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A Flexible, Multipurpose Method for Recording Vegetation Composition and Structure

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ABSTRACT

We present a flexible protocol for recording vegetation composition and structure that is appropriate for diverse applications, is scale transgressive, yields data compatible with those from commonly used methods, and is applicable across a broad range of terrestrial vegetation. The protocol is intended to be flexible in the intensity of use and commitment of time, and sufficiently open in architecture as to be adaptable to unanticipated applications.

The standard observation unit is a 10 × 10 m (0.01 ha) quadrat or "module." Where the extent of homogeneous vegetation is sufficient, multiple modules are combined to form a larger, more representative sample-unit. All vascular species are recorded by cover class and in intensively sampled modules as present or absent in sets of nested quadrats. For each module, tree stems are tallied by diameter class; species with exceptionally high or low stem density can be sub- or supersampled to allow efficient collection of data and assessment of population structure. The most common plot configuration consists of 10 modules arranged in a 2 × 5 array with four modules sampled intensively; this size is often necessary to capture the complexity of a forest community. For rapid reconnaissance or inventory purposes, fewer modules are typically employed, and less information is collected.

INTRODUCTION

The North Carolina Vegetation Survey (NCVS) is a collaborative research program with the general goal of characterizing the natural vegetation of North Carolina and adjacent states. Specific objectives include description, classification and inventory of vegetation, interpretation of vegetation-environment relationships, and long-term monitoring of ecosystem conditions. These objectives reflect the information needs of two important constituencies, the scientific community, which aspires to a better understanding of how vegetation varies through time and with respect to local conditions, and the conservation and natural resource management community, which requires information on the abundance, condition, and threats to conservation of natural ecosystems.

Vegetation type, the purpose and scale of a study, and financial resources all influence decisions on how to record vegetation (Kent and Coker 1992). We sought a core methodology sufficiently flexible as to be applicable in most circumstances and for most purposes. A review of existing methods for recording vegetation revealed none sufficiently flexible to provide consistent, useful information on vegetation composition and structure over the range of natural vegetation in southeastern North America. Moreover, existing methodologies are sufficiently divergent that data collection using one method often precluded inclusion of valuable datasets collected by workers who used other methods. To resolve these difficulties we have developed a methodology for recording vegetation that is sufficiently flexible to cover a broad range of applications and vegetation types, while retaining maximal compatibility with other existing methods. Application at nearly 3,000 sites over a ten-year period have verified the flexibility and efficiency of the resultant protocol. Here, we present an overview of the NCVS protocol for recording vegetation composition and structure. This overview is intended to serve as an expanded explanation of methods for readers of publications that use data collected following this protocol (e.g., Newell and Peet 1998). In addition, we hope our efforts will lead to greater standardization of field methods and thereby facilitate further collaborative research and more effective inventory and conservation of natural vegetation.

OBJECTIVES

The following design objectives guided development of the NCVS protocol.

1. *Appropriate for most types of vegetation.* Textbook recommendations for recording vegetation often include a decision tree based on physiognomy of the vegetation to be studied, with the result that data collected from divergent types such as forests and grasslands are not always directly comparable. We desired a method sufficiently general to provide comparable data from the full array of terrestrial vegetation types in the Southeast, including such divergent communities as grass- and forb-dominated savannas, dense shrub thickets, mesic cove forests, and sparsely vegetated rock outcrops.

2. *Appropriate for diverse applications.* Vegetation plot data provide a record of sampled sites long after the sites have disappeared. Consequently, there are many possible users of and uses for vegetation data beyond the initial study; old data often find uses entirely different from those the original field workers anticipated. Moreover, objectives can evolve during a study, and field data can lead to new insights and new objectives. Accordingly, we sought a set of methods that would accommodate as many of the diverse needs of data collectors and data users as possible.

3. *Flexible in intensity and time commitment.* Some applications require detailed data that are time-intensive to collect, whereas other applications call for extensive data to be collected with limited time and personnel. We required that the NCVS protocol incorporate considerable flexibility in the detail to be obtained at any one location, without sacrificing compatibility at certain fundamental levels.

4. *Scale transgressive.* Vegetation structure and composition can be viewed at many spatial scales, each providing a somewhat different perspective. Choice of scale in vegetation measurement is often based on observations of species-area relationships, which results in sample size variation between studies. Moreover, vegetation measurement is typically directed at "homogeneous" vegetation, but environment and disturbance generate different patterns in vegetation at different scales such that no one scale is ever fully satisfactory for observations. The dependence of species richness observations on scale of observation led Whittaker (1977, Whittaker et al. 1979, Shmida and Whittaker 1981, see Shmida 1984) to develop a recording method that includes several scales of observation. These same considerations led us to seek methods that provide information about species composition across a wide range of spatial scales.

5. *Appropriate for long-term studies.* Many of the data applications we envision require plots that can be resampled (permanent sample plots). Accordingly, vegetation plots should be configured in a manner that facilitates accurate relocation and remeasurement.

6. *Compatible with other methodologies.* Our scientific interests require collection of compositional data suitable for standard analytical procedures and that can be merged with datasets collected using other methods. Similarly, our conservation interests require data suitable for use by collaborating agencies and organizations interested in inventory and classification of natural communities at both the state and national level. For these reasons we required that standard measures such as basal area, tree density, cover, and species richness be obtained. We have also sought to maintain maximal compatibility with widely used methods, such as those of Braun-Blanquet (1964), Whittaker (1960; also Shmida 1984), Daubenmire (1968), and various agencies and organizations, such as the U.S.D.A. Forest Service and The Nature Conservancy.

7. *Easy to learn and use.* Flexibility is bought at the price of greater complexity of methodology and more subjective choices to be made by the practitioner. However, we recognize the need for methods to be moderately easy to use in the field so that only minimal training is

needed for field personnel. Cumbersome protocols are soon discarded as impractical, regardless of their specific merits.

8. Open architecture. To accommodate the many potential users who have their own particular needs, the protocol needs to be based on a fundamentally open architecture; the methods need to be open to adjustment and supplementation as needed for different, specialized applications, provided only that the core architecture that ensures compatibility with other forms of data is retained.

THE MODULE CONCEPT

Two fundamental problems that confront scientists wishing to characterize vegetation are that different vegetation processes are apparent at different spatial scales, and that vegetation typically exhibits strong spatial autocorrelation. Reed et al. (1993) have shown that correlations between vegetation and environment change dramatically with scale of observation. The spatial scale problem also can be seen in the fact that disturbance-caused vegetation patches range from the size of a small anthill to a landscape altered by a vast forest fire. Consequently, no one size (area) of observation will be optimal for all purposes, yet consistency in size is needed to ensure comparability between observations. The spatial autocorrelation problem is apparent in the common observation that plots with high perimeter to area ratios have higher species counts per unit area than circular or square plots (Bormann 1953, cf., Stohlgren et al. 1995), in part because they encompass more microvariation in habitat, and because more combinations of interacting plant species are encountered. Spatially distributed subplots will generally include more species and provide a more representative estimate of composition, but when summed they provide a biased estimate of species co-occurrence.

Our solution to the problems of scale and spatial autocorrelation is to adopt a modular approach to plot layout, wherein all measurements are made in plots comprised of one or more 10 × 10 m quadrats or "modules" (100 m^2 = 1 are = 0.01 hectare). The module size and shape were chosen to provide a convenient building block for larger plots, and because a body of data already exists for plots of some multiple of this size. The square shape is efficient to lay out, ensures the observation is typical for species interactions at that scale of observation, and avoids the biases built into methods with distributed quadrats or high perimeter-to-area ratios.

In effect, our methodology defines most spatial heterogeneity in vegetation at scales below 10 × 10 m as within-community pattern. Smaller-scale processes can be captured to some extent by nested subquadrats as described below, but are generally not well described with our methods. Vegetation that is patchy at a very small scale, such as certain glade and outcrop communities, or which is strongly zoned at the scale of one to a few meters, such as the narrow bands surrounding a depression wetland, will generally be homogenized by plot-based sampling methods.

The flexibility of the NCVS protocol stems primarily from flexibility as to the number of modules included in a plot and the information recorded for each. Numerous configurations are possible. A 2 × 5 module array (0.1 ha) is commonly used and often needed to capture for purposes of classification and description the complexity of a forest community. In contrast, in structurally simpler communities and for reconnaissance or inventory purposes, a small number of modules will often suffice. In situations where a standard plot configuration would not fit or would be inadequate or heterogeneous, investigators are encouraged to modify plot layout to obtain a representative portrayal of homogeneous vegetation. For example, a ridgeline might best be captured with a 1 × 5 array, and a rock outcrop might contain space for only 1 or 2 modules. Where site conditions dictate, it is even possible to change the shape of the module to ensure homogeneity, though this should normally be avoided for reasons related to the spatial autocorrelation of vegetation as stated above. In one particularly extreme case, we "stretched" a module to a 2 × 50 m shape to accommodate a narrow rockface along a steep riverbank.

SPECIES IMPORTANCE

Many attributes of vegetation have been proposed for use in the description of vegetation. We have chosen to include three of the simplest and most widely used forms of data: presence, cover, and woody stem sizes.

Presence

We define "presence" as the occurrence of a species (based on emergence of a stem or stems) within a quadrat, where the species must be "rooted" in the quadrat. Determination of the presence or absence of a species has the advantage that it is entirely objective, assuming careful searching techniques; a clean decision can be made as to whether aboveground parts of a plant are or are not present in a quadrat. It is also a parameter compatible across all growth forms. Many analytical procedures (e.g., ordination, classification) can accept presence/absence data, and presence is used in determination of the most fundamental diversity parameter, species richness.

Nested subquadrats are employed to obtain estimates of species number and co-occurrence at spatial scales less than that of the 100 m^2 module. Species presence is determined for a $\log_{10}$ series of nested subquadrats (e.g., 0.01, 0.1, 1.0, and 10 m^2) established in one or more corners of the module(s) (or in the center, allowing for as many as 5 sets of nested subquadrats that overlap only at the 100 m^2 scale; see Figure 1). The nested subquadrats in a single nest are square and share an outside corner to facilitate establishment and accurate relocation. The number of subquadrats in a nest is referred to as depth, where a depth of 1 indicates presence recorded only at the 100 m^2 or full-module scale, and a depth of 5 indicates presence recorded in a subquadrat of 0.01 m^2. For each nest, the smallest subquadrat is searched first and each species receives a number corresponding to the depth at which it is first encountered. Presence recorded for a particular depth implies presence at all lower-numbered depths as well, which allows the full nest of subquadrats to be recorded as a single column of single digits. A depth of 0 is used to indicate cover in the module contributed by a species that is not rooted in that module.

Depth of sampling and number of nests per module are generally determined by the individual researcher based on the objectives of the project and the time available. Use of nested subquadrats can add substantially to the time and effort required, but this is dependent on the number of nests per module, the depth to which they are recorded, and the attributes of the vegetation. Inclusion of nested quadrats has the advantage that it forces a particularly careful examination of the plants in a module. In practice, depth is almost always set either at 5 (when intensive data are desired) or 1 (when time is limited and a rapid, relevé-style observation is desired). We state that a recorded module is an "intensive" module when all vascular species are recorded by cover class and as present or absent in one or more sets of nested quadrats. In contrast, if species are recorded only at level 1, we refer to a "relevé" module. Although plots within a particular study can vary in sampling depth, it is helpful to be consistent in sampling depth to allow efficient use of the data collected.

Generally, between subquadrat variance increases as subquadrat size decreases, with the result that observation of only one or two nests is often viewed as inadequate for small subquadrats. When we choose to record only a single module at a site, we often include 4–5 nests. More commonly, we observe a set of (usually 10) contiguous modules, in which case two nests are observed for each of four modules that make up a central block of four (400 m^2; see Figure 1).

Cover

In the NCVS protocol, cover is the only quantitative vegetation parameter recorded across all plant growth forms. "Cover" is here defined as the percentage of ground surface obscured by the vertical projection of all aboveground parts of a given species onto that surface. No species may exceed 100% cover, though the sum of cover estimates across all species often exceeds 100%. In this case, the plant need not be rooted in the area under consideration.

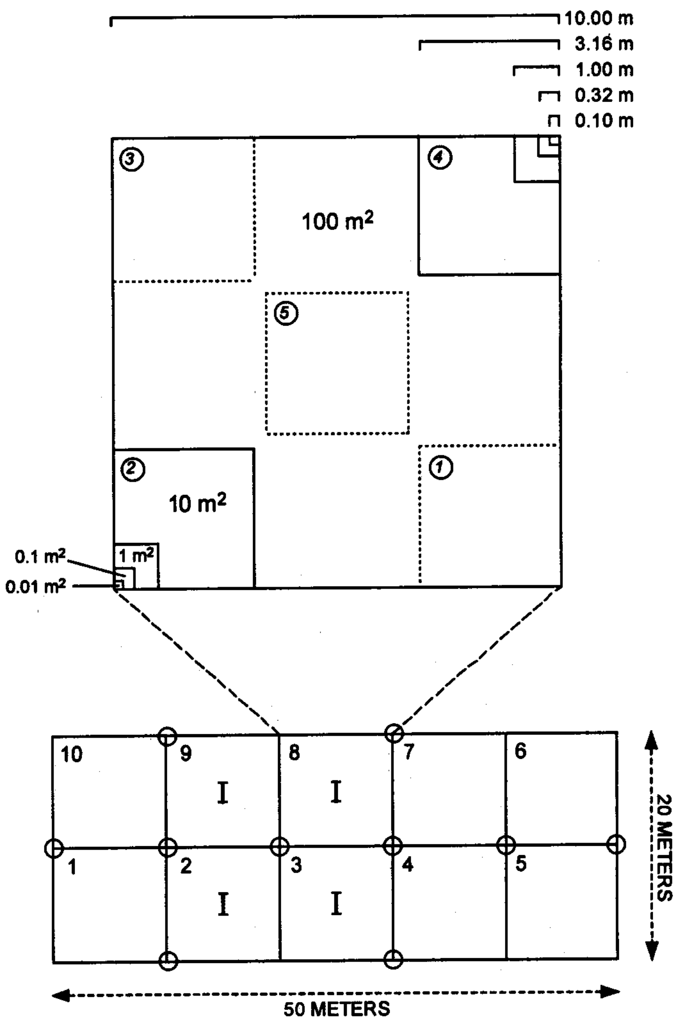


Figure 1. Typical layout of an intensive module, and a set of 10 modules as a 0.1 ha plot. Modules are numbered counter-clockwise. The five standard locations in a module for nested quadrats are indicated, although in the standard 0.1 ha configuration only two nests are recorded (solid lines rather than dashed) in each of the four intensive modules. Typically, these intensive modules are 2, 3, 8 and 9 as intensive modules (marked I), with nested quadrats in the eight corners indicated. The remaining six modules are recorded as an aggregate. Corners within a module are numbered clockwise, starting along the centerline and moving initially along the centerline in the direction that the modules are numbered, as indicated for module eight. Typically a 50 m tape is placed along the centerline and two 20 m tapes cross the main tape along the outside edges of the four focal modules. Permanent metal stakes (circles in the 0.1 ha configuration) are located at the 10 locations where a tape touches the corner of a module.

Percentage cover estimates provide data suitable for quantitative analyses and include all species encountered.

Cover is estimated visually by the researcher, usually at the level of the module (depth 1). Much has been written about the relative merits of cover-class scales versus direct estimation of cover (e.g., Schultz et al. 1961, Mueller-Dombois and Ellenberg 1974, Oksanen 1976, Sykes et al. 1983). We have found that use of cover classes results in more rapid data collection, greater ease of training, and greater agreement and satisfaction among observers as compared to direct estimation of percentage cover. Generally, the human mind perceives cover on a

Table 1. Comparison of Cover-Abundance scales used in different sampling methods

Cover Range	NC	BB	D	K	FS	H-S	NZ
Missing but nearby	.	()					
Solitary	1	r	1	+	T	+	1
Few	1	+	2	1	T	1	1
0–1%	2	1	2	2	T	1	1
1–2%	3	1	3	3	1	1	2
2–3%	4	1	3	3	1	1	2
3–5%	4	1	4	3	1	1	2
5–6.25%	5	2	4	4	2	1	3
6.25–10%	5	2	4	4	2	2	3
19–12.5%	6	2	5	5	2	2	3
12.5–25%	6	2	5	5	2	3	3
25–33%	7	3	6	6	3	4	4
33–50%	7	3	7	7	3	4	4
50–75%	8	4	8	8	4	5	5
75–90%	9	5	9	9	5	5	6
90–95%	9	5	10	9	5	5	6
95–99%	10	5	10	9	6	5	6
100%	10	5	10	10	6	5	6

NC = North Carolina Vegetation Survey; BB = Braun-Blanquet; D = Domin (1928); K = Domin *sensu* Krajina 1933; FS = US Forest Service–Western US (modified from Daubenmire 1968); H-S = Hult-Sernander (Hult 1881); NZ = New Zealand Reconnaissance Plot Sampling (Allen 1992, Hall 1992).r, +, and T = very uncommon with much less than 1% cover.

geometric scale rather than a linear one; our visual abilities are well attuned to doublings and we can much more easily see the difference between 1 and 2 % cover than that between 31 and 32%.

Numerous cover class schemes have been proposed and several of the more popular variants are presented in Table 1. For the NCVS protocol, we devised a ten-point scale consistent with rough doublings of cover (or lack of cover), with breaks placed to assure maximal ease of interconversion with other cover-class scales. Specifically, we use the following scale: 1 = trace, 2 = 0–1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%, 6 = 10–25%, 7 = 25–50%, 8 = 50–75%, 9 = 75–95%, 10 = >95%. These cover classes represent classes that we have found to be generally repeatable to within one class when replicate plots recorded by the same or different investigators are compared. A convenient guide for estimating cover classes at the module scale is to recall that a 1 × 1 m block of leaf area corresponds to 1% cover.

One difficulty with use of cover classes has involved determination of means. To accomplish this, we average the percentages corresponding to cover-class mid-points (e.g., for class 5 = 5–10% we use 7.5%) followed by assignment of the average to the appropriate cover class. As noted by Bonham (1989), use of class midpoints presupposes a symmetrical dispersion of actual cover values within the class, an assumption that is probably incorrect but which introduces only a modest bias toward larger values for species. In contrast, Oksanen (1976) suggested that if cover classes make up a geometric series, the geometric mean of the class limits might be more appropriate for calculating mean cover, but we suspect that this procedure over corrects.

Woody Plant Diameters

Tree stem data are needed for computation of basal area and density, the two most commonly used importance measures for woody species (here including all trees, shrubs, and woody lianas that reach breast height). These measures may be used in various quantitative analyses and permit comparisons with a large body of data from forestry and vegetation science. In addition, tallies by size class allow inferences about population stability.

Woody stem data are collected as tallies of stems in diameter classes established for efficiency of data collection and for maximal compatibility with existing data (including those collected using English units). NCVS diameter classes are 0–1, 1–2.5, 2.5–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, and 35–40 cm. Stems with diameters greater than 40 cm are tallied individually to the nearest cm for efficiency of recording and because small differences in diameter at large sizes produce large differences in basal area. All diameters are measured at breast height (1.4 m). Multiple stems arising from a common root system are recorded separately if they branch below 0.5 m above ground level (stems branching above 0.5 m and below 1.4 m are measured at the narrowest point below the branch). Tallies are maintained by species and are recorded separately for each module (or sometimes as an aggregate for modules recorded after the first four intensive modules).

To increase flexibility and applicability to unusual vegetation, the area surveyed by stem count may be a specified percentage (subsample or supersample) of the module, such as 20% for dense shrublands or 200% for savannas. This is easily implemented in the field by adjusting the width of the module (for purposes of woody plant tallies only).

PLOT AND SITE CHARACTERISTICS

Site and plot characteristics are collected for all plots and include basic information necessary for interpretation of the plot data, documentation of plot location, and placement of the plot within the FGDC/TNC National Vegetation Classification (NVC; Federal Geographic Data Committee 1997). Additional site data for interpretation of the environmental context of a plot can be extremely valuable, but the details of variables needed and how they should be measured vary substantially between studies and regions. Consequently, standards for site characterization are not part of the NCVS protocol.

The following list includes the most basic information collected for all plots. General information must include plot identifier (usually plot number), date sampled, names of researchers, plot size in ares (0.01 hectare modules), identification numbers of intensive modules, depth of nesting for intensive modules and authority for botanical nomenclature. Plot description starts with physiognomic class of the NVC, physiognomic subclass of the NVC, hydrologic class of the NVC if applicable, and height in m and total cover in percent of the dominant (canopy) woody vegetation layer, the herbaceous layer (herbaceous species only) and the bryophyte layer (nonvascular species only). Location is required in the form of geocoordinates (UTM, or latitude and longitude) with a notation as to the method used to obtain the coordinates (e.g., GPS, map and compass, aerial photo). Site physical characteristics nearly always of value include elevation, slope, aspect, and topographic position. In addition, soils data should always be collected. Ideally, a complete profile should be described. In addition to examining the soil profile, we routinely collect soil samples consisting of the top 10 cm of mineral soil for nutrient and texture analysis. Samples are collected from each of the intensive modules, or a single sample is collected when no modules are intensive. B horizon samples are collected in studies where deemed potentially important.

PLOT CONFIGURATION OPTIONS

A NCVS plot may consist of any number of modules. A single module is possible and often appropriate for rapid assessment purposes, but is usually insufficient for obtaining an adequate representation of most woody vegetation. Mueller-Dombois and Ellenberg (1974) recommended an area of 200–500 m^2 for forest vegetation, and we have found that even this area is often too small for an adequate representation of composition in large-stature or species-rich forests. Numerous North American vegetation studies have employed 20 × 50 m plots (1,000 m^2 or 0.1 ha) similar in design to those first employed by Whittaker (1960). The widespread use of 20 × 50 m plots in a variety of forested vegetation types, and the consequent availability of substantial comparative vegetation data at this scale, led to the adoption of this plot size and shape as a standard NCVS configuration.

Within the 0.1 ha plot (2 × 5 array of modules), a prescribed 2 × 2 block of four intensive modules is selected for standard intensive measurement wherein species cover class values and woody stem tallies are recorded separately for each module. An aggregate count of woody stems is made in the remaining six modules, and this area (600 m^2) is searched for species not encountered in the four intensive modules measured previously. Percentage cover estimates are made for these additional species at the 0.1 ha level.

There will be situations where constraints posed by heterogeneity of vegetation and/or environment, researcher time available, or significance of the site makes the standard 0.1 ha configuration inappropriate or impractical. Numerous other configurations of modules are possible. Often, a single module is suitable for obtaining cover and presence determinations in a small patch of vegetation, especially when herbaceous and shrubby strata are of primary concern. However, stem counts for woody species within a single module may be inadequate for characterizing the woody vegetation, and cover estimations may be strongly influenced by the presence of one or more large canopy trees within the module.

Numerous other combinations of modules can be used for special circumstances. Where a full 0.1 ha plot will not fit, a block of four intensive modules (2 × 2 configuration) can be a good substitute. The resulting plot is 400 m^2 in area, within the size range recommended by Mueller-Dombois and Ellenberg (1974) for forest vegetation. Strips of two, three, four, or five modules can be used where homogeneity considerations limit the number of modules. However, it is desirable to increase the number of corners with nested subquadrats in each module when fewer than four intensive modules are measured.

SUPPLEMENTAL DATA COLLECTION

The NCVS protocol is intended to be sufficiently simple that supplemental measurements can be added to accommodate requirements for specific projects. A typical example might consist of mapping exact locations of woody stems to study spatial processes. Another might be incorporation of additional small quadrats of a size particularly appropriate for monitoring abundance of a specific rare species. For some applications, it is valuable to know the vertical distribution of cover by species. A common supplement to the regular 0.1 ha implementation of the NCVS protocol is to record additional cover values for specific vertical strata. A typical implementation of this addition is to record for each woody plant species in each of several vertical strata (e.g., 0–0.5 m, 0.5–2 m, 2–5 m, 5–15 m, 15–35 m, >35 m) the cover value of the species in that stratum averaged over the intensive modules. Details of several such supplements are described in an expanded manual available from the authors upon request.

IMPLEMENTATION

The effectiveness and efficiency of a vegetation measurement protocol such as presented here depends in large part on details of implementation. To facilitate efficient use of the protocol, we summarize procedures developed during 10 years of application, with emphasis on a typical 0.1 ha or 20 × 50 m configuration, but with guidelines for generalization to other configurations. This represents one of the more intensive and complex implementations of the protocol; reconnaissance or inventory plots are simpler as they generally include only a subset of the procedures described here.

Plots should be placed to minimize within-plot environmental heterogeneity, which implies that the long axis of the plot should encounter the least possible variation in these characteristics. A 50 m measuring tape is used to establish the plot midline, and permanent stakes are placed at 10 m intervals along the tape. Plot establishment is completed by centering two 20 m tapes on and perpendicular to the midline tape (Figure 1), typically one 10 m from the start of the 50 m tape and one at 30 m. Stakes are placed at the ends of the two 20 m tapes, thereby defining the outside corners of four intensive modules (2, 3, 8, and 9 when numbered in the standard counter-clockwise fashion). Intensive modules are centrally located to assure the contents are as representative as possible, and to reduce subjective bias associated with starting the tape in close proximity to these modules.

In the typical 0.1 ha configuration, two series of nested subquadrats are recorded for each of the four intensive modules, each series being located in a standard fashion that associates its common corner with a fixed stake (Figure 1). Use of the recommended corners distributes the nests and prevents nests from being adjacent. If disturbance or other unusual conditions suggest that a specific corner would be inappropriate, it is possible to switch corners. With other configurations, the number of nests of subquadrats per module can range from zero to five (Figure 1).

Plant taxa are recorded to as fine a level as possible in as much as subsequent lumping of taxa is always possible, but splitting would usually be impossible. Field names are later transcribed to standard codes, in our case 8-character acronyms consisting typically of the first four letters of the genus, the first three of the specific epithet and a single character for subspecies or variety; special rules apply for potential duplicates and synonymy. If no local list of codes is available, the U.S.D.A. PLANTS Database provides a helpful but less intuitive U.S. national list of species codes.

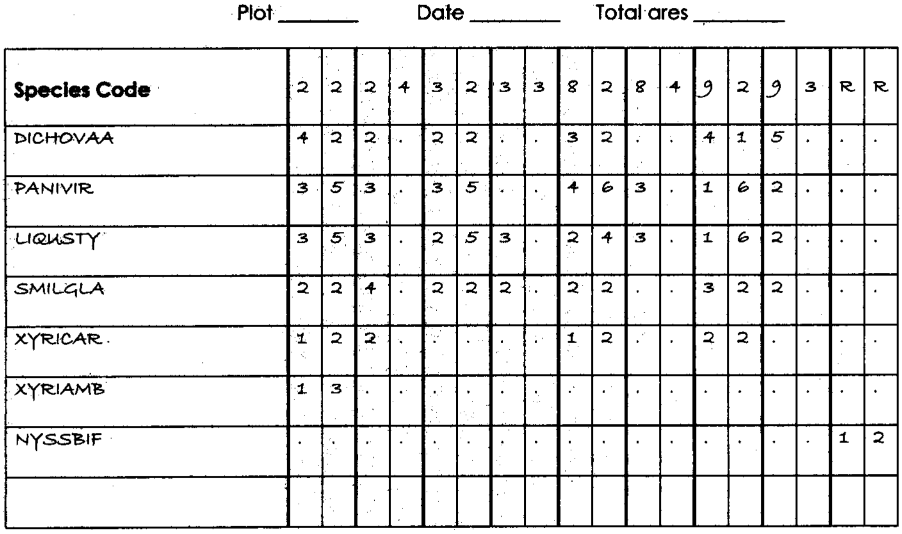
Data are collected and recorded in a standard fashion designed for efficiency of field recording and subsequent data transcription. Presence data are always recorded in the form of a couplet with the first column used for the depth at which a species is first recorded as present and the second for cover. Couplet headings (header line in example below) are module and corner numbers (e.g., 2–2, 2–3, etc.), except for (where applicable) an aggregate pair headed R-R (for "residual") that contains species first encountered in an aggregate of modules that supplement those sampled intensively.

Within a typical intensive module, presence data are recorded for two corners. The normal 8 corners for nests are 2–2, 2–4, 3–2, 3–3, 8–2, 8–4, 9–2 and 9–3 (Figure 1). Starting in the first corner (corner 2) of module 2 (2–2 in the 0.1 ha configuration), all species rooted in (having a stem or stems emerging in) a 0.1 × 0.1 m (0.01 m^2) subquadrat are listed and assigned a value of 5 in the left column of the pair of data columns for corner 2. A 0.32 × 0.32 m (0.1 m^2) subquadrat nested in the same corner is then surveyed for species not encountered in the previous subquadrat; these are listed and assigned a value of 4. A 1.0 × 1.0 m (1.0 m^2) subquadrat is then surveyed and new species encountered are assigned values of 3, followed by a 3.16 × 3.16 m (10 m^2) subquadrat with new species assigned values of 2 in the left column. As an illustration, consider the example in Figure 2. There the species DICHOVAA (*Dichanthelium ovale* var. *ovale*) occurred first in the 0.32 × 0.32 m subquadrat of corner 2–2, whereas LIQUSTY (*Liquidambar styraciflua*) occurred first in the 1 × 1 m subquadrat, and SMILGLA (*Smilax glauca*) occurred first in the 3.16 × 3.16 m subquadrat.

The presence survey is repeated in the second corner of the module (typically corner 4 in module 2). Presence values are again recorded in the left column of the pair for this corner at levels 5, 4, 3, and 2, with new species names added as needed. In our example, DICHOVAA first occurs at the 2 (3.1 × 3.1 m) level for this corner, whereas PANIVIR first occurs at the 3 level, and so on. The presence survey is completed by listing all species within the module that were not encountered in a set of nested subquadrats and assigning each of them a value of 1, which is recorded in the left column of the first corner surveyed (i.e., they occurred at level 1, which is the full 100 m^2, an area shared by all nests within the module). Species not present in the first (or "master") nest of subquadrats surveyed, but present in subsequent nests (XYRICAR in this example), are also assigned a value of 1 in the left data column for the first nest surveyed. In summary, all species with stems emerging anywhere within the focal module should be listed and each of these species should have a value ranging from 1–5 in the left column of the column pair for the first corner surveyed.

Cover data for the module are recorded next. When more than one column is available for recording cover in a module (which will be the case whenever more than one nest is recorded), only the first available column is used and the others are left blank. Cover is recorded after all nests in a module have been completed, thereby assuring a complete species list and maximizing time for familiarization with vegetation in the module.

As a final illustration, consider the species SMILGLA in the example above (Figure 2). For module 2, this species occurs first in corner 2 at depth 2, first at depth 4 in corner 4, and has a cover of 2 in the module. In module 9 this species occurs first at depth 3 in corner 2 and at depth 2 in corner 3 and again has a cover value of 2. By comparison, NYSSBIF is not found in any of the intensively sampled modules and is found only in the residual area where it has an overall cover of 2 (species in the residual can only have a depth of occurrence of 1).



Plot ______ Date ______ Total ares ______

Species Code	2	2	2	4	3	2	3	3	8	2	8	4	9	2	9	3	R	R
DICHOVAA	4	2	2	.	2	2	.	.	3	2	.	.	4	1	5	.	.	.
PANIVIR	3	5	3	.	3	5	.	.	4	6	3	.	1	6	2	.	.	.
LIQUSTY	3	5	3	.	2	5	3	.	2	4	3	.	1	6	2	.	.	.
SMILGLA	2	2	4	.	2	2	2	.	2	2	.	.	3	2	2	.	.	.
XYRICAR	1	2	2	.	.	.	.	.	1	2	.	.	2	2	.	.	.	.
XYRIAMB	1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
NYSSBIF	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2

Figure 2. Example of a portion of a datasheet for recording presence and cover in nested plots. Note that the header line contains couplets with the first number referring to the module and the second to the specific corner (see Figure 1). In the datalines, the first column of a couplet refers to the level in nested quadrats at which the species was first encountered as present, and the second refers to cover in the module. When more than one nested set of quadrats is recorded for a module, cover is recorded in association with presence for the first corner. Species codes are standard acronyms used for data coding (see text), though on real datasheets a field identification would be recorded in a separate column, and the official code would be added later.

Woody stem data are recorded on a separate data form. The basic line of data consists of module number, species code, and columns for tally counts of stem occurrences by set dbh classes, as described earlier. Columns are also provided for listing individually to the nearest centimeter stems larger than 40 cm. Stems are tallied separately for the intensive modules, but can be aggregated for residual modules (6 residual modules in the standard 0.1 ha configuration). Percentage sub- or supersamples used are recorded as needed. Total number of modules must also be recorded to allow interpretation of the area of the residual category.

Adaptability to unusual stem densities is achieved by allowing for designation of a percentage subsample for saplings and a percentage subsample for trees. These refer to the percentage of the module area sampled (or the sampled area of the aggregate of residual modules) surveyed for 0–2.5 cm dbh stems and >2.5 cm stems, respectively. Subsampling and supersampling are generally accomplished by adjusting the distance from the edge of the module adjacent to the midline of the plot by an appropriate percentage (for woody stems only). In a vine thicket a 20% (2 m wide) subsample might be appropriate, whereas in a savanna a 200% (20 m wide) supersample might be selected.

Some species have unusual densities and require, for efficiency of fieldwork, a sample size different from that used for the remainder of the species. For shrubs in a pocosin shrubland or bamboo in a canebreak, a subsample is often appropriate, but the scattered pines in these communities might well require supersample to adequately capture population structure. For this purpose columns are provided on dataforms for percentage subsamples for sapling and for trees on an individual species basis, which overrides the universal subsample designations described in the previous paragraph.

The time and personnel required for plot establishment varies considerably with the complexity of the vegetation and the experience and personalities of the field workers. In general, we have found that an experienced team of two, one of whom is intimately familiar with the flora, can finish from one to three 0.1 ha plots per field day. The floristically experienced team member records the presence and cover data while the assistant completes the tree tally. The first one to finish initiates collection of site information.

DATA TRANSCRIPTION, REDUCTION AND SUMMARIZATION

The flexibility of the NCVS protocol is attained at the price of greater complexity of data reduction. Although data reduction is conceptually simple, there are sufficient options and complications that some researchers will require special software tools for data entry, quality control and extraction of critical summary information. To assist with these tasks we have collaborated with Dr. Richard Duncan of Lincoln University, New Zealand, to construct a series of SAS programs for use in data preparation and summarization. These are available from the authors upon request.

DISCUSSION

Comparison with Other Methods

Many design elements of the NCVS protocol derive from methods proposed and employed by R.H. Whittaker. The 0.1 ha measurement unit was originally proposed by Whittaker (1960), whose example was followed by many others (e.g., Glenn-Lewin 1977, Peet 1981, Wentworth 1981, Rice and Westoby 1983) with the result that a large number of such plots are now available for comparative studies. In the last years of his career, Whittaker became progressively more interested in patterns of species richness and the importance of scale for understanding vegetation, two interests we share with him and which have strongly influenced design of the NCVS sampling protocol. To investigate these issues, he devised a new plot design that he applied widely during his research excursions. This Whittaker diversity sample was an outgrowth of his original 1,000 m^2 plots, but with nested subplots over a range of scales so as to facilitate comparison with other studies and calculation of the slope of the species-area curve (10 1 × 1m plots, 2 1 × 5 plots, 1 10 × 10, and 1 20 × 50; see Naveh and Whittaker 1979, Whittaker et al. 1979, Shmida and Whittaker 1981, Shmida 1984).

The NCVS plot design retains the geometric sequence of subquadrats proposed by Whittaker, but includes a broader range of sizes and more subquadrats of most sizes to compensate for between subquadrat variation. As subquadrat size increases, there is less variance between subquadrats due to averaging out of within subquadrat variance, and a smaller element of chance in whether any one species will be present in a subquadrat (see Reed et al. 1993). A consequence is that the larger subquadrat sizes are well represented by our proposed methodology, but the smaller subquadrats (especially 1 m^2 and less) can be highly variable. This problem has been further articulated by Stohlgren et al. (1995) and Yorks and Dabydeen (1998) whose papers each present a modification of Whittaker's diversity plot, but with a broader spatial dispersion of the smaller subquadrats to more effectively represent variation present in the plot. Unfortunately, these authors aggregate the dispersed subquadrats to obtain estimates of richness at larger scales. Such richness estimates are biased because they ignore the intrinsic spatial autocorrelation of vegetation. In contrast, the NCVS protocol primarily uses averages of single square subquadrats so as to retain the spatial autocorrelation structure of the vegetation in richness estimates. In short, the 0.1 ha configuration of the NCVS protocol appears to provide a substantive improvement over the Whittaker diversity plots, while retaining compatibility with data collected using those methods.

The increased insight allowed by examination of species richness across subquadrats and modules spanning six orders of magnitude of size, as provided by the 0.1 ha configuration of the NCVS protocol, is illustrated in Table 2 by a few representative plots collected in the Nantahala Mountains of North Carolina. In these plots, species richness at 0.1 or 1 m^2 has little correlation with species number at 400 or 1,000 m^2. Vegetation types with many small plants, like meadows and barrens, have high species richness at small scales, but this provides little insight into species numbers at larger scales of observation. Cove forests, which are often suggested to have high species richness, tend to plateau in species richness early, with little increase after the first 100 m^2, largely because of competition for light among the dense herb layer plants, whereas dry oak forests, which have less dense herb layers, plateau much less

Table 2. Species richness values calculated using data from representative 0.1 ha configuration NCVS plots recorded in the Nantahala Mountains, North Carolina

	Plot size (m^2)						
Community Type	**0.01**	**0.1**	**1.0**	**10**	**100**	**400**	**1,000**
Canada hemlock forest	0.38	1.25	1.88	3.4	10.0	16	16
Rich alluvial forest	2.75	5.63	15.00	32.5	77.0	120	146
Carex-Scirpus meadow	2.25	4.38	8.25	13.4	20.7	33	38
Mafic white oak forest	0.38	3.88	14.25	38.9	73.0	109	115
Rich cove forest	1.50	4.25	11.50	23.7	42.5	60	65
Ultramafic barren	3.38	8.13	14.00	20.4	32.0	47	50
High-elevation red oak forest	1.25	2.38	4.25	9.5	21.0	40	50
Dry oak forest	0.75	2.13	5.88	18.6	48.2	85	96

quickly. Rich alluvial forests, where dynamics are driven more by a steady supply of propagules carried by flood waters and less by competition, show little evidence of a plateau even at 1,000 m.

The large, intensive plots advocated by Whittaker and the 0.1 ha NCVS configuration provide detailed information on vegetation structure, but at a significant cost in terms of time required per plot. Where a quick reconnaissance or inventory study is required, a set of simpler and faster plots can be more appropriate, with examples being the traditional *relevé* or *aufnahme* of European workers (e.g., Braun-Blanquet 1964), the "recce" plots used in New Zealand (Allen 1992, Hall 1992), and the reconnaissance plots proposed by Franklin et al. (1970) for use in the Pacific Northwest. For such purposes we recommend recording species presence only to depth 1, and, if necessary, reducing module number. The European relevé is similar in that the core dataset includes a list of species with cover class values. The recce plots of New Zealand ecologists are similar in the focus on rapid reconnaissance (Allen 1992); they also include a species list with cover values, but given by species by six height tiers (<0.3, 0.3–2, 2–5, 5–12, 12–25, and >25 m). The recce method does not use a fixed area because of the emphasis on speed, efficiency, and homogeneous vegetation, whereas the NCVS protocol can provide reconnaissance data with standardized plots that facilitate comparisons.

Some divergence in methodologies occurs in plot size. Mueller-Dombois and Ellenberg (1974) suggest 400 m^2 for forest understories, with smaller plots recommended for grassland and larger ones (1,000–2,500 m^2) for deserts and other arid zones. A major advantage of the NCVS protocol is that several standard plot sizes can be created by combining modules, thereby facilitating comparisons across many kinds of vegetation.

Ten years of experience applying the NCVS protocol has led us to appreciate the flexibility and transportability of the methods. Some variant of the protocol can be applied in nearly all situations and without loss of compatibility with other data collected using the protocol. Intensively sampled modules, and especially as used in the fully elaborated 0.1 ha configuration, provide detailed information on vegetation structure not available with other widely used methods. Consistency with standards applied in other methodologies facilitates data exchange and sharing, which should hasten efforts to describe, inventory and understand vegetation.

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