed to reduce gully erosion could be designed and managed to additionally function as a runoff filter and as a connection in a wildlife corridor without having to install three separate practices.

The USDA NRCS National Planning Procedures (USDA NRCS 2011c) provides a framework suitable for conducting landscape ecological planning and design. The planning area is delineated and landscape conditions are assessed and mapped. Both public and landowner objectives and constraints are defined and the relevant landscape functions are identified. Alternative patterns of landscape structure for achieving multiple ecosystem services are proposed and evaluated using landscape ecology principles. Then, site designs are created by optimizing design criteria for the set of functions that must be performed at each specific location. To support this latter step, substantial design criteria can be obtained from the current criteria for USDA NRCS practices. Compromises and tradeoffs likely will be needed in the designs where a criterion for one ecosystem service has a conflicting or cancelling effect on others. Optimization is an inherent part of the process of creating multifunctional designs.

EXAMPLE OF ECOLOGICAL DESIGN

To illustrate how an ecological design process might work, we will focus on a subset of 11 USDA NRCS conservation practices commonly called vegetative buffers. Vegetative buffers are strips of permanent vegetation typically installed within or at the margins of crop land (or other land uses) and include field borders, contour buffers, grassed waterways, and riparian forest buffers, among others. They can potentially enhance a wide variety of ecosystem services in an extensively agricultural setting. In an ecological design process, distinctions between these practices would dissolve and only the design criteria for enhancing different ecological functions would remain. The design criteria would pertain to where permanent vegetation should be located, what the dimensions should be, what vegetation type(s) and structure these areas should contain, and how it should be managed.

A conservationist can begin to design a vegetative buffer by organizing the desired functions (identified earlier in the planning process) and their design criteria into a matrix like the one illustrated in table

Table 1

Example of a function-criteria matrix for designing a vegetative buffer that would perform three different conservation functions. Only a few design criteria are shown in this simplified matrix in order to clearly illustrate the process of comparing criteria to determine compatibility.

Criterion type	Design criteria			Compatibility
	Function A: Provide shaded aquatic habitat	Function B: Stabilize eroding stream bank	Function C: Provide pollinator habitat	
Location	Near the water's edge. On west and south sides of stream.	Both sides of stream. As close to the toe of the bank as possible.	Near water and moist soil. Within 300 m of cropland.	Compatible, but Function B has the most stringent criterion for the final design.
Dimensions	Minimum width 10 m.	Minimum width 5 m.	Minimum width unknown.	Compatible, but Function A has the most stringent criterion for the final design.
Vegetation	Trees, mature height > 30 m. Fast growing. Dense foliage.	Trees and shrubs, mature height < 10 m with open crowns. Moderate herbaceous ground cover.	Nectar and pollen producing plants. Trees and shrubs for shelter. Retain snag trees.	Conflict: tall shade trees on high banks may topple and increase bank erosion. Compromise: select tall species having open crowns and low weight, avoid placing tall species on high banks, maintain snag trees away from bank.
Management	Weed control through year 3.	Weed control through year 3.	Protect from pesticides.	Compatible, but need to ensure weed control does not adversely impact Function C.

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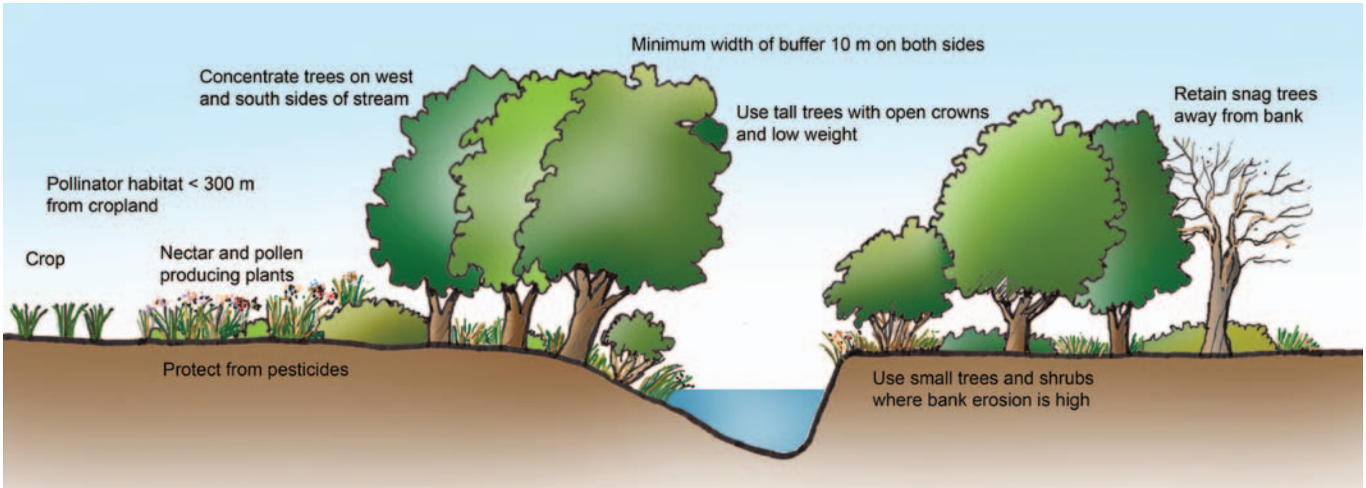
Figure 2

Conceptual diagram of a vegetative buffer designed to provide three ecosystem services: provide shaded aquatic habitat, stabilize eroding stream bank, and provide pollinator habitat.



1. The matrix would be used to compare design characteristics for each function with those of the other functions. This process identifies criteria that are compatible as well as some that conflict. Tradeoffs often will be required to reconcile conflicts and optimize a final design. Among compatible criteria, one may be more stringent and will determine the final design, such as for location and dimensions for the buffer in table 1. A final site design for this example is illustrated in figure 2. For conflicting criteria, such as for vegetation in this example, compromises may produce a design that provides acceptable, albeit less than desired, levels of individual functions. If an acceptable compromise cannot be found, then the desired functions cannot be performed at the same location.

Some ecosystem functions that vegetative buffers can enhance require design and implementation at a landscape scale. In our example, the function "Provide pollinator habitat" may require the location criterion to include "Dispersed placement throughout the planning area" in order to produce a significant area-wide effect on pollination. If we added the function "Provide a corridor for wildlife movement," then a location criterion might include "Continuous along historical dispersion and migration routes," and vegetation criteria would include the appropriate structure for the desired species. Through a process of comparing and optimizing design criteria, designs for individual sites within a landscape could be adjusted to contribute to desired landscape-scale functions.

An ecological design process for buffers can be further enhanced by considering how the surrounding landscape could be designed to improve their effectiveness. For example, tillage practices could be changed to improve infiltration and reduce peak runoff in the adjacent stream, thereby helping to reduce bank erosion and reducing or eliminating the buffer width required for this purpose. By considering the larger landscape, the conservationist could minimize land taken out of production for a vegetative buffer and still produce the desired service. Using the process of ecological design, whole agricultural landscapes can be designed for land-use synergies that yield even more efficient and more sustainable production of ecosystem services.

TRADEOFFS

While unrestricted landscape ecological planning and design may maximize provision of ecosystem services and cost-effectiveness, it would be more difficult to conduct than the current USDA NRCS system. The difficulties range from manpower skills to scientific deficiencies to policy and program needs. Landscape planning and design is more complex than simply matching one of several standard designs to each specific site problem. It would require conservationists to have greater technical knowledge of landscape functions and processes, skills to juggle several functions and design criteria simultaneously, and more time and effort to devote to developing landscape and site plans. There is also a deficiency of quantitative metrics and design criteria for many ecosystem functions (ELI 2003). This deficiency seriously limits planners' ability to assess potential impacts and optimize multiple functions. Scientific deficiency, however, also plagues the current practices system (Maresch et al. 2008). Enhancement of landscape-scale functions is limited further to the extent that multiple individual landowners choose (for their own reasons) not to contribute to a landscape-scale plan (Rickenback 2011). Finally, gauging impacts on ecosystem services in terms of acres of applied practices can act as a disincentive for achieving conservation efficiency.

A WAY FORWARD

For now, landscape ecological planning and design is a vision for where conservation development ultimately needs to go in order to satisfy increasing demand for multiple ecosystem services. The USDA NRCS system of conservation planning and practice application contains many elements of landscape ecological planning and design and seems to be evolving toward this vision; however, in its present form it contains significant limitations. Many of these limitations are tradeoffs dictated by institutional needs, including policy and program requirements. Consequently, many of the agency's tools are not being used to their fullest capability. However, the pressure to achieve more kinds and greater levels of ecosystem services from agricultural landscapes at lower cost is likely to continue increasing into the future and, along with it, the pressure to improve the methods.

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