

# Extent, pattern, and multifunctionality of treed habitats on farms in Vermont, USA

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**Abstract** Agroecosystems can serve as multifunctional landscapes when treed habitats such as woodlots, hedgerows, riparian buffers, windbreaks, and orchards, are conserved on farms. We investigated the extent, pattern, and multifunctionality of on-farm treed habitats for 16 Vermont farms in the Lamoille watershed of the Lake Champlain Basin. The site was selected because the land use pattern is representative of the region, containing a mixture of agriculture and forest in different habitat types. We used a GIS-based approach to delineate treed habitats on farms and conducted semi-structured interviews with farmers to explore their perception of the functions of treed habitats. Through an evaluation of the relationship between farm characteristics and spatial attributes of treed habitats, we found farm size to be an important variable. Larger farms had more land in treed habitats, while the pattern of these habitats was more complex on smaller farms. Average elevation of the farm, an indicator of biophysical conditions, was a stronger predictor of the extent of treed habitats than farm characteristics. From interviews, we found that

farmers benefited from alternative forest products, both for direct consumption and sale, including firewood, timber, maple sugar, edible fruits and nuts, and wood crafts. Most farmers also recognized cultural and ecological functions provided by treed habitats. These results have implications for developing policies to promote the conservation of treed habitats, considering the preferences of the landowner or farmer.

**Keywords** Multifunctional landscape · Farm design · Landscape agroecology · Vegetative buffers · Agricultural systems · Sustainable agriculture

## Introduction

Ecosystem multifunctionality has been recognized as a condition for sustainability in natural systems (de Groot 2006), but recently the interest in multifunctional landscapes has expanded to intensively-managed ecosystems including agroecosystems. Within this context, the concept of multifunctionality suggests that ecological, cultural, and production functions can be integrated on a given site, or landscape (Wiggering et al. 2003). Brandt and Vejre (2004) stress the importance of focusing on “local landscapes” or “intensively used landscapes” as having the greatest potential for future work integrating

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multifunctionality. These would certainly include agricultural landscapes, where human activities drive landscape functions. In agroecosystems, any approaches designed to improve landscape multifunctionality must consider the perspectives of the land owners and stakeholders if they are to be successful (Otte et al. 2007). While the concept of multifunctionality related to agricultural landscapes has been explored in Europe and Asia, it has received much less attention in the US (Bills and Gross 2005; Groenfeldt 2006). Instead, policies in the US focused more on conservation, often separating production and ecological functions. As competition for land continues to rise with the growing demand for food, fuels, and other products, the concept of landscape multifunctionality might offer opportunities for designing agroecosystems and developing appropriate policies that serve the public, as well as landowners or farmers.

Multifunctional landscapes can be evaluated based on the ecosystem services they provide. These services can represent high economic value or “natural capital” resulting from flows of material, energy, and information (Ruggeri 2009). While the values of some services are not captured directly through markets, ecological economists have developed valuation approaches to quantify indirect values in order to support more informed decisions about land use and conservation (Hein et al. 2006). Ecosystem services can be classified as *production services* (i.e., food and fodder), *regulation services* (i.e., climate, water, and soil regulation), *cultural services* (i.e., education, recreation, aesthetic, and spiritual), and *supporting services* (i.e., primary production and nutrient cycling) (Millennium Ecosystem Assessment 2005; Hein et al. 2006). Specific ecosystem services that might be provided by agroecosystems include air filtering, odor reduction, micro-climate regulation, noise reduction, storm water infiltration, waste treatment, soil retention, biodiversity conservation of crop and wild species, recreation, and aesthetics (Farber et al. 2006).

Agroforestry systems have been shown to support many ecosystem services, suggesting they could play an important role in improving multifunctionality of working farms (Pandey 2007; Benayas et al. 2008). We define agroforestry as a land use system containing a combination of woody species with agricultural crops and/or livestock, which interact ecologically and economically (World Agroforestry Centre 2008).

Agroforestry systems occur in a wide range of forms and scales. In addition to commercial plantations, features such as orchards, treed field borders, silvo-pastoral systems, forest fragments, and others also fit the definition (Pandey 2007). While many of these features are not designed or established specifically for their production functions, they can offer a wide range of products for consumption or commercial sale. Potential production functions of treed habitats in agroecosystems include timber, firewood, medicinal products, brushwood for fencing, domesticated fruits and nuts, and game for hunting (Benayas et al. 2008). Some non-timber forest products (NTFP) such as mushrooms, ginseng, and other edible plants, while not woody species themselves, thrive in the shaded forest environment (Emery 2001). In the Northeastern US and some regions of Canada, sap for syrup is harvested from maple trees in forests on land considered unsuitable for cultivated crop production.

In addition to production functions, agroforestry systems also provide important cultural functions by contributing to the visual quality of the landscape and serving as educational resources (Cook and Cable 1995; Deffontaines et al. 1995; Benayas et al. 2008). These habitats can support a wide range of recreational opportunities including hiking, hunting, skiing, and bird watching. Treed habitats may foster a sense of spirituality and place, because they symbolize the natural world, have very long life spans, and can relate strongly to an individual’s personal identity (O’Brien 2006).

The regulating functions provided by treed habitats are also quite extensive. They provide habitat for wildlife, sequester carbon, enhance soil fertility, improve water use efficiency, infiltrate stormwater, remove excessive nutrients, and regulate microclimate (Robles et al. 2008; Montagnini and Nair 2004). Some treed habitats are designed and located to provide specific functions such as hedgerows to harbor natural enemies for biological control, wind breaks to reduce soil erosion, and riparian buffers to reduce erosion and filter pollutants from runoff (Lovell and Sullivan 2006; Roy and de Blois 2008).

Biodiversity conservation and landscape heterogeneity, which can be indicators of ecological functioning, are improved by the integration of agroforestry on farms (Brandon et al. 2005). Privately-owned forests support the conservation of at-risk species (Robles et al. 2008), while providing a mixed plant community

with species utilizing different vertical levels in the canopy. Even small isolated patches and scattered trees have the potential to contribute to larger landscape restoration efforts by serving as seed sources for the surrounding landscape, increasing connectivity, and improving the quality of the matrix (or dominant land use) (Benayas et al. 2008). Many studies have shown the benefits in terms of landscape heterogeneity and plant biodiversity, with the creation or conservation of woodlots, wooded fencerows (Freemark et al. 2002), natural woody hedgerows (Boutin et al. 2002), riparian habitats (Boutin et al. 2002; Jobin et al. 2004), and live fences (León and Harvey 2006). Although these non-crop agroforestry features typically cover only a small percentage of the area in an agroecosystem, their contribution to ecosystem services can be disproportionately large (Freemark et al. 2002; Boutin et al. 2003; Jobin et al. 2004; León and Harvey 2006). Benton et al. (2003) suggest that the quality of agricultural systems would be improved by a specific objective of promoting heterogeneity in the landscape, as it would result in greater biodiversity in agroecosystems. In a critical review of the literature, Bailey (2007) found that increasing the quality of the matrix is probably better for biodiversity conservation than developing corridors in fragmented landscapes. An overall goal of improving matrix quality by reducing land use intensity and increasing semi-natural habitats (such as treed habitats) would still be appropriate for enhancing ecological functions (Bailey 2007; Jackson et al. 2007; Vandermeer and Perfecto 2007).

Clearly, the agroforestry literature provides many examples of the functions provided by these systems, many of which can be considered positive externalities because they benefit the public. Less clear, however, is the role of the landowners or users (farmers) in establishing the extent or pattern of these habitats. Few studies, for example, have focused on the motivations of farmers to retain or restore trees on farms, or on the relationship between farm type and landscape composition (Levin 2007). A study based on interviews of farmers in Denmark suggested that farmers were very involved in changes to the landscape through activities such as the creation and removal of landscape elements (hedgerows, woodlots, etc.), and landscape changes were influenced by demographic characteristics. The strongest relationship was with younger farmers modifying hedgerows (planting/removal) to a greater extent than

their older counterparts (Kristensen et al. 2004). In a study of two different geographic regions of Denmark, Westergaard (2006) found significant relationships between landscape composition and farm type—average field size increased with farm size, and smaller non-crop habitats were established to a greater extent on crop farms than on dairy farms. Seabrook et al. (2008) also found farm size to be an important factor influencing landscape variables on farms in the Bigalow Belt of Queensland, Australia, where larger farms contained higher levels of tree cover on average. In a study of the composition of Dutch organic farms, Levin (2007) found farm size to be negatively correlated with densities of small habitat features such as hedgerows and field margins.

The literature suggests that treed habitats on farms provide important ecosystem services, contribute to landscape multifunctionality, and improve the quality of the agricultural matrix in many regions throughout the world, although the extent and pattern of these habitats can vary depending on farm characteristics and farmer demographics. While many studies exist to further our understanding of agroforestry systems, the review of literature reveals a strong emphasis on tropical regions, with fewer studies focusing on temperate regions such as the Northeastern US. In an effort to gauge the current state of the field of agroforestry, Nair et al. (2005) assessed the content of 750 presentations at the 1st World Congress of Agroforestry held in 2004. The authors found that 88% of the presentations related to tropical regions, even though the conference itself was held in the US (Orlando, Florida). They also noted a difference in the focus of research efforts between tropical and temperate regions. While much of the tropical agroforestry research focused on livelihoods and food security, the research in temperate regions was directed toward conserving ecosystem services (Nair et al. 2005). In our review of the literature, we also found that much of the research on agroforestry systems in North America has focused on assessments of very specific landscape features such as orchards, windbreaks, hedgerows, and riparian buffers, without considering the entire network of treed habitats on farms.

Our study contributes to the growing body of work on ecosystem services provided by agroforestry systems, while also seeking to fill an important gap in the literature on the extent, pattern, and functions

of the complex network of agroforestry found on farms in the Northeastern US, specifically in Vermont. Our approach integrates an analysis of the characteristics of the farms (as reported by the landowner/farmer), with spatial data on tree cover of individual farms in the Lamoille Watershed of Vermont. We explore the benefits, reported by the farmer, of retaining and restoring trees in terms of the production, cultural, and ecological functions these trees provide. The methodology relies upon fine-scale landscape analysis to identify the small features (even individual trees) that contribute to the quality of the agricultural matrix. This approach allowed for a more in-depth assessment of results from a study with a small number of samples, but with a large number of variables. The specific objectives of this research were to: (1) document the extent of tree cover on a representative sample of diversified, non-commodity farms in the Lamoille watershed of Vermont; (2) develop a farm typology based on farm characteristics from interview data; (3) explore the relationship between farm characteristics and tree cover extent and pattern from spatial data; and (4) examine the production, cultural, and ecological functions of on-farm treed habitats from the perspective of the farmer/landowner.

## Materials and methods

### Study site

Our study focuses on Vermont's Lamoille watershed in the Northeastern US, where dairy is a primary agricultural commodity. Vermont's agricultural economy is dominated by the dairy industry, which accounts for 77% of the total receipts from all commodities (USDA Economic Research Service 2009). Despite the economic dominance of dairy in the state, only 1,200 of the 6,200 farms in Vermont are dairy farms, and the remainder focus on other products such as maple syrup, beef, orchard fruits, and vegetables. Many Vermont farms are small operations; in fact, most report less than \$5000 in annual sales, even though more than half (3,486) indicate farming is the primary occupation for the principle operator (USDA National Agricultural Statistics Service 2009). In this study, we focused on non-commodity farms, which constitute a significant

portion of the land base in Vermont, but may not be represented by larger agricultural industries. Our sample, therefore, does not include larger commercialized dairies, but rather represents specialty farms which tend to be more diversified in the products they market.

We investigated the extent, pattern, and functions of on-farm treed habitats for 16 Vermont farms in the Lamoille watershed, part of the Lake Champlain Basin. The Lake Champlain Basin covers 21326 km<sup>2</sup> in Vermont, New York, and Quebec. The quality of the water in the lake has declined partly as a result of agricultural activities in the watershed, including nutrient runoff (especially phosphorus) to rivers that drain into the lake. Efforts to reduce the negative impacts of agricultural practices in this watershed through the incorporation of on-farm treed habitats offer potential for improving the quality of a lake that runs nearly the entire length of Vermont (Vermont Department of Environmental Conservation 2001). The Lamoille River Basin itself drains an area of 1829 km<sup>2</sup>. Local concerns about non-point source pollution from agriculture and land use change resulted in the establishment of the Lamoille River Watershed Council comprised of a diverse set of stakeholders including farmers, foresters, recreationists, regional planners, businesses, and others (Vermont Department of Environmental Conservation 2008). Stakeholders are concerned about sources of pollutants such as manure, fertilizers, and pesticides originating from agricultural sources (Vermont Agency of Natural Resources 2008).

### Farm selection

While the bulk commodity dairy industry dominates the largest economic value for Vermont, we focused on non-commodity farms because their interests are often underrepresented by research programs and governmental funding. The potential growth in these types of farms is significant, as the number of traditional dairy farms declines with low prices for bulk milk. We intentionally selected farms that were diversified, with operations providing multiple products. Thus, to be part of our preliminary list, a farm had to generate at least two main products, which could include vegetables, meat, dairy, maple syrup, hay, etc. A list of approximately 35 private, commercial, non-commodity farms located within the

Lamoille watershed was generated from the following resources: USDA Natural Resource Conservation Service, Northeast Organic Farmer Association of Vermont (nofavt.org), Vermont Fresh Network (vermontfresh.net), and other local farm databases. We contacted nearly all of the 35 farmers that met the selection criteria and interviewed those who were willing to participate in the study ( $n = 16$ ). Spatial analyses were done after the farmer interviews to avoid biasing farm selection based on landscape characteristics.

### Spatial landscape analysis

Land use/land cover (LULC) for the state of Vermont and the Lamoille Watershed were determined using an existing 30 m resolution dataset developed by the University of Vermont Spatial Analysis Lab. This dataset was derived by classifying the 2002 Landsat scenes, using a supervised classification algorithm to define four primary classes for forest, urban, water, and other. Additional data layers including the Vermont Hydrology dataset, USDA Common Land Units, and 2003 National Agricultural Imagery Program (NAIP) orthophotographs were used to further classify the data. A GIS methodology was developed to delineate and classify fine scale tree cover on the 16 participating farms by a semi-automated procedure using 2003 digital orthophotographs (1 m spatial resolution), acquired from the USDA's National Agriculture Imagery Program (NAIP). Habitat delineation (classification) was performed with ERDAS IMAGINE<sup>®</sup> 9.1 via the following process. Individual farm boundaries, identified by Town parcel maps and verified by participating farmers, were stored as ArcGIS<sup>®</sup> 9.2 shapefiles and then used as area of interest (AOI) files in ERDAS to limit subsequent image processing. A principle components analysis (PCA) was run on uncompressed, TIFF images to spectrally enhance them. This step was performed because the NAIP images only have a spectral resolution of three bands (red, green, and blue). The output PCA image was used to manually develop spectral signatures based on supervised classification using the maximum likelihood decision rule. The resulting classified image was subsequently processed using fuzzy convolution ( $7 \times 7$  window, 0.5 weight factor). This operation uses an inverse distance weighting algorithm to create a context-based

classification, reducing the speckling that occurs in the original supervised classification because of anomalies such as shadowing in the source image. To further reduce speckling and misclassification, the output from this operation was run through a majority filter ( $7 \times 7$  neighborhood), then clumped, and contiguous pixel groups smaller than  $202 \text{ m}^2$  were eliminated. This pixel group size was chosen based on ocular analysis of sample imagery to retain individual large trees or groupings of several smaller ones.

Once the treed habitat of a farm was delineated via the automated process described above, it was manually classified into one of three types: continuous, clump or linear. Continuous habitat consisted of large blocks of trees, typically greater than 4.0 ha. Linear features had a width less than 30 m and length greater than 50 m *or* more than double the width. Linear features such as hedgerows and/or wind breaks that were attached to "continuous" treed habitat were manually split off in the GIS so they could be classified as linear. Small patches, generally less than 0.4 ha that did not fit into the continuous or linear classes were classified as clumps. These were often solitary trees or a small grouping of trees in the middle of a hay field or pasture.

### Farmer interviews

Through semi-structured interviews with diversified, non-commodity farmers in the Lamoille watershed, we explored existing and potential future functions of treed habitats, including a focus on the role of treed habitats in protecting water quality of adjacent water bodies. The two main questions asked were: (1) "What are the functions of the treed habitats on your farm?" and (2) "What steps are you taking to alleviate environmental effects on the waterways?" In an effort to document the multifunctionality of on-farm treed habitats from the perspective of the land owner, we questioned the farmers about the specific functions provided by these habitats. Farmers were asked if they obtained any of the following ten functions from their treed habitats: wind barrier; disease/insect barrier; wildlife conservation; recreation; spiritual; aesthetic; maple sugaring; firewood; furniture/crafts/ornamentals; wild edibles; and other. In addition, interviews documented household demographics, farm characteristics, and other variables

related to farmer's perceptions of conservation, participation in conservation programs, and the role of farmers in conservation of ecosystem services. Interviews were conducted on farm and lasted 30–60 min. Most questions were open-ended, allowing for flexible conversation, however, some questions required “yes” or “no” responses to allow for qualitative analysis.

### Statistical analysis

To develop typology of farms, we applied cluster analysis using data from farmer interviews on the sixteen participating farms. Two step cluster analysis was conducted in SPSS, first using a hierarchical cluster analysis (Ward's Method, Squared Euclidean Distance) to determine the appropriate number of clusters based on the following variables: total area of farm, vegetables as top product, and organic certification. K-means clustering was conducted as the second step, specifying four cluster groups in advance (based on output from hierarchical cluster analysis) and using the same variables as in the hierarchical cluster analysis. Comparisons of cluster groups were visualized using boxplots developed in SPSS.

Patch Analyst 4 (<http://flash.lakeheadu.ca/~rremel/patch/>) was used to obtain spatial metrics for treed habitats of each farm. This extension for ArcGIS® uses the same calculations as Fragstats (McGarigal et al. 2002), although it offers fewer total metrics. We selected several key spatial variables to characterize treed habitats: Shannon's Evenness Index (SHEI = distribution of area among patch types), Total Edge (TE = sum of the lengths of treed habitat edges), Edge Density (ED = TE adjusted for landscape area), and Area Weighted Mean Patch Fractal Dimension (FRAC\_AM = degree of complexity of habitat shapes weighted according to size). For more detailed information on the calculation of each metric, see McGarigal et al. (2002). These spatial variables were imported into SPSS Statistical Program to use as dependent variables. Farm size, based on the area calculated in GIS from parcel boundaries was the primary independent variable. Linear regression analyses were performed in SPSS Statistical Program to explore the relationship between farm size and different treed cover variables.

## Results

### Land use in the Lamoille watershed

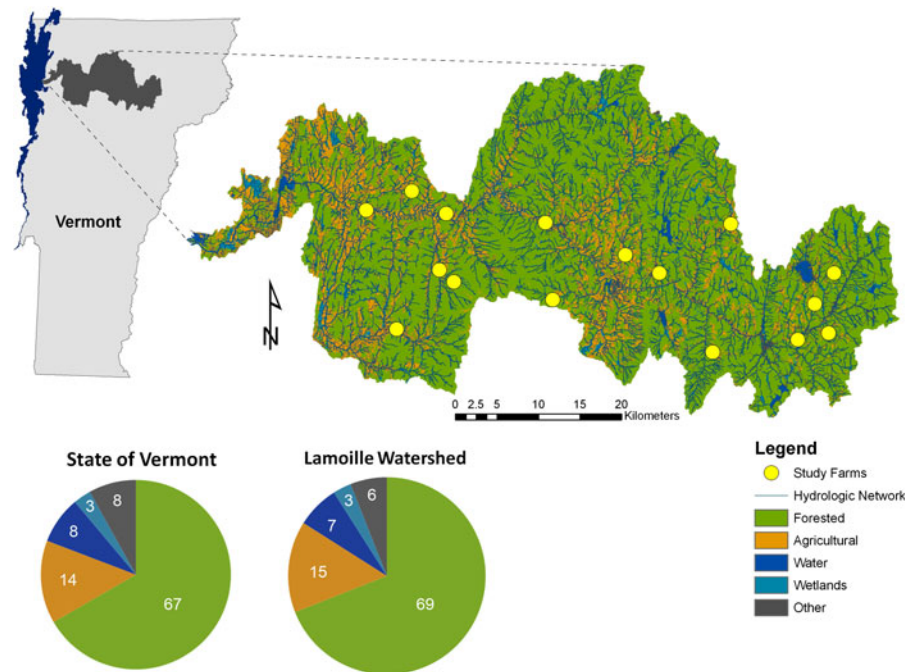
LULC was mapped for the Lamoille Watershed in a Geographic Information System (GIS), along with the locations of the participating farms. The sixteen farms were distributed across the watershed. Land use in the Lamoille watershed is dominated by forest (69%) and agriculture (15%), similar to the land use pattern for the entire state of Vermont in terms of the proportions of each land use type (see Fig. 1). The map indicated a high proportion of the agricultural land exists in close proximity to rivers, so we characterized the agricultural land use within varying buffer zones of the river network. We found that while the percentage of terrestrial land classified as agricultural is relatively low within the entire watershed (18% of the land base), much of the farming occurred in the river valley, in close proximity to sensitive hydrologic features. In those areas, agriculture comprised 28, 34, and 50% of the land cover within 1000, 500, and 100 m buffer zones of the rivers, respectively, when adjusted for terrestrial land area (with water and wetland areas removed). This finding suggests that critical trade-offs exist between agricultural production and water quality functions of riparian buffer zones in these areas.

### Farm typology

Our preliminary analysis of land use in the Lamoille Watershed suggested that diversified, non-commodity farms differed considerably in terms of their land area and specific agricultural uses. A typology based on farmers' estimates of farm size (acreage, later converted to hectares), organic certification (yes/no), and vegetables as the top product (yes/no) resulted in four farm groups (Table 1). The ANOVA from K-means cluster analysis detected significant differences for total farm size ( $P < 0.001$ ) and organic certification ( $P = 0.008$ ), and top product also helped to define the groups. A representative farm from each cluster group is presented in Fig. 2, to show the relative differences in farm size.

Cluster 1 consisted of three small farms ranging in size from 6 to 23 ha (based on farmers' responses). These might be considered “hobby farms,” since each farmer indicated less than 30% of the family income

**Fig. 1** Vermont and Lamoille Watershed showing LULC and locations of participating farms



came from agriculture. None of these farms were organically certified, although at least one used mostly organic practices. The top products for the farms in this category varied from vegetables or dairy, to “other” (agritourism). Cluster 2 included six farms, medium-small in size with areas ranging from 52 to 86 ha. The farms in this cluster group were mostly organically-certified, vegetable/fruit farms. Cluster 3 consisted of medium-sized farms ranging in size from 97 to 121 ha. All of the farms in this group were organically certified, and most were primarily livestock farms with dairy or meat as their top product. The two farms in Cluster 4 were unique in their large

**Farm examples from each cluster group**



**Fig. 2** Representative farms from each cluster type, each displayed at same scale, with treed habitat in *green* and farm boundaries in *orange*

**Table 1** Lamoille Watershed farm classification based on cluster analysis

Farm types	Variables		
	Farm size (mean ha)	Vegetables top product (% cluster)	Organic (% cluster)
1. Small, not organic ( $n = 3$ )	14	33	0
2. Med-small, most organic, most vegetable ( $n = 6$ )	67	83	67
3. Medium-sized, organic, most livestock ( $n = 5$ )	107	20	100
4. Large, organic ( $n = 2$ )	303	50	100

parcel area compared with other non-commodity farms, at 283 and 324 ha. They were also both organically certified, but their top products differed.

#### Extent of treed habitats on participating farms

For each of the 16 farms, GIS spatial analysis was used to verify farm parcel sizes and to determine treed area and % of parcel in tree cover (Table 2). We found that the area farmed ranged greatly across the 16 farms, from approximately 8 to 306 ha, with an average of 101 ha. The average farm size in VT is 80 ha according to the 2007 Census by the USDA National Agricultural Statistics Service (<http://www.nass.usda.gov/>). Within the boundaries of the farm parcel, tree cover ranged from 0.5 to over 273 ha, and the proportion of the area in tree cover was also found to be highly variable, ranging from 7 to 97%. On average, the participating farms contained 57% tree cover—a large extent of the parcel area.

The farmer interviews also included questions about the size of the farm and the area of land in tree cover. From these estimates, we calculated the percent of tree cover based on farmer responses. Most farmers were relatively accurate in their estimates of tree cover, compared with the data obtained from treed habitats delineated in the GIS. In cases

where there was a difference between the farmer's estimate and the data from spatially delineated habitat for tree cover, the discrepancies could be related to differences in the definition of "treed habitat" between farmer and spatial analysis tool. In the case of farm #3, for example, one area that was delineated as tree cover from the aerial image was not considered true forest by the farmer because it had been completely harvested (clear-cut) 14 years earlier and currently exists in an early successional stage. For consistency across the spatial data, we used the area metrics from the GIS delineation in the linear regression models.

Several farm characteristics were evaluated for their impact on treed habitat extent and pattern. Based on *t*-tests, no significant differences (0.05 level) in treed habitat were identified in comparing farms with vegetables versus livestock as the top product. Likewise, organic and conventional farms did not differ significantly in treed habitat spatial metrics, nor did farms participating in conservation programs versus those that did not. The percent of income from farming was not significantly related with extent or pattern of treed habitats. Farm size was the only characteristic significantly related to treed habitat extent and pattern. Based on GIS delineated parcel boundaries and tree cover data, the total area of treed habitat was strongly

**Table 2** Farm sizes and extent of treed habitat on each sample farm in the Lamoille Watershed

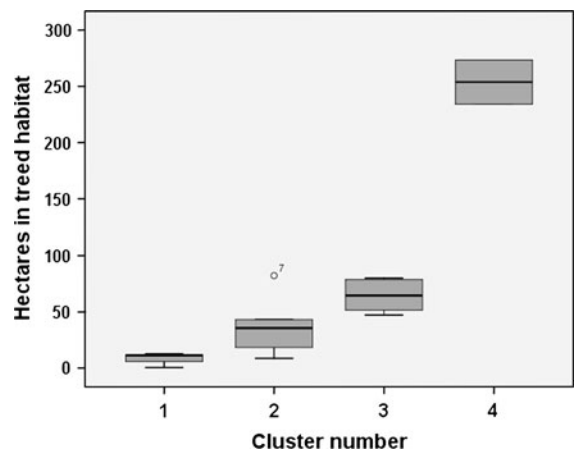
Farm #	Cluster group	Farm parcel (ha in GIS)	Treed area (ha in GIS)	% of parcel treed	% treed based on farmer estimate <sup>a</sup>
1	1	7.7	0.5	7.0	7.1
2	3	117.7	47.2	40.3	33.3
3	1	21.9	12.6	57.8	0.0
4	2	57.8	8.8	15.2	14.3
5	1	14.4	11.2	78.3	71.4
6	3	100.5	64.6	64.3	66.7
7	2	98.3	82.3	83.7	83.6
8	4	305.9	234.1	76.5	50.0
9	3	96.9	51.6	53.2	50.0
10	2	47.2	36.2	76.7	83.6
11	2	69.1	43.2	62.6	56.3
12	4	281.7	273.4	97.0	98.4
13	2	61.2	18.4	30.0	40.0
14	3	119.9	78.7	65.7	49.2
15	2	71.7	35.2	49.0	72.2
16	3	136.8	80.0	58.5	58.2
Ave		100.5	67.4	57.2	52.1

<sup>a</sup> Calculated from farmers' estimates of total farm size and area in treed habitat from interviews



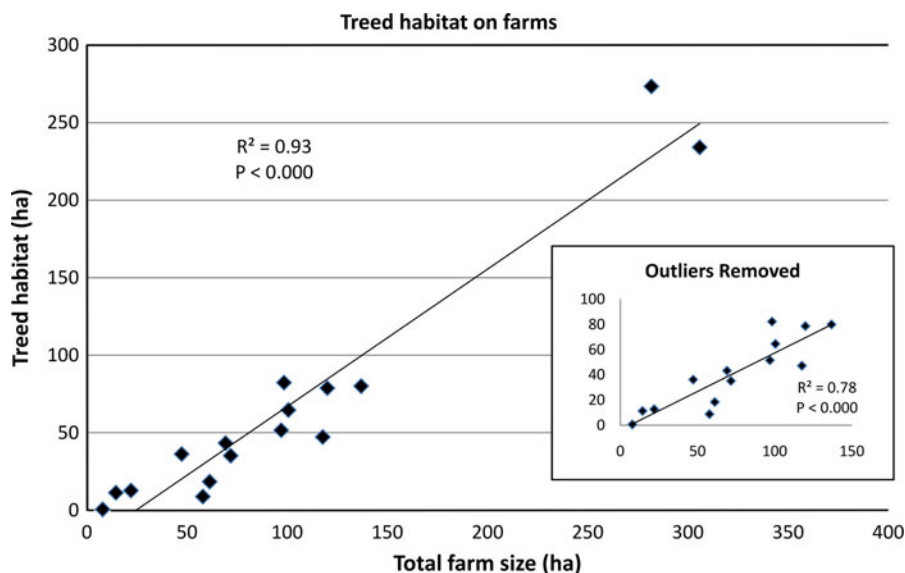
correlated with farm size (Fig. 3); as expected, larger farms had more total land in tree cover. This relationship held even with the larger farms removed from the data set. The differences between cluster groups are shown in boxplot in Fig. 4, which indicates a similar pattern because the groups were defined primarily by farm size. A significant positive relationship existed between the % of treed habitat on the farm and farm size ( $R^2 = 0.26$ ,  $P = 0.045$ ), but this relationship was not significant with the outliers (two large farms) removed (data not shown). While informative in characterizing farms, these results do not provide information to specifically address the cause of the relationship between farm size and proportion of treed habitat.

To begin to address this issue, we examined the extent to which farmers retain tree cover in areas that are suitable for typical agricultural uses (i.e., cultivation). Seabrook et al. (2008), for example, used the response variable “proportion of tree cover on fertile soils most suitable for agriculture” as an indicator that more accurately represents a tradeoff between cultivated agricultural production and forest conservation. For the sample farms in our study, we used the GIS data layer for soil map units classified as “prime farmland” which are defined as those containing the “best combination of physical and chemical characteristics for producing food, feed, fiber, forage, and oilseed crops and are also available for these uses,



**Fig. 4** Comparison of cluster groups based on total area in tree cover within the farm parcel

...[independent of] location, tract size, and accessibility to markets and support industries” (USDA Natural Resource Conservation Service 2006). All of the farms in the study site, with the exception of Farm 1, contained some area in prime farmland. We found a significant positive relationship between farm size and the proportion of prime agricultural soils covered in treed habitat ( $R^2 = 0.31$ ,  $P = 0.030$ ), but this relationship did not hold once the outliers were removed. The comparison of cluster groups, shown in Fig. 5, provides the best representation of these data, indicating cluster groups 1 and 4 (small hobby farms and



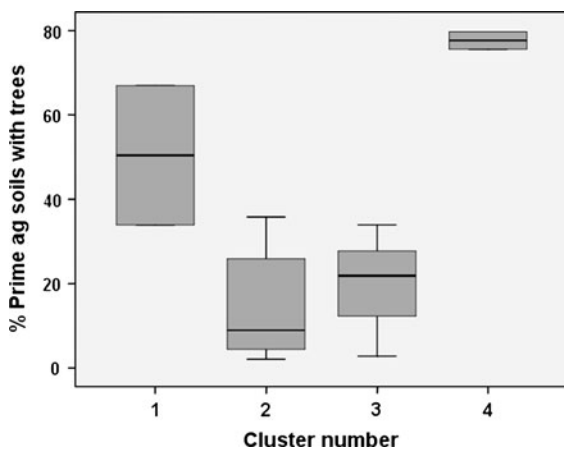
**Fig. 3** Relationship between farm size and total area in treed habitat

large farms, respectively) had a greater proportion of prime farmland containing trees than the other cluster groups of medium-sized farms.

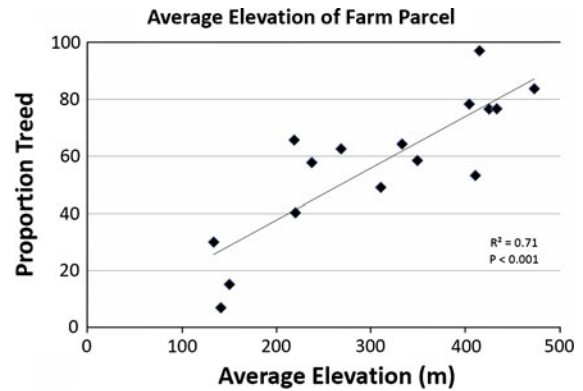
In addition to farm characteristics, we were also interested in the impact of biophysical conditions on the extent of treed habitats on farms. Based on our early assessment of the landscape in the Lamoille watershed, which suggested that much of the cultivated farmland existed in the river valleys, we predicted that the elevation of the farm would be positively correlated with the proportion of treed habitat. Figure 6 shows that this was indeed the case; the relationship was not only significant, but elevation was found to be a strong predictor of the proportion of treed habitat ( $R^2 = 0.71$ ,  $P < 0.001$ ). Average slope of the farm was also positively correlated with the proportion of treed habitat ( $R^2 = 0.36$ ,  $P = 0.014$ ), as shown in Fig. 7.

#### Pattern and complexity of treed habitats on farms

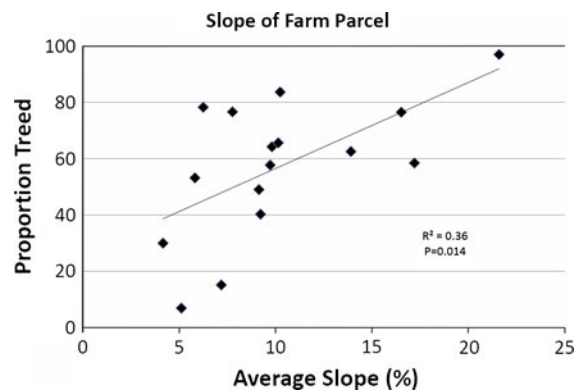
Diversity of treed habitats was evaluated based on Shannon's Evenness Index (SHEI), applied to the polygons of treed habitats on individual farms using the three habitat types (continuous, clumped, and linear). Values closer to 1 indicate a more even distribution among different treed habitats, while values nearing zero indicate dominance of one habitat type. Farm 1, for example, had a well distributed mix of linear, clumped, and continuous (SDI = 0.91), while the treed habitats on farm 16 were almost entirely



**Fig. 5** Comparison of cluster groups based on proportion of prime farmland containing treed habitat. Fifteen of the 16 farms contained some area in prime farmland



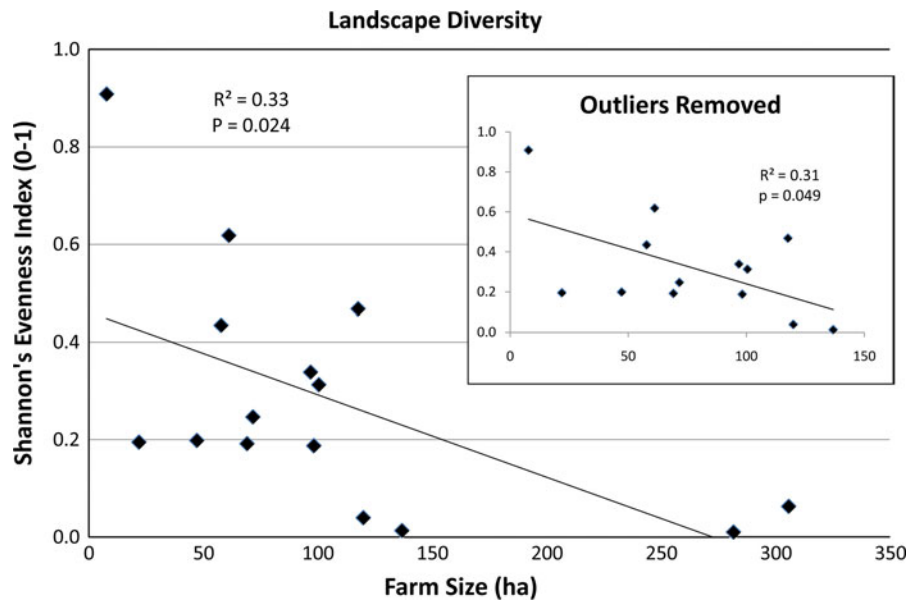
**Fig. 6** Relationship between proportion of the farm parcel in treed habitat and average elevation of the farm parcel



**Fig. 7** Relationship between proportion of farm parcel in treed habitat and average slope of the farm parcel

continuous (SDI = 0.01). The results indicate a significant negative relationship between farm size and landscape evenness ( $R^2 = 0.33$ ,  $P = 0.024$ ), even with outliers removed ( $R^2 = 0.31$ ,  $P = 0.049$ ; Fig. 8). The results do not include farm 5 because it had only one habitat type, and this index requires multiple habitat types.

Results of the analysis of several other landscape variables provide evidence of a relationship between landscape pattern and farm size. The total edge was positively correlated with farm size ( $R^2 = 0.49$ ,  $P = 0.003$ ), as would be expected since the total area in trees was related to farm size (data not shown). Edge density allows a comparison among landscapes of varying size. The linear regression model indicated a negative relationship between farm size and edge density ( $R^2 = 0.32$ ,  $P = 0.023$ ), suggesting smaller farms have a greater density of treed habitat edges



**Fig. 8** Relationship between landscape diversity (Shannon's Evenness Index) of treed habitats and farm size

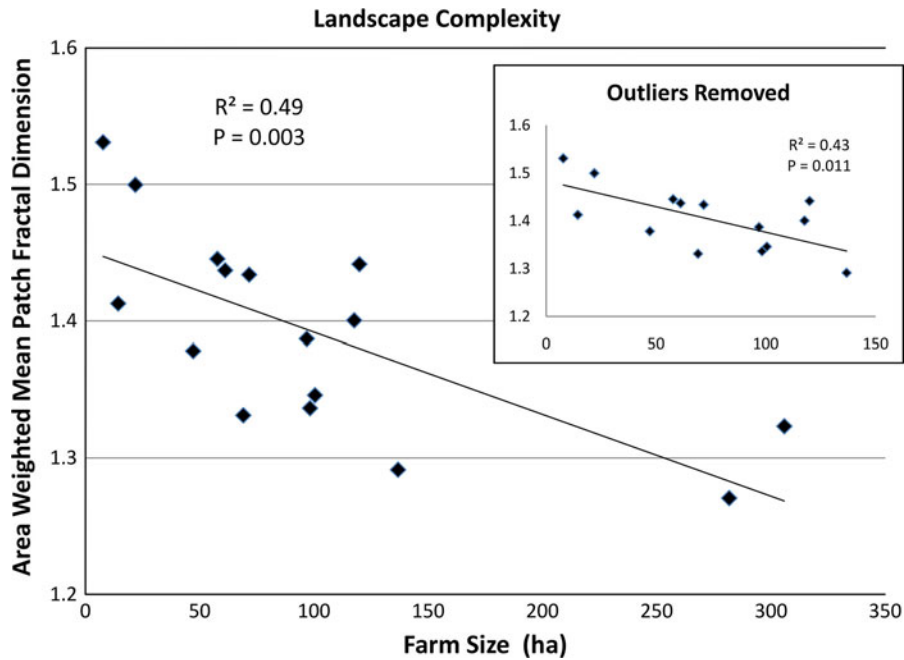
than larger farms. However, this relationship did not hold once the two largest farms (outliers) were removed from the dataset (data not shown). The landscape variable area weighted mean patch fractal dimension (FRAC\_AM) specifically quantifies the complexity of the treed habitats at the landscape level, by weighting patches according to their size. This metric is based on the concept that the simplest shapes, such as a circle or rectangle would have a value of “1” and increasingly complex shapes approach a value of “2.” The values for the sample of farms in the Lamoille Watershed ranged from 1.27 to 1.53, with an average of 1.39. The FRAC\_AM values were negatively related with farm size, with or without outliers ( $R^2 = 0.49$ ,  $P = 0.003$  and  $R^2 = 0.43$ ,  $P = 0.011$ , respectively; Fig. 9), indicating the area of treed habitats on smaller farms has a more complex geometry than that of larger farms. Complexity for cluster groups averaged 1.48, 1.39, 1.37, and 1.30 for groups 1, 2, 3, and 4, respectively, as shown in the boxplots in Fig. 10.

#### Contributions of treed habitats to multifunctionality of farms

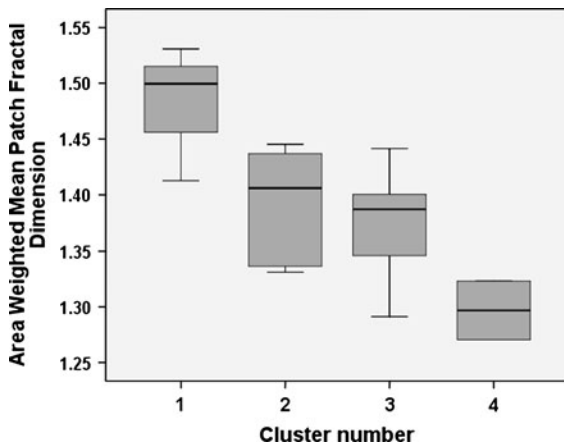
Figure 11 summarizes the reports from farmers that recognized different production, cultural, and ecological functions. Production functions included

firewood (14 farms), wild edibles (11), and timber/lumber (11). Most of the farmers we interviewed recognized cultural functions including aesthetics (15), recreation (14), and spiritual value (12). Wildlife conservation was the most frequently selected ecological function (14), followed by the function of treed habitats as a wind barrier (11). In addition to the categories of functions provided in the interview, farmers indicated other functions of treed habitats including wildflowers, Christmas tree source, child's play area, and shelter for livestock. No significant relationships were identified between the number of functions the farmer indicated for treed habitats and the size of farm, total area in treed habitat, or proportion of farm in treed habitat (data not shown).

Through the interviews, we also explored the types of innovative practices farmers were employing to obtain additional functions from their treed habitats. When asked about general innovative practices implemented on their farms, few of the responses were related to agroforestry or tree cover on farms. Exceptions included the use of mycelium woodchips to filter runoff, wood from the maple sugar forest to heat buildings using an outdoor furnace, and tree breaks planted in pastures. It might be argued, however, that some of the practices mentioned in other parts of the interviews, such as harvesting wild

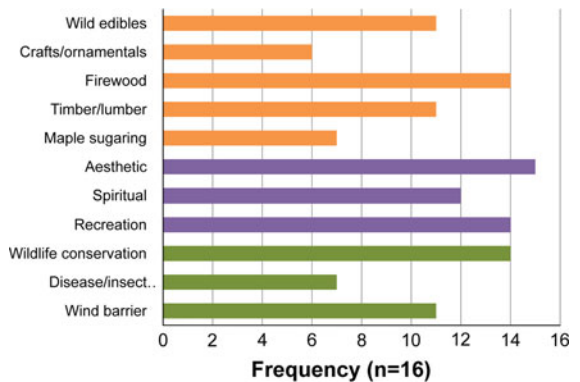


**Fig. 9** Relationship between complexity of treed habitats (Area Weighted Mean Patch Fractal Dimension, FRAC\_AM) and farm size



**Fig. 10** Comparison of cluster groups based on complexity of treed habitats (Area Weighted Mean Patch Fractal Dimension, FRAC\_AM)

edibles, grazing livestock under tree cover (silvopastoral systems), and directly using timber from the forest to build structures on the same property, would be considered innovative, even if the farmers did not recognize them as such. While these data are somewhat anecdotal, the results do highlight additional potential and future uses that were not detected through our specific questions.



**Fig. 11** Number of farmers indicating the treed habitat on their farm provides a specific production, cultural, or ecological function. *Line colors* indicate the type of function: *orange* production functions, *purple* cultural functions, and *green* ecological functions

**Discussion**

Extensive area in treed habitats on Vermont farms

The landscape of Vermont is characterized by a heterogeneous mix of forested and agricultural habitats that contribute to the state’s economy in terms of commodity products (i.e., dairy), specialty crops (i.e.,

vegetables and fruit), and a strong tourism industry benefitting from both recreational and agricultural functions (Wood et al. 2000). The results of this study suggest that farms and forests are not independent land units isolated by ownership boundaries, but rather they often exist as compatible habitats, integrated within individual ownership parcels. Vermont farms, in fact, contribute extensive areas of treed habitat to the landscape, although the contribution is highly variable among farms. On average, the participating farms in our study area contained 57% tree cover—a large extent of the parcel area. According to the USDA Census, woodland accounts for 42% of the total farmland on average in Vermont (USDA Economic Research Service 2009), which is much greater than the national average of 8% of farm area in woodland.

While forests and other treed habitats cover extensive proportions of individual parcels and the state's landscape in general, this was not always the case. After the arrival of the colonialists, Vermont's forests were nearly completely cleared for the timber and wool industries (Klyza and Trombulak 1999). Then with the historical intensification of agriculture in the Midwest and Western United States in the late 1800s, there was a decrease in agricultural land uses in Vermont, and thus an increase in reforestation (Klyza and Trombulak 1999; Albers 2000). Compounding this historical transition, policies in the US have tended to support and subsidize high yielding, commodity agriculture ([www.usda.gov/farmland](http://www.usda.gov/farmland)), and much of the diverse land in Vermont is not suitable for this type of production system (beyond dairy). Farmers in Vermont may instead benefit from high value, specialty products that have more intensive labor inputs, but lower land area requirements. The production of mixed organic vegetables on relatively small fields in Vermont, for example, can be profitable when a premium price is obtained from organic certification and support for local products.

These agriculture trends place less pressure on treed habitats for conversion back to agricultural production, but other factors may also contribute to the high proportion of treed cover on lands suitable for some production functions. Some programs exist specifically to support forest systems in Vermont, including the Forest Stewardship Program ([http://www.vtfpr.org/resource/for\\_forres\\_steward.cfm](http://www.vtfpr.org/resource/for_forres_steward.cfm)), which is a voluntary program providing

landowners with assessment and consulting services from County Foresters to develop ecologically sustainable forest management objectives, while also meeting landowner preferences and needs. Other programs such as the Environmental Quality Incentives program (EQIP), are designed to share the costs of stewardship activities, using public funds allocated through the USDA's Natural Resources Conservation Service (<http://www.nrcs.usda.gov/programs/eqip/>). Tax benefits can also encourage landowners to retain forested areas. Landowners participating in the Vermont Use Value Appraisal program pay a property tax rate based on the value for forestry rather than for market value driven by development potential ([http://www.vtfpr.org/resource/for\\_forres\\_useapp.cfm](http://www.vtfpr.org/resource/for_forres_useapp.cfm)). Finally, in addition to the program support, treed habitats in Vermont could be retained because of the specific functions they provide, as we discuss further below.

#### Farm size impacts treed habitat extent and pattern

In addition to characterizing the extent of treed habitats on farms, this study also demonstrated significant relationships between farm size and spatial attributes of treed habitats. This finding is interesting, but not unique to Vermont. In an assessment of trees on farms in Queensland, Australia, Seabrook et al. (2008) showed that when a wide range of economic, demographic, cultural/social, and perception variables were considered, farm size had the strongest influence on the proportion of treed habitat on the property. They found a positive correlation between farm size and proportion of area in treed habitat. This relationship also held for areas containing more fertile soil, which were assumed to be suitable for cultivated agricultural activities. Our results show a similar relationship, where the proportion of treed habitat on prime farmland was positively correlated with farm size. It should be noted, however, that the significance of this relationship relied upon the addition of the two large farms, which could be considered outliers for this dataset on non-commodity farms. The comparison of cluster groups for the prime farmland with trees suggests that the relationships for some variables are more complex than linear regressions, and that for certain variables, the comparisons of farm types (even though defined partially by farm size) yield the most useful information.

For the relationship between farm size and the proportion of treed habitat (typically showing a greater proportion of treed habitat on larger farms), several explanations have been proposed. First, farmers may not be strongly driven to remove treed habitats from farms, beyond the area required to obtain an adequate income from agricultural activities (Seabrook et al. 2008). Any excess area could be managed much less intensively as forest. A similar explanation is provided in a study of 450 farms in Ecuador, which indicated more intensive use of the soil (forest clearing) occurred on smaller parcels because the person-to-land ratio drove the need for agricultural production (Pichon 1997). Sood and Mitchell (2009) found that trees were more likely to be established on larger farms (versus smaller farms) in a region of the Western Himalayas, presumably because the farmers had more space and could withstand the extra risk associated with retaining trees in lieu of cultivating the land.

In our study, farm size impacted not only treed cover extent, but also the pattern of treed habitats in terms of evenness and complexity. Each of these variables was negatively related to farm size. Studies in other regions have shown similar trends. In a study of the landscape composition of Danish organic and conventional farms, Levin (2007) found a negative relationship between farm size and the densities of small habitat types, suggesting smaller farms have more fine-scale features such as hedgerows and field margins. Several studies have demonstrated that larger farms contain larger field sizes (Westergaard 2006; Levin 2007), which would tend to reduce the field boundary lengths and area in non-crop habitats such as field margins. There are several possible explanations for these relationships between the scale of the farm and the coarseness of the features. One is that the management of small-scale features such as hedgerows requires additional inputs in time, and that this effort is greater as the farm size increases. Another possible explanation is that smaller farms may use smaller equipment (tractors and associated implements) that allows greater flexibility in maneuvering around fine-scale features such as solitary trees and linear features. Farmers managing smaller parcels may tend to leave or plant trees where others may have them removed to increase plowing/harvesting efficiency. Finally, the negative relationship between farm size and treed habitat complexity could

be related to the visual quality attributes or other cultural functions provided by treed habitats. This argument would be based on the fact that a typical farm would contain one homestead, and that with smaller parcels, a greater proportion of the parcel usually exists in close proximity to the homestead to provide specific benefits to the inhabitants. Therefore, solitary trees (e.g., large shade trees), clusters of trees (e.g., ornamental species), and orchards planted to support the needs and preferences of a single household would account for a larger proportion of the parcel for small farms.

#### Other factors influencing extent and pattern of treed habitats

Farm size significantly impacted spatial metrics of treed habitats, but this variable still only explained 26% of the variability in proportion of treed habitat, 34% of evenness, and 49% of the complexity. While our study did not clearly link other farm characteristics (primary products, income from agriculture, and organic certification) with treed habitat extent, other studies have identified significant relationships. Westergaard (2006) and Kristensen et al. (2001), for example, found that crop farmers in Denmark established more small, fine-scale landscape features such as hedgerows and field margins than dairy farms.

In addition to farm demographic variables, biophysical features of the landscapes can also be important drivers for retaining treed habitat on farms. Numerous studies demonstrate the importance of soil fertility on the location and extent of treed habitats (Seabrook et al. 2007). Not surprisingly, areas of high fertility tend to be deforested and remain so for agricultural use. Climate is also a primary factor influencing the incidence of agriculture and forestation in areas (Fisher and Harris 1999). In our study, average farm elevation was the most influential variable related to the proportion of treed habitat on farms. This may be due to the fact that areas at high elevations usually contain thin rocky soils (less suitable for agriculture), are often inaccessible to certain activities (e.g., cultivation with machinery), and are harder to reach by farmers (Seabrook et al. 2007).

Historical and cultural conditions can also play an important role in the extent of on-farm tree cover. Kristensen et al. (2001) found correlations between

farmers' involvement in modifying treed habitats (planting/removal of new forest, Christmas trees, or hedgerows) and local conditions or traditions unique to areas in Denmark. These connections may have some historical basis, as Seabrook et al. (2008) concluded, "once agricultural development has occurred, landscapes often exhibit strong persistence in the patterns of native vegetation retained." In Vermont, some remnants of the historical legacy of the landscape still exist including stonewalls and cellar holes embedded in the reforested uplands, original hedgerows still in place, and the pattern of European settlement (town centers surrounded by open working lands) still lending dominant character to much of the Vermont landscape.

#### Multifunctionality of treed habitats

Our study demonstrated that many farmers recognize and appreciate the production, ecological, and cultural functions provided by treed habitats, and this finding helps to explain the high proportion of farmland with trees. While many land use decisions are based on farm profit, the retention or restoration of treed habitats is driven to some extent by quality of life factors, since some important functions recognized by farmers are not captured by markets (i.e., spirituality and aesthetics). O'Brien (2006) explored the value of trees to people in Vermont through in-depth interviews and discussion groups and found that easy access to forests was considered to be important. Residents valued a wide range of recreational functions in forests including skiing, snowshoeing, snowmobiling, hiking, biking, horse riding, hunting, and fishing. Ethnobotany, or picking wild food, was also a valued activity by some residents, and the skills were passed from one generation to the next. The author suggested that trees in particular (more so than other vegetation) are important to "sense of place" because they often represent the natural world, they are long-lived even surpassing human life span, they are often connected with personal memories, and they can represent personal identity (O'Brien 2006).

Many functions of treed habitats have the potential to be translated into economic benefits or improved livelihoods for the farmers. Treed habitats can provide direct income as marketable products, resources for bartering to obtain other products or

services, or cost-replacement when items consumed or used by the landowner do not need to be purchased elsewhere. Weyerhaeuser and Kahrl (2006) found that trees planted on farms in Southwest China contributed more to farmer livelihoods and conservation of ecosystem services than trees from plantations. On-farm trees also provided many products that were directly used by the farmer including fuelwood, fruits, and nuts (Weyerhaeuser and Kahrl 2006). Acharya (2006) found that trees on farms in Nepal support farm business ventures and contribute to farmer livelihoods. In that case, the functions and benefits of treed habitats were not equally distributed among farm types. More tree species were found on larger farms, and this could result in a wider range of functions for the farmer (Acharya 2006). Nybakk et al. (2009) found that owners of large forest parcels were also more successful in transforming innovation into economic performance. Weyerhaeuser and Kahrl (2006) suggest farmers could benefit from selecting specific tree species and woody plant communities to provide desired functions.

While treed habitats provide important functions for the landowner, the benefits of these features extend beyond the boundaries of the parcel. The integration of treed habitats into the landscape can increase landscape heterogeneity and contribute in a positive way to the quality of the agricultural matrix (Lovell and Johnston 2009). The literature on landscape structure suggests that the design of the landscape offers one of the greatest opportunities for improving multifunctional performance. Intentionally designing heterogeneity into the landscape pattern can improve ecosystem services in intensively-managed areas by increasing function and resilience (Fischer et al. 2008). The re-introduction or conservation of a mosaic structure including hedgerows, fencerows, woodlots, and wetlands can increase biodiversity, eventually resulting in a more sustainable system (Altieri 1999; Gliessman 2006). Furthermore, landscape heterogeneity can also be linked to cultural services including visual quality preference (Angileri and Toccolini 1993; Dramstad et al. 2001; Arriaza et al. 2004; de Val et al. 2006) and public education (Miller 2005). A variety of habitats can be designed with specific structure, pattern, and plant communities to provide greater ecological function and ecosystem services.

This approach to the design of the landscape supports the concept of “wildlife-friendly farming,” where patches of native vegetation are scattered throughout the landscape, so agriculture and “nature” coexist in the same landscape. The European agri-environmental schemes are based on this concept (Green et al. 2005), which encourages land planners to move beyond thinking of the landscape as a binary system (good/bad) where agriculture and conservation are separate, and instead consider the benefits of fine grained features such as treed habitat patches that contribute to landscape heterogeneity. This ecosystem approach considers humans as part of nature, and ecosystem functions can be evaluated in terms of the services or benefits they provide for humans (ecosystem services approach). The “wildlife-friendly farming” approach may be most appropriate for landscapes with complex topography (Fischer et al. 2008), like Vermont.

#### Methodological contributions

In this study, we used an innovative approach for integrating research on natural and human systems, by combining results of spatial analysis with on-farm interviews. This approach offers the opportunity to consider the perspectives of landowner/farmer, as they impact land use. Otte et al. (2007) argue that in order to be successful, approaches for developing multifunctional landscapes must consider the perspectives of the land owners and stakeholders. We will continue to develop this methodology, in an effort to systematically assess of the extent and functions of different landscape features. The impact of these features on important ecosystem services such as water treatment and wildlife conservation warrants further study.

The research presented here also makes an important contribution in terms of the scale and resolution of analysis. Very limited research is conducted at the scale of the farm or parcel, using high resolution data to distinguish fine features of the landscape. Smeding and Joenje (1999) call for a multiscale approach including the landscape and the farm scale for integration of farming and nature, recognizing that non-crop habitats must be compatible with agricultural production on the individual farm. Rotz et al. (2005) and Rigby et al. (2001) recommend the farm scale as a frame of reference

because that is the scale at which management and land use decisions are made. Seabrook et al. (2008) suggest that initiatives to conserve trees on farms would be more successful if they were compatible with the preferences and values of residents and farmers. For landowners living on the property, these preferences are particularly important. Primdahl (1999) found that for farmers using the farm as a place to live (homestead), many land use decisions had little to do with production, but instead were related to visual quality, cultural traditions, and recreation.

Finally, this study used an integrated approach including on-farm interviews and fine-scale spatial analysis that resulted in very detailed information. While the greater depth in analysis limited the study to the Lamoille Watershed, where a relatively small population was available for sampling, we feel that this was a worthwhile tradeoff, as we try to integrate methods from different disciplines.

#### Conclusions

Long and Nair (1999) suggest that small-scale tree plantings or agroforestry systems often provide a diverse mix of products and services that benefit the landowner, the local community, and society as a whole. Our study contributes to this body of work by focusing on the Northeastern region of the U.S., where few studies have been conducted on this topic. Our sample, representing diversified farms in Vermont, suggests that many of these agricultural properties could potentially provide important environmental benefits through their extensive treed habitats, including carbon sequestration, biodiversity conservation, wildlife habitat, water use efficiency, and stormwater treatment. In some cases, the treed habitats on farms might help to offset the negative environmental impacts of more intensive agricultural activities, such as using treed buffers to capture sediment and nutrients from cultivated fields.

We propose several opportunities to further this research, building on our methodology that integrated parcel-based social and spatial data. The first area of research is the exploration of opportunities to increase multifunctionality in treed habitats, particularly integrating production functions to encourage conservation of existing habitats and promoting the



establishment of new habitats. For example, Long and Nair (1999) propose combining trees and agriculture to diversify production and support conservation on marginal lands. Another important research focus involves the mapping of specific functions within the landscape, to further investigate relationships between landscape structure and function to inform the design of farms. Methods have been developed to map and quantify various functions to support planning at the landscape scale (Willemen et al. 2008), but fine-scale mapping could further support farm design. More research is also needed to characterize cultural functions more explicitly. In particular, recreation and visual quality are strongly influenced by the landscape characteristics and are very specific to a given region. More work is needed to define and quantify cultural functions in different areas. Finally, future research could focus on examining the relationships between farmer demographics and land use. Farmer demographics (e.g., age of farmer and land ownership duration) can have a strong influence on landscape changes related to the conversion from production-oriented to a multifunctional landscape that includes the creation of fine-scale elements such as hedgerows and small woodlands (Kristensen et al. 2004). These research areas could further support the multifunctionality of treed habitats, potentially increasing their adoption and their benefits to landowners and the public.

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