Agricultural Systems 103 (2010) 327–341

Contents lists available at ScienceDirect

Agricultural Systems

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

Integrating agroecology and landscape multifunctionality in Vermont: An evolving framework to evaluate the design of agroecosystems

Sarah Taylor Lovell [a,*], S'ra DeSantis [b], Chloe A. Nathan [b], Meryl Breton Olson [b], V. Ernesto Méndez [b], Hisashi C. Kominami [b], Daniel L. Erickson [b], Katlyn S. Morris [b], William B. Morris [b]

[a] Department of Crop Sciences, 1009 Plant Science Laboratory, University of Illinois, Urbana, IL 61801, USA
[b] Plant and Soil Science Department, Hills Agricultural Science Building, 105 Carrigan Drive, University of Vermont, Burlington, VT 05405, USA

ARTICLE INFO

Article history:
Received 7 July 2009
Received in revised form 26 February 2010
Accepted 11 March 2010
Available online 3 April 2010

Keywords:
Multifunctional agriculture
Landscape multifunctionality
Ecosystem services
Ecological design
Food systems
Rural planning

ABSTRACT

Agroecosystems cover vast areas of land worldwide and are known to have a large impact on the environment, yet these highly modified landscapes are rarely considered as candidates for landscape design. While intentionally-designed agricultural landscapes could serve many different functions, few resources exist for evaluating the design of these complex landscapes, particularly at the scale of the whole-farm. The objective of this paper is to introduce an evolving framework for evaluating the design of agroecosystems based on a critical review of the literature on landscape multifunctionality and agroecology. We consider how agroecosystems might be designed to incorporate additional functions while adhering to agroecology principles for managing the landscape. The framework includes an assessment tool for evaluating farm design based on the extent of fine-scale land use features and their specific functions, to consider the present state of the farm, to plan for future conditions, or to compare alternative futures for the design of the farm. We apply this framework to two farms in Vermont that are recognized locally as successful, multifunctional landscapes. The Intervale Center, an agricultural landscape located within the city limits, serves as an incubator for new farm startups and provides unique cultural functions that benefit the local community. Butterworks Farm, a private operation producing organic yogurt and other food products, achieves important ecological functions through an integrated crop-livestock system. These farms and many others in Vermont serve as models of a framework that integrates landscape multifunctionality and agroecology in the design of the landscape. In the discussion section, we draw from the literature and our work to propose a set of important themes that might be considered for future research.

1. Introduction

The percentage of terrestrial land covered by agriculture (cropland and pasture) has steadily increased to approximately 50% of the habitable land on earth (Tilman et al., 2002; Clay, 2004). As a result, we must face the reality that "agriculturalists are the principal managers of global useable lands and will shape, perhaps irreversibly, the surface of Earth in the coming decades" (Tilman et al., 2002). Agricultural activities influence the environment and ecosystem services (benefits humans derive from ecosystems) at many scales (Millennium Ecosystem Assessment, 2005; Tscharntke et al., 2005). At the local scale, individual farms affect nearby water quality, nutrient cycling, micro-climate control, and visual quality of the landscape. At the regional and global scales, agriculture can have far-reaching impacts on the quality and availability of large water resources, biodiversity conservation, and carbon sequestration (Scherr and McNeely, 2008). Research on various agricultural management practices in a wide range of crops and regions throughout the world is vast and continuing to grow, including many studies that focus on sustainable agricultural practices that integrate ecological principles. Much less attention, however, has been directed toward the extent and arrangement of individual spatial features in the agricultural landscape – in other words, the *design* of the agricultural landscape.

In an effort to address an issue that spans several disciplines, some common terms must be defined based on the context of this work. For the purposes of this discussion, "landscapes" are defined as "the visible features of an area of land, including physical elements such as landforms, living elements of flora and fauna, abstract elements such as lighting and weather conditions, and human elements such as human activity or the built environment" (Sustainable Sites Initiative, 2007, p. 1). The term "design", as applied to the landscape, can be used as either a noun or a verb.

---

* Corresponding author. Tel.: +1 217 244 3433; fax: +1 217 244 3469.
E-mail address: stlovell@illinois.edu (S.T. Lovell).

0308-521X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.agsy.2010.03.003

The verb "design" refers to the intentional transformation or modification of landscape features for a given area expressed as a graphic representation, conceptual description, and/or physical manifestation. As a noun, we use "design" to refer to the spatial arrangement of landscape features resulting from the design (verb) process, either in the existing state or proposed future state(s). An agroecosystem can be defined as "… an interactive group of biotic and abiotic components, some of which are under human control, that forms a unified whole (ecosystem) for the purpose of producing food and fiber" (Elliott and Cole, 1989, p. 1598).

In this paper, we focus on the scale of the whole-farm, including all parcels owned and managed by an individual farmer or farm business unit. We chose this scale of analysis because it is at this level where most land use and management decisions occur. Smeding and Joenje (1999) state that the integration of farming and nature should consider both the landscape scale and the farm scale. While we might consider the landscape scale to be more of a regional planning directive, requiring coordination of different land owners and institutions through policy, the farm scale would rely upon a landscape *design* approach developed at least in part by individual land owners or users. In considering the sustainability of agriculture and its contribution to the provision of ecosystem services, few published studies have focused on the farm scale (Rigby et al., 2001; Lowrance et al., 2007). A whole-farm approach to design would offer many benefits, including opportunities to manage nutrient flows at or near the source (e.g. manure for fertility), to customize strategies for managing ecosystem services to match the specific farm situation, and to consider the farm and farmer type as they relate to spatial attributes of land use.

Currently, few resources are available to evaluate or design a multifunctional landscape at the whole-farm scale. As a result, the spatial arrangement of landscape features has primarily been a result of land use patterns established by current and past land owners to support agricultural production, often strongly influenced by biophysical landscape features that determine land suitability for certain agricultural functions. In most cases, however, multiple alternatives exist for the types of crops and management practices, as well as the arrangement of fields and supportive infrastructure in the landscape. Farmers regularly make decisions about changes to the farm landscape through activities such as the creation and removal of landscape elements (hedgerows, woodlots, etc.) and conversion of fields to alternative perennial crops (Kristensen et al., 2004). Some evidence suggests that these decisions about the design of the agricultural landscape can be strongly impacted by factors beyond biophysical landscape features or profit maximization. These factors can include farmers' values (Busck, 2002), individual preferences (Deuffic and Candau, 2006), farm function, and landscape context (Deffontaines et al., 1995). Another important consideration in the design of agroecosystems is the common use of the farm as the homestead of the farmer, suggesting decisions may be based on more than production alone and might include consideration of aesthetics, cultural traditions, and recreational amenities (Primdahl, 1999).

Fortunately, advances in the use of Geographic Information Systems (GIS), Google Earth™, and other mapping and spatial analysis tools offer new opportunities to evaluate and design agroecosystems. Ecological inventories have been used to characterize existing landscape features and assess the suitability of areas for different functions using layers on a map to indicate the relationships between natural and man-made resources (McHarg, 1969). GIS is now used regularly to map and assess existing land use, topography, hydrology, soils, sociodemographic factors, and many other spatial data as they might inform the design of the landscape (Lovell and Johnston, 2009). From the field of landscape ecology, landscape pattern indices such as habitat proportion, connectivity, and heterogeneity have been used to assess landscapes (Corry, 2004), to compare different alternatives for the design of a given area (Berger and Bolte, 2004; Santelmann et al., 2006), or to identify appropriate locations for establishing new patches of native vegetation (Lafortezza and Brown, 2004).

The primary objective of this paper is to introduce an evolving framework for designing agroecosystems based on a critical review of the literature in related fields, particularly agroecology and landscape multifunctionality. The framework includes a multifunctionality assessment tool to evaluate the farm design based on specific functions and spatial contributions of individual landscape features. We present two case studies of farms which exemplify agricultural landscapes designed not only to maximize production but also to provide ecological and cultural functions. The farms are located in Northern Vermont where agriculture is a major component of both the landscape and the cultural heritage, in spite of the region's challenging mountainous terrain and cold climate. These case studies illustrate some of the on-farm innovation that is occurring in the US, working in concert with existing landscape features and ecosystems, as well as incorporating historical and cultural considerations in farm design. While Vermont is an ideal place to consider this approach, we expect that this framework could be adapted for agricultural landscapes in other regions.

2. Literature review

This section includes a review of the literature on different approaches to study sustainable agricultural systems, with a specific focus on their contributions and limitations related to our understanding of the design of agroecosystems. The primary approaches selected for this analysis are agroecology and landscape multifunctionality because they have been particularly influential in the discussion of sustainable agriculture in recent years, often promoting similar principles but employing distinct strategies appropriate for different scales (Altieri, 2004a; Renting et al., 2009). For each approach, we summarize the guiding principles, highlight the contributions to landscape design, and consider the potential limitations when the approach is used alone in evaluating farm design.

2.1. Agroecology

The field of agroecology developed as an alternative to industrial, high external input agriculture and uses ecological principles to guide the design and management of agroecosystems (Altieri, 1987; Gliessman, 1990). Agroecosystem design has been an important part of agroecological conceptualization and practice (Ewel, 1986; Altieri, 1995). The design dimension in agroecology draws from two main sources of knowledge: (1) natural ecosystems and (2) traditional, pre-industrial agroecosystems (Gliessman et al., 1981; Ewel, 1986; Altieri, 2004b). Agroecologists have recognized the influence of social and cultural factors in the development of traditional agriculture, but ecological science has been the driving principle for agroecosystem design. In agroecology, design approaches have usually focused on the plot or field scale, with the guiding principle that agroecosystems should bear a greater resemblance to natural ecosystems (Soule and Piper, 1992; Gliessman, 2007).

An important strength of agroecology is its emphasis on traditional practices, frequently employed by indigenous peoples, as they might inform the design of sustainable agroecosystems. For example, in considering a cacao (*Theobroma cacao*) production system in Talamanca, Costa Rica, Altieri (2004a) suggests that farm design should promote synergies and integration so that different parts of the agroecosystem support each other, while promoting biodiversity conservation, food production, and other income-generating activities. These design principles are exemplified in tropical homegardens, typically designed and managed by households to include a variety of components such as trees, herbaceous crops, and animals, in order to meet a variety of needs (Méndez et al., 2001). Such agroecosystems not only provide products for consumption or sale, but they also support cultural functions and conserve ecosystem services (Kumar and Nair, 2006).

Agroecology also emphasizes the importance of farm design in pest management. For example, there is evidence that densities of herbivorous pests and their natural enemies within agricultural fields are influenced by the landscape features adjacent to those fields including field margins, riparian buffers, and forest edges (Nicholls and Altieri, 2001). This implies the importance of considering the spatial layout of buffers and margins when designing agroecosystems. Research in organic vineyards in northern California showed that incorporating corridors of natural vegetation into crop fields may encourage beneficial insects from nearby forests into the center of fields, reducing pest pressure near the corridor (Altieri et al., 2005). Another example comes from the long-term re-design of strawberry (*Fragaria* sp.) production in California. Researchers improved ecological management by integrating *Brassica* crops to control disease, improve nutrient management, and reduce runoff. The incorporation of trap crops around strawberry fields, as well as insectary crops between strawberry rows, provided habitat for predators (Gliessman, 2007). While it could be argued that these approaches deal primarily with field-scale management, using elements such as trap crops may require intentional design beyond the field boundaries in order to achieve the correct spatial arrangement to draw pests away from the primary crop.

Until recently, agroecological approaches tended to focus mainly on the ecology of agricultural production and management. However, a group of agroecologists in Spain have focused their work on better integrating social and political perspectives of agroecology (Guzmán-Casado et al., 1999; Sevilla-Guzmán, 2006). This work was further strengthened in 2003, when a group of recognized agroecologists redefined the field as the "the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions" (Francis et al., 2003, p.100), placing a greater emphasis on social and cultural considerations, as well as food systems, as integral in agroecological research and implementation. This shift is relevant to farm design because the social and economic systems in which farmers participate will influence how they design their farms. These include regional and global market venues, research, extension and social networks (Gliessman, 2007; Warner, 2007). Other recent work in agroecology has also provided support for farmers to connect with alternative farmer networks using participatory research approaches (Méndez, 2010).

There are some limitations in using agroecology alone as a basis for farm design. While agroecologists acknowledge the role and influence of agroecosystems at the landscape scale (Wojkowski, 2004; Gliessman, 2007), and several researchers have integrated agroecological concepts to analyze agricultural landscapes in a diversity of settings (Ellis, 2000; Méndez et al., 2007), the applications in research and practice are limited (Dalgaard et al., 2003). Dalgaard et al. (2003) state that when defining agroecology as a scientific discipline, "scaling is a problem because results of agroecological research are typically generated at small spatial scales whereas applications are frequently implemented at larger, administrative units" (p. 133). Furthermore, when designing agroecosystems in a cool, humid inner-continental climate such as in northern Vermont, there are few examples from which to draw. Most examples in the agroecology literature come from tropical or coastal areas such as Central America, California, and Spain. Natural ecosystems are extremely complex, and they vary greatly in regional and climatic conditions. If we are to mimic natural ecosystems with intentionally designed agroecosystems, research and design examples are needed from a variety of climates and environments.

2.2. Landscape multifunctionality

While the field of agroecology has historically focused on field-scale management and design, the landscape multifunctionality approach considers the functions of the larger landscape. In the context of agroecosystems, multifunctionality suggests that agriculture can provide numerous commodity and non-commodity outputs, some of which benefit the public without compensating the farmer. Non-commodity outputs (public services) provided by farms include both ecological functions (e.g. biodiversity, nutrient cycling, and carbon sequestration) and cultural functions (e.g. recreation, cultural heritage, and visual quality). The idea of landscape "functions" is consistent with the popular "ecosystem services" framework, where the provisioning, regulating, and cultural services are provided by different ecosystems or landscapes (Madureira et al., 2007). The 1997 book entitled "Nature's Services – Societal Dependence on Natural Ecosystems" contains entries from many authors that have been pivotal in developing a shared understanding of ecosystem services as they contribute to landscape multifunctionality (Daily, 1997). In applying these concepts to agroecosystems, the multifunctional landscape approach suggests that overall performance of the agricultural system can be improved by combining or stacking multiple functions in the landscape (offering additional ecosystem services), as opposed to a focus constrained by production functions (Lovell and Johnston, 2009; Jordan and Warner, 2010).

Landscape multifunctionality has been promoted through agricultural policy in some regions. In Europe, multifunctionality of agroecosystems is supported by public funds through agri-environmental schemes (Wade et al., 2008), which seek to align biodiversity conservation with other public benefits such as water quality, carbon sequestration, and rural tourism, by paying farmers for the public benefits they provide (Sutherland, 2004). While multifunctionality has been explored and supported in Europe and Asia, the US has been slow to adopt policies that support functions beyond commodity production for agricultural landscapes (Boody et al., 2005; Groenfeldt, 2006). Since 1985, the United States Department of Agriculture (USDA) has administered the Conservation Reserve Program (CRP), which takes land out of agricultural production, but this typically results in a separation between agriculture and conservation and offers very little consideration of cultural functions. Recently, however, the United States Department of Agriculture (USDA) has developed new directives prioritizing multifunctionality as a research initiative (http://www.csrees.usda.gov/fo/managedecosystemsnri.cfm). These initiatives suggest interest in this approach is growing, and farmers will need new tools to re-design landscapes to address the goals set forth. One step in this direction is the development of extension materials, such as those published by Hansen and Francis (2007) to share landscape multifunctionality concepts with planners, extension boards, and other agricultural experts who could work with farmers on such strategies.

Landscape multifunctionality is an appropriate approach for designing farms for many reasons; the first is its focus on larger spatial scales such as the whole-farm or an entire rural region. Wilson (2007, 2008, 2009) and Holmes (2006) offer compelling arguments for using the concept of multifunctionality as more than a policy-based initiative, instead considering multifunctionality as a normative process to describe what is happening on the ground at the farm level. A second benefit of integrating landscape multifunctionality is the inherent focus on cultural functions provided by agricultural landscapes. By incorporating cultural functions such as visual quality, recreation, and historic preservation, multifunctional landscapes can contribute to preservation of landscape history and public enjoyment of the rural environment (Carey et al., 2003). In some countries such as The Netherlands, the multifunctionality approach has been used to support sustainable rural development, considering social and economic benefits provided by rural landscapes (Oostindie et al., 2006).

A third advantage of landscape multifunctionality is an embedded framework for evaluating the success of the landscape design. Unlike the more ambiguous term "sustainability", the concept of multifunctionality suggests an opportunity to develop specific goals or targets for ecological, production, and cultural functions to improve landscape performance. Performance of the landscape might be considered based on the total value of different functions and on the balance across a range of functions (Sal and Garcia, 2007; Lovell and Johnston, 2009). Alternatively, multifunctional performance can be compared based on monetary values applied to the ecosystem services provided by the landscape, including both direct market values for commodity outputs and indirect valuation of non-commodity outputs (Farber et al., 2006). Finally, the landscape multifunctionality approach offers an advantage in its flexibility, in that it can be applied to unconventional agroecosystems. In adapting this approach to landscape design and planning, the opportunity exists to consider not only adding ecological and cultural functions to productive landscapes, but also incorporating agriculture into settings that typically do not include production functions (e.g. private yards, urban parks, school campuses, or other municipally owned land).

While landscape multifunctionality strongly contributes to a framework for designing agroecosystems, some limitations and constraints must be considered. For one, we must recognize that trade-offs between functions can exist on farms. When profit maximization is the primary goal, some cultural and ecological functions will most likely be sacrificed to increase production, unless alternative markets are identified for non-commodity outputs (Farber et al., 2006). Complicating the issue further, is the challenge in evaluating landscape performance when multiple interacting commodity and non-commodity functions are considered simultaneously (Madureira et al., 2007). The complexity resulting from aggregation of indicators and integration of multiple objectives at different scales has probably limited the applications of these strategies (Zander et al., 2007). Constraints on farmers' finances and time also limit their ability to incorporate additional functions on the farm (Jongeneel et al., 2008). This leads to another limitation of this approach – the lack of attention given to the impacts of multifunctionality on farmer livelihoods at the household level, except to recognize that public funds may be necessary to incentivize ecological and cultural functions.

3. Framework for designing agroecosystems

For designing agroecosystems, we propose an evolving framework that incorporates different aspects of agroecology and landscape multifunctionality as described above, while also recognizing contributions from other fields such as permaculture (Mollison, 1997; Jacke and Toensmeier, 2005), agroforestry (Long and Nair, 1999), and ecoagriculture (McNeely and Scherr, 2002; Buck et al., 2006). The landscape multifunctionality model provides a structure for designing at the whole-farm scale considering cultural, ecological, and production functions. These landscape features can be intentionally designed into the landscape and arranged to optimize the benefits they provide. The recognition of the value of cultural functions is important, and these might include visual quality, cultural heritage, historic preservation, artistic expression, and recreation – all of which have the potential to influence the farmers' land use decisions and impact the surrounding environment. Cultural functions might be supported by preserving historic features on the farm (e.g. barns and stone walls) and incorporating new features such as recreational trails, demonstration plots, and outdoor art. A heterogeneous landscape pattern including a mix of forest and pasture will also contribute to the visual quality of the farm (de Val et al., 2006; Dramstad et al., 2006).

As noted earlier, agroecology makes an important contribution to the design of agroecosystems, though it focuses primarily on the field scale and its immediate surroundings. In designing or redesigning an entire farm, it might not be practical to prescribe specific crops and management strategies, but rather to consider integrating perennial features such as field margins and windbreaks. These features would offer benefits for many cropping systems by providing habitat for natural enemies, reducing erosion, and capturing excess nutrients. Agroecology also suggests that agroecosystems should be designed to mimic the natural environment, with a diversity of species. In regions where forests are the dominant habitat, for example, greater emphasis on productive agroforestry systems might be considered in the design of the farm, while herbaceous perennial polycultures would be more appropriate for regions that were once prairie systems (Sala and Paruelo, 1997; Soule and Piper, 1992). Fig. 1 shows how agroecology and landscape multifunctionality contribute to a design framework, acting at different scales.

We developed an agroecosystem design assessment tool to facilitate the process of characterizing and analyzing whole-farms, in order to make more informed decisions about land use. The tool accounts for the spatial contribution and multiple functions of a landscape including landscape features or units, area of land in that feature/unit, and ratings for the attributes of different functions. In order to rate the attributes, a reference point is needed to determine what the landscape features are being compared to. A reliable reference land use would be the agricultural system that is most prominent in the area (i.e. conventional pasture systems in Vermont). For theoretical purposes, we have proposed a set of attributes appropriate for Vermont farms, but these could (and arguably, should) be adapted for other regions in cooperation with local farmers, stakeholders, and experts (Van Calker et al., 2005). The scale of the area of assessment, and even the level of detail in features, remain flexible. A finer-scale approach could include each ecotope as a separate polygon, recognizing that spatial location and specific management practices can impact functions (e.g. individual fields, separate vegetative buffers, etc.).

This tool is not intended to replace or compete with other approaches that assess farm sustainability based on a specific set of non-spatial indicators or attributes. There are many examples of cases in which such approaches have been successfully used within the fields of agroecology and landscape multifunctionality (Bockstaller et al., 1997; Halberg et al., 2005; Payraudeau and van der Werf, 2005; van Calker et al., 2005; Makowski et al., 2009). Instead, the proposed tool could complement these more data intensive approaches, many of which can only be realistically undertaken as part of expert-based research projects. Our approach is unique in its attempt to achieve some balance across functional areas and optimization of multiple attributes for different land use types based on the proportion of land they cover. Unlike most other strategies, our approach also focuses on the spatial extent of individual landscape features or units, essentially weighting the features based on the proportion of land they cover, similar to the approach by Bockstaller et al. (1997), in which indicators were weighted by field size. This tool, however, is not proposed as a stand-alone assessment, but rather one that could be used in combination with other strategies such as life cycle analysis, environmental impact assessment, and agro-environmental indicator evaluation (Payraudeau and van der Werf, 2005). To illustrate the

We propose that agroecology and multifunctionality provide key concepts for an evolving framework for the sustainable design of agricultural landscapes. We do not, however, believe this framework requires any new terminology or definitions that might dilute the overall intent of various efforts to improve sustainability of agricultural systems. Instead we emphasize the need for integration of existing approaches, particularly agroecology and multifunctionality, each of which should continue to serve research and applications in its own right. Our intention is not to replace them, but to bring them together as an integrated framework specifically focusing on the *design* of sustainable agricultural landscapes.

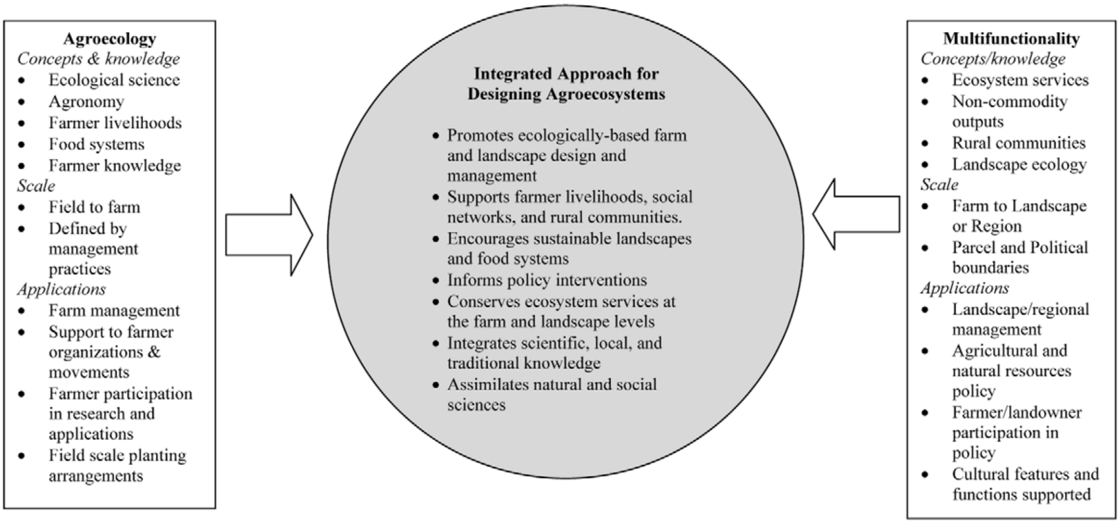


Fig. 1. Conceptual diagram of proposed framework for designing agroecosystems integrating agroecology and landscape multifunctionality.

application of our framework, we use the assessment tool to evaluate the design of two Vermont farms recognized locally as multifunctional landscapes.

4. Methods

4.1. Study site

With its agricultural heritage, heterogeneous landscape, and growing support for local, organic, and diversified food production, Vermont is an ideal place to consider strategies for integrating agroecology and multifunctional landscapes (Center for Rural Studies, 2008). Land cover in Vermont is dominated by forest (approximately 75%), but agriculture also contributes significantly to the landscape, making up approximately 15% of the land cover (NOAA, 2006). Top agricultural products in the state include dairy, beef, fruits and vegetables, and maple syrup. Vermont's agricultural output was $758 million in 2007 (USDA Economic Research Center, 2008a), which is approximately 4% of Gross State Product. The landscape also supports a thriving tourism industry (including agri- and eco-tourism) which accounts for another $1.63 billion (8.4%) of Vermont GSP (Vermont Department of Tourism and Marketing, 2002). However, few studies have been undertaken to highlight the agricultural design and multifunctionality of the Vermont agricultural landscape. Two well-known, multifunctional farms in northern Vermont were chosen to apply the framework. Both farms are diversified, sell specialized products, are managed organically, and host educational and recreational activities. Butterworks Farm is a private dairy farm, while the Intervale Center is a non-profit organization that leases land to several independent organic vegetable, fruit, and flower farmers.

4.2. Semi-structured interviews

Semi-structured interviews were conducted with one of the owners of Butterworks Farm and one of the farmers who leases land (and is also an author on this paper) at the Intervale. Interviews documented farming practices, history of the farm, and impacts of the surrounding landscape. Questions were open-ended, allowing for informal conversation. Informal interviews with the managers of the Intervale Center Farms Program and the Intervale Compost Project were conducted to complement information on the Intervale Center.

4.3. Agroecosystem design assessment tool

The agroecosystem design assessment tool was developed to evaluate the design of farms using input on boundaries of farm parcels, type and extent of landscape features or units, and ratings for the attributes of production, cultural, and ecological functions. For Butterworks Farm, the area of interest included the home farm and the clusters of remote parcels operated as part of the farm. These were identified using Farm Service Agency (FSA) Common Land Unit (CLU) parcels, where CLUs are defined as "the smallest unit of land that has a permanent, contiguous boundary, a common land cover and land management, a common owner and a common producer" (USDA Farm Service Agency, 2009). The total area included within these boundaries was just over 480 ha, distributed among ten discrete groupings of parcels in the towns of Westfield and Troy. In the case of the Intervale Center, the area of interest was defined as land owned or managed by the center, which was delineated using tax parcel maps in consultation with Intervale Center staff. Unlike Butterworks, the land owned by the Intervale existed in one contiguous parcel.

Individual landscape features were identified in ArcGIS 9.3 using both automated classification and manual delineation processes. One-meter resolution aerial imagery from the visible and near-infrared spectra (USDA National Agricultural Imagery Program from 2008) was extracted for the area of interest. This imagery was pre-processed via a principal components transformation. Training polygons representing forested, open field, built/

impervious and surface water land cover types were delineated on the imagery, and a maximum likelihood algorithm supervised classification was then performed. A majority filter was then applied to this surface to remove all groupings of pixels smaller than 0.05 acres, and the result was converted to vector polygon format for editing. In the case of Butterworks Farm, all open field polygons were intersected with the CLU parcel layer to acquire field boundaries and crop information. Polygons were then manually classified into the following 15 landscape feature types using visual assessment of the aerial imagery and input from farmers: cultivated field, fallow field, pasture/hay, forest, hedgerow (defined as treed areas less than 55 m wide with length at least four times width), riparian buffer (defined as treed areas within 30 m of a river or stream), water, wetland, built infrastructure, greenhouse, compost pile, orchard, roads/trails, community gardens, and native plant nursery.

The ratings for each of the production, ecological, and cultural attributes were determined through a combination of landowner input and expert knowledge. Farmers were asked the extent to which each of these landscape features impacted or enhanced each functional attribute on their farms. Each landscape feature was assigned a score ranging from 2 to -2, where 2 = strongly improves functional attribute, 1 = slightly improves functional attribute, 0 = neutral or no impact, -1 = slightly negative impact on functional attribute, and -2 = strong negative impact. The scores, based on the descriptions provided by the farmers, were ultimately determined by two of the authors in order to ensure consistency across the two case studies. Summing scores for each category of functions, the highest score a landscape feature could receive was 10 and the lowest -10, for a total possible score of 30 for the three functional areas. The output of the agroecosystem design assessment tool is a bar chart indicating the contributions of each landscape feature to the overall multifunctionality of the farm. The height of the bars corresponds to the total score of each landscape feature, and the width of the bars represents the percentage area of that feature in the farm landscape. We should note that for these examples, the output bar chart is set to 1% increments, so features covering less than 1% of the area (when rounded), do not show up on the chart, although the information is still retained in the worksheet.

5. Results

5.1. Regional characterization and context of Vermont agricultural landscape

An important step in designing farms or evaluating the farm design is to characterize the landscape and historical context of the farm, in this case, considering the unique qualities of the state of Vermont. Many Vermont farms incorporate ecological principles and a social mission along with agricultural production. Not only is Vermont a leader in organic agriculture, with the seventh highest number of certified organic operations in the country (USDA Economic Research Service, 2008b), but the state also has a strong movement for local agriculture (UVM Center for Sustainable Agriculture, 2009). There are more than 65 Community Supported Agriculture (CSA) programs in Vermont (NOFA Vermont, 2007), enabling consumers to buy food directly from farmers. The number of farmers' markets in Vermont has more than tripled in the past two decades, and as of 2006, there were farmers' markets in more than 50 communities with gross sales of $3.7 million. The local foods movement has been motivated by the desire for fresh and nutritious foods, to support local farmers and the Vermont economy, increase food security, and reduce the environmental impacts of food transportation (Timmons, 2006).

5.2. Case study 1: the Intervale

5.2.1. Overview and site history

The Intervale, a 280 ha segment of floodplain, is a diverse agricultural landscape that has evolved into a multifunctional site, in part due to its unique location. The wide variety of functions and landscape features are represented in the map in Fig. 2. The Intervale is situated mostly within the city limits of Burlington, Vermont (population approximately 40,000), which functions as a center for commerce and tourism. Located on rich alluvial soils where the Winooski River meets Lake Champlain, the Intervale has been a working agricultural landscape for more than 10,000 years. The Abenaki (a tribe of Native American and First Nations people) first cultivated this fertile agricultural land more than 1000 years ago. As European settlement progressed through New England, the Intervale became the location for the homestead of Ethan Allen, a founder of the state of Vermont. Subsequently, tenant farmers serving Ethan Allen and his brother Ira displaced the Abenaki at the site. Wheat and rye fields dominated the landscape until 1866 when the Central VT railroad made it possible to bring in cheaper crops from the Midwest. By the 1900s, the land was used to raise livestock. The last Intervale dairy farm stopped production in 1991.

The Intervale Center (IC), formerly known as the Intervale Foundation, was formally launched in 1988 as an agricultural non-profit organization to promote sustainable land use, agricultural education, and financially successful small-scale farms. Agroecology-based principles have been encouraged in the farm management from the beginning. The IC currently manages approximately 180 ha of farmland and runs several projects including the Farms Program, which leases land to thirteen organic farms through an incubator program. This program supports the establishment of new farming operations by providing a discount on land rent and other fees, access to shared equipment, and technical assistance from mentor farms. Through the years, the IC has helped to incubate over 30 farms. Through a cooperative model, each new farm has access to necessary infrastructure without incurring heavy debt loads. The Intervale also houses a community garden managed by the city with 150 garden plots for Burlington residents.

5.2.2. Production functions

The Farms Program at the IC started in 1990, and currently supports 13 independent farms, which are required to utilize organic practices, although some are not USDA certified. Of the 50 ha under cultivation, the majority is managed for vegetable and fruit production, much of which is marketed locally. Over 250,000 kg of produce are grown and distributed annually, providing approximately 6% of total consumption of fresh produce in Burlington and $500,000 in revenue to the local economy (Intervale Center, 2009). Other products generated at the Intervale include eggs, chickens, honey, flowers, jam, native trees for riparian restoration, compost, and other soil products. Most of the items produced in the Intervale are distributed within Chittenden County (where Burlington is located) through wholesale accounts, farmers markets', pick-your-own operations, and community supported agriculture (CSA) shares.

5.2.3. Ecological functions

The ecological functions identified in the study are supported through agricultural management practices, such as organic crop production. In addition, all farms are required to plant cover crops on at least one-third of their annual fields to allow the fields to regenerate, and they are encouraged to sow a winter cover crop on all land. Farmers are required to rotate crops to increase soil fertility and reduce disease in the fields. These agricultural practices, which have a basis in agroecology, can help maintain some of the

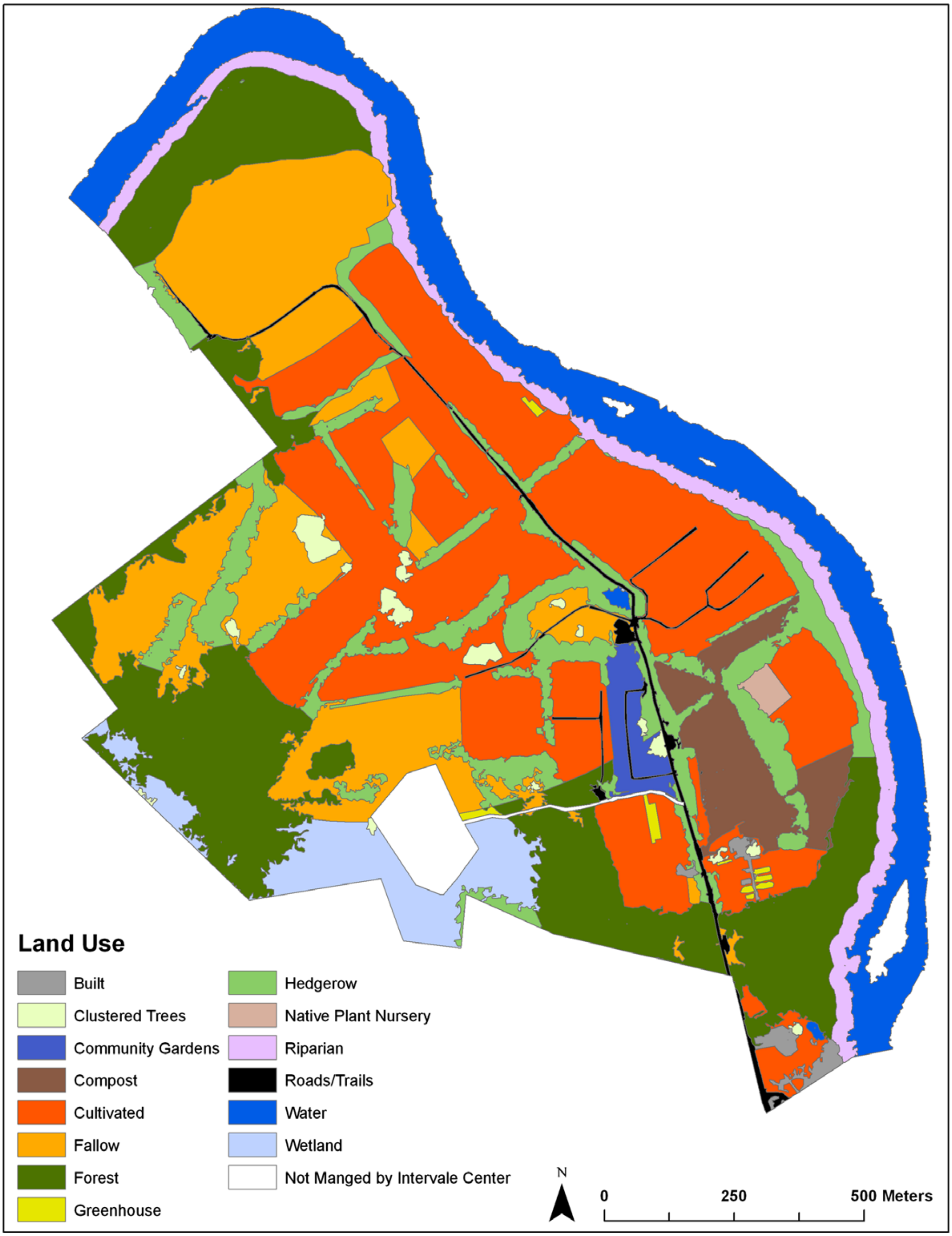


Fig. 2. Map of land use and landscape features of the Intervale Center, used as input in the agroecosystem design assessment tool.

"regulating" ecosystem functions (such as nutrient cycling) in cultivated fields. Non-crop habitats are also retained within the agricultural landscape to reduce erosion, conserve biodiversity, support native species (Freemark et al., 2002), and provide habitat for wildlife. Landscape features such as hedgerows, riparian areas, and forested areas are integrated throughout the site. Plants in windbreaks and hedgerows also encourage natural enemy populations of herbivore pests, making crops less susceptible to insect infestation (Altieri, 1999). These non-crop features increase the heterogeneity of the landscape, improving the quality of the agricultural matrix (Benton et al., 2003).

5.2.4. Cultural functions

The Intervale supports multiple cultural functions including historic preservation, recreation, education, and visual quality. The rich combination of diverse habitat types at the Intervale enhances the visual quality of the region. Education is supported by a number of programs including Healthy City, a non-profit farm that teaches at-risk youth how to grow and market food, providing teenagers with a positive way to interact with the community and gain skills for future work. The IC hosts the Gleaning Project where volunteer community members harvest produce from the fields that the farmers cannot sell and redistributes this food to over ten social service organizations in the Burlington area. Several historic buildings have been preserved for use as administrative offices and community events. Recreational activities offered by the IC include trails for hiking, biking, and cross-country skiing. To support food systems education, the IC hosts weekly summer events with music, food, and presentations about gardening or about the cultural heritage of the site. The IC also hosts several agriculture related workshops each year and provides tours for school and university groups.

5.2.5. Multifunctional landscape assessment

The diversity of crops, organic management practices, and food systems approach through local marketing make the Intervale a good example of agroecology-based production functions. The agroecosystem design assessment tool was used to evaluate the multifunctionality of the site, using the area of landscape features from the map (Fig. 2) as inputs into the worksheet (Fig. 3), to develop the output (Fig. 4). The total land area is 187 ha, with most of the land use in cultivated fields (27%), forest (19%), fallow fields (16%), and vegetative buffers (16%). The total treed habitat is 64.5 ha, encompassing 34.6% of the site. Greenhouses, built infrastructure, and the native plant nursery make up less than 1% of the land use and thus were not included in the output of the assessment tool. Cultivated fields and community gardens scored the highest for the production function (both rating 9 out of 10). Forested areas and vegetative buffers (hedgerows and riparian areas) scored the highest for the ecological function with scores of 10 and 9, respectively. Built infrastructure scored the highest for the cultural functions (9), followed by the community gardens (6).

The highest rated landscape feature was the native plant nursery with an overall score of 20 (out of a possible 30), though it only occupies 0.3% of the land area. This feature provides ecological functions over a much larger area by providing nearly 35 species of ecologically grown trees and shrubs for conservation projects throughout Vermont. It also provides production functions, and cultural functions including education. The community gardens are also highly multifunctional due to the productive and cultural functions they serve for community members who rent garden plots every year, but they also cover only a small area of the site (1.1%). These functions are in high demand, as the number of residents seeking garden plots exceeds the number of available plots every year, demonstrating that an expansion of these might be an appropriate consideration. These non-traditional landscape features suggest the Intervale is a landscape uniquely positioned to support multifunctional activities.

Several features at the Intervale were assigned negative scores for ecological functional attributes. These include cultivated fields, composting facility, built infrastructure, greenhouses, and roads and trails. While all of the farmers at the Intervale practice organic agriculture, which has less of a negative ecological impact than industrialized, high-input agriculture, even these activities decrease ecological functions when compared with a natural ecosystem. The compost facility received a negative ecological score due to its close proximity to the Winooski River and a negative cultural score due to its location on Abenaki archeological remains. Built infrastructure and greenhouses at the Intervale received negative ecological scores due to the high energy inputs required for their operation. Because roads and trails do not allow for plant biodiversity, water conservation, or soil conservation, they also received a negative ecological score.

While the assessment tool highlights the multifunctionality of the site, some conflicts or trade-offs do exist, particularly between cultural and production functions. For example, the Agency of Historic Preservation has designated certain areas in the Intervale off

FUNCTIONAL ATTRIBUTES (rating -2 to +2)	Cultivated fields	Fallow fields	Forest	Vegetative buffers	Water	Built infrastructure	Roads/trails	Greenhouses	Community gardens	Native plant nursery	Compost	Wetland	
Production Functions													
Productivity/Yield	2	0	1	1	1	1	0	2	2	1	2	0	
Efficiency of inputs	1	1	1	1	1	-1	0	-2	1	1	2	0	
Diversification of products	2	0	0	0	0	0	0	2	2	2	1	0	
Product quality/specialty	2	0	0	0	0	0	0	2	2	2	1	0	
Economic value	2	0	0	0	1	1	0	2	2	2	2	0	
TOTAL	*9*	*1*	*2*	*2*	*3*	*1*	*0*	*6*	*9*	*8*	*8*	*0*	
Ecological Functions													
Biodiversity/wildlife habitat	-1	1	2	2	1	-1	-1	0	1	2	-2	2	
Low chemical application	2	2	2	2	2	2	2	2	2	2	2	2	
Carbon Sequestration	-1	1	2	2	0	-1	0	-2	0	2	1	2	
Water quality/conservation	-1	2	2	2	0	0	-1	-1	1	2	-2	2	
Soil conservation/building	2	1	2	2	0	0	-1	0	2	2	1	2	
TOTAL	*1*	*7*	*10*	*10*	*3*	*0*	*-1*	*-1*	*6*	*10*	*0*	*10*	
Cultural Functions													
Living place/shelter	0	0	1	0	0	2	1	1	0	0	0	0	
Visual quality/Art	1	1	2	2	1	1	0	0	2	1	-1	2	
Recreation/Entertainment	0	1	2	1	1	2	2	0	2	0	0	1	
Historical preservation	0	0	0	0	0	2	0	0	0	0	-2	0	
Education/Research	2	0	0	0	0	2	1	1	2	2	2	0	
TOTAL	*3*	*2*	*5*	*3*	*2*	*9*	*4*	*2*	*6*	*3*	*-1*	*3*	
Performance Sum	**13**	**10**	**17**	**15**	**8**	**10**	**3**	**7**	**21**	**21**	**7**	**13**	
													TOTAL
Area (ha)	50.5	30.0	35.3	29.2	21.6	1.0	2.3	0.5	2.0	0.5	6.6	7.1	187
% Landscape Contribution	27.1	16.1	18.9	15.7	11.6	0.6	1.2	0.3	1.1	0.3	3.5	3.8	100

Fig. 3. Intervale agroecosystem design assessment worksheet based on land use and landscape features.

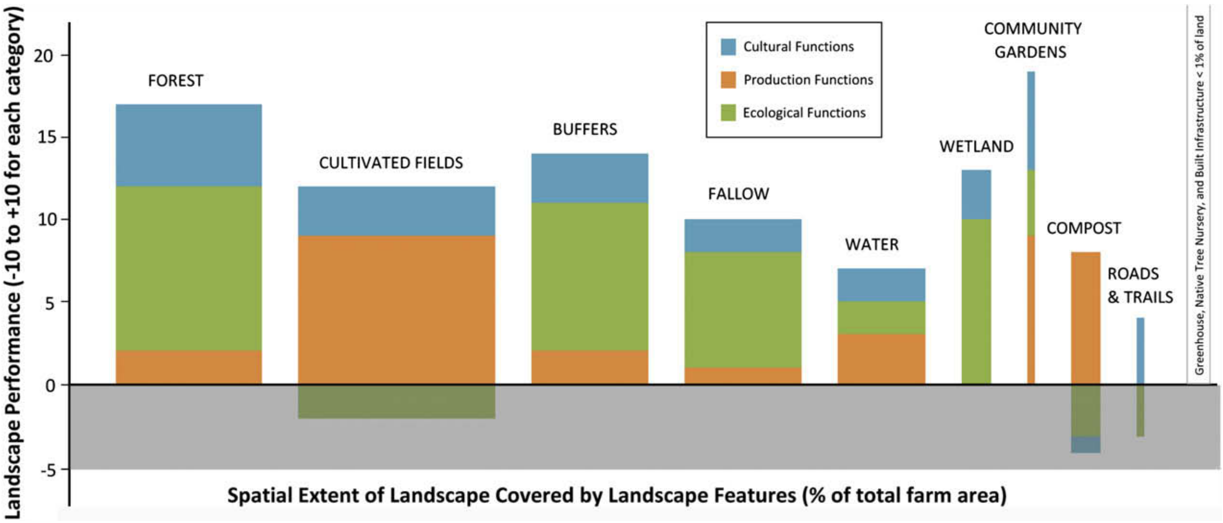


Fig. 4. Intervale agroecosystem design assessment output indicating the spatial extent of functions provided by landscape features.

limits for any type of agricultural uses because archeological digs have uncovered many Abenaki artifacts. The use of the Intervale road by bicyclists represents another conflict, as the movement of large farming equipment poses a safety hazard for recreational users. The location of the Intervale in a 100-year floodplain demonstrates a tradeoff between ecological and production functions. The Federal Emergency Management Agency (FEMA) has enforced an arduous permitting process for farmers who want to improve or build any infrastructure such as hoophouses, greenhouses, or sheds. The purpose of this restriction is to minimize water displacement by built infrastructure in the floodplain. The Intervale case study demonstrates that conflicts and trade-offs are important considerations in designing agroecosystems, although they may not be fully captured in the assessment of the landscape.

5.3. Case study 2: Butterworks Farm

5.3.1. Overview and site history

Butterworks Farm, owned by Anne and Jack Lazor, is located in Northeastern Vermont, less than 15 km from the Canadian border and 95 km from Burlington. Butterworks is an organically-certified, diversified farm with a value-added dairy as the economic backbone of its operation. The Lazors and their employees cultivate more than 120 ha of land located on ten parcels, located within an 18 km radius of the home farm (Fig. 5). The Lazors own 135 ha of land, 46 ha of which are forested. The remaining cultivated land is rented both from private landowners and from a public landowner, the nearby town of North Troy. The recorded history of the home farm property extends back to the late 1830s when an English settler named Thomas Trumpass established a farm on the site (Jack Lazor, personal communication). The Lazors arrived in 1976 and, with the milk of three cows, began selling dairy products from their kitchen to neighboring families. Since then, the milking herd has grown to 45 cows and the business is licensed by the Vermont Department of Agriculture to produce dairy products in an on-farm processing facility. Today, Butterworks products are distributed throughout Vermont and the Northeast.

The design of Butterworks Farm is determined by many variables, some of which are related to the use of the farm as a residence for the farmers. The siting of the original homestead, roads, fields and hedgerows, are strongly influenced by the land use of the original colonial settlers, while newer features were located based on the Lazor's own analysis of the landscape. The home site was selected to be protected from the wind and set back from the road, but still close to the barn. The windmill was located on the windiest spot, with close proximity to a power-line and a road for maintenance access. Land use decisions for individual fields are influenced by proximity to the barn and homestead, flooding regime, micro-climate, soil quality, and other factors. For example, fields near the barn have been devoted to pasture, providing the cows with easy access to the barn. Farmers, with their intimate knowledge of their land, can often take advantage of biophysical conditions to design for maximum landscape multifunctionality.

5.3.2. Production functions

Dairy products, mainly yogurt and cream, are the backbone of the Butterworks operation, but the farm also produces dry beans, corn meal, sunflower (*Helianthus annuus* L.) oil and wheat (*Triticum aestivum*) flour for human consumption, and corn, oats (*Avena sativa*), barley (*Hordeum vulgare*), soybeans (*Glycine max*), and alfalfa (*Medicago sativa*) for the cows. The gross annual sales of the farm exceed one million dollars. The family also produces eggs, chicken, pork, cheese, fruits, and vegetables for their own consumption, meeting 85% of their own year-round food needs. Much of these non-commercial products are shared with employees and used elsewhere to barter for products and services. While Vermont was once considered the ‘‘bread-basket of America,” the state has produced little of its own oils and grains since the 1840s (Jack Lazor, personal communication). Now, Butterworks is one of the few oil and grain producers in the state, and thanks to the growing interest in foods produced locally, demand for these products is so high that the supply runs out early each season.

5.3.3. Ecological functions

The Lazors strive to support ecological functions in the management of the farm, with agroecology principles providing the basis for their integrated crop-livestock system. They have been farming organically since 1976 (certified since 1987). They use intensive rotational grazing and are almost completely self-sufficient, growing all the food consumed by their cows. In 2001, they built a greenhouse pack-barn in which manure and bedding accumulate, providing a high quality composting material used to fertilize the crops. The cultivated fields are managed in a standard 3 year rotation designed to build and maintain soil health, and this rotation is adjusted when necessary in response to weed pressures, flooding regimes, and other factors. While the cultivated fields require regular management, forest and wetland portions of the owned and leased land are left mostly untouched except for occasional

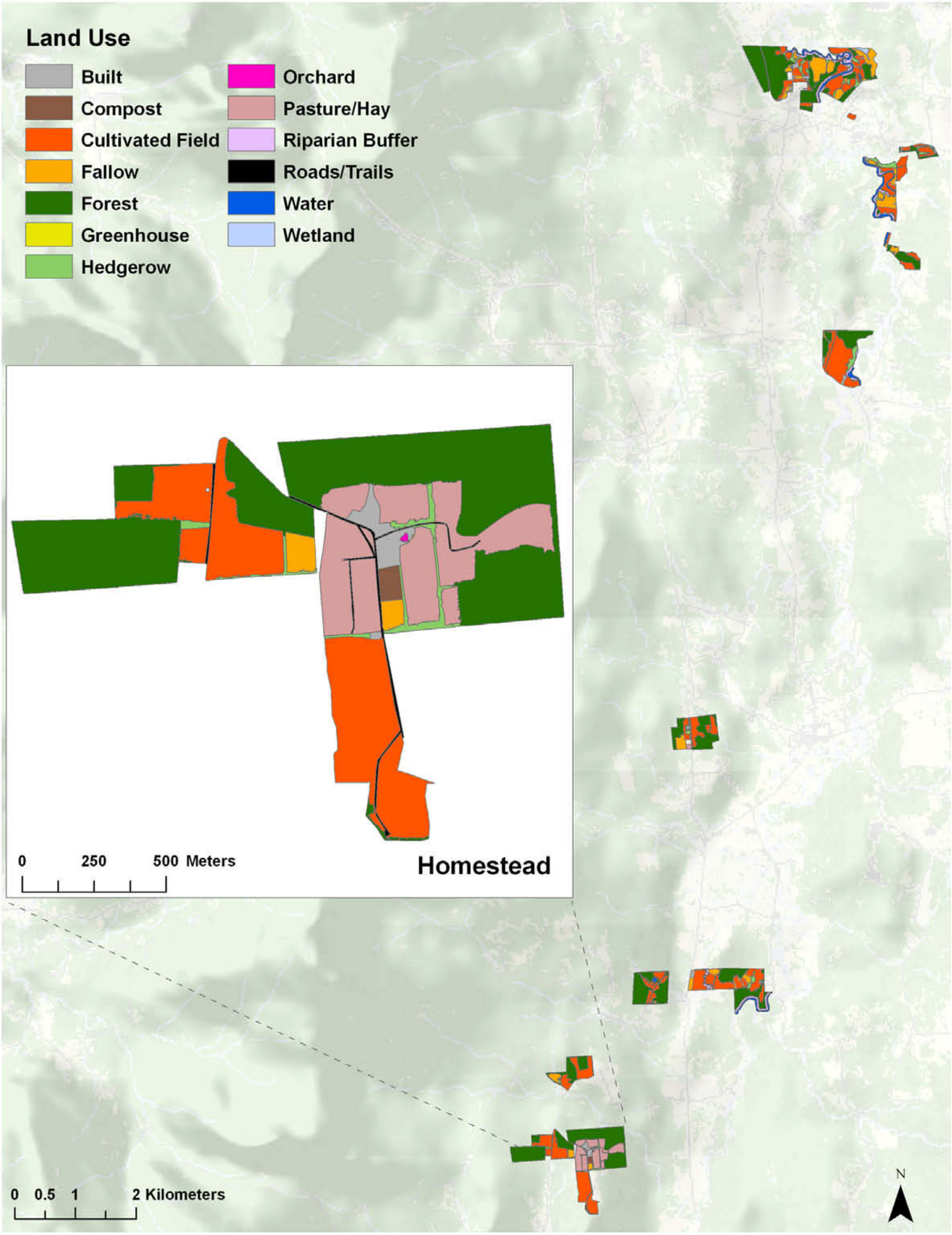


Fig. 5. Map of land use and landscape features of the Butterworks Farm, used as input in the agroecosystem design assessment tool.

firewood or timber harvests. The Lazors also participate in a number of conservation programs through the Natural Resource Conservation Service (NRCS), and all but 23 ha of their land are under a conservation easement to protect from development. They are committed to sustainable energy, using a windmill on the home farm to provide 35% of the annual energy needs. Recently, the farm was awarded a research grant to explore the feasibility of installing a biomass burning boiler to provide the remainder of their energy.

5.3.4. Cultural functions

Besides supporting the local rural economy by providing employment for three full-time and nine part-time staff, both Anne and Jack Lazor provide cultural services as leaders in the agricultural community, especially in the organic and localvore movements. Jack regularly lectures at conferences and other events, and both Anne and Jack serve on state-wide agricultural committees. Anne is a local expert on homeopathic treatment for animals, providing support to other farms. Additionally, Butterworks hosts agricultural extension workshops and school groups and serves as a research site for university and extension projects. For example, local elementary school students visit the farm once a year to bake corn bread, first searching to find the ingredients. The Lazors have never posted "no trespassing" signs on their property to restrict use by the public. Jack Lazor explains that as long as their livestock are respected, hunters and other local residents are welcome to enjoy the land. By allowing space on the farm for community involvement, Butterworks demonstrates the agroecological principle of reconnecting people to the landscapes that grow their food.

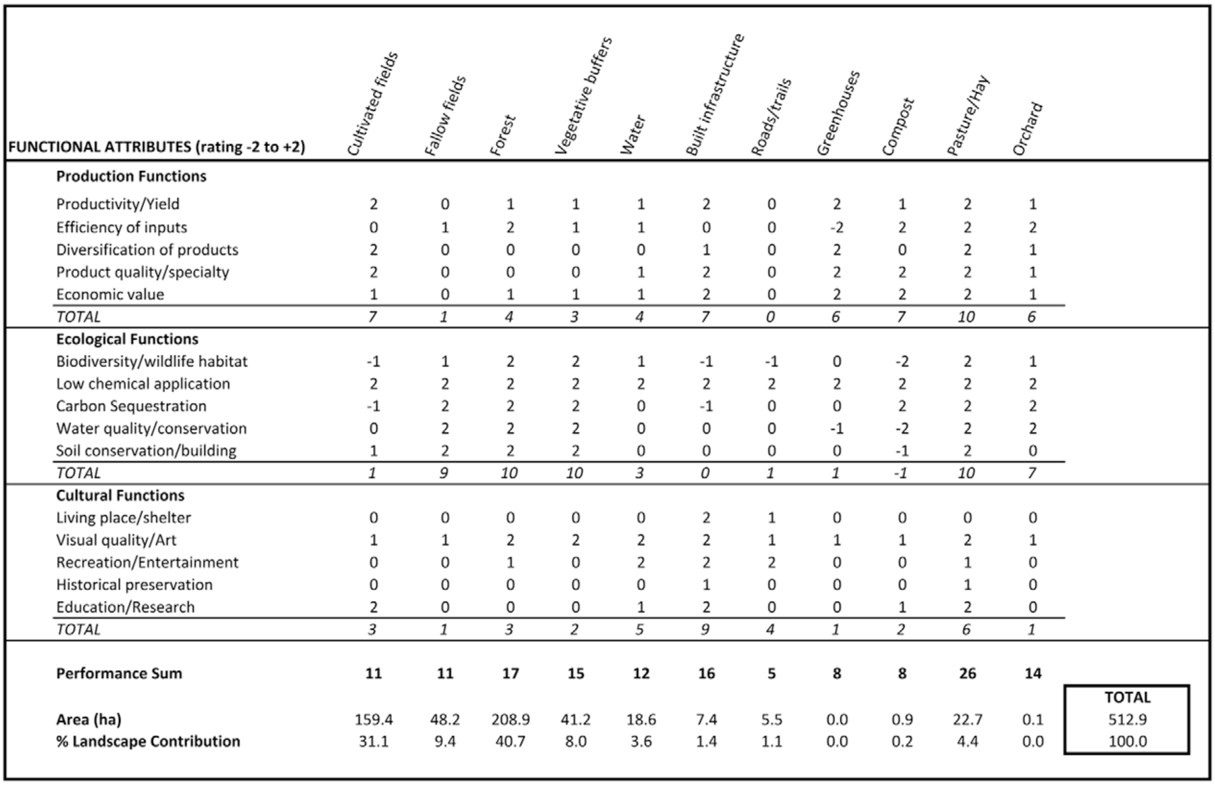
5.3.5. Multifunctional landscape assessment

Like the Intervale, most of the Butterworks landscape features (rated for both the owned and leased properties) provide production, ecological and cultural functions, as demonstrated in the results of the agroecosystem design assessment (Figs. 6 and 7). Of the habitat types on the farm, forest covered the greatest proportion of the landscape (40.7%) and scored the second highest for multifunctionality, with 17 points of a possible 30. The forest ranked high on all ecological attributes, but it also provided some production and cultural functions. Vegetative buffers, which covered 8% of the landscape scored slightly lower than forest in each of the functional categories. Pasture/hay, which covered 23 ha of the farm landscape, scored the highest overall (25 out of 30), with high rankings on production and ecological function attributes, reflecting high economic value, agricultural productivity, efficiency of inputs, plant biodiversity, soil conservation, and water quality. Pasture/hay also provided important cultural functions recognized by the Lazors including aesthetic value, a site for education and research, and historic preservation of old stonewalls. Despite the plethora of functions provided by pasture/hay, it covers a relatively small land area (4.4% of total farm area) compared to the forest and cultivated fields. The amount of pasture is limited in part by the size of the dairy and need to have it in close proximity to the barn.

Negative scores in the ecological functions section were incurred by the cultivated fields, built infrastructure, roads/trails, greenhouses, and compost. These negative scores reflect the inherent trade-offs between production and ecological functions whereby simply practicing agriculture, even with organic and ecologically-minded practices, causes disruption of the natural environment. Composting scored most negatively in the ecological functions section, despite the known ecological benefits of recycling nutrients within an agricultural system. In the relatively small land area it occupies (0.2%), composting concentrations nutrient-rich materials in one place, posing a potential threat to water quality and creating an "unnatural" localized environment not habitable by most native flora and fauna.

Despite the high level of multifunctionality and spatial efficiency exhibited by Butterworks, some conflicts and trade-offs exist between functions. Butterworks has received much publicity for its commercial success, long-time organic practices, and support for the sustainable agriculture movement. While the Lazors are committed to sharing their knowledge, public outreach efforts have reduced the time and energy they have to spend on the farm, demonstrating a tradeoff between cultural (education and outreach) and production functions (time and energy efficiency for land managers). Other conflicts exist as a result of their commitment to a diversified, local production system. The Lazors are passionate about supporting the return of grains to the Vermont agricultural landscape, helping the state reach a higher level of food independence. While the Butterworks grain operation has grown steadily in the past 10 years, Jack Lazor admits that the grain operation is financially supported by the yogurt business and would not be viable without the success of the yogurt.

Despite the challenges faced by these farms, both Butterworks and the Intervale remain viable agricultural enterprises, providing important food products and offering a wide range of functions that benefit the local community and surrounding environment.



FUNCTIONAL ATTRIBUTES (rating -2 to +2)	Cultivated fields	Fallow fields	Forest	Vegetative buffers	Water	Built infrastructure	Roads/trails	Greenhouses	Compost	Pasture/Hay	Orchard	
Production Functions												
Productivity/Yield	2	0	1	1	1	2	0	2	1	2	1	
Efficiency of inputs	0	1	2	1	1	0	0	-2	2	2	2	
Diversification of products	2	0	0	0	0	1	0	2	0	2	1	
Product quality/specialty	2	0	0	0	1	2	0	2	2	2	1	
Economic value	1	0	1	1	1	2	0	2	2	2	1	
TOTAL	*7*	*1*	*4*	*3*	*4*	*7*	*0*	*6*	*7*	*10*	*6*	
Ecological Functions												
Biodiversity/wildlife habitat	-1	1	2	2	1	-1	-1	0	-2	2	1	
Low chemical application	2	2	2	2	2	2	2	2	2	2	2	
Carbon Sequestration	-1	2	2	2	0	-1	0	0	2	2	2	
Water quality/conservation	0	2	2	2	0	0	0	-1	-2	2	2	
Soil conservation/building	1	2	2	2	0	0	0	0	-1	2	0	
TOTAL	*1*	*9*	*10*	*10*	*3*	*0*	*1*	*1*	*-1*	*10*	*7*	
Cultural Functions												
Living place/shelter	0	0	0	0	0	2	1	0	0	0	0	
Visual quality/Art	1	1	2	2	2	2	1	1	1	2	1	
Recreation/Entertainment	0	0	1	0	2	2	2	0	0	1	0	
Historical preservation	0	0	0	0	0	1	0	0	0	1	0	
Education/Research	2	0	0	0	1	2	0	0	1	2	0	
TOTAL	*3*	*1*	*3*	*2*	*5*	*9*	*4*	*1*	*2*	*6*	*1*	
Performance Sum	**11**	**11**	**17**	**15**	**12**	**16**	**5**	**8**	**8**	**26**	**14**	
												TOTAL
Area (ha)	159.4	48.2	208.9	41.2	18.6	7.4	5.5	0.0	0.9	22.7	0.1	512.9
% Landscape Contribution	31.1	9.4	40.7	8.0	3.6	1.4	1.1	0.0	0.2	4.4	0.0	100.0

Fig. 6. Butterworks Farm agroecosystem design assessment worksheet based on land use and landscape features.

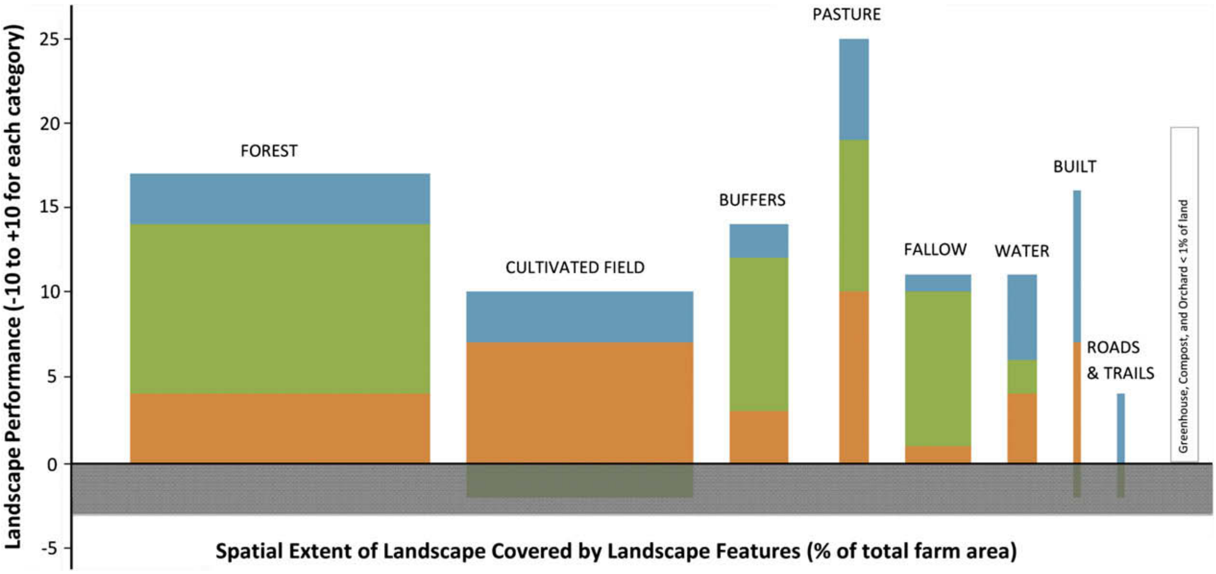


Fig. 7. Butterworks Farm agroecosystem design assessment output indicating the spatial extent of functions provided by landscape features.

Their success is due in part to creative multifunctional farm designs that integrate agroecological principles.

6. Discussion

In this study, we drew concepts from the fields of agroecology and landscape multifunctionality to develop a framework for analysis of the agricultural landscapes. The Northern Vermont region represents an important study area because it contains successful and innovative farming operations, despite the challenging mountainous terrain and limited growing season. The designs of many of the farms in the region reflect an agrarian cultural heritage that has sought to maintain a high level of harmony with nature, resulting in a landscape that provides multiple functions. We introduced an agroecosystem design assessment tool to evaluate agroecosystem design at the whole-farm scale, accounting for the spatial contribution and multiple functions of individual landscape feature types or land units of the farm. While the specific details of the assessment tool were developed to evaluate farms in Northern Vermont, the tool could be adapted for other regions using input from local farmers, stakeholders, and experts to identify locally relevant functional attributes and landscape feature categories.

6.1. Study limitations

While the agroecosystem design assessment tool is valuable for evaluating and comparing designs for farms, some limitations should be recognized. As a spatially explicit tool derived from land use and functions, the assessment does not fully account for the extent of impacts a specific landscape feature could have on the landscape or ecosystem beyond the boundaries of the feature itself. The Intervale Compost Project, for example, scored negatively for the ecological dimension because of the impacts within the boundaries of the site, but the assessment tool did not account for the amount of food and yard waste that was diverted from landfills and turned into a useable product. The assessment also underrepresented the scale of impacts the runoff from the compost area has on the ecology and health of nearby water resources. In fact, features representing less that 1% of the total land area did not appear in the output, even though some of these features may have far-reaching effects or consequences (e.g. dams or filter strips). The purpose of the design assessment tool, however, is to allow farmers and stakeholders to evaluate the extent and diversity of multifunctionality of the entire farm based on all of the individual features, in a way that goes beyond the scale of the field. For a more thorough investigation of impacts of individual landscape features, other tools such as ecological footprint approach or life cycle analysis should be used.

The relatively low importance placed on economic aspects may also be considered a limitation of this framework and the assessment tool, particularly since short-term profits often drive the decisions that affect the design and management of farms. The argument could be made, however, that the economies of agricultural systems are driven to a great extent by government programs and subsidies, which are not always aligned with the preferences of the public or what is best for the environment. If we want to consider new opportunities for designing farms to support non-commodity outputs for the future, we need to move beyond current limitations, such as lack of alternative markets and unbalanced support for production functions. This would contribute to a rationale and effort that justifies support for ecological and cultural functions. While our approach would likely not offer the best economic solution for the farmer based on the current market and institutional trends, it may instead help in identifying opportunities that could evolve with new economic tools to support ecosystem services. Van Huylenbroeck et al. (2007) contend that multifunctionality is not contradictory with efficiency, but instead that efficiency should be measured on more than just profit alone. More specifically, efficiency should also account for socially and ecologically desirable outcomes.

6.2. Future research

The framework and assessment tool provided in this paper are just an initial step in developing an interdisciplinary approach to design and assess agricultural systems. While we demonstrated the applications and outcomes of our approach with two farms in Vermont, more work is needed to expand the approach to evaluate other types of landscapes. In the Midwest US, where the native habitat was a mesic prairie community, perennial polycultures have been proposed as an alternative to the existing highly industrialized, monoculture grain production systems that dominate the rural landscape (Soule and Piper, 1992). In regions that once contained arid or semi-arid grasslands, such as the western Great Plains of

North America, grazing systems could be incorporated into agroecosystem design to support a range of ecosystem services, such as carbon sequestration, micro-climate control, soil conservation, and others (Sala and Paruelo, 1997). The framework and assessment tool provided here could help land owners, extension agents, and rural community planners to identify the landscape features that might support recreation, cultural heritage, education, tourism, and visual quality of the rural landscape.

6.3. Emerging themes

The evolving framework provided in this paper contributes to several important themes that transect agroecology and landscape multifunctionality, listed below.

6.3.1. Theme 1: policy-driven versus grass-roots initiatives

One of the greatest debates in both agroecology and landscape multifunctionality is on the emphasis on top-down (policy-driven) versus bottom-up (grass-roots) initiatives. Agroecology began as a bottom-up approach guided by the specific needs of farmers (Méndez, 2010), while multifunctionality of agriculture has been used primarily to support agricultural policy (Wade et al., 2008). We suggest that these strategies need not be mutually exclusive and that instead policy might be *guided by* our understanding of what is going on at the farm level (Wilson, 2007, 2008, 2009). For countries that have used multifunctional agriculture to support sustainable rural development, there is an appreciation for the intrinsic multifunctionality that agricultural landscapes provide (Holmes, 2006; Oostindie et al., 2006; Noe et al., 2008). Therefore, the foundation of new policy directives can be found in the rural population, instead of imposed by outside experts (Oostindie et al., 2006; Jordan and Warner, 2010). Multifunctionality has been proposed as a unifying concept for rural development based on the uniqueness, strengths, and opportunities of a farming community (Van Huylenbroeck et al., 2007). The focus on rural livelihoods in the field of agroecology follows a similar line of thinking, in recognizing the importance of agriculture for community development (Méndez, 2010).

6.3.2. Theme 2: assessment methods and tools

A number of different approaches have been used to assess the impact of farming, including life cycle assessment, environmental impact assessment, agro-environmental indicators, and others (Payraudeau and van der Werf, 2005). Indicators have been extensively employed in both agroecology and landscape multifunctionality to assess and monitor environmental impacts of farmers' management practices, structural properties of the landscape, species diversity and heterogeneity, changes in agroecosystems over time, and effects of agro-environmental policies (Halberg et al., 2005; Wiggering et al., 2006; Makowski et al., 2009). However, developing indicators for certain types of functions (particularly cultural functions) can prove difficult, since many aspects are not fully measurable (Stobbelaar et al., 2009). Furthermore, the ability to stack multiple indicators is particularly challenging (Bockstaller et al., 1997). Wilson (2007) proposes that "the use of absolute indicators is most likely *not* the right way forward" (p. 323) for assessing multifunctional quality. Instead, we should be integrating qualitative and ethnographic methods that might be informed by other disciplines including rural studies, sociology, psychology, environmental sciences, or human geography (Bohnet et al., 2003; Van Calker et al., 2005; Wilson, 2007; Van Huylenbroeck et al., 2007).

6.3.3. Theme 3: synergies and integration of functions

Shellhorn et al. (2008) stated that a "challenge for the future is to design landscapes that are beneficial for a range of functions" (p 1556). Several experts have called for more holistic frameworks and integrative research tools to assess and design farming systems considering synergistic and multiplier effects (Knickel and Renting, 2000; Groot et al., 2007; Wilson, 2007). Multifunctional agriculture has been proposed as an appropriate strategy for exploring synergies and focusing on positive externalities such as recreation, natural habitats, and others (Knickel and Renting, 2000; Oostindie et al., 2006; Shellhorn et al., 2008). The field of agroecology has also promoted the exploration of synergies and interactions between functions, just as a natural ecosystem would also rely on these complementary interactions (Altieri, 2004a; Gliessman, 2007). However, new strategies are needed to integrate research and understanding across disciplines, including holistic approaches and shared communication or 'language' of sustainability for farms (Noe et al., 2008), particularly for translating across the social and the natural sciences (Stobbelaar et al., 2009).

6.3.4. Theme 4: geography of agricultural systems

A review of different methods for assessing agroecosystems indicates the need for more emphasis on the spatial dimension (Payraudeau and van der Werf, 2005). Many models developed for agricultural systems ignore spatial issues, even though the importance of spatial arrangements and relationships has been recognized (Rossing et al., 2007). Wilson (2009) argues that there is insufficient research into the geography of multifunctionality, and few studies acknowledge the importance of spatial territory to which multifunctionality should apply. The geography of agriculture requires attention to the appropriate scales for applying assessment tools and administering policies. The farm level is the scale at which most overlap exists between agroecology and landscape multifunctionality approaches. This is also where management activities occur, decisions regarding land use are made, and ultimately, where a transition to stronger multifunctionality would occur (Wilson, 2007). Furthermore, researchers have recognized that the actions of individual farmers can have far-reaching impacts at the local and even regional scale (Shellhorn et al., 2008).

6.3.5. Theme 5: alternative farm types

Another important consideration for agricultural systems and rural communities is the emergence of non-traditional farms that do not fit the typical farm model (an individual full-time farmer or family depending almost entirely on the production functions to support the family's livelihood). Instead, many alternative farms are emerging, with the transition to diversified production systems, new residents moving onto farms without agricultural skills ("hobby" or "lifestyle" farms), and groups of urban residents cooperatively working on urban farms. Bohnet et al. (2003) suggest that the trend of non-farm residents moving to rural areas could support multifunctionality, as they may be more willing to manage the landscape for cultural and ecological functions. Urban and peri-urban farms also offer unique potential for strong multifunctionality (Wilson, 2007), and their location near dense population centers could improve the successful transfer of ecosystem services from these farms. Extension and outreach efforts, along with government programs and subsidies, are needed to support these alternative farms in adopting agroecological practices and integrating multiple functions (Bohnet et al., 2003; Labarthe, 2009; van der Ploeg et al., 2009).

7. Conclusion

We have presented an evolving framework for designing agroecosystems based on recent developments in agroecology and multifunctionality. Our approach seeks to bridge the gaps between disciplines, while also addressing several current debates surrounding sustainable agriculture. We propose that the fields of agroecology and multifunctionality, which have developed separately, might be integrated to form a more comprehensive offering for agroecosystem design. Our approach ties together several themes, including: (1) an integration between policy-driven and grass-roots initiatives; (2) the need for new assessment methods and tools that go beyond quantitative biophysical indicators; (3) optimization of synergies and integration of functions on farms; (4) a stronger research and policy focus on the geography and scale of agricultural systems; and (5) the prospect of considering alternative farm types.

We trust that the evolving framework we have presented in this paper will contribute to each of the themes presented above. The framework offers the opportunity to integrate scientific, local, and traditional knowledge, in an effort to develop solutions that benefit farmers and the greater public. The assessment tool was developed to specifically address the need for more methodological tools that consider multiple dimensions, including cultural functions, without being limited by the requirement for absolute indicators. Instead of using absolute *indicators*, the assessment tool presented in this study uses *attributes*, which are developed and rated based on substantial input from the farmers. We have also taken a step toward integrating functions and exploring synergies, based on individual landscape features as they exist in relation to other features. The framework and assessment tools also contribute to our understanding of the geography of agricultural systems, considering scale and spatial relationships. This approach might be particularly useful for alternative farm types such as diversified farms and small ‘‘hobby” farms in rural areas or community farms in urban areas. We have continued to refer to the framework as an “evolving” one, because we expect it will continue to develop as more cases integrate the multifunctionality and agroecology perspectives at the farm level. We hope this work might inspire further research and even debate that would ultimately progress the movement to improve the health of farming communities.

Acknowledgements

The authors would like to thank the Intervale Center and Jack Lazor for their participation in this project. We also thank three anonymous reviewers for their very valuable insight, particularly related to the theoretical basis of the evolving conceptual framework.

References

Altieri, M.A., 1987. Agroecology: The Scientific Basis of Alternative Agriculture. Westview Press, Boulder, CO.

Altieri, M.A., 1995. Agroecology: The Science of Sustainable Agriculture. Westview Press, Boulder, CO.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agriculture Ecosystems & Environment 74, 19–31.

Altieri, M.A., 2004a. Agroecology versus ecoagriculture: balancing food production and biodiversity conservation in the midst of social inequity. Commission on Environmental, Economic & Social Policy CEESP Occasional Papers, pp. 8–28.

Altieri, M.A., 2004b. Linking ecologists and traditional farmers in the search for sustainable agriculture. Frontiers in Ecology and the Environment 2, 35–42.

Altieri, M.A., Ponti, L., Nicholls, C.I., 2005. Manipulating vineyard biodiversity for improved insect pest management: case studies from northern California. International Journal of Biodiversity Science & Management 1, 191–203.

Benton, T., Vickery, J.A., Wilson, J., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology & Evolution 18, 182–188.

Berger, P.A., Bolte, J.P., 2004. Evaluating the impact of policy options on agricultural landscapes: an alternative-futures approach. Ecological Applications 14, 342–354.

Bockstaller, C., Girardin, P., vanderWerf, H.M.G., 1997. Use of agro-ecological indicators for the evaluation of farming systems. European Journal of Agronomy 7, 261–270.

Bohnet, I., Potter, C., Simmons, E., 2003. Landscape change in the multi-functional countryside: a biographical analysis of farmer decision-making in the English high weald. Landscape Research 28, 349–364.

Boody, G., Vondracek, B., Andow, D.A., Krinke, M., Westra, J., Zimmerman, J., Welle, P., 2005. Multifunctional agriculture in the United States. Bioscience 55, 27–38.

Buck, L.E., Milder, J.C., Gavin, T.A., Mukherjee, I., 2006. Understanding Ecoagriculture: A Framework for Measuring Landscape Performance, Summary. Department of Natural Resources, Cornell University, Ithaca, NY.

Busck, A.G., 2002. Farmers’ landscape decisions: relationships between farmers’ values and landscape practices. Sociologia Ruralis 42, 233–249.

Carey, P.D., Short, C., Morris, C., Hunt, J., Priscott, A., Davis, M., Finch, C., Curry, N., Little, W., Winter, M., Parkin, A., Firbank, L.G., 2003. The multi-disciplinary evaluation of a national agri-environment scheme. Journal of Environmental Management 69, 71–91.

Center for Rural Studies, 2008. Looking ahead: Vermonters’ Values and Concerns. Summary Report. University of Vermont. <http://crs.uvm.edu> (accessed 01.06.09).

Clay, J., 2004. World Agriculture and the Environment. Island Press, Washington, DC.

Corry, R.C., 2004. Characterizing fine-scale patterns of alternative agricultural landscapes with landscape pattern indices. Landscape Ecology 20, 591–608.

Dalgaard, T., Hutchings, N.J., Porter, J.R., 2003. Agroecology, scaling and interdisciplinarity. Agriculture, Ecosystems & Environment 100, 39–51.

Daily, G.C. (Ed.), 1997. Nature’s Services – Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.

de Val, G.D.L.F., Atauri, J.A., de Lucio, J.V., 2006. Relationship between landscape visual attributes and spatial pattern indices: a test study in Mediterranean-climate landscapes. Landscape and Urban Planning 77, 393–407.

Deffontaines, J.P., Thenail, C., Baudry, J., 1995. Agricultural systems and landscape patterns – how can we build a relationship? Landscape and Urban Planning 31, 3–10.

Deuffic, P., Candau, J., 2006. Farming and landscape management: how French farmers are coping with ecologization of their activities. Journal of Agricultural and Environmental Ethics 19, 563–585.

Dramstad, W.E., Sundli Tveit, M., Fjellstad, W.J., Gry, G.L.A., 2006. Relationships between visual landscape preferences and map-based indicators of landscape structure. Landscape and Urban Planning 78, 465–474.

Elliott, E.T., Cole, C.V., 1989. A perspective on agroecosystem science. Ecological Society of America, 1597–1602.

Ellis, E.C., 2000. Long-term change in village-scale ecosystems in China using landscape and statistical methods. Ecological Applications 10, 1057–1073.

Ewel, J., 1986. Designing agricultural ecosystems for the humid tropics. Annual Review of Ecology and Systematics 17, 245–271.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C.S., Kahn, J., Pincetl, S., Troy, A., Warren, P., Wilson, M., 2006. Linking ecology and economics for ecosystem management. BioScience 56, 121–133.

Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., Poincelot, R., 2003. Agroecology: the ecology of food systems. Journal of Sustainable Agriculture 22, 99–118.

Freemark, K.E., Boutin, C., Keddy, C.J., 2002. Importance of farmland habitats for conservation of plant species. Conservation Biology 16, 399–412.

Gliessman, S., 2007. Agroecology: The Ecology of Sustainable Food Systems. CRC Press, New York.

Gliessman, S.R. (Ed.), 1990. Agroecology: Researching the Ecological Basis for Sustainable Agriculture. Springer-Verlag, New York.

Gliessman, S.R., Garcia-E, R., Amador-A, M., 1981. The ecological basis for the application of traditional agricultural technology in the management of tropical agro-ecosystems. Agro-ecosystems 7, 173–185.

Groenfeldt, D., 2006. Multifunctionality of agricultural water: looking beyond food production and ecosystem services. Irrigation and Drainage 55, 73–83.

Groot, J.C.J., Rossing, W.A.H., Jellema, A., Stobbelaar, D.J., Renting, H., Van Ittersum, M.K., 2007. Exploring multi-scale trade-offs between nature conservation, agricultural profits and landscape quality – a methodology to support decisions on land-use perspectives. Agriculture, Ecosystems & Environment 120, 58–69.

Guzmán-Casado, G., González de Molina, M., Sevilla-Guzmán, E., 1999. Introduccion a la agroecologia como desarrollo rural sostenible. Ediciones Mundi-Prensa, Madrid.

Halberg, N., Verschuur, G., Goodlass, G., 2005. Farm level environmental indicators: are they useful? An overview of green accounting systems for European farms. Agriculture, Ecosystems & Environment 105, 195–212.

Hansen, T.M., Francis, C.A., 2007. Multifunctional Rural Landscapes – Economic, Environmental, Policy and Social Impacts of Land Use Changes in Nebraska. <http://www.communicationsmgr.com/projects/joslyn_castle/docs/Multifunctional Rural Landscapes. pdf> (accessed 26.12.09).

Holmes, J., 2006. Impulses towards a multifunctional transition in rural Australia: gaps in the research agenda. Journal of Rural Studies 22, 142–160.

Intervale Center, 2009. <http://www.intervale.org/> (accessed 01.06.09).

Jacke, D., Toensmeier, E., 2005. Edible Forest Gardens, Volume Two: Design and Practice. Chelsea Green, White River Junction, VT.

Jongeneel, R.A., Polman, N.B.P., Slangen, L.H.G., 2008. Why are Dutch farmers going multifunctional? Land Use Policy 25, 81–94.

Jordan, N., Warner, K.D., 2010. Enhancing the multifunctionality of US agriculture. BioScience 60, 60–66.

Knickel, K., Renting, H., 2000. Methodological and conceptual issues in the study of multifunctionality and rural development. Sociologia Ruralis 40, 512–528.

Kristensen, L.S., Thenail, C., Kristensen, S.P., 2004. Landscape changes in agrarian landscapes in the 1990s: the interaction between farmers and the farmed landscape: a case study from Jutland, Denmark. Journal of Environmental Management 71, 213–244.

Kumar, B.M., Nair, P.K.R. (Eds.), 2006. Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry. Springer, Dordrecht, The Netherlands.

Labarthe, P., 2009. Extension services and multifunctional agriculture. Lessons learnt from the French and Dutch contexts and approaches. Journal of Environmental Management 90, S193–S202.

Lafortezza, R., Brown, R.D., 2004. A framework for landscape ecological design of new patches in the rural landscape. Environmental Management 34 (4), 461–473.

Long, A.J., Nair, P.K.R., 1999. Trees outside forests: agro-, community, and urban forestry. New Forests 17, 145–174.

Lovell, S.T., Johnston, D.M., 2009. Creating multifunctional landscapes: how can the field of ecology inform the design of the landscape? Frontiers in Ecology and the Environment 7, 212–220.

Lowrance, R., Sheridan, J.M., Williams, R.G., Bosch, D.D., Sullivan, D.G., Blanchett, D.R., Hargett, L.M., Clegg, C.M., 2007. Water quality and hydrology in farm-scale coastal plain watersheds: effects of agriculture, impoundments, and riparian zones. Journal of Soil and Water Conservation 62, 65–76.

Madureira, L., Rambonilaza, T., Karpinski, I., 2007. Review of methods and evidence for economic valuation of agricultural non-commodity outputs and suggestions to facilitate its application to broader decisional contexts. Agriculture Ecosystems & Environment 120, 5–20.

Makowski, D., Tichit, M., Guichard, L., Van Keulen, H., Beaudoin, N., 2009. Measuring the accuracy of agro-environmental indicators. Journal of Environmental Management 90, S139–S146.

McHarg, I., 1969. Design with Nature. Natural History Press, Garden City, NY.

McNeely, J.A., Scherr, S.J., 2002. Ecoagriculture: Strategies to Feed the World and Save Wild Biodiversity. Island Press, Washington, DC.

Méndez, V.E., 2010. Agroecology. In: Warf B. (Ed.), Encyclopedia of Geography. Sage Publications, Thousand Oaks, CA.

Méndez, V.E., Gliessman, S.R., Gilbert, G.S., 2007. Tree biodiversity in farmer cooperatives of a shade coffee landscape in western El Salvador. Agriculture, Ecosystems & Environment 119, 145–159.

Méndez, V.E., Lok, R., Somarriba, E., 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforestry Systems 51 (2), 85–96.

Millennium Ecosystem Assessment, 2005. <http://www.millenniumassessment.org/> (accessed 01.06.09).

Mollison, B., 1997. Permaculture – A Designers' Manual. Tagari Publications, Tasmania, Australia.

Nicholls, C.A., Altieri, M., 2001. Manipulating plant biodiversity to enhance biological control of insect pests: a case study of a northern California organic vineyard. In: Gliessman, S. (Ed.), Agroecosystem Sustainability: Developing Practical Strategies. CRC Press, New York., pp. 29–50.

NOAA, 2006. US Northeast Region 30m resolution Land Cover for the Year 2005. NOAA Coastal Services Center. <http://www.csc.noaa.gov/crs/lca/northeast.html> (accessed 05.06.09).

Noe, E., Alroe, H.F., Langvad, A.M.S., 2008. A polyocular framework for research on multifunctional farming and rural development. Sociologia Ruralis 48, 1–15.

NOFA Vermont, 2007. Community Supported Agriculture (CSA) Resources for Growers. <http://www.nofavt.org/market-organic-food/community-supported-agriculture> (accessed 01.06.09).

Oostindie, H., Roep, D., Renting, H., 2006. Definitions, references and interpretations of the concept of multifunctionality in The Netherlands. European Series on Multifunctionality 10, 41–81.

Payraudeau, S., van der Werf, H.M.G., 2005. Environmental impact assessment for a farming region: a review of methods. Agriculture, Ecosystems & Environment 107, 1–19.

Primdahl, J., 1999. Agricultural landscapes as places of production and for living in owner's versus producer's decision making and the implications for planning. Landscape and Urban Planning 46, 143–150.

Renting, H., Rossing, W.A.H., Groot, J.C.J., van der Ploeg, J.D., Laurent, C., Perraud, D., Stobbelaar, D.J., Van Ittersum, M.K., 2009. Exploring multifunctional agriculture – a review of conceptual approaches and prospects for an integrative transitional framework. Journal of Environmental Management 90, S112–S123.

Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. Ecological Economics 39, 463–478.

Rossing, W.A.H., Zander, P., Josien, E., Groot, J.C.J., Meyer, B.C., Knierim, A., 2007. Integrative modeling approaches for analysis of impact of multifunctional agriculture: a review for France, Germany and The Netherlands. Agriculture, Ecosystems & Environment 120, 41–57.

Sal, A.G., Garcia, A.G., 2007. A comprehensive assessment of multifunctional agricultural land-use systems in Spain using a multi-dimensional evaluative model. Agriculture Ecosystems & Environment 120, 82–91.

Sala, O.E., Paruelo, J.M., 1997. Ecosystem services in grasslands. In: Daily, G.C. (Ed.), Nature's Services – Societal Dependence on Natural Ecosystems. Island Press, Washington, DC, pp. 237–252.

Santelmann, M., Freemark, K., Sifneos, J., White, D., 2006. Assessing effects of alternative agricultural practices on wildlife habitat in Iowa, USA. Agriculture, Ecosystems and Environment 113, 243–253.

Scherr, S.J., McNeely, J.A., 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. Philosophical Transactions of the Royal Society B – Biological Sciences 363, 477–494.

Sevilla-Guzmán, 2006. De la sociología rural a la agroecología. Icaria Editorial, Barcelona.

Shellhorn, N.A., Macfadyen, S., Bianchi, F.J.J.A., Williams, D.G., Zalucki, M.P., 2008. Managing ecosystem services in broadacre landscapes: what are the appropriate spatial scales? Australian Journal of Experimental Agriculture 48, 1549–1559.

Smeding, F.W., Joenje, W., 1999. Farm-nature plan: landscape ecology based farm planning. Landscape and Urban Planning 46, 109–115.

Soule, J.D., Piper, J.K., 1992. Farming in Nature's Image – An Ecological Approach to Agriculture. Island Press, Washington, DC.

Stobbelaar, D.J., Groot, J.C.J., Makowski, D., Tichit, M., 2009. Multifunctional agriculture – from farm diagnosis to farm design and institutional innovation. Journal of Environmental Management 90, S109–S111.

Sustainable Sites Initiative, 2007. The Sustainable Sites Initiative – Standards and Guidelines: Preliminary Report. <http://www.sustainablesites.org/SustainableSitesInitiative_PreliminaryReport_110107.pdf> (accessed 22.12.09).

Sutherland, W.J., 2004. A blueprint for the countryside. Ibis 146, 230–238.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677.

Timmons, D.S., 2006. Measuring and Understanding Local Foods: The Case of Vermont. MS Thesis, University of Vermont, Burlington, VT.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem services management. Ecology Letters 8, 857–874.

USDA Economic Research Service, 2008a. State Facts Sheet: Vermont. <http://www.ers.usda.gov/Statefacts/VT.HTM>. (accessed 01.06.09).

USDA Economic Research Service, 2008b. Data Sets: Organic Production. <http://www.ers.usda.gov/Data/Organic> (accessed 01.06.09).

USDA Farm Service Agency, 2009. Imagery Product Fact Sheet: Common Land Unit (CLU). <http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prod&topic=clu> (accessed 05.06.09).

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J., Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. Agriculture and Human Values 22, 53–63.

van der Ploeg, J.D., Laurent, C., Blondeau, F., Bonnafous, P., 2009. Farm diversity, classification schemes and multifunctionality. Journal of Environmental Management 90, S124–S131.

Van Huylenbroeck, G., Vendermeulen, V., Mettepenningen, E., Verspecht, A., 2007. Multifunctionality of agriculture: a review of definitions, evidence, and instruments. Living Reviews in Landscape Research 1, 3.

Vermont Department of Tourism and Marketing, 2002. The Impact of the Tourism Sector on the Vermont Economy – 2001. Prepared by University of Vermont Department of Community Development and Applied Economics, and School of Natural Resources. <http://www.uvm.edu/~snrvtdc/publications/2001_Economic_Impact_Report.pdf> (accessed 01.06.09).

Wade, M.R., Gurr, G.M., Wratten, S.D., 2008. Ecological restoration of farmland: progress and prospects. Philosophical Transactions of the Royal Society B – Biological Sciences 363, 831–847.

Warner, 2007. Agroecology in Action: Extending Alternative Agriculture Through Social Networks. The MIT Press, Cambridge, MA.

Wiggering, H., Dalchow, C., Glemnitz, M., Helming, K., Muller, K., Schultz, A., Stachow, U., Zander, P., 2006. Indicators for multifunctional land use – linking socio-economic requirements with landscape potentials. Ecological Indicators 6, 238–249.

Wilson, G.A., 2007. Multifunctional Agriculture – A Transition Theory Perspective. CABI, Oxfordshire, OX, UK.

Wilson, G.A., 2008. From 'weak' to 'strong' multifunctionality: conceptualising farm-level multifunctional transition pathways. Journal of Rural Studies 24 (3), 367–383.

Wilson, G.A., 2009. The spatiality of multifunctional agriculture: a human geography perspective. Geoforum 40 (2), 269–280.

Wojkowski, P.A., 2004. Landscape Agroecology. Food Products Press, New York, NY.

Zander, P., Knierim, A., Groot, J.C.J., Rossing, W.A.H., 2007. Multifunctionality of agriculture: tools and methods for impact assessment and valuation. Agriculture, Ecosystems & Environment 120, 1–4.