RESEARCH ARTICLE

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Evaluating Error in Using the National Vegetation Classification System for Ecological Community Mapping in Northern New England, USA

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ABSTRACT: At the landscape scale, representation of reality using ecological community maps is limited by: how well the chosen classification system represents actual vegetation community composition; how effectively aerial photography captures the distinguishing features of each mapping unit within the classification; and how well these mapping units are delineated by photo-interpreters. Three errors deriving from these factors can be defined as classification system error, photo-limitation error, and mapper error. We evaluated the relative importance of these error types for ecological community mapping in a 7283 ha area including the Lake Umbagog National Wildlife Refuge (LUNWR). We used the association level of the National Vegetation Classification System (NVC) to classify and map ecological communities through combined aerial-photo interpretation and fieldwork. Map accuracy assessment using an error matrix yielded an overall map accuracy of 46 ± 9%. Fuzzy set analysis and use of a "goodness-of-fit" table showed that classification system error accounted for 25% of the error, photo-limitations for 66% of the error, and mapper error for the remaining 9%. To improve map accuracy, classification system error can be reduced by: (1) refining class definitions to decrease ambiguity, (2) adding new classes to more adequately describe the complex of local vegetation patterns, or (3) using a higher level of classification within the NVC. Photo-limitation error can be reduced by: (1) defining mapping units by aggregating NVC associations into photo-interpretable groups, (2) utilizing aerial photographs with a higher resolution than the 1:15,840 scale photographs used in this study, or (3) mapping primarily using fieldwork.

Index terms: accuracy assessment, ecological community mapping, fuzzy set, Lake Umbagog National Wildlife Refuge, National Vegetation Classification System

INTRODUCTION

Ecological community classification and mapping are used increasingly for land conservation and management purposes. While classification and mapping are separate activities, classification is the traditional tool for thematic mapping (Foody 1999), and they are often done together as part of one project. Error in community maps can, therefore, derive from the classification itself (classification system error) or the application of the classification to mapping. Errors related to the application of a classification to mapping can result from limitations in the data used for mapping (photo-limitation error in the case of mapping from aerial photographs) or mistakes in analyzing the data (mapper error). For accurate maps, defined classes must represent the full range of local community composition to minimize classification system error. Differences between classes must be distinguishable on aerial photographs to minimize photo-limitation error. As in any mapping project, mapper error is minimized by training, experience, and thoroughness.

The National Vegetation Classification System (NVC) is being developed to standardize community classification in the United States so that ecological data can be more easily compared across regions. Ecological communities are "assemblages of species that co-occur in defined areas at certain times and that have the potential to interact with one another" (Grossman et al. 1998). While the nature of ecological communities has been debated at least since Clements (1916) and Gleason (1926) put forth their opposing views on community organization (see Whittaker (1962) and Mueller-Dombois and Ellenberg (1974) for detailed discussion), most ecologists now hold that a vegetation continuum better reflects reality (McIntosh 1967). Austin and Smith (1989) noted that a community is a spatial concept relevant for a particular landscape, while the continuum concept is applicable to abstract environmental space where vegetation changes in response to an environmental gradient. This distinction allows for the recognition and classification of community types in a landscape where specific combinations of species are found repeating in similar environmental settings with similar disturbance histories, even though the exact boundaries of communities may not be distinct.

An assumption in community classification is that the entire compositional continuum of vegetation can be represented within the categories of the classification if classes are flexibly defined to accommodate the variation present in nature (Grossman et al. 1998). In theory, the entire range of possible species compositions will be represented in one or another unique class within the classification. A second assumption in classification is that a limited number of recognizable species assemblages are present in any given area, since the number of classes must be limited for the classification to be useful.

The NVC has a hierarchical structure with five levels derived from the UNESCO World Physiognomic Classification of Vegetation (1973) and based primarily on physiognomic characteristics of vegetation and secondarily on substrate, hydrologic, and climatic factors (Grossman et al. 1998). The lowest physiognomic level is that of the formation which is defined as "vegetation types that share a definite physiognomy or structure within broadly defined environmental factors, relative landscape positions, or hydrologic regimes" (Grossman et al. 1998). In contrast, the two finest levels of classification, the alliance and association, were developed through analysis of plot data and are defined through plant species composition (floristics). Associations are defined by Jennings et al. (2003) as "a vegetation classification unit defined on the basis of characteristic range of species composition, diagnostic species occurrence, habitat conditions and physiognomy," while an alliance is "a vegetation classification unit containing one or more associations, and defined by a characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the uppermost or dominant stratum of the vegetation." This is a definition of degree rather than kind. Alliances are defined by the dominant species of the uppermost vegetation strata, while associations include secondary species and species in other strata (Grossman et al. 1998).

Aerial photo-interpretation uses features such as shape, size, pattern, tone, and texture on photographs combined with outside knowledge of the site and timing of photography to identify landscape features (Lillesand and Kiefer 1994). For delineating ecological communities from photographs, the upper stratum of vegetation is the most visible feature, although under-story vegetation, substrate features, and hydrology can be observed in some situations, depending on the timing of the photographs and the properties of the community. To successfully classify and delineate ecological communities from aerial photographs, these features must be sufficient for identifying all classes within the chosen classification.

Finally, the photo-interpreter (mapper) must have sufficient training and experience in photo-interpretation, and knowledge of plot data on the composition, structure, and distribution of ecological communities present on the study area. A certain amount of subjectivity is inherent in photo-interpretation, but experience allows the mapper to consistently extract the greatest quantity and detail of information from photographs and to minimize avoidable errors.

As recommended by the United States Geological Survey – National Park Service (USGS-NPS) mapping program for ecological community mapping at scales of 1:24,000 (TNC and ESRI 1994*b*), we used NVC associations (NatureServe 2002) to map ecological communities at the Lake Umbagog National Wildlife Refuge (LUNWR) through combined aerial-photo interpretation and fieldwork. In this paper, we analyze this application of the NVC, and compare our results to ecological community mapping projects using the NVC at Isle Royale National Park and Voyageurs National Park. We discuss sources of error in classification and mapping and make recommendations as to the best use of the NVC in this context.

METHODS

Study site

Ecological communities were mapped on 7283 ha within and around the Lake Umbagog National Wildlife Refuge (44° 50'N, 71° 06'W) in northern New Hampshire and western Maine (Rapp 2003). Open and forested wetlands cover 2004 ha within the mapping area, and most of the remaining area is covered by upland forest, including lowland spruce – fir forest (*Picea rubens – Abies balsamea – Betula papyrifera* Forest), northern hardwood forest (*Acer saccharum – Betula alleghaniensis – Fagus grandifolia / Viburnum lantanoides* Forest), and mixed hardwood-conifer types. The Refuge was created in 1992, although much of its current land area was acquired more recently. Before acquisition by the U.S. Fish and Wildlife Service (USFWS), most of this land was owned by private timber companies and managed for timber production. Although at the time of fieldwork there was no active logging on Refuge lands, much of the forest had been harvested in the recent past, and there was active logging in small parts of the study area outside of USFWS ownership. Upland forest conditions in the study area ranged from recent clearcuts to small areas of mature forest. Much of the forest was early- to mid-successional.

Ecological community map production

Description and mapping of ecological communities was completed between June 2002 and February 2003 following standard methods (TNC and ESRI 1994b, Thompson and Sorenson 2000). Detailed methods are described in Rapp (2003). In general, ecological community mapping is an iterative process involving initial aerial photo-interpretation to delineate presumed community boundaries, field data collection, and more photo-interpretation to adjust boundaries based on the knowledge gained through fieldwork. We collected data describing the location, environmental setting, vegetation structure, and plant species composition of communities at 344 plots. These data, along with field notes taken along transects between plot locations were used in classifying, describing, and mapping communities. A local community classification of 48 classes based on the NVC (NatureServe Explorer 2002) was developed before final mapping from aerial photographs was completed. Digital black-and-white ortho-rectified aerial photographs (1:15,840) served as a base layer for mapping, with stereo pairs of color infrared aerial photographs (1:15,840) used for reference. The minimum mapping unit was 0.5 ha.

Map evaluation

Sampling design and data collection

We established accuracy assessment plots using stratified two-stage random sampling to maximize efficiency in data collection while maintaining geographic breadth in sampling. A grid of 94 1 km x 1 km blocks was first placed over the mapping area. Blocks were then stratified into 11 groups of six to 12 blocks that shared a geographic location as well as similar geologic, topographic, and hydrologic features (e.g., shoreline, part of a wetland complex, or well drained slope and ridge). Within each group, one or two blocks were chosen (depending on the size and configuration of the group) at random. For each block chosen, 10 points were randomly selected for field sampling (Figure 1). These points were located in the field using a handheld Garmin 12CX GPS unit. Points more than 40 m outside the mapping area were discarded. Points less than 40 m from the mapping area were moved the minimum distance necessary for the plot to be entirely within the mapping area. Points less than 40 m from a community boundary (determined in the field) were also moved. In this case, two plots were taken, one in each community. Again, the plot centers were moved the shortest distance such that the entire plot was fully within one community. In total, we established 103 accuracy assessment plots.

At each sample point, a 0.5 ha (40 m radius) accuracy assessment plot was established (TNC and ESRI, 1994a). This size was chosen to match the minimum mapping unit of the original map. Occasionally the fieldworker modified the dimensions of the plot to sample from within the boundaries of one community (TNC and ESRI, 1994a). At each plot, a preliminary association name was assigned, cover class (0-25%, 25-50%, 50-75%, or 75-100%) was estimated for the three dominant species in each of the tree, shrub, and herb layers, vegetation structure (forest, woodland, shrubland, shrub/herb, herbaceous) was noted, and hydrology (upland, saturated, flooded) was recorded. Additional notes and a sketch of the plot were also included.

To assure that mapping was independent of accuracy assessment, data for assessing map accuracy were collected by a fieldworker not involved in photo-interpretation, and data were archived until the final map was complete. In addition, each plot was classified based on recorded data after the final map classification was determined.

Error analysis

For each point in the accuracy assessment data set, we compared community class as predicted from the map to the community class as determined from plot data. The results were collated in an error matrix (also called a contingency table or confusion matrix). Error matrices are described by Congalton (1991) and are the suggested method of reporting accuracy assessment data (TNC and ESRI 1994a). In an error matrix, observed communities are column headings, and predicted communities are row headings. Each cell of the table shows the number of plots in which the predicted community was actually a particular observed community. The overall accuracy, the percent correct plots to the total number of plots, is also derived from the error matrix. We calculated overall accuracy for the association, alliance, and formation levels of the NVC, although we have given the accuracy of the mapped associations the most attention in this paper.

Two assumptions of error matrices are that: (1) there is one, and only one, correct community assignment for each plot, and (2) the reference data (accuracy assessment plot data) are 100% accurate. Commonly, these assumptions are not satisfied for thematic maps (Foody 2001). An alternative to the traditional error matrix is derived from fuzzy set theory, which recognizes intrinsic ambiguity in the natural world (Li and Rykiel 1996) and can simulate this natural variability (Townsend and Walsh 2001). In contrast to classical set theory, which is applicable to discreet variables where an element is or is not a member of a set, fuzzy set theory is applicable to continuous variables where an element can have partial membership to a set (Roberts 1986). Applied to ecological community classification, floristic composition is a continuous variable, and a particular point in a landscape can have a floristic composition that can have partial membership in more than one class. Because fuzzy sets more closely represent vegetation variability, accuracy assessments using fuzzy sets often report higher map accuracy than traditional accuracy assessment methods (Townsend and Walsh 2001, Laba et al. 2002).

In a fuzzy set, a value of appropriateness of each community designation is assigned to each point of plot data. Here, the following linguistic scale was used (from Gopal and Woodcock 1994): 1 = absolutely wrong; 2 = understandable but wrong; 3 = acceptable answer; 4 = good answer; 5 = absolutely right. Accuracy assessment plot data were used to assign these numerical values to each plot. Plot designations were reviewed a second time and adjusted where needed to maintain consistency in what are subjective designations

From the fuzzy set, two accuracy values were calculated using the MAX and RIGHT functions of Gopal and Woodcock (1994). The MAX function returns the percent of "best fit" class assignments. The RIGHT function returns the percent of acceptable matches (designated as 3, 4, or 5). Both functions return a value similar to the user's accuracy for each class as calculated with the traditional error matrix and yield an overall map accuracy, but allow for the uncertainty inherent in classifying ecological communities. Laba et al. (2002) have noted that the RIGHT function provides a more useful accuracy value for biological conservation purposes.

In addition, each plot was assigned a "goodness-of-fit" code based on the relationship of the predicted association to field observations and subsequent photo-interpretation. The following scale was used: 0 – wrong, should have been interpreted correctly from available data (mapper error); 1 – wrong, easily confused on aerial photos but easily distinguishable in the field (photo limitation error); 2 – wrong, easily confused both in the field and on aerial photos because vegetation composition does not classify unambiguously into just one class (classification system error); 3 – correct, not a perfect fit with classification; 4 – correct, perfect fit. Again, this is a subjective designation and assignments were reviewed for consistency.

Type 1 errors were further classified into sub-categories: boundary placement – the boundary between adjacent communities is not easily distinguished on photos; environmental setting – the distinction between communities is based at least partly on differences in environmental setting (usually hydrologic position) which is not easily observed on photos (as compared to vegetation differences); mosaic – the mapped

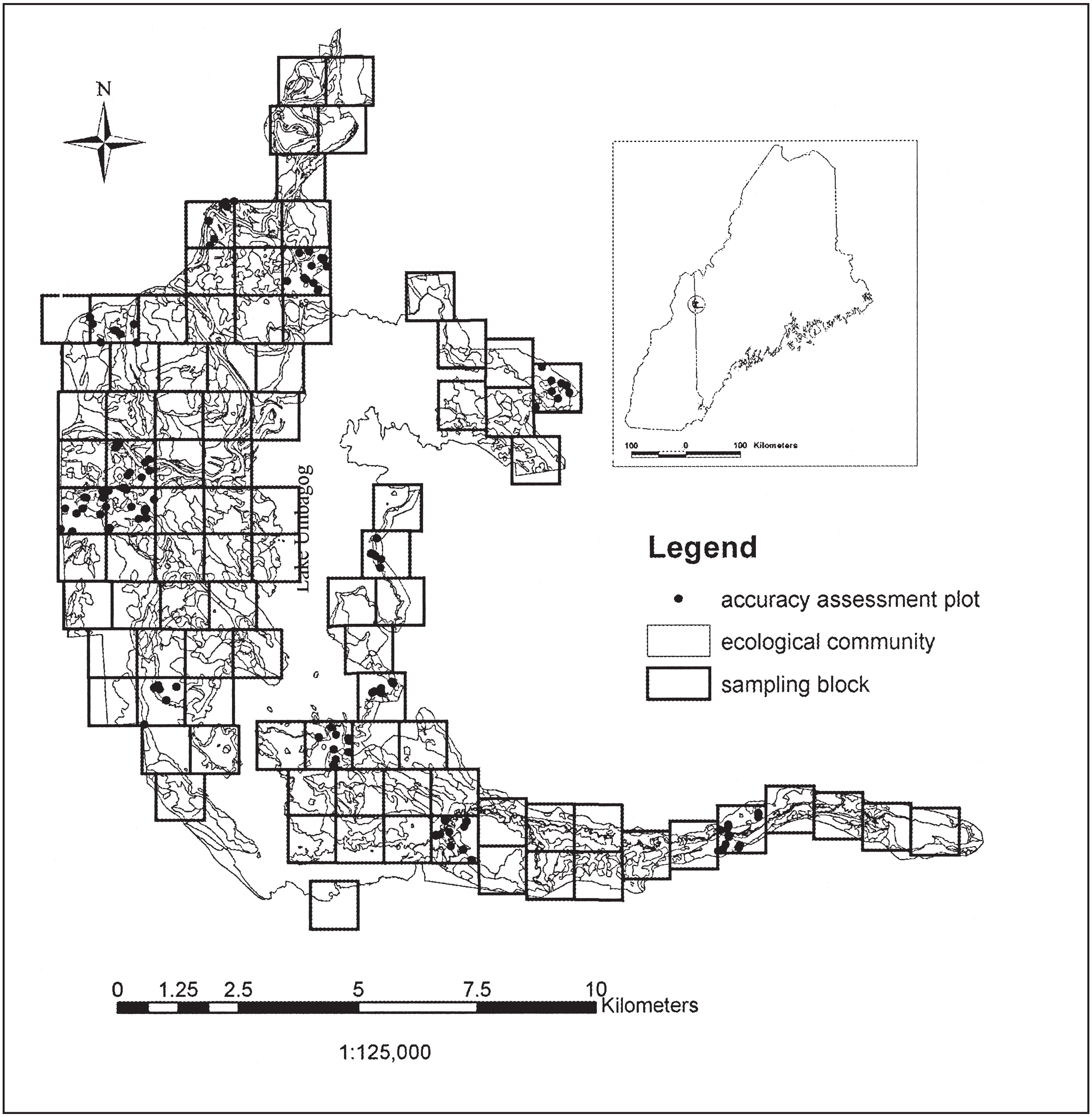

Figure 1. Study area at the Lake Umbagog National Wildlife Refuge. Shown are the boundaries of ecological communities as mapped, sampling blocks created for accuracy assessment data collection, and accuracy assessment plot locations.

polygon is a mosaic of communities not easily split apart using photo-interpretation and only one of these communities is named; photo-signature: pattern – the mapped community has a similar photo-signature to the observed (but different) community; photo-signature: temporal – the community observed in the field does not show up on photos because of the time of year the photos were taken or because the community has changed since the photos were taken (e.g., recent logging).

Comparison to other mapping projects

The accuracy assessment of the LUNWR ecological community map was qualitatively compared to accuracy assessments of ecological community maps created for Isle Royale National Park (TNC 1999, AIS and ESRI 2000) and Voyageurs National Park (Hop et al. 2000) as part of the USGS-NPS Mapping Program. These parks were chosen because of the relative similarity of vegetation with that of LUNWR. We compared overall accuracy of the three maps and differences in procedures at LUNWR and Voyageurs (methods for Isle Royale were not reported in sufficient detail for comparison).

RESULTS AND DISCUSSION

Error matrix

When plotted on the map, accuracy assessment plots were predicted to occur in 18 mapping units (17 communities plus open water). In contrast, 24 of the 48 possible community classes were observed at these plots, suggesting that the actual vegetation is more complex than mapped. Overall map accuracy was 46 ± 9%, much lower than the 80% accuracy standard of the USGS-NPS Vegetation Mapping Program (TNC and ESRI 1994a), but close to the 50-70% accuracy range commonly realized in regional mapping programs (Laba et al. 2002).

Only five communities were consistently observed to actually be the community predicted to occur, and these were sampled in an average of only 2.6 plots each. Some communities were observed more often than predicted, while others were observed less often than predicted. Beyond these evident patterns, the error matrix reveals nothing directly about error source (Zhang and Foody 1998). Inferences could be made based on the distribution of errors, but this is better done through analysis of the fuzzy set and goodness-of-fit data.

Fuzzy set analysis

Fuzzy set analysis provides more detailed information on error magnitude and direction (Townsend and Walsh 2001). The MAX function, which returns the percentage of plots in which the predicted community designation was the observed "best-fit" class designation as determined by plot data, yields a total map accuracy of 52 ± 9%. For seven plots, the community predicted by the map shared the maximum value in the fuzzy set with the community class assigned from plot data, demonstrating the ambiguity in classifying some vegetation compositions, at least when classified from plot data. If community class descriptions are considered compositional nodes in the vegetation continuum, the classification of a site is done by comparing the similarity of its floristic composition to that of the nodes (Roberts 1989). Vegetation compositions that are intermediate between nodes may be appropriately classified in more than one class.

The RIGHT function returns 59 ± 9% acceptable predicted community designations. This includes seven plots in which the class predicted by the map was not the "best-fit" designation, but was still acceptable. Fourteen plots considered wrong in the error matrix had more than one suitable class assignment, again reflecting the ambiguity involved with assigning a community classification to vegetation within plots. When comparing the class accuracy calculated with the RIGHT function with the user's accuracy as calculated with a traditional error matrix, six community types show increased accuracy, with all but one of these being upland forest types. This could be because these classes in general had larger sample sizes than other classes (and hence, had a greater probability that at least one point would change its correctness designation if this were merely a random process), but it also suggests that ambiguity is especially pronounced in the classification of upland forest at LUNWR, where past disturbance (logging) has created vegetation in various successional stages.

Goodness-of-fit

We quantified the frequency of each of three error types, and accounted for the error not explained through use of the fuzzy set using goodness-of-fit values (Table 1). For 47 of 103 total plots, the community name assigned from the accuracy assessment plot data was the same as the predicted community (designated type 3 or 4), although the actual fit of the data to the community description was variable. Mapper error (type 0) accounted for only five of 103 total plots and 9% of the total error, suggesting that avoidable error in photo-interpretation was relatively minor. The bulk of the error occurred in plots designated either type 1 (photo limitation error - 37 plots, 66% of total error) or type 2 (classification system error - 14 plots, 25% of total error).

Classification system error (type 2)

The 14 classification system errors (the same errors accounted for in the fuzzy set analysis) derived from ambiguity in assigning plot data to a class (type 2 errors). This ambiguity often arose from the successional stage of vegetation observed in plots. Communities presumed to be ecologically different can have similar floristic composition depending on disturbance history and stand development (e.g., a mature mixed hardwood-conifer community versus a mixed community presumed to be successional to a conifer dominated community). Similarly defined (on the basis of floristics) classes can introduce significant amounts of confusion in classification (Smith et al. 2003). Other areas that are in superficially similar environmental positions can have variable species compositions due to disturbance

Table 1. Frequency distribution of goodness-of-fit designations by plot and class, percent of total error for each error type, and percent of classes sampled that were affected by each goodness-of-fit type.

Goodness of fit designation	Number of plots	Percent of total error	Number of associations
(0) Mapper error	5	9	4
(1) Photo limitation error	37	66	13
boundary placement	*11*	*20*	*5*
environmental setting	*3*	*5*	*3*
mosaic	*12*	*21*	*5*
photo signature-pattern	*8*	*14*	*6*
photo signature-temporal	*3*	*5*	*2*
(2) Classification system error	14	25	6
(3) Correct, not perfect	13	-	7
(4) Correct, perfect fit	34	-	14
Total	103	100	18

(e.g., beaver meadows), and are perhaps better classified on the basis of vegetation structure and/or site conditions than by species composition.

Photo limitation error (type 1)

Eleven "boundary placement" errors resulted from difficulties in determining the exact boundary between communities on aerial photographs. This was especially problematic when delineating successional forest communities of variable species composition. Boundaries between communities with similar photo-signatures (such as evergreen swamp forest types) were also problematic.

Only three errors were attributed to "environmental setting." Although classes differentiated largely by environmental setting may have similar species compositions, it is often possible to distinguish these communities given clues as to their relative position to other, more easily interpretable communities. For example, a band of dark evergreen vegetation between northern hardwood forest and a *Thuja occidentalis* L. swamp is surmised to have substrate conditions intermediate between those two communities and be classified as *Picea mariana – Picea rubens / Pleurozium schreberi* Forest rather than a spruce-dominated class with a more upland or wetland setting.

There were 12 "mosaic" errors, where areas mapped as one class actually contained multiple communities. This happened when classes with similar photo-signatures were adjacent to one another (e.g. mature and successional hardwood communities), or the vegetation was especially heterogeneous because of logging history.

Eight errors were designated "photo-signature: pattern," where two or more communities had a similar photo-signature (common with conifer-dominated classes at LUNWR) or a particular photo-signature was unknown. The three previous error types are special cases of this type. The common feature of this general error type is the difficulty in distinguishing similar communities from the canopy species observed on aerial photographs. Landscape heterogeneity where multiple classes are found in spatial proximity (Smith et al. 2003, Zhu et al. 2000, Laba et al. 2002) contributes to this general error type.

Only three points were designated "photo-signature: temporal." While this error source has been significant in other projects (Laba et al. 2002, Zhu et al. 2000), at LUNWR it was a relatively unimportant type of error except in areas that were open water when photos were taken (spring or early summer) but contained emergent vegetation when accuracy assessment data were collected in late summer. This type of error could also occur if vegetation cover changed (e.g., through timber harvesting or regeneration) between when the photos were taken and fieldwork completed.

Accuracy at alliance and formation levels of the NVC

The relative amount of error caused by confusion between similar (as defined in the NVC hierarchy) associations can be determined by analyzing accuracy improvement when higher levels of the NVC hierarchy are mapped. Overall accuracy of mapped alliances was 53 ± 9%, while that for formations was 61 ± 8%. The improvement in accuracy at the alliance level results from eight points that were wrongly mapped as a different association in the same alliance. Four of these errors at the association level were due to classification system error (type 2 goodness-of-fit code), while the other four errors derived from difficulties in differentiating the associations on aerial photographs (type 1). In addition to these eight points, eight more were mapped as different associations in the same formation (but different alliances), leading to the improvement in accuracy at the formation level. Four of these additional points were affected by classification system error at the association level, while four other errors derived from photo limitations.

Improvement in accuracy at the alliance level results from the lumping of communities with similar canopy species that were confused at the association level. Improvement at the formation level includes these communities as well as communities that share similar physiognomy of the upper canopy of the vegetation, but not necessarily the same species composition. It is not always possible to differentiate canopy species from one another on aerial photographs, but physiognomy is easier to determine. However, in landscapes with heterogeneous forest in various stages of succession, even physiognomy does not stay constant within community types because of variations in stand ages, and this probably limited map accuracy at LUNWR.

Comparison to other mapping projects

Following similar, although not identical, procedures of mapping and accuracy assessment, overall accuracies of 49% (252 correct out of 515 total plots) for Isle Royale (TNC 1999) and 82% (1031 out of 1251 total plots) for Voyageurs (Hop et al. 2000) were reported. At Isle Royale, 31 mapping units were used, the majority of which were NVC associations. Four of the mapped units were local variants of NVC associations, and three mapping units were complexes (mosaics) made up of two or more associations. At Voyageurs, 45 mapping units were used, the majority of which were also NVC associations, although in nine cases mapping units were composed of multiple associations (mosaics). Also, in 14 cases, a single association was assigned to more than one mapping unit.

The higher accuracy reported at Voyageurs can be explained in part as a function of how the accuracy assessment was carried out. First, plot sampling was stratified by mapping unit, and points falling near polygon boundaries were discarded (a common practice). This was done to minimize the chance of a plot falling into an ecotone. In addition, in data analysis, errors due to plots falling into ecotones were considered "false errors" and corrected (Hop et al. 2000). Both of these actions bias sampling toward homogenous areas, a practice that may lead to "optimistic" accuracy results (Stehman and Czaplewski 1998, Plourde and Congalton 2003, Zhu et al. 2000). Errors resulting from GPS inaccuracy or because plots were placed in communities considered inclusions within a larger polygon were also considered "false errors" and corrected. Errors due to temporal change in the vegetation (five plots) were dropped from the assessment. In comparison, none of these "false errors" were corrected in the Umbagog accuracy assessment. Except for the possible exception of errors resulting from GPS inaccuracy, these "false errors" may better be described as "unavoidable errors" because they are inherent to the mapping process and therefore unavoidable by the map producer, but still represent real errors to the map user. Also, using a "fuzzy" classification by mapping areas as mosaics of multiple associations likely increased the accuracy of the map by allowing more flexibility in assigning plots to a class. Two hundred seventy-six of the 1251 accuracy assessment plots (22%) were classified as mosaics.

CONCLUSION

Mapping ecological communities at LUNWR, through combined photo-interpretation and fieldwork, to the level of NVC association resulted in a map with accuracy considerably lower than the 80% accuracy standard of the USGS-NPS mapping program. The majority of the error was attributed to photo limitations in resolving community identification to the association level, while classification system error and mapper error were less important. Distinguishing between upland forest types was especially problematic, likely because of the high heterogeneity of forest cover in the region due to recent and historical timber management. Ecological communities are highly disorganized at LUNWR, with the same dominant tree species being common in many different communities. This presents difficulties for both field classification and photo-interpretation.

Classification system error results when observed vegetation is not adequately described by an existing class description. In logging-disturbed landscapes such as LUNWR, harvesting history and the resulting successional gradients create an extremely heterogeneous vegetation cover. These gradients can be sharp (e.g., where a clear-cut abuts undisturbed forest), or the situation can be more complicated (e.g., where selective harvesting has taken place in a patchwork pattern in both time and space). The timing, size, and distribution of the gaps created by logging will affect the composition of species present at any given site because each species responds differently to disturbance (Pickett and White 1985). In addition, successional pathways can proceed in multiple directions for any one site (Cook 1996), leading to differences in the vegetation cover of areas with similar site characteristics.

Natural community classifications have addressed this problem by using multiple factors, including potential natural vegetation and environmental factors driving community development, instead of just existing vegetation (Grossman et al. 1998). This has the effect of eliminating successional vegetation types and compositional anomalies from the classification, and generally results in a less complex classification than one for existing vegetation at the same floristic level of detail.

Although the NVC attempts to describe the existing vegetation, class descriptions are most complete for late-successional communities, and not all possible vegetation compositions are fully described. To use the NVC for a local classification and mapping project, new classes usually need to be described. At LUNWR, seven variants of existing classes were defined. Similarly, new types were created in mapping projects at Isle Royale and Voyageurs (TNC 1999, Hop et al. 2000).

Even with the creation of new classes for local classification, sites with unique vegetation compositions may not be well described by existing classes. In this case, the site can be classified by comparing its affinity to other types (Jennings et al. 2003), and site conditions may be the most appropriate basis for this comparison. This is, in effect, using the NVC as a natural community classification. An example of this at LUNWR was where a pure stand of *Larix laricina* (Duroi) K. Koch. that had established after logging in an upland area was classified with the surrounding less recently disturbed *Picea rubens – Picea mariana /Pleurozium schreberi* Forest with which it shared similar site characteristics. Since there were no other examples of this vegetation composition at LUNWR and the type was not described in the NVC for the Northern Appalachian–Acadian Ecoregion, it did not meet the requirement that ecological communities occur repeatedly across the landscape (Grossman et al.

1998), and was, therefore, not classified separately.

Photo-limitation error results when features observable on photographs are not sufficient for distinguishing all community types at a site. At LUNWR, photo-limitation (type 1) was the largest source of error, suggesting difficulty in distinguishing NVC associations on aerial photographs of the scale used in this study (1:15,840), even when it was possible to classify the vegetation in the field. This was usually because communities had similar photo-signatures due to similar canopy composition or because exact canopy composition could not be determined using the photographs, but sometimes it was because landscape changes occurred between photo acquisition and fieldwork. At Voyageurs and Isle Royale, combining associations into complexes for mapping may have improved the accuracy of these maps by making the classification "fuzzy." Photo-limitation errors can be reduced by combining associations into photo-interpretable mapping units and by using higher resolution aerial photographs.

To create photo-interpretable mapping units, a higher level of the NVC hierarchy can be used or NVC associations can be combined into artificial groups. Using NVC alliances and formations, the next two highest levels in the NVC hierarchy did lead to increased accuracy at LUNWR, but still did not bring accuracy to desired levels. Although using a higher level within the existing NVC structure would be preferable for comparison to other mapping projects, another possibility is to create an artificial classification based on photo-signature rather than ecological relationships. For instance, forest and woodland types in different formations are often difficult to distinguish on aerial photographs. A classification based on photo-signature would result in the most accurate maps.

It should be noted, however, that it might still be useful to use a classification based on NVC associations for classifying communities in the field since this provides the most detailed description of vegetation. It may be desirable, therefore, to generate two classification systems: one for vegetation surveying and one for mapping. Field survey of vegetation can generate a local classification based on the NVC (and can, in turn, feed back into NVC development). A separate mapping classification can then be created by merging some community classes into photo-recognizable types before vegetation mapping proceeds (Pearlstine et al. 1998). Thus, ecological knowledge gained from field surveys is retained while accounting for the limited resolution of aerial-photographs. Attempting to use a classification based on field surveys for mapping from aerial-photographs can lead to lower map accuracy.

Mapper error, although not a major error source in this project, is minimized by experience with photo-interpretation, field experience with the local expression of communities on the landscape, the use of multiple data sets (aerial photographs taken at different times, plot data, field notes, etc.), and the use of a consistent mapping protocol.

To create high accuracy maps in logging-disturbed landscapes like LUNWR, creating a local classification that refines descriptions of existing NVC associations and adds new classes can reduce classification system error. Photo-limitation error can be reduced by using higher resolution aerial photographs than the standard 1:15,840 scale and by creating a mapping classification that aggregates NVC associations into photo-interpretable groups based on photo-signature similarity or uses a higher level in the NVC hierarchy. Mapping ecological communities in the field eliminates photo-limitation and mapper error as defined in this paper. For small projects, field mapping may be economically efficient; for larger projects where photo-interpretation must be utilized, the other strategies will need to be used. In either case, there is no substitute for fieldwork in discovering the ecological details of a landscape, because images, no matter how detailed, can never show all of the important characteristics of communities.

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