Humans have been transforming the environment to support production and cultural functions for thousands of years, yet until recently, most ecologists had not been involved in the design of these intensively managed landscapes. The publication of Ian McHarg’s *Design with Nature* in 1969 challenged landscape designers to provide an ecological analysis of the landscape prior to recommending landscape changes (McHarg 1969). Since that time, landscape ecology has emerged as an applied field for studying the past, current, and future structure of the landscape, including the analysis of spatial metrics and the development of analytical models for assessing ecological, hydrological, and other impacts. These efforts have often been implemented within the context of computation, including geographic information systems (GIS), but, more importantly, represent major advances as analytical tools for studying spatial relationships, landscape change, land suitability for various functions, and social impacts (Hulse et al. 2004; Grove et al. 2006; Johnston and Braden 2007). Even so, the contribution of ecology to the design process, beyond initial landscape assessment, has been limited. We suggest that opportunities exist for using ecological principles to influence the design of the landscape, from initiation through to completion, and that ecologists should be actively involved in this effort. A design approach based on ecological principles will “inform, guide, and inspire designers towards landscapes that are environmentally sustainable as well as being culturally and aesthetically appropriate” (Makhzoumi 2000).

This paper is certainly not the first attempt to develop a framework and process for ecological landscape design; indeed, a number of publications provide valuable guidelines that have been considered in this study. Diaz and

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**In a nutshell:**

- Ecological landscape design will benefit from a greater focus on the development of multifunctional landscapes, strongly grounded in ecological principles.
- A framework for ecological design of landscapes demonstrates how ecology can guide each step of the design process and how collaboration between ecologists and landscape designers will help bridge the gap between scientific/technical knowledge and design applications.
- In order to meet future challenges related to human population growth and competition for resources, our research and education systems need to encourage the level of interdisciplinarity that will produce experts trained in both ecology and design.

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**CONCEPTS AND QUESTIONS**

Creating multifunctional landscapes: how can the field of ecology inform the design of the landscape?

Sarah Taylor Lovell* and Douglas M Johnston

The opportunity exists to improve intensively managed landscapes (urban and agricultural areas dominated by human activities) through greater engagement of ecologists in the process of ecological landscape design. This approach encourages exploration of multifunctional solutions to meet the needs of growing populations in many areas around the world, while minimizing the negative impacts of human activities on the environment. This is achieved by incorporating theoretical and applied principles from the fields of landscape ecology, agroecology, and ecological design. Multifunctional landscapes can be designed to provide a range of environmental, social, and economic functions, while considering the interests of landowners and users. Here, we propose a process for designing multifunctional landscapes, guided by ecological principles in the following steps: (1) defining the project site and landscape context, (2) analyzing landscape structure and function, (3) master planning using an ecosystem approach, (4) designing sites to highlight ecological functions, and (5) monitoring ecological functions. The development of a framework for ecological design of landscapes demonstrates the importance of a multi-scale approach for connecting sites to their surroundings, the benefits of a multifunctional design for sustainability, and the value of involving ecologists throughout the entire design process. The ecological design approach is explored for the University of Illinois Field Research Station.
Apostol (1992), for example, proposed an analysis and design process for large-scale, forested landscapes (5000 to 50 000 acres) through the following steps: (1) information gathering on resources and public expectations (inventory), (2) data analysis and interpretation, (3) review and synthesis of data by an interdisciplinary team, and (4) development of a proposed course of action. Steinitz (2002) described a framework for teaching design to students through different levels of inquiry, using representational models to describe the landscape, process models to indicate landscape function, evaluation models to determine if the landscape is working well, change models to consider potential landscape transformations, impact models to predict the outcomes of alternative transformations, and decision models to determine the appropriate change for the landscape. Lyle (1999) proposed a paradigm for ecological design, adapted from a systems approach, which also includes a sequence of steps: (1) statement of goals, (2) analysis, (3) development of alternatives, (4) comparative evaluation of alternatives, (5) selection of the most effective alternative, (6) implementation, and (7) monitoring. Makhzoumi (2000) applied an ecological design methodology to the development of a landscape master plan, based on a process of defining the context, describing the site, identifying ecological landscape associations, and evaluating these associations.

In this paper, we illustrate a process for ecological design of landscapes that builds upon previously proposed methods, by extending the role of the ecologist through the entire process and by incorporating the most recent advances in the ecological transformation of multifunctional landscapes found in landscape ecology, agroecology, and ecological design. We propose five basic steps in a multi-scale design process: (1) defining the project site and landscape context, (2) characterizing and analyzing landscape structures and functions, (3) master planning using an ecosystem approach, (4) designing sites to reveal ecological functions, and (5) monitoring ecological functions. For each step, the role of an ecologist in the design process is considered (Figure 1). We use the University of Illinois Field Research Station (UIFRS) as a case study for this approach and as an example of the development of a design for a multifunctional landscape.

### Defining the project site and landscape context

Most designers and ecologists would agree that, for a landscape to function as part of a healthy ecosystem, the context of the site must be considered through a multi-scale approach (Spirn 1985; Watzin and McIntosh 1999). Nearly every site affects its surroundings through positive and negative interactions. The economic term “externalities” is used to refer to the costs and benefits of decisions that are not directly accounted for by the person making the decision – in this case, the land owner. Externalities result from lateral flows of water, air, soil, fire, substances, or organisms from one area of land to another and can be affected by landscape features that serve as barriers, filters, or corridors (van Noordwijk et al. 2004). For example, a vegetation buffer zone might be established to reduce the flow of soil from a field into a stream, where it would result in a negative externality (Lovell and Sullivan 2006). Positive externalities should also be considered, such as a well-designed park, which can increase the value of nearby residential properties (Anderson and

![Figure 1. Schematic diagram of the ecological design process, the role of the ecologist, and examples of specific questions that could be considered at each phase. While this figure may suggest roles for the ecologist that are traditionally covered by landscape architects, we propose that separating these two fields is not necessary and may, in some cases, restrict the process of ecological design. Increasingly, experts are developing skills in multiple fields, and this can only serve to advance aspects of both.](image-url)
West 2006). This concept has important applications, as the consequences of certain activities related to a specific area of land may impact stakeholders in adjacent areas. Landscape ecologists (among others) should be involved in the assessment of the landscape in the very early stages of the design process, in order to maintain or improve the landscape. A multi-scale approach is necessary to consider the impact of landscape pattern as it relates to different processes (e.g., hydrology, wildlife movement) and the functions of a diverse range of organisms (Diaz and Apostol 1992).

Characterizing and analyzing landscape structures and functions

The development of a multifunctional landscape must include consideration of biophysical features important for conservation of biodiversity and ecological processes (Baschak and Brown 1995). Topography, hydrology, vegetation, soil type, and other features help to inform the design of landscapes by guiding decisions on the location of new landscape features, restoration of ecological functions, and production of food or other resources. Characterizing existing land uses, such as open green space, agricultural cropping systems, and built features, is critical to understanding the landscape and suitability for future functions. Socioeconomic features, including population density, household incomes, and land values, should also be considered in the design, to facilitate a better understanding of the cultural values of the site. The work of Ian McHarg demonstrates the specific contributions of ecology to the characterization of existing features through the comprehensive development of an “ecological inventory”, which includes climate, geology, hydrology, soils, vegetation, and wildlife. Today, these inventories are often developed as spatial data layers for use in GIS and help us to understand landscape conditions by providing a mechanism for characterizing existing landscape features and historical data (Watzin and McIntosh 1999). Ecologists can play an important role in determining the types of geophysical data that should be considered in the inventory.

Landscape analysis builds upon the inventory (characterization) by synthesizing complex data, aggregating values from established criteria, and modeling ecological processes (Baschak and Brown 1995). Classification systems to analyze ecological performance, based on heterogeneity in landscape spatial pattern, have been widely accepted (Gustafson 1998), but integrated approaches that include other metrics, such as plant community structure and landscape processes, are increasingly used to develop landscape associations (Baschak and Brown 1995; Makhzoumi 2000). Process models can be used to assess the existing and proposed conditions of the site, including hydrology, geomorphology, climatic conditions, habitat suitability, wildlife movement, risks to specific species, disturbance patterns, spread of invasive species, habitat fragmentation, and a range of ecological functions. These models can also be used to evaluate landscape modifications and compare design alternatives. The involvement of ecologists is critical during the stage of characterization and analysis of existing features, as they can identify key structure–function relationships within the existing site and recognize the importance of landscape pattern to the flows of resources and organisms.

- Developing a master plan using an ecosystem approach

The development of the master plan design, though often considered a provisional stage in the design process, serves multiple roles: it establishes a framework for future designs, provides a basis for feedback from stakeholders, and demonstrates a commitment to the project (Makhzoumi 2000). Using the ecosystem concept as a basis for master planning will provide a greater understanding of the landscape at multiple scales, while incorporating the needs of society and interactions between human activities and the environment (Spirn 1985). Ecosystem management can be defined as “the application of ecological and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified period” (Lackey 1998). With this approach, the framework for local land-use planning is the ecosystem and the ecological processes contained within it (Brody 2003); humans are considered a component of the ecosystem (Haueber 1998). While ecosystem management plans have typically focused on natural and semi-natural areas, such as forests, prairies, and conservation lands, the same concepts could be applied to intensively managed urban and agricultural landscapes at the master planning stage (Spirn 1985). We suggest several design objectives, based on an ecosystem concept that would benefit from the input of ecologists, resulting in a greater likelihood of long-term success for the project as a healthy, functioning ecosystem.

The first objective is to improve landscape performance by developing designs that integrate multiple functions in the landscape. Ecosystem multifunctionality has been recognized as a condition for sustainability in natural systems (de Groot 2006), and recent interest has focused on multifunctionality of intensively managed landscapes (Wiggering et al. 2003; Brandt and Vejre 2004). Within this context, we define multifunctionality as the provision of multiple environmental, social, and economic functions in a given area of land (Wiggering et al. 2003), taking into account the interests of landowners and users (Otte et al. 2007). In contrast to the more abstract concept of “sustainability”, the goal in designing a multifunctional landscape is to consider ecological, production, and cultural functions within the same site. This approach encourages the designer to aim for multiple targeted performance standards, such as conserving and producing energy; providing food; managing water quality and quantity; reducing, reusing, and treating waste; con-
serving and increasing biodiversity; meeting visual quality expectations; and providing recreational opportunities. The incorporation of local food production into common landscapes, for example, would not only add provisioning services, but would also serve an educational function by connecting people more directly with their food systems (Viljoen 2005). If creatively designed, multifunctional working landscapes can serve as a platform to integrate ecology, economy, and society (Hough 1995).

A second objective is to increase heterogeneity in the spatial pattern of the landscape. Recent studies suggest that increasing heterogeneity can improve ecosystem services in urban and agricultural landscapes by increasing function and resilience (Fischer et al. 2006). The addition of features such as woodlots, natural woody hedgerows, riparian buffers, greenways, and parks can all contribute to landscape heterogeneity, improving the quality of the landscape matrix and conserving biodiversity. These features can also support the development of ecological networks, which provide a spatial link between ecosystems through a variety of different configurations, by focusing on opportunities to increase total ecosystem area, improve ecosystem quality, increase network density, and provide landscape permeability. “Ecological land-use complementation” (ELC) is a variation on the ecological network concept, emphasizing conservation of biodiversity and provision of ecosystem services through the clustering of complementary land uses. This spatial arrangement encourages movement between habitat patches, provides resources in close proximity to each other, and enlarges the area available in a habitat – all without changing the total area of each land-use type (Colding 2007).

Conserving and promoting biodiversity is a third ecologically based design objective. Humans rely on a wide range of plants and animals to supply food, fiber, fuel, medicines, and many indirect services, such as nutrient cycling and waste decomposition. But global biodiversity is severely threatened by a number of human-related activities, including pollution, invasion by exotic species, and, most importantly, continued habitat loss and degradation – all of which can be affected by the design and planning of the landscape. Landscape change often involves modifications to land cover or habitat composition, directly impacting biodiversity. It is therefore vital to incorporate the restoration and protection of biodiversity as a specific goal of the project (Ahern et al. 2006). Biodiversity can also be promoted in productive landscapes (eg biofuel production based on mixed-prairie systems, which offer added benefits of visual quality, recreation, and improved water quality; Jordan et al. 2007).

A fourth objective is to improve and manage water quality and quantity. Any transformation of the landscape involving a change in built structures, topography, vegetation, or soil structure will impact the hydrology of the site and areas well beyond. Development typically results in large areas of impervious or “sealed” surface, in the form of rooftops, roads, parking lots, and other built features. These impervious surfaces can greatly increase the stormwater runoff from the site, resulting in an excessive volume of water containing pollutants, including heavy metals, suspended solids, nutrients, and bacteria. In agricultural areas, soil erosion and stormwater runoff containing excess nutrients and pesticides are the primary threat to water resources. The negative impacts should be minimized through the design and implementation of a master plan that includes the objective of protecting existing hydrologic features (rivers, lakes, and wetlands) and treating stormwater flows on site (Thompson and Sorvig 2000). New design solutions offer opportunities for stormwater infiltration (downward penetration into the soil) and treatment on site, through bioretention facilities such as rain gardens and larger constructed wetlands. These features can be designed into the landscape, to provide a wide range of ecological functions, such as water infiltration, water treatment, microclimate control, wildlife habitat, and biodiversity, as well as cultural functions, including education and visual quality (Dunnett and Clayden 2007). Landscapes can also be designed to conserve valuable freshwater by reusing stormwater or graywater (domestic drain water from sources other than toilets) for irrigation and by selecting species that are well adapted to the climate and efficient in water use.

### Designing sites to highlight ecological functions

The development of key sites within the larger landscape can highlight ecological functions and bring them to the attention of the public. Plant selection and arrangement, choice of building materials, and development of hydrologic features can all have an important impact on the local ecology, while providing an opportunity to draw attention to ecological functions at the site scale. Guiding principles for designing a site might include: reduction in use of, and reuse of, building materials, protection and treatment of water, conservation of biodiversity, production of food and energy, and special consideration of cultural functions (Orr 1992; Nassauer 1997; Todd et al. 2003). “Eco-revelatory design” supports the concept of highlighting ecological functions, based on the assumptions that landscapes can reflect cultural values of nature and that they have the power to communicate those values (Brown 1998). Examples include projects designed to reveal stormwater capture and reuse, extent of groundwater rise and toxin levels, water conservation in arid agricultural landscapes, phytoremediation of contaminated sites, land-use changes, and natural or anthropogenic landscape disturbances – each of which could contribute to “environmental problem solving” if experimental design is incorporated into the planning process (Galatowitsch 1998). Hough (1995) recommends “making visible the processes that sustain life” by using design to connect people to stormwater flows, food production, restoration, waste processing, and other environmental processes, including the negative conse-
quences of human actions that often remain hidden and unknown in anthropogenic landscapes.

### Monitoring ecological functions

The final stage of the design process, and one that is often neglected entirely, involves monitoring ecological functions. Monitoring on the landscape scale can provide quantifiable evidence of multifunctional land use and assessment of overall performance (project success). It seems obvious that the only way to truly advance our knowledge of ecological landscape design is through efforts to monitor function over time, but only rarely are funds allocated for this purpose. The incorporation of monitoring infrastructure into design should be considered one more opportunity to increase multifunctionality. Landscape features might be located or structured in ways that facilitate various forms of experimentation, considering approaches that require replication and manipulation, as well as those that do not require modification of the environment for data gathering. In this phase of the project, ecologists should be involved in defining appropriate indicators and variables to characterize the dynamic nature of the landscape.

#### Case study: University of Illinois Field Research Station

The UIFRS serves as an exploratory case study for the process of ecological design of the landscape. The new site for the UIFRS includes nearly 10,000 ha of farmland located south of the University of Illinois at Urbana–Champaign, in the rural–urban fringe, where agricultural activities and residential interests often collide (Figure 2).

#### Defining the UIFRS site and surrounding context

As a first step in the design process, descriptions of the site and landscape context were developed through observation of activities in and around the site, informal interviews with stakeholders, and a review of historical information related to the site and its connection with the community. Through this process, negative externalities resulting from the agricultural activities of the UIFRS were identified: habitat alteration, livestock odors, pesticide drift, traffic congestion from slow-moving machinery, and dust from field activities. The UIFRS is situated in the very upper reaches of the Embarras River watershed, so nutrient and pesticide contamination, alterations to flow, and sediment accumulation were important issues that could impact downstream landscapes. The UIFRS also offers potential positive externalities for the public, including the visual quality attributes of an agrarian landscape, connectivity with other key landscape features (e.g., nearby park, campus arboretum), educational opportunities, and recreation (e.g., birdwatching, biking, photography).

#### Landscape structure and function of a research farm

As a second step in the design process, we developed an inventory of existing features and functions through a GIS database that included population, road, topogra-
phy, hydrology, and soil-type layers. The database was used to develop maps that would later guide decisions about the most suitable locations for crop trials, circulation patterns, wetlands to treat runoff from fields, riparian buffers, and a host of other landscape features. As an illustration of the opportunities to develop a better understanding of the site through landscape analysis, the surface flow hydrology of the UIFRS was modeled to define the drainage system, explore hydrologic connectivity between fields and functions, and reveal areas for water quality monitoring (Figure 3). To conduct the study, the ArcHydro tools (Maidment 2002) for ArcGIS (www.esri.com) were applied to a digital elevation model (DEM) available from the US Geological Survey (http://seamless.usgs.gov). The model was used to illustrate overland flows and to identify equivalently sized catchments that might be used for monitoring water quality and quantity from land with different agricultural functions. This model also helped to demonstrate the benefit of analysis at the landscape scale in complementing traditional research at the field or plot scale.

An ecosystem approach that emphasizes multifunctionality

Guided by the site descriptions, feature inventories, and the surface flow analysis, the primary stakeholders participated in the master planning process considering different ecosystems appropriate for the site. Three alternative designs were developed to allow exploration of the strengths and weaknesses of different functional categories: production functions (supporting food, fodder, and energy), cultural functions (education, recreation, and visual quality), and ecological functions (climate regulation, water quality, biodiversity, and nutrient cycling). From the feedback on these designs, a final design was developed to demonstrate how the incorporation of multiple functions would improve the performance of the site by supporting the existing research needs through an ecosystem management approach (Figure...
4). The design would increase the heterogeneity, and thus the matrix quality, of the landscape, through the addition of new landscape features or perennial habitats, including wetlands at drainage outlets, riparian buffers along the river, hedgerows between fields, and a native prairie patch in one large section of the site. Flora biodiversity would increase with the addition of plant community structure in these perennial habitats, with faunal biodiversity likely to follow. Biodiversity would also be supported by the corridors created along the river and field margins. The new perennial habitats would provide important ecological functions for water regulation and treatment: hedgerows and riparian buffers to capture sediment, nutrients, and pesticides in stormwater runoff from fields; wetlands to treat water from tiles draining the fields before it entered the river; and native prairie patches to allow direct infiltration of stormwater to recharge the groundwater system. In addition to the non-crop habitats, experimental plots were incorporated into the entire site to study production, ecological, and social functions, as well as new opportunities to combine all three in a single area.

**Ecological function at the community interface**

A Research and Education Center was proposed in the northeastern corner of the site, to serve as the interface between UIFRS and the community and larger university campus (Figure 5). This area would provide an opportunity for visitors to experience a multifunctional landscape through exhibits and demonstrations of the practices employed, using the concept of eco-revelatory design to highlight the specific functions through innovative interpretive approaches. Designated areas would be established for demonstrating alternative cropping practices that promote biodiversity and ecosystem health. By showcasing a range of edible plant species that can be grown locally, the project helps to connect people to their food systems. The site design revealed local hydrologic functions through management of stormwater with permeable pavements, vegetative swales, and a constructed wetland to treat and store rooftop runoff, but the design also successfully incorporated cultural functions – research, education, and recreation.

**Monitoring ecological functions across the multifunctional landscape**

While the value in monitoring will be realized after a new design has been implemented, a monitoring plan and appropriate infrastructure should be considered during the design process. For the UIFRS, water-quality monitoring stations are proposed in several locations along the Embarrass River, as well as the drainage points from equally sized catchments identified with the hydrologic model. Water quality of runoff from each catchment can be monitored to allow comparisons between catchments with different land use and management (ie contaminants and nutrients from a catchment dominated by intensively grazed pastures might be compared to that of an equivalent-sized catchment dominated by hay fields). The efficiency of the wetlands in reducing nutrient loads and treating other agricultural chemicals would be assessed at input and outpoint points. To better understand the impacts of different landscape features, such as windbreaks, woodlots, and riparian buffers, on microclimate (climate of a small area or microhabitat), weather stations could be located throughout the site. Many opportunities exist for incorporating monitoring into the design development of the site-scale projects. One example is designing the parking area of the Research and
Education Center to permit comparison of stormwater infiltration and treatment from different paving materials (permeable asphalt, permeable pavers, gravel).

**Conclusions**

The development of a framework for ecological design of landscapes demonstrates the importance of a multi-scale and multi-temporal approach for creating multifunctional landscapes strongly grounded in ecological principles from the fields of landscape ecology, agroecology, and ecological design. We recognize, however, that ecological landscape design is a complex process, including critical feedback loops that will alter the outcome. In order to be successful, these projects should include involvement of ecologists throughout the entire design process. This study also brought to light several areas of concern regarding the relationship between the fields of ecology and landscape design. The first is that ecologists rarely remain involved in the design process beyond the initial phases of landscape assessment, perhaps due to funding limitations on individual projects. In this paper, we have provided some basic recommendations for the role of ecologists throughout the design process, but a greater effort is needed to encourage communication between design professionals and research scientists, and adequate funds must be appropriated to facilitate this effort.

A second concern is the absence of applied research that might provide specific design guidelines for multifunctional landscapes. Calkins (2005) demonstrated that the lack of research on ecological design strategies has limited their implementation in design projects. Another critical limitation to the full integration of ecology in design is the lack of support for design projects by much of the scientific community; the very small number of design projects found in the scientific literature is evidence of this. If we are to bridge the gap between the scientists who study the landscape and the professionals who design the landscape, we must consider opportunities to publish research on designed landscapes and support the inclusion of research-based design projects in peer-reviewed publications.

Finally, we are concerned that our research and education systems have not encouraged the interdisciplinary programs that might produce experts who understand both ecology and design. We feel that this problem needs to be addressed in the very early stages of the education process, by promoting the enrollment of ecology students in design studios, and encouraging design students to expand their coursework in the sciences. As McHarg appropriately stated in 1969, “There clearly is a desperate need for professionals who are conservationists by instinct, but who care not only to preserve but to create and manage” (McHarg 1969). If ecologists do not recognize the importance of the designed landscape to their field and become involved in the design process, they will not be prepared to meet the challenges of the future: human population growth, degradation of landscapes, and competition for limited natural resources.

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