



# An evaluation of GIS-derived landscape diversity units to guide landscape-level mapping of natural communities

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## Summary

As conservation planning increases in scale from specific sites to entire regions, organisations like The Nature Conservancy face a critical need for GIS-based tools to evaluate landscapes on a regional scale. An existing, field-based approach to analyse the diversity of a landscape is by delineating natural community types, which is a time-intensive process. This study evaluated the utility of using an existing, GIS-derived landscape diversity model as a predictive tool for mapping natural communities on a large (8369 ha) upland forest site in the northern Taconic region of Vermont. The GIS model incorporates four geophysical factors: elevation, bedrock type, surficial deposits, and landform. A significant level ( $\alpha = 0.05$ ) of association between eight pairs of landscape diversity unit (LDU) types and natural community types was found. However, the strength of these associations is low (Cramer's  $V$  values  $\leq 0.172$ ), suggesting a poor predictive efficiency of landscape diversity units for natural community types. The results suggest that variables in the LDU model are relevant to natural community distribution, but the LDU model alone is not an effective tool to aid in mapping of natural community types of upland forests in Vermont. Until better landscape-level techniques are developed, the role of this type of model is limited to screening the landscape for areas with a particular set of geophysical characteristics, which can help an ecologist interpret the patterns on the landscape, but cannot substitute for a field-based approach to natural community mapping.

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## Introduction

As conservation planning increases in scale from specific sites to entire regions, organisations like The Nature Conservancy face a critical need for GIS-based tools to evaluate landscapes on a regional scale. This paper examines the extent to which a GIS-based model developed previously for large-scale conservation planning could be useful in predicting the actual distribution of forested natural community types found on a site.

The Landscape Diversity Units (LDUs) used in this study are the product of a GIS model that classifies each  $30 \times 30$  m pixel on the landscape according to four variables: bedrock geology, surficial geology, elevation, and landform (Ferree, 2000). An aggregate of cells with identical combinations of these four variables is termed a LDU. Each combination of the four geophysical variables represents a different LDU type. A strong association between natural community types and LDU types would suggest a relationship between the natural community types and those geophysical variables that combine to define the LDUs, providing a novel method for the prediction of natural community distributions.

The LDU model was designed to help evaluate diversity of the landscape across thousands of square kilometres for the Vermont Biodiversity Project, a state-wide conservation planning effort in Vermont. A similar model is also being used by The Nature Conservancy in their regional landscape assessments (Anderson, Ferree, Kehm, & Olivero, 2001). Without the critical environmental variables, such as soil characteristics and aspect, it may be that such models are too simplified to predict actual distributions of natural communities. However, the physical factors in the LDU model are likely to influence the distribution of natural communities because of the indirect effect of these factors on soil characteristics that have been shown to affect forest composition (Mueller-Dombois & Ellenberg, 1974). For this reason, it is useful and relevant to examine the extent and limits of the predictive value of this conservation tool.

This use of geophysical data to predict distribution of natural community types is based on the assumption that there is a relationship between geophysical features and the actual environmental factors controlling the establishment of individual plant species and their associated community complex. This relationship is suggested with respect to geomorphological features (Meilleur, Bouchard, & Bergeron, 1994) and with respect to slope, elevation, and aspect (Vincent et al., 1986). Both of these studies entailed extensive vegetation

sampling, subsequent identification of natural community types based upon cluster analyses, and finally an evaluation of the level of association between natural community types and various geophysical factors.

This study differs from previous examinations of the relationship between geophysical characteristics of the landscape and natural community types in three general ways: (1) it uses a pre-existing statewide vegetation classification system rather than a site-specific classification; (2) it relies upon geophysical data from a GIS model that is of a statewide scale, rather than upon detailed field data or site-specific maps; and (3) it attempts to answer a question of practical applicability for conservation planning: "Can a GIS model of geophysical parameters increase the efficiency of region-wide mapping of natural community types?"

The concept of natural communities is one classification system used increasingly by conservation organisations and state government agencies (Grossman et al., 1998). The definition of a natural community as it is used in this paper is: "an interacting assemblage of organisms, their physical environment, and the natural processes that affect them" (Thompson & Sorenson, 2000). Grossman et al. (1998) noted that this concept of natural communities is intermediate between the continuum concept (Gleason, 1926; Curtis, 1959; Whittaker, 1962) and the community unit concept (Clements, 1916). A classification system based upon natural communities is often developed individually for each state and cross-referenced to the National Vegetation Classification System (Grossman et al., 1998) to provide for consistency across the United States. These natural communities are used by organisations such as The Nature Conservancy as a basic unit for their approach to biodiversity conservation.

In contrast to other classification systems for forested ecosystems, such as the broad SAF Forest types (Eyre, 1980) or Westveld's (1956) forest zones of New England, natural community types are defined not only by dominant tree species, but by the relative abundances of canopy species as well as characteristic understory species. In many situations, this distinction can allow for greater resolution when mapping a landscape. However, more intensive field sampling is required to delineate these community types, as opposed to forest-type mapping that can often be done with remote sensing techniques. Because geophysical features are critical to the distributions of many plants and other organisms (Hunter, Jacobson, & Webb, 1988), and because many geophysical features may be more easily mapped than individual species via remote

sensing techniques, GIS modelling using geophysical data may provide a predictive approach to natural community mapping.

## Methods

The 8369-ha area that was the focus of this study is located west of the city of Rutland, Vermont, USA, at the northern and eastern end of the Taconic mountain range (Centrum of study area: N43°42'40", W73°07'00"). Elevation ranges from 122 to 640 m over hilly topography. Average annual precipitation is 101–127 cm. The frost-free period is approximately 120 days, based upon regional data from Meeks (1986). The study area is bounded by the Otter Creek valley on the east and partially by North Briton Brook on the west. The complex bedrock geology of the site is a mix of shales, schist, and limestones. The majority of the terrain is upland forest, with only 1% of the land area classified as wetland (M. Anderson, The Nature Conservancy, pers. com.). There are abundant first- and second-order streams on the site. The majority of the land within the site is privately owned, and much of it is actively managed for timber production. Historically, many of the hills were entirely cleared and supported sheep and cattle grazing until the 1940s.

The GIS model and the development of the LDUs is described in detail by Ferree (2000); however, a brief summary is presented here. In the study area, three different bedrock types were the focus of investigation: calcareous clastic and metamorphosed calcareous clastic rocks; slate, graywacke, and conglomerate; schist, phyllite, and gneiss. These types were based upon ecologically important bedrock categories developed by a group of ecologists and geologists for the state of Vermont (M. Gale, Vermont Dept. of Environmental Conservation, pers. com.). Till was the primary surficial deposit type found in the study area. Three elevation classes were represented: 0–234 m, 234–533 m, and 533–762 m. These elevation classes are based upon elevations that are relevant to the distribution of forest types in Vermont (Siccama, 1974). Landform is the most complex category, with 14 classes: flat summit or ridgetop; slope crest or ridge-gentle grade; slope crest or ridge-moderately steep; steep slope; cliff; slight convexity-broad/low; low rounded summit or ridge; upper sideslope or rounded ridge; flats; valley or toe slope-gentle grade; lower sideslope or gentle draw; flat in valley; bottom of draw or valley, or bench; cove or draw. These classes were assigned to each cell

based upon a focal analysis (a type of neighbourhood analysis) of a digital elevation model. Aspect was not included in the existing GIS model, and it was beyond the scope of this study to integrate this parameter into the model.

Vegetation data were collected in the field from June to August, 2000. At each sample point, latitude, longitude, and natural community type were recorded. Dominant species and percent cover in the canopy, shrub, and herb layers were also recorded to enable confirmation of the natural community at each point. Areas that were non-forested in the 1940s were identified on USGS topographic maps. These areas, as well as regions with obvious recent human disturbance, were not sampled in order to reduce the confounding effects of past land use on current vegetation. Sampling locations were chosen without reference to the boundaries of LDUs. Vegetation data and GPS location were recorded along transects whenever a change in landform or natural community type was encountered. Sampling was limited to upland forested natural communities. Although this sampling procedure was not random, it was used because of the need to cover as much terrain as possible during the summer study period.

To evaluate the relationship between LDU types and natural community types, data were analysed with Chi square contingency tables using SAS statistical software (SAS Institute Inc. 2000). The large number of LDUs and natural community types resulted in a contingency table of over 100 cells. Given a sample size of less than 350, the expected values for a large percentage of the cells were less than five. Such extremely low expected values result in unacceptable type I error when the Chi square test is used. For this reason, LDUs were grouped by bedrock type, and in separate analyses, grouped by landform type and elevation class. The larger expected values permitted the use of the Chi square test to determine if there was an overall association between natural community types and physical characteristics represented by the LDUs. Cramer's *V* values also were calculated to obtain a measure of the magnitude of any association.

To maintain the full suite of LDUs and compare them to different natural community types, dichotomous variables were used: each observation point had a value of '0' or '1' for each natural community type, and a value of '0' or '1' for each LDU type. Comparing a single natural community type and a single LDU at a time yielded numerous 2 × 2 contingency tables. Although this analysis did not provide information regarding the overall relationship

between LDUs and natural community types, it did provide a method to determine whether there is a relationship between specific pairs of LDUs and natural community types. An identical approach was used to compare a single natural community type to a single geophysical variable by grouping LDUs, as above, by elevation, bedrock, and landform. In cases where low expected values could not be avoided, Fisher's exact test was used in place of the Chi square test.

## Results

A total of 334 observation points were sampled, comprising 26 natural community types and 19 LDU types. Five natural community types and 11 LDU types had  $\geq 13$  observations each, for a total sample size of 233, and therefore were the focus of most analyses (Table 1). These 11 LDU types represent two bedrock types, two elevation classes, and seven landform types.

The distribution of individual natural community types across LDU types was generally uneven (Table 2). This non-uniform distribution suggests an association between LDU types and natural community types. Four natural community types were concentrated on three LDU types, while one (northern hardwood forest) was more evenly distributed. LDU type 7 was not a common location for any of the five natural community types.

Eight of the 55 possible pairs of LDU type and natural community type were significantly associated based upon results from contingency tables (Table 3). The magnitude of these associations, as measured by Cramer's  $V$  values, ranges from 0.124 to 0.172. Cramer's  $V$  values can range from 1.0 to  $-1.0$ , so the associations reported in Table 3 are relatively weak. Two of the pairs demonstrate significant negative associations (Cramer's  $V < 0$ ), indicating that it would be unlikely to find that specific natural community type on that LDU type.

Grouping the LDU types by landform, elevation, and bedrock type allows an examination of the specific variables that are used in the model. A contingency table of natural community types and LDU types grouped by the two bedrock types gave no evidence of an overall association between these data ( $P = 0.324$ ,  $n = 233$ ). However, there was a significant association between the mesic-maple-ash-hickory-oak natural community type and the two dominant bedrock types (Fig. 1).

To examine the relationship between landform and natural community distribution, LDUs were grouped by landform class. These seven classes were grouped further into four categories to create a contingency table with adequate expected cell sizes for analysis. Comparing these categories to the five most common natural community types demonstrates a significant level of association ( $P < 0.05$ ,  $n = 233$ ). Fig. 2 shows the distribution of individual natural community types across these four LDU categories. Dry oak forests were

**Table 1.** The 11 LDU types and the five natural community types with 13 or more observation points recorded during this study

LDU	LDU Description
1	234–533 m/Calcareous clastic rock/upper sideslope
2	234–533 m/Calcareous clastic rock/lower sideslope
3	234–533 m/Slate-graywacke-conglomerate/steep slope
4	234–533 m/Slate-graywacke-conglomerate/gentle slope crest
5	234–533 m/Slate-graywacke-conglomerate/moderate slope crest
6	234–533 m/Slate-graywacke-conglomerate/low summit
7	234–533 m/Slate-graywacke-conglomerate/upper sideslope
8	234–533 m/Slate-graywacke-conglomerate/valley, toe slope
9	234–533 m/Slate-graywacke-conglomerate/lower sideslope
10	533–762 m/Slate-graywacke-conglomerate/gentle slope crest
11	533–762 m/Slate-graywacke-conglomerate/moderate slope crest
Natural community type	Abbreviation
Northern hardwood forest	NHF
Dry oak forest	DOF
Dry oak-hickory-hophornbeam forest	DOHF
Mesic maple-ash-hickory-oak forest	MMF
Hemlock forest	HF

LDU description: elevation class/bedrock class/landform.

**Table 2.** A matrix of the 11 most common LDU types and the 5 most common natural community types

Natural community type	LDU types										
	1	2	3	4	5	6	7	8	9	10	11
NHF						X			X	X	X
DOF		0	X	X	X	0			0		
DOHF				X	X			0		X	
MMF	X	X						X		0	0
HF	0			0	X			X	X	0	0

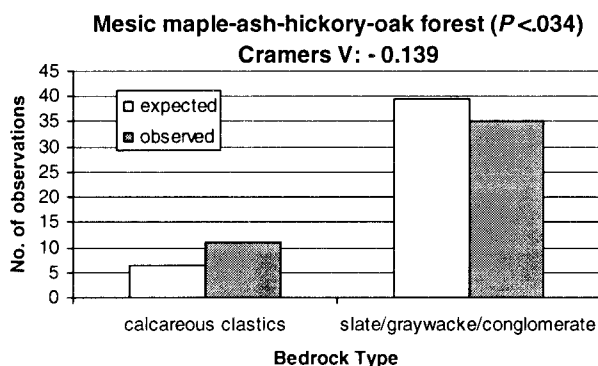
For each natural community type, > 50% of all observations of that natural community type occurred in the set of LDU types marked with an "X". For example, of the 42 MMF observation points, 22 were located in just 3 LDU types (#s 1, 2, and 8). If the distribution were entirely random, these 42 points would be evenly distributed across the 11 LDUs. Cell values of 0 indicate no occurrences of a particular natural community type occurred on that LDU type. All remaining cells had at least one occurrence. MMF: mesic maple-ash-hickory-oak forest, NHF: Northern hardwood forest, DOF: Dry oak forest, DOHF: Dry oak-hickory-hophornbeam forest, HF: Hemlock forest.

**Table 3.** Significant associations between natural community types and LDU types

LDU type	1	3	4	5	9	10	11	
Natural community type	MMF	DOF	DOHF	NHF	NHF	DOHF	NHF	MMF
<i>P</i> value	0.035 <sup>a</sup>	0.01 <sup>a</sup>	0.023 <sup>a</sup>	0.015	0.014	0.013 <sup>a</sup>	0.004	0.019 <sup>a</sup>
Cramer's <i>V</i>	0.124	0.172	0.139	-0.133	0.135	0.162	0.158	-0.124

Shown are *P*-values from Chi-square test and Fisher's exact test, and Cramer's *V* values for 2 × 2 tables of one natural community type (row 2) vs. one LDU type (row 1). The 8 pairs shown were the only pairs with *P* < 0.05. The Cramer's *V* values show the relatively low strength of the associations between the LDUs and natural community types. MMF: mesic maple-ash-hickory-oak forest, NHF: Northern hardwood forest, DOF: Dry oak forest, DOHF: Dry oak-hickory-hophornbeam forest, HF: Hemlock forest.

<sup>a</sup>Indicates Fisher's exact test was used because the expected values of one of the cells of the contingency table was < 5.



**Figure 1.** Comparison of actual number of observation points of Mesic-maple-ash-hickory forest on each of two bedrock types with the number of points expected assuming no association between natural community type and bedrock type. This natural community type is positively associated with calcium-rich bedrock (*P* = 0.034, Chi-square test, Cramer's *V* = 0.139).

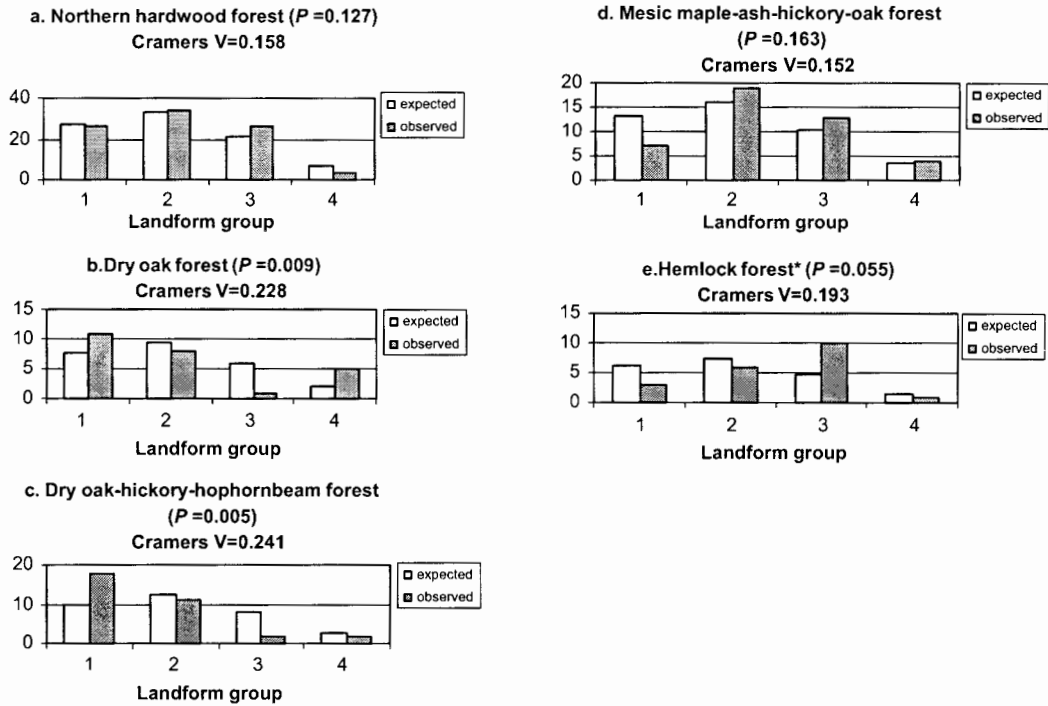
negatively associated with valleys, positively associated with rounded summits, and very strongly associated with steep slopes and ridges. Dry oak-hickory-hophornbeam forests show a similar pattern

of distribution, except that they have a negative association with rounded summits. Hemlock forests, on the other hand, show a reversed pattern. They occurred twice as often in valleys and half as often on ridges, as would be expected if landform had no association with natural community type.

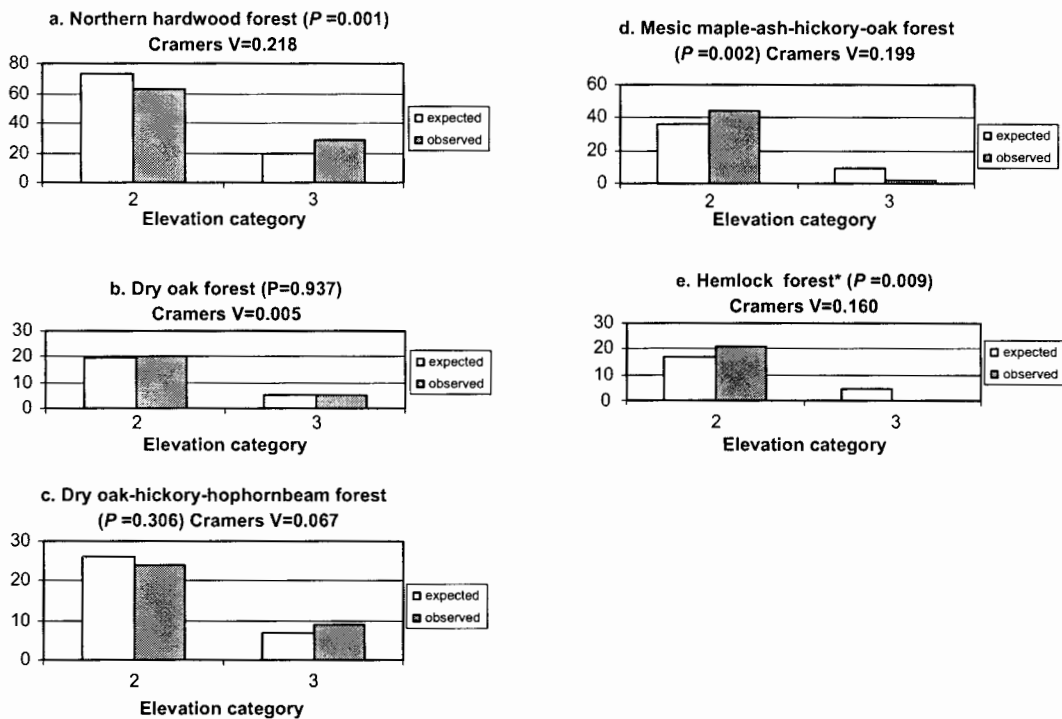
Assessment of natural community-type associations with LDU types grouped by the two elevation classes indicates northern hardwood forests and mesic maple-ash-hickory-oak forests were, respectively, positively and negatively associated with higher elevations (Fig. 3). Hemlock forests demonstrated a positive association with the lower elevation class.

## Discussion

Results of our analysis (Table 2) suggest that eight pairs of LDUs and natural community types have an association that is statistically significant. This result confirms that the LDU model uses variables that are relevant to natural community distribution. However, despite the statistically significant



**Figure 2.** (a–e) Comparison of number of actual observation points in 4 different landform groups, with expected number of observation points assuming no association between landform and natural community. Results for the five natural community types with greater than 10 total observation points are shown. \*Fisher’s exact test used due to > 25% of cells with expected values < 5. Landform groups: 1 = slope crests/ridges; 2 = rounded summits, upper side slopes; 3 = valleys, lower side slopes, toe slopes; 4 = steep slopes.



**Figure 3.** (a–e) Comparison of number of actual observation points in two elevation categories, with expected number of observation points assuming no association between elevation and natural community. Results for the five natural community types with greater than 10 total observation points are shown. \*Fisher’s exact test used due to > 25% of cells with expected values < 5. Elevation categories: 2 = 234–533 m; 3 = 533–762 m.

levels of association, the predictive value of particular LDU types for identifying a natural community type, as represented by the Cramer's *V* values, is quite low. There is not a single LDU/natural community-type pair with a Cramer's *V* value of greater than 0.2. As a tool to predict the distribution of forested natural community types, the information contained in LDUs is not sufficient to substitute for field reconnaissance.

Nolet, Domon, and Bergeron (1995) contended "there is only a weak relationship between physical and vegetation variables." Although Meilleur et al. (1994) found 24 community types to be associated with at least one morphogenic feature, the other 23 community types in their analysis showed no such relationship. On the other hand, Vincent, Bergeron, and Meilleur (1986) concluded that an approach to integrating abiotic factors should be based on landform (slope, elevation, and aspect) because of the logical connection between landform and site conditions. Given the unique approaches of each of these different studies, it is difficult to directly compare the results of the current study. Our data indicated a relationship between geophysical variables and natural communities, although the level of association is low. We suggest four reasons for the observed low magnitudes of association reported here.

- (1) LDUs, by design, do not include the ecologically important factors of aspect and soil characteristics. The inclusion of these factors in LDUs would add an enormous level of complexity to the model. However, the influence of aspect on microclimate and thus on vegetation has been recognised for many years (Cottle, 1932; Potzger, 1939; Shanks & Norris, 1950). Soil factors, such as soil moisture and texture, have also been shown to be important factors affecting the distribution of flora (Pretzinger & Barnes, 1982; Nichols, Killingbeck, & August, 1998). Any model missing this information will certainly be incomplete, and therefore unable to account for differences in vegetation resulting from these important factors.
- (2) Although a major advantage of LDUs is the fact that they are based upon readily available GIS data layers, the data themselves introduce some error. The low resolution of some of the data cannot reflect changes that occur on a very localised scale. For example, the bedrock of the study site is extremely complex. There are differences in the bedrock types present in the site with regard to soil forming properties and calcium levels—two important factors affecting vegetation. However, the data used to form the LDUs is based upon a statewide bedrock geology map mapped at a scale of 1:250,000. There are certain to be localised areas where the bedrock types intergrade to the extent that delineation is impossible, or areas where the mapping simply does not reflect the actual bedrock patterns.
- (3) The large differences in sizes of individual LDUs may also be an important issue. While a 10-ha, high-elevation summit LDU is likely to have a different natural community than the adjacent slopes, it is possible that an identical LDU of only 1 ha will be much more likely to have a natural community identical to the surrounding slopes. This difference in LDU sizes points to the broader question about the degree to which community distribution is influenced by factors other than the physical environment. Hubbell (2001) argues that communities are subject to demographic stochasticity, just as they are subject to the physical factors that are addressed in the LDU model. Neither the LDU model nor the study design directly address this issue of random factors that influence community distribution.
- (4) Past disturbance is another factor that is not included in the LDU model but it certainly affects natural community distribution. Meilleur et al. (1994) concluded that the high number of disturbed communities within their study made it very difficult to develop a useful classification system based on vegetation. Ohmann and Spies (1998) also cite "unpredictable historical events" as one of the main sources of unexplained variability in species distribution encountered in gradient analyses. Indeed, with the widespread historical human disturbances across this study site, involving complete clearing of many areas and grazing of sheep and cattle along with various intensities of timber harvesting, disturbance is a factor that cannot be entirely controlled. However, the sampling method was designed to minimise this effect.

All of these factors combine to limit the predictive power of a model based solely upon geophysical variables. Despite all of these known obstacles, it is noteworthy that significant levels of

association were found between single LDU types and natural community types. This finding suggests that the LDUs are ecologically meaningful. Although LDUs alone may be inadequate to predict natural community distribution with confidence, the model does provide a tool with which to view the landscape in a useful manner, to help prioritise field work, and to conduct landscape-level assessments.

Grouping LDUs to isolate individual factors provides insight about which factors affect distribution of natural communities. The mesic maple-ash-hickory-oak community type shows a statistically significant affinity to the calcareous clastic bedrock type, and to the 234–533 m elevation zone. This finding is partially explained by the knowledge that the dominant tree of this community type, *Acer saccharum*, tends to grow in higher pH soils (Muller, 1982; Nigh, Pallardy, & Garrett, 1985). The northern hardwood forest type showed no significant association with landform type, as might be expected from such a widespread community. Its association with the higher elevation class is supported by descriptions by Thompson and Sorenson (2000). The two natural community types that occur on dry sites were associated with ridge and summit landforms—typically the most well-drained sites across the landscape. This type of analysis is an example of the utility of this GIS model to further our understanding of the factors that control vegetation distribution.

In its current form, the LDU model examined in this study, has the best predictive value for natural communities that are associated with unique portions of the landscape (such as dry oak forests on ridgetops). The limitation with this relatively simple LDU model is the fact that the more subtle differences that control changes in the more homogeneous sections of the landscape are not distinguished. In order to obtain a higher predictive value from such a model that might be more useful for the less distinct areas of the landscape, it would be necessary to incorporate at least one soil variable and an aspect variable. However, with the simple LDU model used in this study, there were 126 different LDU types in the study area. Adding just two more variables, each with three classes would result in 1134 LDU types. This is such a large number of units that it would require the use of a screening system to obtain a useful subset of the model.

## Conclusion

The results suggest that variables in the LDU model are relevant to natural community distribution, but

the LDU model alone is not an effective tool to aid in mapping of natural community types of upland forests in Vermont. As demonstrated by Kintsch and Urban (2002), who were searching for individual species, our results also suggest that a physically based model cannot substitute for actual site visits to determine natural community types. Until better landscape-level techniques are developed, the role of this type of model is limited to screening the landscape for areas with a particular set of geophysical characteristics, which can help an ecologist interpret the patterns on the landscape, but cannot substitute for a field-based approach to natural community mapping.

Another role of the GIS model examined in this study that is currently under investigation is its ability to identify areas of high levels of species biodiversity across the landscape. Although the results of this study do not provide evidence to support this role, current research is in process to determine if a diversity of LDU's correlates with a diversity of species (Capen, 2003, pers comm.).

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