Final Draft

Field Methods for Vegetation Mapping

USGS/NPS Vegetation Mapping Program

December 1994

Prepared For:

United States Department of Interior
Unite States Geological Survey and
National Park Service

Prepared By:

The Nature Conservancy
1815 N. Lynn St.
Arlington, Virginia 22209
USA

Environmental Systems Research Institute, Inc.
380 New York Street
Redlands, California 92373

ARC/INFO LIBRARIAN, ARCSHELL, ARCEDIT, ARCPLOT, ARC Macro Language (AML), Simple Macro Language (SML), DATABASE INTEGRATOR, IMAGE INTEGRATOR, WorkStation ARC/INFO, ArcBrowser, ArcCensus, *ARC News*, ArcKits, ARCware, ArcCity, ArcDoc, ArcExpress, ArcFrame, ArcScan, ArcScene, ArcSchool, ArcSdl, ArcStorm, ArcTools, ArcUSA, ArcWorld, Avenue, FormEdit, Geographic User Interface (GUI), Geographic User System (GUS), Geographic Table of Contents (GTC), ARC Development Framework (ADF), PC ARCEDIT, PC ARCPLOT, PC ARCSHELL, PC OVERLAY, PC NETWORK, PC DATA CONVERSION, PC STARTER KIT, TABLES, University LAB KIT, the ESRI corporate logo, the ARC/INFO logo, the PC ARC/INFO logo, the ArcView logo, the ArcCAD logo, the ArcData logo, ESRI—Team GIS, and ESRI—The GIS People are trademarks of Environmental Systems Research Institute, Inc. ARCMAIL, ArcData, and Rent-a-Tech are service marks of Environmental Systems Research Institute, Inc.

Other companies and products herein are trademarks or registered trademarks of their respective trademark owners. The information contained in any associated brochures is subject to change without notice.

Table of Contents

Section **Page**

List of Tables and Figures

Page

Executive Summary

The objective of the U.S. Geological Survey/National Park Service (USGS/NPS) Vegetation Mapping Program is to develop a uniform hierarchical vegetation classification standard and methodology on a Service-wide basis and, using that classification standard and methodology, generate vegetation maps for most of the park units under NPS management. This program is in response to the National Park Service's Natural Resources Inventory and Monitoring Guideline (NPS-75) issued in 1992. The vegetation data are to be automated in a GIS-compatible format, which will provide great flexibility in map design and production, data analysis, data management, and maintenance activities.

The use of a standard national vegetation classification scheme and mapping protocols will facilitate effective resource stewardship by ensuring compatibility and widespread use of the information throughout the NPS as well as by other federal and state agencies. These vegetation maps and associated information will support a wide variety of resource assessment, park management, and planning concerns. They will provide a structure for framing and answering critical scientific questions about vegetation types and their relationship to environmental processes across the landscape. They will provide a consistent means for the inventory and monitoring of plant communities and they will support "ecosystem management" by providing a consistent basis for the characterization of the biological components of different ecosystem units.

The first step toward the implementation of the mapping program includes the development and documentation of standards and protocols. This is being initiated in three studies: (1) a proposed National Vegetation Classification Standard, (2) Field Methodologies, and (3) Accuracy Assessment Procedures. This document is the result of the second study. The fundamental purpose of this study is to review the scientific basis for vegetation sampling and to propose a standardized field methodology that will serve the objectives of this project. The planning process and field methods that will be used to sample and accurately map the National Vegetation Classification units across all parks are described.

The National Vegetation Classification System is the result of synthesizing a great body of earlier scientific effort as well as twenty years of field data collection and scientific analyses by The Nature Conservancy (TNC) and Natural Heritage Program scientists. Confidence levels are assigned to each community type to identify the quantity and the quality of information available. The classification is rigorously reviewed and updated as new data become available. This work is representative of some of the best field ecology and constitutes an important body of vegetation descriptions and characterizations.

The starting point for this study is the classification standards and field methods that have been developed by The Nature Conservancy and the network of Natural Heritage Programs. Nevertheless, it is anticipated that the methods will need to be expanded and/or modified if the study is to meet the challenge of ecosystem management across the diversity of National Park System environments and circumstances. This further development of the field methods and classification system will be accomplished with standard methods and procedures. These standards will preserve the overall integrity of the field methods as they are further developed, and will enable the full use of the powerful tools of a geographic information system (GIS). The vegetation classification will be significantly advanced during the course of this USGS/NPS mapping program.

The field methods will begin with the evaluation of existing information on the biology, ecology, disturbance events, and land use history of the park. The resource management needs of the individual parks will be assessed in relation to this program. The availability of local expertise and collateral information will help to determine how the sampling should be stratified, where it should be concentrated, and how much new information will be required to meet the objectives of this project.

Sample locations and number of sample points will be determined by the size, accessibility, and complexity of a park. Park size will determine the level of sampling that can be efficiently carried out. Whereas every polygon can be visited on the small parks, pilot sites must be selected for sampling on the large and inaccessible parks. These pilot sites are subsections of the park that are predicted to represent the diversity of vegetation types across the park. The selection of pilot sites will primarily be determined from the environmental stratification of the park and the interpretation of the photography. Environmental and vegetational complexity will force additional field sampling to interpret the patterns of variability.

Depending on the complexity and distribution of the environmental gradients, there may be one or more pilot areas selected for a park. The photography will be interpreted across the sample areas and the sampling points will be chosen for each putative vegetation type. Areas with unique photo signatures will need to be included as additional pilot sites. Accessibility and sampling efficiency will be factored into the final selection of the sample areas.

Field data will be collected to develop the classification and characterization of the vegetation within the National Vegetation Classification Standard, and to ensure the accurate mapping of the vegetation types across the park. Each vegetation polygon will be classified to the finest floristic level (community element), although field and imagery conditions may require a coarser level of classification for certain vegetation types. The successful implementation of this program will require a close working relationship between the vegetation ecologists, the photo interpreters, and the National Park Service staff.

Based on the development of the vegetation classes and the photo signatures, a preliminary map will be generated for the park. A map validation exercise will proceed with a new set of stratified sampling points. Vegetation classification will occur at these points and an error assessment will be completed on the validity of the preliminary map product. The methodology will be refined to address any problems that are identified up to this point. The vegetation mapping will then proceed across the park. New vegetation types will be documented as they are encountered. The final stage of this program will be the generation of the final vegetation map and the formal accuracy assessment that will document the positional and class accuracy of this product.

Similar field methods have been previously used to produce vegetation maps as a component of TNC conservation assessment and planning projects. Though the general objectives have been consistent, the applications have varied in terms of scale, resources, types of remotely sensed data, and desired end product. Specific mapping projects at the Gray Ranch in New Mexico and the Yampa River in Colorado are discussed in this report.

Deliverable products from this USGS/NPS Vegetation Mapping Program will include a digital file of vegetation maps, digital metadata files, textual descriptions, and keys to the vegetation classes, hard-copy maps, and map accuracy verification reports.

1.0 Introduction

The National Park Service/U.S. Geological Survey (USGS/NPS) Vegetation Mapping Program is ambitious in scope and unique in vision. It is in response to the NPS Inventory and Monitoring Guideline (NPS-75) and the NPS Natural Resources Management Guideline (NPS-77). For the first time in the history of land management in the United States, this project provides a means to map vast acreage — most National Park System units — using a single vegetation classification and mapping standard. The U.S. Geological Survey is a partner with the National Park Service in this project and is largely responsible for technical oversight of protocols and methodology development as well as technical review and approval of the vegetation maps produced.

1.1 Objectives of this Report

The NPS Vegetation Mapping Project will require the use of a consistent planning process and field methodology to classify and map the vegetation across selected National Park Service lands. The purpose of this report is to review the scientific basis for vegetation sampling and to propose a standardized field methodology that will serve the objectives of this project.

This report will be reviewed by scientists, resource managers, and park management staff to evaluate whether the proposed field methodology is appropriate for mapping and will meet the program objectives. The review is expected to stimulate dialogue among all involved researchers, provoke constructive feedback and comments, and ultimately help to refine the methods to realistically meet the objectives of USGS/NPS.

1.1.1 Relationship to Other Reports in This Series

This is the second of a set of three reports that are being completed to describe the proposed methods for the USGS/NPS Vegetation Mapping Project. The first report describes the vegetation system proposed for the classification and mapping standard. This second report describes the field methods that will be employed to implement an accurate vegetation mapping process across all national parks. The third report describes the accuracy assessment methods that will be utilized to measure the quality of the vegetation maps.

1.2 Structure of the Report

This report proposes a standardized planning and field methods process that will meet the objectives of the USGS/NPS Vegetation Mapping Project.

Section 1 reviews the USGS/NPS Vegetation Mapping Program objectives and requirements for the development and application of a standardized planning and field methods system.

Section 2 provides the theoretical background for the standard field methods that are proposed to meet the objectives of the National Park Service and the U.S. Geological Survey for the Vegetation Mapping Program.

Section 3 provides an overview of the planning process and implementation of field methods.

Section 4 provides details for the planning process.

Section 5 provides details for the field methods that will be used in the program.

Section 6 describes the collection, management, and analysis of data to build up the NVCS and apply it to the development of vegetation maps and descriptions.

Section 7 reviews the map validation and accuracy assessment process that will be implemented to ensure the final quality of the vegetation map.

Section 8 reviews some of the alternative technologies that may be used in the implementation of this program, and the effect these would have on prior work.

Section 9 review the products that will be generated through this program.

Section 10 lists the authors and contributors to the report.

Section 11 lists the literature that was cited in the report.

Section 12 contains all appendixes referenced in the report.

1.3 Terms of the Vegetation Mapping Project

1.3.1 Project Objectives

The primary objective of the USGS/NPS vegetation mapping project is to produce high-quality, standardized maps of the vegetation and other land cover occurring within the national parks and environs. These maps and associated information are required to support a wide variety of resource assessment, management, and conservation concerns. These resource assessments are needed at the individual park as well as the regional and national levels. The use of a standard national vegetation classification scheme and mapping protocols will facilitate effective resource management by ensuring compatibility and widespread use of the information at multiple geographic scales throughout the NPS as well as by other federal and state agencies.

1.3.2 Contract Requirements

1.3.2.1 Classification System

The standard classification system must be applied across all national parks. The NVCS must be compatible with the standards being developed by the Vegetation Subcommittee of the Federal Geographic Data Committee (FGDC) (1993).

1.3.2.2 Map Scale

Vegetation maps will be produced at the scale of 1:24,000. The size of the minimum mapping unit is 0.5 hectares.

1.3.2.3 Map Accuracy

The vegetation maps must meet the National Map Accuracy Standards for positional accuracy, and the minimum class accuracy goal across all vegetation and land cover classes is 80 percent.

1.3.2.4 Digital Products

The maps will be provided in both hard-copy and digital format. The field data will be provided in an SQL-based digital database management system (DBMS). Deliverable products also include a digital file of vegetation maps, a digital metadata file for each data file delivered, textual descriptions and keys to the vegetation classes, and documentation for map accuracy assessment.

2.0 Field Sampling Theory

Three areas of ecological theory should be given consideration in the sampling design for vegetation classification and mapping: (1) the nature of vegetation as a biotic component of ecosystems, (2) the nature of the abiotic component, and (3) the vegetation/abiotic relationships. The treatment of these issues will effect decision making for the sampling design and the most appropriate measurements for characterization and mapping of vegetation for the NPS/USGS vegetation mapping program. Therefore, this section reviews specific issues in the above three areas of ecological theory and their impact on vegetation sampling.

2.1 Nature of Vegetation

Vegetation refers to the great diversity of plant species which occur in repeating assemblages over the face of the earth. Before attempting to inventory and map vegetation, it is necessary to understand certain features of the nature of vegetation.

2.1.1 Definitions

It is beyond the scope and purpose of this document to provide a glossary of terms and a comprehensive discussion of the many concepts and terms embodied in community ecology. Instead, a few key terms and concepts essential to the program are defined and discussed. A thorough understanding of these concepts is critical to the sampling design and vegetation survey.

In nature, plant species are always part of an assemblage, or community of species populations living together in the same area. A general definition of community is any assemblage of populations of living organisms in a prescribed area or habitat. A more scientific definition of plant community was given by Mueller-Dombois and Ellenberg (1974); "A plant community can be understood as a combination of plants that are dependent on their environment and influence one another and modify their own environment."

The concept of community has been central to plant ecology, or more specifically, to plant sociology, all through this century; consequently, a series of terms has been specially devised to describe it. The fundamental unit of plant sociology is the plant association — a vegetation community of definite floristic composition.

Walter (1973) described the relationship between plants, community, and vegetation as follows: "Plant species are the building blocks of the plant communities that together constitute the vegetation of the different regions."

2.1.2 Community vs. Continuum

For many years, plant ecologists were divided in their opinions as to whether vegetation consists of a series of distinct communities or whether vegetation types grade into one another (i.e., vegetation is a continuum). During the 1960s and 1970s, major debates resulted over the fundamental issues of whether communities/associations were real or abstract and whether a delimited community was a natural or artificial construct. Debate focused around F.E. Clements' (1936) view of communities as discrete "supra-organisms" with characteristics of an individual as opposed to H. Gleason's "individualistic" concept proposing that species responded individually to environmental gradients. Full treatment of this debate can be found in Whittaker (1962) and Mueller-Dombois and Ellenberg (1974). Over time, however, studies converged in supporting Gleason's continuum/gradient concept, and it has received widespread acceptance. Recently, Austin and Smith (1989) have reformulated the continuum concept and readdressed the community/continuum from a new perspective. They emphasize that the two ideas are not really dichotomous, but are based on incompatible frames of reference. This is in agreement with the current widespread use of both classification and gradient analysis (ordination) in a single methodology informally known as complementary analysis (Kent and Coker 1992).

Vegetation is characterized by the link between individual species distribution patterns, their occurrence in landscape features, and the distribution of the landscape features. Therefore, various aspects of both the continuum and the community views of vegetation complement rather than exclude each other (Westhoff and Van der Maarel 1978, Austin 1991). Species can be individually distributed along gradients, unidimensional or complex, following any of the possible models (Austin 1987, Austin and Smith 1989). The pattern of distribution of the landscape features that control environmental factors constrain the pattern of species combinations, their distribution in the landscape, and their frequency.

2.1.3 Vegetation Structure

The overall appearance of the vegetation is called its physiognomy (Kuchler and Zonneveld 1988). The physiognomy is used to describe the broad features of the vegetation, such as the growth forms and/or the life form of dominant species within a plant community. Life form is a very important characteristic of vegetation and is used in many vegetation classification systems.

The floristic composition of vegetation includes all species occurring within a plant community. However, most plant communities consist of so many species that it is not practical to discover all species within a community. It is common to use dominant species in naming plant communities and in legends with vegetation maps.

Vegetation profile is defined as the vertical aspect of the vegetation. Stratification is the most obvious application of the study of vegetation profile. The strata are not always horizontal, such as epiphytic bryophyte and/or lichen layers in forests. The vertical structures of vegetation are very important for the physiognomic aspect of the standard NVCS as well as for photo interpretation.

A combination of physiognomy, floristic composition, and profile is essential information to identify and describe plant communities.

2.1.4 Parameters of Vegetation Description

Community ecologists are often interested in obtaining information pertaining to a large number of variables in a community. Much work in community ecology is motivated by a desire to elucidate and describe patterns in the data sets, rather than formally testing a priori hypotheses (Green 1980). This is even more true for the NPS/USGS vegetation mapping program. It is recommended that field teams only collect the vegetation information necessary for characterization and mapping of vegetation in parks. This objective leads to the following brief descriptions of most common vegetation parameters recommended to be used for this program.

2.1.4.1 Species Occurrence

As mentioned above, the species component is the fundamental structure of a plant community. A species list is an essential part of all vegetation survey activities.

2.1.4.2 Frequency

The frequency of a species is defined as the probability of finding it within a plot when the plot is placed on the ground. The prime requirement in estimating frequency is to use as large a sample size as possible.

2.1.4.3 Cover

The cover of a species is defined as the proportion of ground occupied by vertical projection. Cover is normally expressed as a percentage and the maximum cover of any one species is 100 percent. For classification purposes, the most common practice is estimation of cover in field. There are a number of "scales" or ratings based on cover (Mueller-Dombois and Ellenberg 1974, Causton 1988). Sampling of percentage cover is very similar in principle to the sampling of frequency. Thus, the recommendation of having a large sample size is also applicable to cover.

2.1.5 Vegetation Dynamics: Seasonal Variations and Succession

Vegetation is a dynamic system in terms of species composition and spatial structure. Even though the objective of the NPS/USGS vegetation mapping program is only to describe existing vegetation patterns across national parks in both documentation and maps, it is necessary to review and discuss the dynamic characteristics of vegetation and consider the dynamic features when developing the sampling methods.

2.1.5.1 Seasonal Variations

Vegetation follows the seasonal variation of the radiation climate. Of particular interest here are phenological patterns over the course of a year. Many plant communities have distinct seasonal peaks of growth and flowering activity, and different components of the vegetation often grow at different times of year. An extreme example of this phenomenon is an annual grassland where live vegetation is present for only part of the year. The seasonal variation can markedly affect spectral reflectance. On the other hand, seasonal changes can be used to differentiate between herbaceous vegetation and woody vegetation or among different woody vegetation types with different phenological patterns.

2.1.5.2 Succession

Succession is the dynamic process by which population of plants replace one another over a period of time until relative community stability is achieved. The series of successional communities can be recognized as different stages, and each stage is treated as an existing vegetation type once the structure and composition of the stage reaches a relatively stable state.

2.1.6 Ecotone

Even those ecologists who favor the community idea of vegetation recognize that boundaries of communities are indistinct. They coined the word "ecotone" to describe the area of the boundary or the transition zone. Very often the ecotone is found to be more species-rich than either of the communities it separates, and the ecotone could really be recognized as a community itself.

2.1.7 Spatial Distribution of Vegetation: Implications for Sampling Design

At the landscape level, individual plant species distributions along gradients combine to produce plant species assemblages. Austin (1991) and Austin and Smith (1989) observed that the frequency of combinations of species is often used as a criterion to recognize communities. Therefore, the occurrence of a species combination is a consequence of a particular landscape pattern; the frequency of species combinations is also a function of the landscape pattern. As a result, the mapping of these landscape patterns is central to a successful sampling design.

When defining landscape patterns, three types of environmental variables or gradients need to be considered (Austin et al 1984, Austin 1985, and Austin and Smith 1989):

(1) Indirect factors that do not necessarily have an physiological influence on the species components of the ecosystems (e.g., elevation)

(2) Direct factors that have a direct physiological influence but are not consumed as a resource (e.g., temperature and pH)

(3) Resource gradients that can be used directly by species (e.g., nutrients)

In principle, sampling design for vegetation surveys should be based on the most proximal variables that can be measured or estimated.

Theories and methodologies used to define the environment (indirect factors, direct factors and resource gradients) fall into two major categories:

(1) Delineation of landscape units containing recurrent patterns of landform and/or landscape characteristics (e.g., the ecological land units)

(2) Identification of bioenvironments (i.e., classes in environmental variables that take into account key ecological interactions and processes)

The first approach has been to use broad environmental patterns alone or broad correlations between vegetation and environment to describe and delineate habitats of plant communities. Land classifications have been developed using climatic attributes either alone or in conjunction with other attributes (e.g., Austin and Yapp 1978, Omernik 1987, Walter 1979, Bailey 1976, Bailey et al. 1993). A great variety of systems based on combinations of soils, lithology, and landform have been used alone or combined with vegetation data to produce classifications of biophysical regions or natural landscape units. In Canada, Rowe and Sheard (1981) detailed a landscape system for identifying units of lands that are meaningful at the ecosystem level.

The strength of this approach is that it allows a direct analysis of the spatial and temporal scales of landscape features (Delcourt and Delcourt 1988, Urban et al. 1987), which is necessary to match patterns and processes (Levin 1992). For example, in a mountainous landscape in Northwestern Montana, Lathrop and Peterson (1992) tested whether watershed morphological characteristics and ecological processes exhibited the same basic properties at various spatial scales (self-similarity). They established structural self-similarity but did not conclusively demonstrate self-similarity for ecological properties. Establishing a relationship between landscape structure and vegetation attributes across a range of spatial scales has important implications for the proper scaling of vegetation sampling design at all relevant scales.

On the other hand, the main weakness of this approach is that it relies to heavily on indirect factors (soils, landform, etc.) without explicitly stating the ecological relationships between vegetation and environment. For example, landform patterns have often been used to stratify areas into natural landscape units on the basis of a single factor attribute. The units are argued to represent natural levels of ecological integration with respect to environmental regimes and key processes, and, indeed, there is compelling evidence that this is the case (Swanson et al. 1988). Geomorphic pattern, through erosion/sedimentation processes, has been shown to control carbon, nitrogen, and phosphorus cycles in soils of riparian forests in southern France (Pinay et al. 1992). However, the actual test of the strength of the hypothesized relationship between vegetation and environment is not always performed. For example, Kovalchik and Chitwood (1990) used geomorphology in addition to a floristic classification of the vegetation of riparian zones in central Oregon but did not explicitly test the purported vegetation/geomorphological process relationship.

A second approach has recently been developed in Australia out of concern for the problems outlined above. This approach recognizes the need of the sampling design to be based on environmental units that summarize the limited set of dominant environmental variables that comprise the primary niche dimensions (Nix 1982) such as radiation, thermal, moisture, mineral nutrient, and the biotic regimes (Nix 1982, Mackey et al. 1988, 1989) to which species respond. The aim of the methodology is to summarize environmental variability, identify the distribution of major environmental gradients, and indicate where significant shifts in ecological variability might occur (Mackey et al. 1988, 1989). Site-specific data are used to generate classes of sites sharing similar ranges of values of the environmental variables (direct and resource gradients). A map of these classes, or bioenvironments, can be used alone in the assessment stage of an area for given purposes (DeVelice et al. 1993), and/or in conjunction with vegetation data for quantifying biotic–abiotic correlations (Mackey et al. 1989).

Sampling ecologically significant factors in the physical environment at sufficient resolution ensures that key processes and interactions can be taken into account (Mackey et al. 1988). Estimating the key attributes involves the modeling of terrain–climatic interactions including simple surface-fitting procedures, as well as models that take into account known effects of physical processes. However, the accuracy of the results is limited by the extent to which the processes and interactions are known.

The consequences for vegetation sampling are as follows. Attempts to describe patterns in abiotic factors or habitats for cost-effective and efficient vegetation sampling design can be successful only if the ecological meaning of the factors is understood. There is a difference between natural landscape units and bioenvironments. The former refer to geographical phenomena, the latter to an ecological space. An actual combination of natural landscape features (for example, elevation class x landform x geologic substrate) may be found in two different regions. However, a change in regional climate may change the overall suitability of the habitat for particular species. When characterizing and mapping the physical environments of a region, it should not be assumed that all occurrences of a mapped environment are ecologically identical. With changes in climatic-terrain interactions occurring over large areas, the values of the direct factors and resource gradients to which the biota respond also change gradually. Therefore, similar physical environments may correspond to different bioenvironments.

The accuracy and utility of describing and mapping natural landscape features or bioenvironments for sampling vegetation patterns are functions of the environmental variables selected, the relationship between indirect and direct factors, the estimation procedures and mapping scales used, and the strength of the purported relationship between the vegetation and the selected environmental criteria.

2.2 Common Sampling Approaches

The complex spatial nature of the vegetation presents a number of problems when designing optimal sampling schemes for a landscape. First, there is a lack of useful information on the spatial characteristics of the vegetation. Second, little attention has been given to extensions of traditional sampling theory for two-dimensional sampling of vegetation.

2.2.1 Sampling Scale Issue

Vegetation is a multilevel phenomenon, that is to say the scale of pattern ranges from the region of influence of an individual plant to the ecoregion. The choice of scale for observation is of great importance in vegetation inventory. Hierarchies of observation scale present different issues because scale can be changed in a continuous manner, while the hierarchies of vegetation classification systems emphasize the importance of distinguishing types. It is important to understand this to ensure that different types are not mixed by using various observation scales.

The relation of vegetation and environment and ecological processes are also scale dependent phenomena. Several studies (Allen and Starr 1982, Weir and Wilson 1988, Reed et al. 1993) indicated that multiple scales of observation in ecological investigations can be critical for understanding vegetation patterns and processes. However, due to the objectives of the field inventory for the NPS/USGS vegetation mapping program, it is recommended that observation scales vary only among vegetation types and not within vegetation types.

2.2.2 Ecological Gradients

Plant communities may be distributed over large areas, sometimes in several regions (for example, the spruce fir forests of the Rocky Mountains). However, in designing sampling procedures for vegetation classification, all occurrences of a community should not be assumed to have identical properties. With numerous species in a community, the individual distribution of species ensures gradual intracommunity changes along regional gradients. Occurrences of the same community may have different overall composition, frequency, and size of areas, resulting in different properties relevant for vegetation classification and landscape evaluation. It is likely that the same community found at different locations along a regional gradient or in different climatic regions would respond differently to a specific conservation-management practice. Therefore, species distributions need to be established with data spanning the range of environmental variability along which they are distributed. Communities need to be defined using data preferably covering the range of environmental variability in all landscapes in which they occur. Effective sampling for vegetation classification and mapping requires adequate replication within communities to allow for and detect geographical variability and gradient relations.

2.2.3 Random vs. Representative Sampling

The primary goal of vegetation surveys is to characterize as many vegetation patterns as possible within the study area(s). The recovery of vegetation pattern is not necessarily accomplished by the usual statistical sampling procedures. Sampling theory emphasizes randomization in order to provide a probability structure for statistical analysis or to give credibility to the statistical model used (Gillison and Brewer 1985). Gillison and Brewer (1985) argue that randomization procedures may be counterproductive to the intent of ecological surveys, especially where the occurrence of natural pattern is known to be nonrandom. Data sets need to be representative of the full range of variability in biological patterns in response to variability in the environment.

In vegetation surveys, two aspects of pattern recognition should be considered: (1) the recognition of the pattern itself (e.g., a specific forest type) and (2) the frequency and distribution of patches of the pattern (i.e., spatial distribution, number and size of forest stands) (Godron and Forman 1983, Gillison and Brewer 1985). In landscapes, vegetation patch frequency and distribution vary as a scale-sensitive function of environmental complexity and the level of resolution of the vegetation classifications used to characterize the pattern (Gillison and Brewer

1985). This variability in landscape level vegetation configuration should be analyzed in terms of the driving variables (the abiotic factors) controlling the vegetation.

2.2.4 Stratified Random Sampling

In standard sampling design, each spatial point in the landscape is given an equal probability of being sampled. Random placement of sample sites will not accurately reflect the full range of variability of the biotic and abiotic components of ecosystems at regional scales unless the sampling intensity is very high (Gauch 1982, Orloci 1978, Pielou 1984).

To alleviate the shortcomings of standard random sampling, stratified sampling schemes have been used to provide both accuracy in the recovery of patterns and statistical validity. Stratified sampling divides a study area into compartments and locates samples randomly within compartments. This approach has been used successfully over large heterogeneous areas with mostly unknown patterns. For example, a nested stratified random sampling design by landform and ecoregions was used in southern Yukon, Canada, to characterize vegetation pattern and its underlying environmental gradients (Orloci and Stanek 1979). The results of the study indicate that the selected stratifying variables accounted for a large part of the regional variation in vegetation.

2.2.5 Gradient-Oriented Transect (Gradsect) Sampling

Orloci and Stanek's (1980) sampling design is very similar to a methodology known as gradient directed transect (gradsect) sampling. Gradsect sampling is a variant of stratified random sampling schemes. This approach, first described by Gillison and Brewer (1985), is based on the distribution of patterns along environmental gradients. The gradsect sampling design (Gillison and Brewer 1985, Austin and Heyligers 1989) is intended to provide a description of the full range of biotic variability (e.g., vegetation) in a region by sampling along the full range of environmental variability. Transects that contain the strongest environmental gradients in a region are selected in order to optimize the amount of information gained in proportion to the time and effort spent during the vegetation survey (Austin and Heyligers 1989). In addition, sampling sites are deliberately located to minimize travel time. The method has been shown statistically to capture more information than standard designs (Gillison and Brewer 1985).

Helman (1983) and Austin and Heyligers (1989, 1991) have expanded the gradsect methodology to include levels of environmental stratification within each gradsect. The procedure, as modified, thus becomes a two-stage sampling design: (1) gradsects are chosen; (2) adequate environmental stratification and replication are performed within gradsects.

The relative efficiency of gradsect sampling compared to other sampling techniques has been analyzed (Gillison and Anderson 1981, Gillison and Brewer 1985, Austin and Adomeit 1991), where efficiency is assessed with respect to the ability to recover ecological patterns. A gradsect sample was found to have greater logistical efficiency than a systematic grid sample of vegetation in a 7 hectare small mammal study, while providing adequate data for vegetative classification and prediction of small mammal distributions (Gillison and Anderson 1981). In another study, an existing vegetation map derived from high-density point sampling of a 424 km^2 area was used as the test base for comparing gradsects to random transects (Gillison and Brewer 1985). Gradsects were found to be 27 percent shorter on average than random transects and logistically better located. They also were on the average 21 percent richer in vegetation types than random transects of the same length.

A simulation study was conducted to evaluate several traditional statistical sampling methods as well as gradsect sampling (Austin and Adomeit 1991). The simulated data set used for the tests was based on an actual landscape, with realistic biotic/environment relationships (Belbin and Austin 1991). Austin and Adomeit (1991) provided "informed guesses" of sampling costs for the various methods. Among the three statistical sampling methods compared, random sampling recovered more species than systematic sampling or transect sampling at intermediate cost. Transect sampling was found to have the highest costs and detected the fewest species. Gradsect sampling methods were compared to random sampling. Various rules for gradsect sampling within a grid cell were included in the test. These pertained to resampling within a grid cell and choice of samples from topographic units. In general, gradsects detected more species than random sampling and some gradsect sampling rules achieved this result at lower cost.

The results of tests of efficiency show that gradsects are generally more efficient than traditional statistical techniques in recovering the greatest amount of ecological pattern per sampling effort. The gradsect method allows placement of samples in logistically more accessible areas than statistical techniques such as systematic or random sampling, thus improving cost-effectiveness. Costs can also be reduced and effectiveness maximized when stratifying variables are carefully chosen using existing information (Austin and Adomeit 1991).

2.3 Relationships Between Classification and Mapping

The types identified in a vegetation classification are not mapping units. Kuchler (1988) described a vegetation map as an application of a given vegetation classification. A map assumes that the vegetation categories are established in a manner that can be visualized. The intimate relationship between classification and mapping (Kuchler 1988) is that the choice of a classification strongly affects a map and the purpose of a map determines the classification approach that should be used.

The vegetation classification system that has been developed by The Nature Conservancy can be used for pure vegetation maps (sensu Kuchler 1988), or as a basis for ecological maps (Zonneveld 1988) or maps of land units (Zonneveld 1989). The use of a pure vegetation map will be limited by the lack of predictability of vegetation dynamics unless mapping is repeated over a certain period of time (see discussion in Kuchler 1988).

2.3.1 Scale Considerations

Other important factors to consider in surveys for vegetation classification and mapping include the notion of scales (spatial and map scales). Complexity and scale complicate the relationship between classification and mapping. Plant communities form complex patterns on the landscape, each community representing a different combination of environmental conditions. At the scale of a small area, a map of plant associations can be used to characterize vegetation within the area itself. Even at this fine scale, plant communities may form complex mosaics composed of various phases. In terms of classification, the choice between recognizing one plant community for the entire mosaic or one plant community per phase is essentially a matter of philosophy of classification, although ad hoc tests exist for making a decision. In terms of mapping, it is essentially a matter of scale. Communities that can be mapped independently at the 1:24,000 scale cannot be mapped 1:100,000 and smaller. At these scales (such as a midscale of 1:250,000), vegetation needs to be mapped as complexes. In this case, it is even more important to relate vegetation patterns to the ecological factors that shape them in order to be able to interpret the map units. Tests of homogeneity of mapping units exist (see Task 4).

2.4 Characteristics of a Successful Sampling Approach

There are a number of factors that must be addressed in the development of a successful sampling approach, particularly for the USGS/NPS Vegetation Mapping Program.

2.4.1 Flexibility

Vegetation types differ in their relationship to numerous variables. The sample areas will be of different sizes and levels of biological complexity, and the prior knowledge of areas will differ. Therefore, all aspects of the sampling design need to be flexible to fit area-specific ecological and programmatic conditions.

2.4.2 Replicability (Explicit and Consistent Sampling Procedures)

The notion that vegetation surveys are objective and/or void of assumptions about the phenomena the data seek to explain is unrealistic. Scientists have an implicit mental model of the relationships between the different components of the systems that they study (Austin 1991). This knowledge is used in the routine procedures followed by the field practitioner, whether this is explicitly stated or implicit. Therefore, it is necessary to explicitly state assumptions made in all stages of the design. Once the assumptions are tested, they should be consistent across the entire methodology. Furthermore, all steps in the design need to be applied consistently during implementation. Replicability and flexibility of sampling procedures need not be antagonistic criteria and, in fact, should be met simultaneously.

2.4.3 Cost-Effectiveness

An important feature of a vegetation survey, and of its associated sampling design, is its cost-effectiveness. Cost-effectiveness can be defined as the recovery of all vegetation patterns found in an area with the smallest number of samples, smallest sampling crew, and shortest amount of time. To achieve cost-effectiveness, the domain and grain of the data set need to match the domain and grain of the ecological system (i.e., vegetation) under study. Therefore, cost-effective procedures for data collection need to take into account ecological interactions at various scales (Austin 1991, Mackey et al. 1989, Gillison and Brewer 1985, Bourgeron et al. 1993). Therefore, a few basic theoretical concepts of vegetation structure, composition and function influence every step of the process of vegetation characterization and mapping, from data collection to interpretation (Austin 1987). These theoretical concepts need to be clearly defined and continually reassessed in the light of new developments (see Section 3).

2.4.4 Integrated Field Methods to Support Multiple Objectives

There are multiple objectives to be met through the acquisition, analysis, and presentation of field data. The methods to support these objectives must be fully integrated to succeed.

2.4.4.1 Correlation of Vegetation and the Environment

In order to use a vegetation map for conservation planning and/or management of any element of the vegetation, a correlation must be established between the vegetation and the environment. To be of optimal use, the analysis should be expanded to include the use of regional gradients in the field inventory. It should be noted that if a particular plant community occurs over a range of environmental conditions (i.e. along an environmental gradient), the inventoried areas should encompass the full range of variability of environmental conditions encountered along the gradient in order to sample a representative set of individual species populations, species assemblages, and ecological processes. The process of sampling specific areas to determine the patterns of vegetation and associated ecological processes calls for integrated inventories and assessments of vegetation and key environmental variables at the same time.

2.4.4.2 Classification

The goal of any classification is to elucidate pattern and reduce a large number of objects to a smaller number. Thus classification reduces the dimensionality of systems to those that are functionally important for the objectives of classification. In ecological classification systems the objective is to identify vegetation and/or land units with similar characteristics and to use those units to understand ecosystem relationships (Larson and Schlatterer 1984, Nelson et al. 1984). A complementary step to the classification itself is the identification of the agents of formation (sensu Urban et al. 1987) of the pattern (in this case the vegetation types). Vegetation types are characterized by the link between individual species distributions and their co-occurrence with a set of environmental factors (e.g., physical, biological, and disturbance factors). In a given area the distribution pattern of the landscape features controls the environmental factors constraining species distributions. At a local scale, then, vegetation types are a function of landscape features (e.g., landform, soils, geologic substrate) and the distribution of these landscape features (Bourgeron and Engelking 1993).

It is essential to integrate sampling of vegetation and relevant environmental/ecological attributes in a common methodology. The objectives of an integrated field methodology for vegetation classification and mapping are

(1) To describe vegetation types and establish their regional patterns of distribution

(2) To identify the fundamental relations of the vegetation types to the ecological processes that act upon them

(3) To analyze the role of processes at regional and landscape scales on local vegetation structure

(4) To use the identified classification units and processes in characterizing and evaluating landscapes in terms of their vegetation patterns

2.4.4.3 Characterization

The fourth objective listed above is central to the successful mapping of vegetation. A three-step process is involved in the characterization of a vegetation type or complex of types found in a given location. This characterization would include the description of relationships with environmental variables that shape a vegetation type and its response to disturbance factors or management scenarios. First, a classification is needed to identify the type itself. Second, the environmental conditions, or habitat factors, need to be delineated, leading to the mapping unit boundaries. Indeed, plant communities are characterized as recurrent patterns of species co-occurring in similar landscape features. Third, as a result of the individual distribution of species (the continuum concept), gradual intracommunity changes along regional environmental gradients need to be quantified. Examples of the same vegetation type found in different areas will more likely express different characteristics of that type.

In terms of sampling design, the consequences are (1) the objective of defining communities should be extended to determining their range of distribution, and (2) the specific overall species composition of each individual occurrence of a community needs to be documented and related to environmental/ecological constraints. The fact that communities and mapping units are not invariant is important to acknowledge for conservation planning because occurrences of a given community differ in their contribution to local/regional patterns of diversity and could respond differently to a specific conservation-management scenario depending upon their locations along regional gradients (Bourgeron and Engelking 1994).

2.5 Variability of Existing Information

A necessary step in conducting regional surveys is determining the types of data already available and whether they may be useful and cost-effective for a specific purpose even if biases exist (Austin 1991b). Maps of vegetation, soils, geology and climate exist in many cases. These maps could be used as initial surrogates for field data. However, data layers at different scales can add to the initial uncertainty and error rate inherent in each map. This approach has been used successfully by various investigators. For example, in Australia, maps of land systems (Christian and Stewart 1953) were used to build a database to describe the range of natural environments in the study region. This database was later used to sample the range of natural variability contained in various areas in the region (Pressey and Nicholls 1991).

Remote sensing (digital) imagery is readily available over North America. This may be a cost effective approach for broadscale mapping of land cover. However, there are significant challenges in producing maps from remote sensing data that pertain to the scale of measurement of the data (Davis et al. 1991). There has been a recent trend to acquire ground and remote sensing data over a range of scales (Sellers et al. 1988, Davis et al. 1991). Davis et al. (1991) concluded that some of the problems in remote sensing relate to understanding spatial scale dependence of processes and patterns. This search for multiscaled patterns and processes (Levin 1992, Milne 1993, Minshall 1993, Turner et al. 1993) requires, in turn, the collection of ground data at the appropriate intensity and frequency.

Another source of existing data is herbarium and museum records. Databases have been developed that compile this kind of information. The work of the Natural Heritage Programs and The Nature Conservancy (Jenkins 1976) with the Biodiversity and Conservation Database (BCD) software provides an example. Herbarium and museum records for specific plant and animal species, plant communities, and/or ecosystems (identification, location, ownership, and any relevant biological and management information) are collected and entered on the BCD for each state. Although the database is descriptive, extremely cost-effective use is made of these existing data for many purposes. Another example is the work of the U.S. Fish and Wildlife Service Gap Analysis Project (Scott et al. 1987) or GAP. State GAP programs combine species distribution information with vegetation maps. New survey costs can be minimized by using existing data because old records may suggest historically suitable areas for specific species or communities that have not been visited in decades. Repeat visits of such areas have yielded important information on changes in grassland and forest ecosystems in the western United States. (Fisser 1980, Gruell 1983).

A final source of existing data is plot data collected during previous vegetation surveys. If these data are incorporated into a standardized database, a very cost-effective tool for vegetation classification and landscape evaluation can be created. One limitation in the use of existing survey data is that the same biotic or abiotic information is rarely collected across surveys. However, if a minimum list of attributes common to all surveys is established, data can be used for a variety of purposes (Austin 1991b, Jensen et al. 1993).

Such databases can be used to determine which areas and/or which part of environmental gradients have not yet been sampled. By systematically reexamining existing data, duplication of survey effort is avoided and maximum use of resources can be made. Disadvantages (cost of establishing a database; limitation to a minimum list of attributes at the regional scale) are offset by potential cost reduction and increasing effectiveness of new surveys and by providing an initial regional overview of the information.

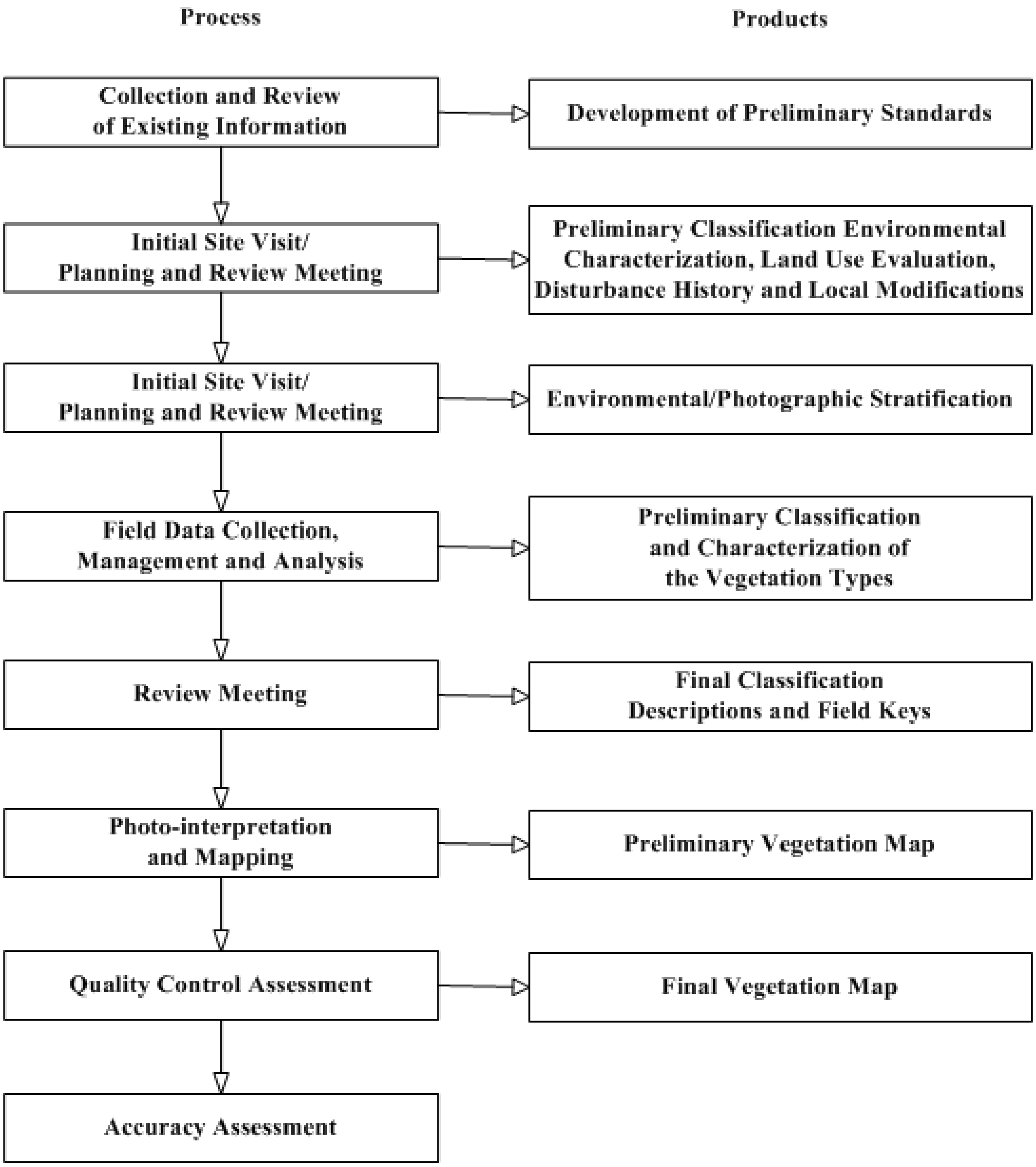
3.0 Overview of Planning Process and Field Methods

The planning and field methods for the USGS/NPS Vegetation Mapping Program will entail the evaluation of existing data and information, the collection of new field data, the analysis and interpretation of the data, and the creation and evaluation of the vegetation maps. Many different parties will be working together to complete this process. The implementation of field methods will demand a consistent interaction between park resource personnel, vegetation ecologists, and photointerpretation specialists.

Although the field methods are described for a park, this actually refers to both the "park" and its "environs". In many cases the planning and field work will be carried out for a "cluster" of parks that share the same environmental context and vegetation types. The development of the field teams and completion of field work will similarly be determined from an efficiency model that will be based on the size and ecological similarity among the parks.

An overview of the planning and field process is provided below and shown in **Figure 1** along with the products that will be developed at the different stages of this process. These topics will be fully described in the remainder of this document.

Figure 1. Overview of Vegetation Mapping Process



3.1 Preliminary Collection and Review of Existing Information

The first step in the process is to review pertinent information concerning the biology, ecology, and site history of the park. Based on this information, a preliminary list of the vegetation types that are expected to be found on the park will be compiled. This list will be based both on the The Nature Conservancy national classification, and regional and local classifications. The completeness of the list of National Vegetation Classification System (NVCS) types for this park will also be documented.

In addition, an initial determination of the driving environmental variables for the park will be developed along with an assessment of data availability for these factors. Much of this research will take place during an initial site visit to the park.

3.2 Initial Site Visit and Planning Meeting

3.2.1 Information Gathering and Team Development

The initial site visit will be conducted to further assess the existing information and level of expertise concerning the park, and to gather key individuals to evaluate the data in light of the goals of this program and the needs of the park.

3.2.1.1 Data Review and Identification of Experts

All pertinent data and other information that is available for the park will be identified. The quality and utility of these data will be assessed in light of this project. Useful data are specifically needed in the areas of

- Thematic spatial data (e.g., soils, geology, elevation, etc.)
- Basemaps
- Recent imagery
- Species inventories and range maps
- Environmental data
- Vegetation information (e.g., classifications, lists and maps)
- Significant disturbance events
- Patterns of land management

Experts who are knowledgeable about the biology and ecology of the park will be identified, and a determination will be made concerning their participation and review of the process.

3.2.1.2 Identification of Park Resource Management Needs

The specific resource management challenges and objectives for the park will be reviewed in light of this program. Where appropriate, modifications and refinements to the standard classification and inventory protocols will be implemented at the early stages of the project. Modifications may include a finer level of classification or mapping resolution, or additional data to be collected in the field.

3.2.1.3 Team Development

The team structure will be finalized to identify who is responsible for the various components of the program on a park. This will consist of the project oversight team, the training team, the field ecologists and photo interpreters, and the accuracy assessment team. Many individuals will be involved in more than one team. Park service personnel, if available, will be valuable members of the teams.

3.2.1.4 Park Reconnaissance

A field reconnaissance trip will be conducted during the initial site visit to introduce the team to the vegetation, environment and the photographic signatures. The classification, photointerpretation, and mapping team(s) will begin field recognition of the vegetation, biophysical environments, landforms, and the relationship of these features to the aerial photography. In addition, the teams will evaluate the resource management concerns, ownership patterns, and boundaries of the mapping exercise with which they will be working on this program.

3.2.1.5 Park Logistical Support

The level of park logistical support will be determined at this time. This will include accommodation, vehicles, program staff, and equipment that will be dedicated to this program.

3.2.2 First Planning and Review Meeting

This meeting held during the initial site visit, will be used to present the information that has been gathered and to refine numerous parameters of this study.

3.2.2.1 Representation

The invited members of this meeting will include

- Park management representatives
- NPS Inventory and Monitoring representatives
- Project teams consisting of employees and contractors from
    - ESRI
    - TNC
    - HP
    - NPS
    - USGS
- Park scientists and resource managers
- Local experts

3.2.2.2 Objectives

The major objectives for this meeting are to

(1) Introduce the USGS/NPS Vegetation Mapping Program to interested and involved parties so they fully understand the purpose, scope, methods, and products that will be coming out of the NPS/USGS Vegetation Mapping Project.

(2) Clarify the management concerns and other special situations on the park that may require refinement or modification of the standards to collect and portray the appropriate data.

(3) Review the approach of the standard NVCS and the list of vegetation types within this and other systems that are known or suspected to be present in the park.

> (a) Identify the vegetation types on the list that are definitely found in the park and summarize the known geographical locations and environmental conditions with which they are generally associated.
>
> (b) Identify vegetation types on the list that are not expected to be found in the park.
>
> (c) Identify vegetation types that are not found on the list but are known or expected to be found on the park. The environment characteristics and known

geographical locations for these community types should be described at this time.

(4) Review the gradsect methodology for the stratification of biophysical environments across the park that will support the identification of representative pilot sample sites. Review the preliminary list of driving environmental variables and their classes, and refine

(a) The division of the park into biophysical subregions

(b) The driving variables that will be mapped by subregion

(c) The appropriate classes for each environmental variable that will be mapped as ecologically important units

3.3 Determination of Sampling Approach

The next step will be the identification of the pilot area(s), subsections of the park that are representative of the biophysical environments and vegetation. The identification of pilot sites will only be necessary when the size of the park and/or constraints on accessibility make it impossible to complete a thorough sampling of the entire site. The project team will merge the different layers of thematic information and create a map of the major biophysical environments across the park. These maps are most efficiently generated and analyzed with spatial database technology (GIS), but this process can efficiently and cost effectively be completed by hand with simple overlays. The maps serve to guide the stratification of field work and to generate a deeper understanding concerning the relationship of ecological dynamics to the distribution of vegetation types across the park.

The different biophysical classes are primarily characterized by the number of polygons of each class, the total cover of each class, and the geographic range of each class across the site. Additional landscape characters will then be used to derive maximum efficiency in the sampling protocol. These protocols will be determined by the relationship of the biophysical environment polygons to levels of site accessibility, and through the identification of areas with the clustering of multiple biophysical environments into concentrated areas.

Pilot study areas will be selected (manually or digitally) to cover at least 15 percent of the spatial extent of each biophysical class. Rarer biophysical environments will receive a proportionately higher rate of sampling than the more common types.

3.4 Field Data Collection, Management, and Analysis

Field data collection will be completed to classify, and fully describe all vegetation types across the park.

The polygons of different vegetation types will be delineated through the interpretation of aerial photography across the pilot study areas. Standard photointerpretation rules will be employed that depend on the identification of homogeneous patches of color, texture, and pattern. New boundaries to the original imagery polygons will be added as the field teams identify additional polygons in the field.

The field work will be stratified to sample all vegetation types on all biophysical classes across the pilot area. Field teams will collect standardized plot data (see section on Field Forms) on approximately ten samples of all vegetation classes across the pilot area(s). The exact number of samples per class will be determined by total coverage and number of polygons of each type, and will be flexible to account for the degree of biological and environmental variability. In many cases, only three to five samples will be necessary.

Plot size and data collection protocols will be specified by physiognomic type (see **Section 5**, **Table 2**). Complete vegetation descriptions for all types found in the park based on the broader knowledge of this type across its entire range will be developed. In addition, field keys will be completed along with photointerpretation keys to detail the characteristics, environmental correlates and distribution of this type within the park.

3.5 Review Meeting

A second meeting will be held to review the efficacy of the methods and results of the pilot survey. The audience will be the same as the first planning and review meeting.

The results of the environmental stratification of the park, the selection of pilot areas, the photointerpretation procedures, and the field methodology will be presented for discussion. The list of vegetation types that were encountered through the field work will be presented with the descriptions and field keys.

Specific feedback will be requested from the participants to refine the list of classification units and to develop the descriptions of the vegetation types, and the key environmental factors. There will be a concerted attempt to identify any gaps in the pilot study in terms of biophysical environments, vegetation types, and additional features that should be mapped. The modified list of inventory units will be incorporated into the methodology from this point.

The list of vegetation types, with descriptions and decision rules for the photointerpretation process will be extended to incorporate the new information.

3.6 Photointerpretation and Mapping

The methodology and experience from the pilot areas will be then be extended across the park. The vegetation classification, description, environmental "position" and photointerpretation decision rules will be applied to continue the vegetation mapping across the rest of the park. Photo signatures that do not match existing keys and descriptions will be "flagged" as unknown. These polygons will require ground sampling either by park subregion or across the entire park.

The vegetation keys and descriptions will be constantly updated with the addition of new information on known types and the documentation of new types.

3.7 Map Validation

After the preliminary vegetation map has been completed for the park, an assessment of class accuracy will be carried out. The vegetation class accuracy will be determined through the stratification of sample points by class throughout the park. These validation points will be spread over the full range of the geographic and environmental distribution for each vegetation class.

The methods will be refined to address any problems that are documented from the map validation phase and the preliminary map will be corrected to produce the final vegetation map.

3.8 Accuracy Assessment

A separate report has been written in this series of papers to explain the protocols that will be followed for accuracy assessment. The vegetation class accuracy will be determined through the stratification of sample points by class throughout the park. These assessment points will be spread over the full range of the geographic and environmental distribution of each vegetation class.

4.0 Project Planning

In preparation for implementation of this program, there will be a preliminary review of the size and accessibility of the park, along with an evaluation of the availability of useful data and park resources that can be used for this program.

The initial site visit will provide the opportunity to further evaluate the information on the park and interact with experts who can assist with the mapping program. It will also facilitate the review of park management needs and logistical support for the field work, and the determination of field teams that will work together to complete the program.

Preliminary field reconnaissance trip(s) will commence at this time to initiate the classification, photointerpretation and mapping team(s) to the relationship between the vegetation and imagery. Simultaneously, they will begin to develop a better understanding of the key biophysical variables, management concerns, accessibility issues, ownership patterns, and the boundaries of the mapping program on the park. All of these factors must be understood to develop the stratification and classification protocols for the park.

4.1 Collection and Review of Existing Information

To ensure the full application of existing data and other information on the park, information on the park's resources will be reviewed and fully evaluated for their quality and utility to this project. In addition, an attempt will be made to identify and contact all individuals who have expertise concerning the biology and ecology of the park. The availability of adequate data will have some effect on the ability to develop the sampling protocols on a park-by-park basis.

4.1.1 Imagery

All classified and unclassified imagery for the park will be fully evaluated for application to this program. Imagery that may be used includes any recent photography, videography, and satellite imagery with a format and scale that will facilitate the mapping of vegetation of the park. If recent imagery of suitable format, accuracy, and scale is not available, new imagery will be acquired for the park. The assessment of land cover patterns and vegetation types can begin through analysis of existing imagery.

4.1.2 Biodiversity Information

All information concerning the biological diversity of the park will be collected and evaluated for use in the vegetation mapping program. Types of information that will be collected include

- Vegetation classifications and other information
- Vegetation type distributions
- Species inventories
- Species range maps
- Species and community distribution in relation to environmental variables
- Species and community distribution in relation to disturbance events
- Biological collections derived from the park

4.1.3 Vegetation Data

Because a key component of this program is to inventory and classify all vegetation types across a park using the National Vegetation Classification System (NVCS), information on the vegetation of the park is of greatest importance. A critical amount of information will be needed to fit types within the NVCS, add new types to the classification, and describe the vegetation types and their specific expressions in the park.

During the planning phase for each park, all previous work on vegetation classifications, lists of vegetation types, vegetation maps at appropriate scales, and vegetation plots will be fully reviewed and assessed for utility.

The existence of a well-inventoried and described list of park vegetation types that conforms to the standards of the NVCS will affect the sampling approach implemented on a park-by-park basis and will streamline the classification and characterization process. The more information that has been developed on the park vegetation, the less new data that will need to be collected to classify and characterize the vegetation. In areas where the vegetation classification is poorly understood and documented, sampling will be used to gather data on all possible variants of vegetation and land use across the park.

4.1.4 Environmental Information

Another important component of the program is to develop a functional description of the relationship between the vegetation and the ecological processes that determine their distribution across the park. To do this, the parks will be mapped in terms of the most important environmental variables that are believed to reflect the variation in the vegetation. The vegetation will be sampled across these biophysical units, and will be described in terms of its relationship to these environmental variables. To efficiently proceed with the environmental stratification, all environmental data and maps, all research associated with the relationship of the vegetation to the environment, and any information on the history and location of significant land management and disturbance events will be collected and reviewed.

The availability of suitable data on key environmental factors will have an effect on the sampling protocol implemented on a park-by-park basis. Information on the key environmental variables across the park is required to fully characterize the landscape and map the biophysical environments. This information will support the sampling stratification and evaluation of the relationship between vegetation and the environment. The environmental stratification process can be completed regardless of the level of existing knowledge and data, though the process will certainly be streamlined in parks where the information is available.

In the best-case scenario, the environmental data layers for a park will be digitally mapped. The appropriate thematic layers (e.g., elevation, soils, geological substrate, etc.) will be broken into ecologically relevant classes and merged within a geographic information system to produce a map of the biophysical environments. This "best-case scenario" will not be a common situation across most national parks.

In most situations, there will be knowledge of the key environmental factors to which the vegetation is responding, along with some environmental data and maps. It will be necessary to create some digital or "hard-copy" map overlays from which the environmental stratification can be completed. The environmental thematic layers that will be chosen will most directly represent the key environmental variables.

The environmental stratification provides a coarse landscape filter that supports the sampling stratification and ecosystem characterization. This work does not need to be precise to be useful, so it will proceed regardless of the level of available data. The identification of biophysical environments will take somewhat longer to carry out and will be completed to a coarser degree than if detailed data were available. This is not sufficient cause to bypass the environmental stratification process, as the benefits for sampling efficiency and building up the critical knowledge base are critical to the goals of this program.

4.1.5 Existing Plot Data

Whenever possible, existing data on the vegetation and the environment will be incorporated into the study and the sampling protocol. Any vegetation plots that exist will be assessed for their use in this program. In order to be of value, existing plots must be able to be relocated and sufficiently recent to reflect existing vegetation. They must have been taken at an appropriate sampling scale using compatible information-gathering protocols to provide the data necessary for vegetation classification and characterization. This information must include the list of plant species with structural and cover data, critical environmental information, and sufficient site history information.

4.1.6 Existing Vegetation Maps

The existence of prior vegetation maps will be evaluated early in the data-gathering stages for every park. The presence of vegetation maps ensures a cursory level of prior vegetation classification and description of the types as well as critical information on the distribution of these types across the park.

When the vegetation maps are quite new and contain detailed information, a decision will be made whether or not a new vegetation map should be generated. If it is not clear whether the existing maps will meet the NPS Inventory and Monitoring criteria, these maps will be analyzed to determine the level of difference between them and the proposed classification and map accuracy standard. If this evaluation is requested, two major activities will follow. The first will be to establish the relationship between the classification units on the map and the NVCS units. Assuming that the units have a high degree of similarity, the next step will be to carry through with the accuracy assessment methodology (see Accuracy Assessment Report) to document the level of class accuracy represented by the map product. If these criteria do not meet the NPS Inventory and Monitoring requirements, it will be determined on a park-by-park basis whether or not to fix the old map or to create a new vegetation map.

4.2 Planning and Review Meetings

During the initial planning stages of the program for each map, a meeting will be held with key park personnel and other experts on the parks vegetation to identify any park-specific objectives for the vegetation map and to begin to develop an understanding of the parks vegetation and the key environmental factors governing it.

4.2.1 Review of Park Specific Objectives

There will be an evaluation of the resource management and stewardship data needs for the park in relation to the specific data requirements for the vegetation mapping program. When feasible, the program will be used as an opportunity to generate data for critical park stewardship concerns. Specific management objectives for the park will be identified immediately so that modifications and refinements to the classification and inventory protocols can be considered early in the project.

4.2.2 Review of Vegetation and Environmental Information

The concepts related to the NVCS and the sampling stratification approach for the characterization of biophysical environments will be explained during the planning meeting. The group will then be asked to review the preliminary list of vegetation types in the NVCS that are known or suspected to be present in the park. They will also be asked to review the list of driving environmental variables and their classes. The input from the group during the planning meeting will be used to refine the preliminary list of vegetation types on the park and the environmental stratification used to direct the sampling.

More specifically, the group will be asked to

(a) Identify the vegetation types on the list that are definitely found in the park and summarize the known geographical locations and environmental conditions with which they are generally associated.

(b) Identify vegetation types on the list that are not expected to be found in the park.

(c) Identify vegetation types which are not found on the list but are known or expected to be found on the park. The environment characteristics and know geographical locations for these community types should be described at this time.

(d) Review the environmental variables that should be used for the stratification (where appropriate).

(e) Review and refine the classes for each environmental variable that will be used to develop the stratification.

(f) Help refine the initial stratification of the park into biophysical subregions.

4.2.3 Logistics

The logistics of carrying out the mapping program will vary based on the park size, physical accessibility, biological and ecological sensitivity, environmental and vegetational complexity, and the status of existing knowledge of the park. The degree of logistical support at the park may also play an important role in the protocols that will be employed to implement the park mapping program. Specific logistics will be worked out during the planning meetings.

4.2.3.1 Team Structure

Program teams will be developed for

- Project oversight and training
- Field reconnaissance, ecology, and photointerpretation
- Accuracy assessment

The team members will be assembled from Environmental Systems Research Institute team including: The Nature Conservancy, Aerial Information Systems, Merrick & Company, EA Engineering Science, and Technology, National Center for Geographic Information and Analysis', and the network of state Natural Heritage Programs. National Park Service personnel will also be invited to participate as team members.

5.0 Field Methods

The vegetation will be sampled to identify and characterize the full representation of all vegetation types across a park and to identify the photographic signatures that are associated with each type. The samples chosen to characterize the full variation of vegetation types will be determined through an environmental stratification approach, which will ensure a broad approach to sampling that should portray the fullest possible range of representative variation of all vegetation types across the park. The number of sample points for each vegetation type will depend on the amount of information that has already been gathered about the vegetation type, the inherent variability of the vegetation type, and the complexity of the environment. Sampling intensity will be further clarified in Section 5.3.

5.1 Ascertaining How Much of the Park will be Sampled

The geographic extent of vegetation sampling from one park to another will vary upon the individual conditions of the park. The size of a park and other factors that limit accessibility will be the primary determinants of the extent of the park that can be sampled. The four approaches to sampling that will be used are presented in **Table 1** and illustrated in **Figure 2**. The sampling approach will be designated on an individual park basis, depending on conditions and complexity.

5.1.1 Small Parks

For parks in the "Small" category, it will be possible to visit most, if not all, vegetation polygons. Environmental characterization of the park will be completed to help characterize the vegetation types and explain their distribution across the park.

5.1.2 Medium Parks

In the "Medium" category, the sample area will consist of the entire park. Environmental stratification will be carried out to map the biophysical units across the park. Representative polygons for each vegetation type will be selected for sampling across the park based on the stratification of each type across the different biophysical environments.

5.1.3 Large Parks

For parks that fall within the "Large" category and those without full accessibility, pilot areas will be identified to represent the greatest possible diversity of vegetation across the park. An environmental stratification will be completed for all parks using the gradsect approach (Austin and Heyligers, 1989), and the resulting map of biophysical units will be used to determine the pilot area(s) that will be sampled. Pilot areas will be selected to include a minimum of 15 percent of the areal coverage of each biophysical class across the park (see **Section 5.2.1** below). Concentration of the greatest number of biophysical units (steep environmental gradients) and efficiency of sampling (accessibility) will determine the selection of pilot areas that represent the full array of environments across the park.

Photointerpretation will then provide a first approximation of the vegetation types within the pilot areas and sample plots will be allocated to each vegetation class as stratified across each biophysical class (see **Section 5.2.2** below). Additional pilot areas will be selected wherever photographic signatures have been noted that are not represented in the initial set of pilot areas.

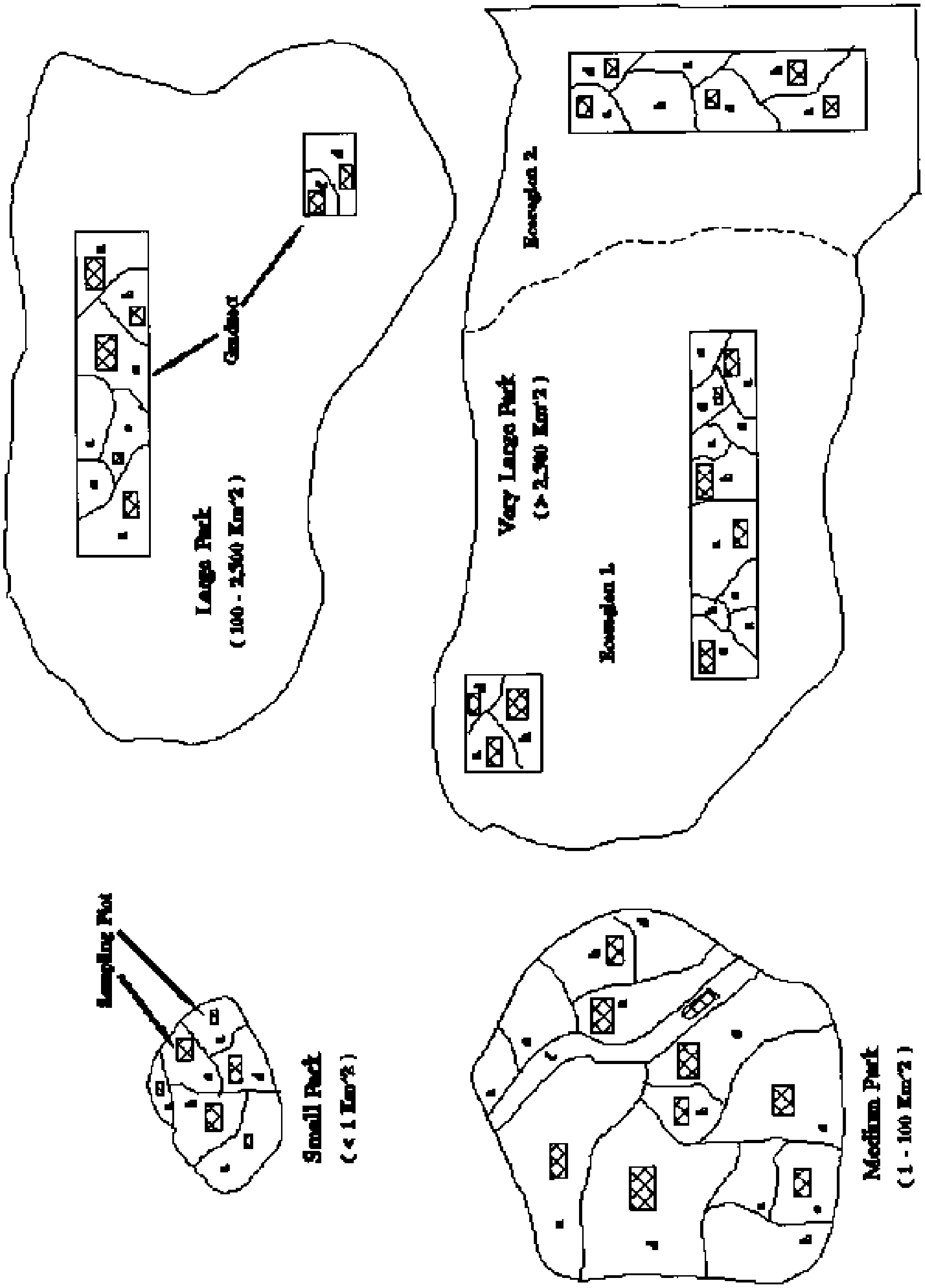
5.1.4 Very Large Parks

The "Very Large" park category refers both to the actual size of the park and to the complexity of the environments encompassed by the park. Very large parks are those that extend over more than one major physiographic province or ecoregion. As such, the key environmental variables that are affecting the distribution of the vegetation will be significantly different in each region within the park. An efficient sampling approach in these situations will require the initial separation of the park into the different ecoregions, and these must be sampled individually by the appropriate method for the size and complexity of that region. Where there are very large ecoregions represented in one park, each region will be treated as a separate "Large" park for sampling purposes. Where one of the ecoregions may be a small component of the park, it may receive the sampling treatment of a "Small" or "Medium" park. As in all sampling approaches, any new photographic signatures that fall outside of the pilot areas must be included as additional pilot areas.

Table 1. Park Size and Sampling Strategy

Park Size Class	**Approximate Size**	**Sampling Approach**
Small Park	< 1 km^2	Every polygon
Medium Park	1 – 100 km^2	Representative polygons across entire park
Large Park	100 – 2,500 km^2	Gradsect
Very Large Park	> 2,500 km^2	Multiple gradsects per ecoregion

Figure 2: Park Size and Sampling Strategy



5.2 Identifying Where Sample Areas will be Located within the Park

Pilot areas for sampling will be selected to represent the expected variation of vegetation types across the park. This will be accomplished through spatial analysis of key environmental gradients in conjunction with land use and disturbance history across the park. Those subsets of the park that are accessible and represent the full set of variation of the environmental, land use, and disturbance variables will be selected for the pilot areas for sampling. Within these pilot areas, the vegetation sampling protocol will be directed through the interpretation of patterns that can be recognized from aerial photography.

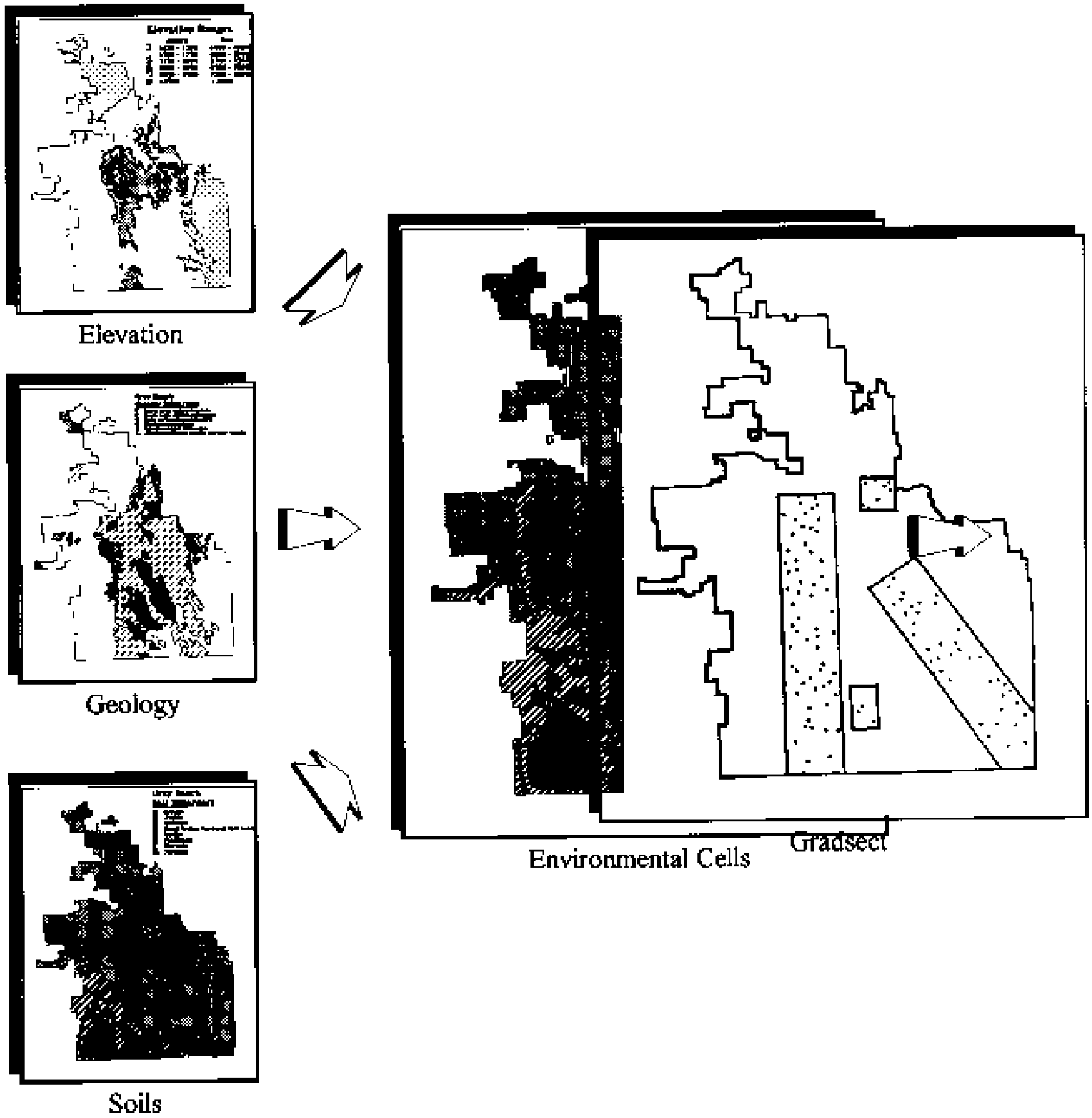
5.2.1 Environmental Stratification (Gradsect Approach)

Environmental stratification methods will be applied to locate pilot sampling areas when it is not possible to cover the entire park due to size and accessibility criteria. The second benefit of the environmental stratification approach is that it builds a stronger knowledge of the relationship between the vegetation and the key ecological processes and environmental variables. A description of the application of these methods by The Nature Conservancy is provided in **Appendix 12.2**.

Key environmental variables will be identified across the park. These variables are based on prior knowledge of major environmental factors that are believed to determine the distribution of the vegetation. Up to three of these variables will be chosen and broken down into three to five classes that are ecologically relevant. Each of these environmental 'themes' will be mapped across the park and the maps of all themes combined to generate a working map of the biophysical environments of the park which represent unique combinations of all the variables and classes across the park (see **Figure 3**).

The pilot sample sites will be chosen to contain a minimum area (15%) of all representative biophysical units across the park. These represent areas with sharp environmental gradients that will reflect all biophysical environments in relatively small and contained areas that are preferentially accessible for sampling. There are some parks where one of these "gradsects" can account for all of the biophysical environments, but it is usually necessary to identify two or more "gradsects" to fully capture the key environmental gradients for sampling.

Figure 3. Environmental Stratification for Vegetation Sampling.



5.2.2 Imagery Stratification through Photointerpretation

The photointerpretation process will proceed step by step along with the environmental stratification and vegetation sampling. The imagery will be interpreted for patterns of tone, texture, color, and contrast to identify homogeneous patches of vegetation. These patterns will be assigned to a preliminary vegetation type from the NVCS based on the preliminary review of the vegetation types in the park. The complete range of photo signatures will need to be represented in the sampling areas to ensure they are fully interpreted in relation to the vegetation types across the park. Where the signatures pose interpretation questions, additional samples will be selected to clarify their biological meaning.

5.2.3 Combined Environmental and Imagery Stratification

The stratification of the landscape into sampling area and sampling units will, therefore, be a result of both environmental characterization and imagery interpretation. Pilot areas that are determined through the environmental gradsect approach will be supplemented by additional pilot areas reflecting photo signatures that have not been included.

5.2.4 Other Issues Directing Sampling

There are many other practical criteria and issues that also affect where and how sampling will need to proceed. These criteria are primarily associated with accessibility and sensitivity issues that will affect which polygons can efficiently and safely be chosen for sampling and where the actual samples can be placed on the landscape.

5.2.4.1 Accessibility

Accessibility to many areas will be limited by the physical terrain (e.g., stability, elevation, slope) or actual time and logistics of the travel that would be required. There may be limited access to private property surrounding the park based on concerns of the local landowners. All of these issues will need to be thoroughly addressed in the development of the sampling protocol.

5.2.4.2 Sensitivity

Field sampling sites will be chosen to avoid adverse effects to populations of rare and threatened species and sensitive habitats, and to prevent undue or undesired interference with species behavior patterns.

5.2.4.3 Safety

The safety of the field team will be considered both in terms of the physical terrain and the reaction of certain species to the presence of field crews. The sampling crew must be aware of danger that certain sites may pose from certain species at certain times of the year and select their sites accordingly.

5.2.4.4 History of Land Use and Disturbance

The distribution of the vegetation across the landscape may be different than expected due to historical land uses or patterns of natural disturbance. The patterns of land use, heavily managed landscapes and location of major disturbance events need to be recognized early in the sample allocation process to ensure that these areas are effectively sampled to reflect the additional land cover variation across the landscape.

5.2.4.5 Research Needs

All major research agendas for the park will be assessed early in the process to make sure that this program assists their data needs wherever possible. In some cases the selection of particular polygons for sampling will directly support a research project. Other projects will directly benefit from the collection of additional data. There will be many opportunities where a minimal alteration of standard sampling protocol will help the park or individual researcher meet critical research goals.

5.3 Determining How the Plots will be Allocated within the Sample Areas

Once the general sampling strategy is determined based on the size of the park and accessibility issues, individual polygons will be selected for plot sampling. The following section describes the number of plots that will be placed in each vegetation type and describes how the polygons will be selected within the sample areas. The methods for placement of the plots within the polygons and the plot size, shape, and methods for marking permanent plots is also discussed.

5.3.1 Total Number of Plots and Plot Distribution

For small parks, a plot will be placed in every vegetation polygon that has been identified on the aerial photographs. For medium, large, and very large parks, at least ten plots of each vegetation type on the park will be sampled. In parks for which an environmental stratification is used, the plots will be distributed so that at least one plot is placed in every unique environmental cell in which a particular vegetation type occurs. Within each unique environmental cell type, plots will be located in randomly selected polygons. For medium parks, the polygons will be selected from across the entire park. For large and very large parks, the polygons will be selected from within the pilot area. In addition to the environmental stratification, plots will also be placed in polygons that represent the full variability of the signatures. If inaccessible polygons are selected through this process, they will be replaced with another randomly selected, accessible site with the same vegetation according to a fixed set of decision rules. This will generally be determined prior to the field visit.

There are several special cases that will require greater or fewer than ten plots per vegetation type to be taken. If the vegetation type falls into more than ten environmental cells, then more than ten plots will be sampled for that vegetation type. More than ten plots per vegetation type will also be taken for types that are particularly variable, or those for which there is relatively little data available across their range. For vegetation types that occur in fewer than ten polygons, all polygons will be sampled. Fewer than ten plots may also be taken for vegetation types that are particularly homogeneous or those for which the vegetation is extremely well known.

If there is existing plot data for vegetation types in the park that meet the data standards (e.g., precise location information and complete species lists, environmental information, etc.) and plot allocation standards (e.g., distributed across environmental cells), these plots will be used as a substitute for plots allocated in the standard sample allocation procedure. If there are not at least ten plots for each vegetation type in the existing field data set, or if the data are not stratified across all environmental cells, additional field data will be collected to supplement these data.

5.3.2 Number of Plots per Polygon

One plot per polygon across the sample area will generally be taken. Exceptions requiring more than one plot per polygon include (1) where multiple vegetation types appear to be present within a single polygon delineated on an aerial photo (note: where this occurs, the photointerpretation will be revised to represent actual ground conditions), (2) where the polygons are very large, (3) where polygons contain extremely complex or heterogenous vegetation cover, (4) where the vegetation types have very few occurrences across the park. In these cases additional plots will be taken to accurately assess the classification of the map units and to provide enough information to describe them in sufficient detail.

5.3.3 Plot Placement

Plots will be placed in representative structurally and floristically homogeneous areas of the polygon at least 30 meters from the boundary between two or more vegetation types. Structural uniformity will be assessed by evaluating all layers of the vegetation. Floristic homogeneity will be assessed by evaluating the general uniformity and consistency in species composition, especially with respect to the dominants (Mueller-Dombois and Ellenberg, 1974). In cases where a vegetation polygon unit appears to be extremely heterogeneous, multiple plots will be taken (see above).

5.3.4 Plot Size (Area) and Plot Shape

When determining the appropriate plot size needed to sample the vegetation, the goal is to select a minimum area that will fully represent the species composition of the community. The minimal area can vary widely depending on the structure, scale of patterning, and species diversity of the community. The plot areas and dimensions below (Table 2) will be used as guidelines for selecting plot sizes (Mueller-Dombois and Ellenberg, 1974; Whittaker 1977; Looman, 1980; Rice and Westoby, 1983). The actual plot sizes will be selected based on the community structure, patterning, and diversity to ensure a representative sample. If samples larger than the maximum guidelines below are needed to fully represent the species composition of the vegetation, more than one plot per polygon will be sampled within a polygon. Sample plots will generally be rectangular in shape but will be varied to fit the nature of the occurrence (e.g., irregular plot shapes are used for seep communities that follow ravines).

In some cases, a plot that is large enough to characterize the tree layer in a forest, woodland, or sparse woodland plot will be larger than is necessary to characterize the shrub or herb layer. Nested subplots will be used to characterize the understory when this occurs. The guidelines in **Table 2** will also be used to determine the appropriate size of the subplots (i.e., the Herbaceous class guidelines will be used to determine subplot sizes appropriate for sampling the herbaceous layer of a forest community).

Table 2. Guidelines for Determining Plot Size

Class	Area	Dimensions
Forest	100 – 1,000 m^2	10x10 – 20x50
Woodland	100 – 1,000 m^2	10x10 – 20x50
Sparse Woodland	25 – 1,000 m^2	5x5 – 20x50
Shrubland	25 – 400 m^2	5x5 – 20x20
Sparse Shrubland	25 – 400 m^2	5x5 – 20x20
Dwarf shrubland	25 – 400 m^2	5x5 – 20x20
Sparse Dwarf shrubland	25 – 400 m^2	5x5 – 20x20
Herbaceous	25 – 400 m^2	5x5 – 20x20
Nonvascular	1 – 25 m^2	1x1 – 5x5

5.3.5 Plot Permanence

Information on the temporal and spatial dynamics associated with each vegetation type is often important for resource planning and management. If the plots sampled during the mapping process can be relocated and remeasured, they can be used to detect change in individual species abundance over time, to determine successional pathways among community types or to examine community responses to management practices (Austin 1981), provided that enough samples have been taken. During this project specific technologies for relocating plots will be investigated. Plots will be marked permanently as necessary to meet park-specific monitoring objectives. Additional research will be conducted to relocate plots using GPS technology.

5.4 Data to be Collected Within the Plot

The data collected in an individual plot falls into four broad categories: biological data, environmental data, locational data, and biological interactions/historical/disturbance data. Each is described in detail below.

5.4.1 Biological Data

Within each homogeneous area, plot boundaries will be marked and the general physiognomy of the community will be recorded. The vegetation will be visually divided into layers (strata) and the average height and percent cover of each stratum will be recorded. Within each stratum, all species will be identified, and the relative abundance of each described by a visual percent cover estimate. Species that are present in the community but not in the sample will be noted on the forms but not given an abundance estimate. Sample field forms with complete instructions are provided in **Appendix 12.1**.

5.4.2 Environmental (Abiotic Variables) Data

In addition to the species information, a number of environmental variables will be sampled from each plot to characterize the precise conditions under which the sampled vegetation occurs. This will include measured abiotic variables, additional biological data, historical/disturbance data, and landscape relationships. There will be a mixture of continuous, discrete and standardized categorical variables to describe the range of site attributes. These will be used in later analysis to help understand the patterns identified with the floristic data.

The major variables are outlined below, and detailed descriptions are provided in **Appendix 12.1**. Field forms will be tailored to fit the local needs within the limits of the national standards. Additional observations about the plot and its setting will be noted in text form on the data sheets.

(1) Elevation of the plot

(2) Topographic Position and Landform: The position of the community/sample within the landscape will be assigned to one or more of a standardized list of categories.

(3) Slope: The slope of the area, in degrees, will be measured using a clinometer.

(4) Slope Aspect: The aspect will be recorded from a compass correcting for the magnetic declination.

(5) Surficial Geology: The significant geological features will be described using a geological map of the area, and, when possible, further notes on the composition of exposed outcrops will be noted at the site.

(6) Hydrologic regime for Wetlands.

(7) Basic soil profile description.

(8) Soil texture.

(9) Soil Drainage: Soil drainage will be estimated in the field using topographic position, soil texture, and apparent moisture regime.

5.4.3 Locational Data

Each field form will be labeled with a unique code to identify the polygon and plot sampled. Other locational information to be recorded includes state, park name, park site name, county name, and the name of the topographic map (quad) on which the location occurs. Precise latitude and longitude of the plot will be measured using a Global Positioning System. Specific locational information will be recorded on a photocopy of the base topographic map or aerial photograph with an image or patch identifier. The location of the plot will also be recorded on the photocopy of the topographic basemap and the aerial photograph. Directions to the site using a readily identifiable landmark as the starting point will be provided. Distances will be given as precisely as possible using compass directions. In addition, directions to the plot within the site will be recorded. Names of the surveyors and the survey date will be written on each sample form.

Information on the plot dimension, plot permanence, plot representativeness, and whether photos have been taken will also be recorded.

5.4.4 Biological Interactions/Historical/Disturbance Data

Effects of biological interactions, historical land uses or periodic disturbance is important but often difficult to determine. For community unit/occurrence the size of the occurrence in comparison to other known occurrences of this community type will be noted. The presence of stumps, plow line, old field characteristics, stone walls or other fence lines, "wolf trees," other indirect evidence of land use will be noted. For forested communities, the age or DBH of largest trees, will be recorded along with the presence of snags, pit and mound microtopography, and other possible old-growth characteristics. Evidence for probable succession relationships will be noted, particularly for suspected fire-dependent communities. As time permits, the land use history may be assembled from town records, literature, knowledgeable individuals or other reliable sources. Evidence of anthropogenic or other negative disturbances will be noted. These may include trash dumping, trampling, undesired beaver flooding, overbrowsing by deer, invasive species, and evidence of alterations in hydrology. Absence of, or disruption to, natural disturbance patterns such as fire or flooding etcetera will also be noted.

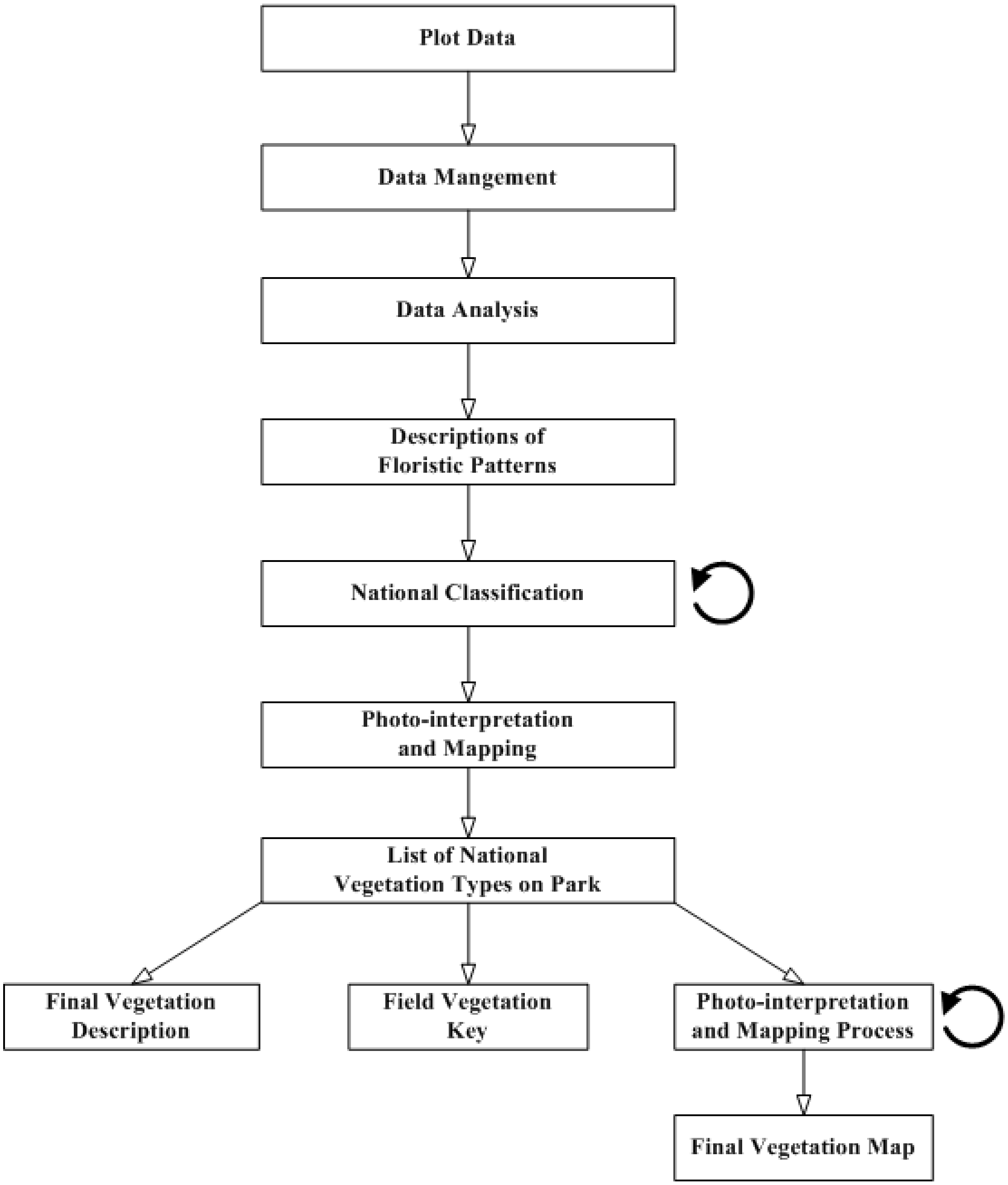
6.0 Data Management and Analysis for Vegetation Mapping

The following section describes how the plot data will be managed, analyzed, and linked with the photographic signatures to create vegetation descriptions, field keys, photointerpretation keys, and vegetation maps. See **Figure 4** for a diagram of the flow of information from the plot data to the final map product.

The field-collected plot data will be entered and managed in a standardized relational database management system that will have the capability to output data into standard vegetation analysis programs (see **Section 6.1** below). The plot data will be analyzed to illustrate floristic patterns and to relate these patterns to key environmental variables (see the National Vegetation Classification System [NVCS] document for a detailed description of this process).
The descriptions of the floristic patterns will then be fit within the NVCS. The NVCS will be continuously updated as new information becomes available. The result of this process will be a list of all of the vegetation types found on the park organized within the NVCS. Each community occurring in the park will be thoroughly described based on the data collected on the park and the information available for the community from the NVCS classification (see **Section 6.3** below and the Vegetation Classification document). Vegetation field keys will be produced using the biological and environmental characteristics of the community identified from the plot data (see **Section 6.4**).

Photointerpretation keys will also be developed which link the patterns identified on imagery to the vegetation types of the NVCS (see **Section 6.4.1** below). To accomplish this, the photointerpreters will review the characteristics of the signatures (texture, tone, color, etc.) to identify which characteristics are diagnostic of the vegetation types from the NVCS (see the National Vegetation Classification System document for a detailed discussion of this process). The signatures initially identified on the imagery will then be documented to provide a guide for interpreting and mapping vegetation from the aerial photography.

Figure 4. Flow of Information from Plot Data to the Final Vegetation Mapping Map



6.1 Plot Data Management

All plot data will be managed using a relational database management system (RDBMS) with a file structure that is compatible with the Biological and Conservation Data system (BCD) used by the Natural Heritage Network. The data fields will have the same (or compatible) values as that of the fields in the Community Element Occurrence database in the BCD system, which was developed to manage the polygon-specific information collected on the field forms (see the National Vegetation Classification System document for a detailed description of the fields in this database). A database to manage plot-specific information is currently being developed and will be completed for this project. The plot data will be entered into this system and will be available for export to standard analysis packages.

The RDBMS used to manage plot data will be built using the Structured Query Language (SQL). SQL is a computer language used to interact with relational databases. Some major features of SQL, such as software independence, portability across computer systems, SQL standards, and client/server architecture, will help overcome the difficulty of data transformation, file compatibility, and connections with other systems that are often associated with sharing information. Programming the RDBMS in SQL will facilitate transfer of information within NPS systems as well as with other agencies. The RDBMS will provide a powerful tool to manage vegetation information for individual parks and for National Park Service (NPS) as a whole system in terms of data standardization, analysis, and transformation within and across agencies.

Automation of field data collection (field data loggers integrated with Global Positioning System and Geographical Information System) will be investigated during the prototype stage of the program (see **Section 7** below). This could eliminate the need to transfer between field data sheets and the plot RDBMS. The various input/output (I/O) functions and open file structure of the RDBMS will allow easy linkage and transfer of data between the RDBMS and standard statistical analysis programs and GIS. Standard data output functions will be written to facilitate export of data from the RDBMS to analysis software such as TWINSPAN (Hill 1979), CANOCO (ter Braak 1990), DECORANA (Hill 1980), SAS (1994), and others.

The aerial photointerpretation can be supported with the plot data by integrating the plot data with a GIS system. Most GIS systems have built-in interfaces with RDBMS so the data can be easily transferred among the systems. A GIS point coverage can be created from the locational fields in the plot database to display the spatial distribution of field plots to support the photointerpretation. This methodology will also be investigated during the prototyping effort.

6.2 Data Analysis

The plot data collected in the field will be used for multiple objectives, including evaluating the list of vegetation types within the park, creating vegetation keys, describing the range variation of vegetation across the mapping area, and creating aerial photointerpretation keys. All of these tasks will be accomplished through scientific analyses of the field plot data.

6.2.1 Park-based Vegetation List

Identifying the floristic patterns on the park and creating a complete park-based vegetation list will be based on both the plot data collected in the field during this project and any suitable existing vegetation information. Floristic patterns and their general relationship to key environmental variables in the park will be identified either quantitatively using analysis programs such as TWINSPAN (Hill 1979), CANOCO (ter Braak 1990), DECORANA (Hill 1980), SAS (1994), or qualitatively (see the National Vegetation Classification System document for a detailed description of the analysis procedure). The floristic patterns resulting from this analysis will be compared to the initial list of vegetation types identified for the park and to the initial signatures identified on the aerial photography.

The recognition of the distribution patterns of vegetation along environmental gradients will facilitate vegetation mapping based on remote sensing data and subsequent management of the parks resources. Because plot data collected at each site contain both environmental and vegetation information of the sampled plant community, trends in the relationship between the vegetation and the environment will be identified. Rigorous statistical analysis of these relationships, however, is not possible with the current design of the project and is beyond the scope of this project.

The result of these analysis procedures will be a preliminary description of the floristic patterns on the park and their broad relationships to the environmental gradients. These results will be reviewed by ecologists from The Nature Conservancy, the Natural Heritage Network, park staff, and other experts, and modified to develop a complete park-based vegetation list.

6.2.2 Relating the Floristic Patterns on the Park to the NVCS

The floristic patterns identified in the park will then be fit within the NVCS. The types will be placed into the physiognomic hierarchy and be compared to the corresponding types within the NVCS based on qualitative analysis of structure, species composition, and environmental characteristics. There may be interest on the part of the individual park, the National Park

Service or the U.S. Geological Survey, The Nature Conservancy, or other researchers in gaining a more rigorous understanding of the relationship between a particular type which occurs in the park and the characteristics of the types across its entire range. When this occurs, and funding is available, additional existing data on the type across its entire range will be quantitatively analyzed using the methods identified in the National Vegetation Classification System document. Types identified as new to the NVCS will be described based on the data collected in the park and assigned an appropriate confidence level.

The result of this analysis will be a complete list of all the types from the NVCS that occur in the park. This list will be thoroughly reviewed by the experts identified above.

6.3 Development of Vegetation Descriptions and Keys

All existing data will be used to develop descriptions and field keys for the vegetation across each park. These vegetation descriptions and keys will allow researchers and resource managers to rapidly identify vegetation types in the field. Detailed descriptions and keys will be necessary to ensure accurate evaluation of the vegetation in the field during the map validation and accuracy assessment process (see **Section 7.1.3**).

6.3.1 Vegetation Descriptions

Each vegetation type that occurs in the park will be fully described. The descriptions for each type will draw from the plot data collected in the park and other available information on the type from across the entire range of distribution. The descriptions will include a general characterization of the type based on the range-wide information and then focus on particular expressions of the type that are specific to the park. The descriptions will include information on the physiognomic and biotic traits of the vegetation, as well as environmental relationships, dynamic processes, community variability and other relevant factors. The descriptions will follow the format provided in the Community Characterization Abstract file of the Biological and Conservation Data System designed by The Nature Conservancy (See the **Appendix of the National Vegetation Classification System document**). Examples of the fields in this database file that may be completed in the description of each community are provided in **Table 3**.

Table 3. Minimum Set of Fields for Community Descriptions

Scientific name
Common name
Synonym
TNC system
Physiognomic class
Physiognomic subclass
Formation group
Formation
Alliance
Classification confidence level
Range
Environmental description
USFWS wetland system
Strata
Most abundant species
Diagnostic species
Vegetation description
Other noteworthy species
Conservation rank
Rank justification
Comments
References

6.3.2 Vegetation Keys

The field keys to the vegetation types will be developed on a park by park basis using the distinguishing physiognomic characteristics and species composition of the vegetation, along with the environmental relationships. These keys will be developed to identify the vegetation types formally classified in the NVCS as well as any non-homogeneous mapping units such as community complexes, mosaics and transition zones. The features that will generally be used to develop keys will be the structure and cover of the vegetation, along with the dominant and associated diagnostic species. When the vegetation information alone is not sufficient to confidently distinguish between closely related types, key environmental factors will be used to aid the field identification. The environmental variables that may be used as discriminating features include topographic position, elevation, slope/aspect, moisture regime, landform, soils, and surficial geology.

The NVCS hierarchy includes many of the distinguishing characteristics that can be used to key out the vegetation in the field. The field keys that will be developed on a park will only use the minimal number of characteristics that are required to correctly identify the type in the field. It will rarely be necessary to apply all of the physiognomic levels in the classification hierarchy in order to key out the vegetation on a particular park. Because each park will contain a different subset of the communities in the NVCS, different characteristics may be used to distinguish the same vegetation type from one park to another park.

The example below illustrates the minimal characteristics that were needed to identify the NVCS Deciduous Forest Alliances in the state of Maine (Maine Natural Heritage Program, 1991). The keys to the vegetation types for each National Park in the USGS/NPS Vegetation Mapping Program will follow a similar format.

Example: Field Key to the Deciduous Forest Alliances of Main

1a. Trees (woody plants usually over 5m tall) present and forming 10-100% cover.

    2a. Trees with their crowns interlocking, forming 60-100% [FOREST] 3

        3a. Deciduous species contribute >75% of the total tree cover **Deciduous Forest**

            4a. Upland 5

                5a. *Acer saccharum* dominant in the canopy 6

                    6a. Forest of sheltered hillsides or pockets (coves), with moist comparatively rich soils, sometimes bouldery; Acer saccharum usually strongly dominant; herb layer may contain rare species such as *Dryopteris goldiana, Panax quinquefolius, or Impatians pallida* .... ***Acer saccharum-Fraxinus americana-Tilia Americana* Forest Alliance**

                    6b. Forest of mid-elevation slopes and ridgelines; Acer saccharum typically co-dominant with *Betula alleghaniensis* and/or *Fagus grandifolia* .... ***Acer saccharum-Betula alleghaniensis-Tilia Americana* Forest Alliance**

                5a. *Quercus rubra* dominant in the canopy .... etc.

            4b. Wetland .... etc.

        3b. Deciduous species contribute <75% of the total tree cover .... etc.

    2b. Trees forming open to very open strands, with crowns not usually touching .... etc.

1b. Trees absent, or less than 5m tall, or forming <10% cover .... etc.

6.4 Photointerpretation Process

Once the list of the vegetation types in the park has been fit within the NVCS, the photointerpreters will begin to delineate these communities on the phot image. The photointerpretation and mapping process is one of successive approximation (see the National Vegetation Classification System document for a detailed description of this process). When in the field with the ecologists collecting the plot data, the photointerpreters will begin to identify and describe characteristics of the vegetation (e.g., crown shape and leaf characteristics of individual species, the composition and density of species, and the distribution of species) that create visual differences on the aerial photographs (e.g., differences in texture, tone, contrast, and color). When the initial floristic patterns are fit within the NVCS, the photointerpreters will begin to refine the characteristics they use to identify the vegetation in the field to those that are characteristic to the types in the NVCS.

The extent to which the photointerpreters can distinguish the diagnostic characteristics of the vegetation on the imagery will determine the level of information that can be mapped. For some vegetation types, the key characteristics of the vegetation will not be identifiable on the photographs (i.e., understory species composition). In these cases, the photointerpreters will use other clues to discern the vegetation types on imagery. For example, the key biological and environmental variables for vegetation type may also be used to assist the photointerpretation process. Where there are difficulties in identifying the diagnostic characteristics on the imagery, the type can be mapped at a higher level of the hierarchy, or with less accuracy (see the National Vegetation Classification System document for a detailed description of this issue).

The photointerpreters will continually refine their understanding of the characteristics of the vegetation on the imagery to create a set of decision rules for identifying every vegetation type in the park. These decision rules (or "photointerpretation keys") may represent vegetation types from different levels of the hierarchy due to the limitations described above. The decision rules (keys) will be accompanied by both written description and aerial photo examples. Throughout the project, the keys will be adjusted and refined to provide an accurate representation of the vegetation for the final map products.

6.4.1 Aerial Photointerpretation Keys

It is planned that photointerpretation keys will be developed as part of the park vegetation mapping process. Their purpose is to facilitate the training and orientation of the production staff and users, document the interpretation process, and help the photointerpreter to evaluate the photography in an organized and consistent manner.

Ideally, these keys would take the form of a dichotomous key, which allows the interpreter to find the correct answer through a process of elimination. However, dichotomous keys for vegetation identification cannot be developed in as straightforward a manner or as reliably as those that can be developed for cultural features or plant taxonomies. The differences in vegetation signatures are often very subtle and can be quite variable depending on the circumstances under which the photo was captured. Such things as soil moisture differences, wind conditions, photo processing, season, and sun angle can introduce considerable range in the expected signature of a vegetation type. By their nature, dichotomous keys force decisions. Errors will result when there is uncertainty about the choices.

The more useful approach is to develop keys based on photo/signature examples. Some aspects of a dichotomous key can be used to move through the physiognomic levels but the floristic-based units will be illustrated by numerous photographic samples with descriptive text. The descriptive text should include discussions on color, tone, texture, and pattern of the overall signature, the shapes and form of individual elements such as tree crown where visible and, just as importantly, the context in which the signature occurs. The discussion on context should address items such as drainage, slope, aspect, and other visible elements of the environment.

6.4.2 Photointerpretation Quality Assurance

The most important steps of the quality assurance process will occur at the field reconnaissance and photointerpretation stages of the effort. Any errors made at this stage, whether positional or thematic, will propagate throughout the entire process and will be extremely expensive to fix. The quality assurance objectives at this stage are to achieve consistency, accuracy, completeness, and documentation. This can be accomplished by planning and monitoring for the following:

> (1) Selecting and assigning field ecology and photointerpretation staff (PIs) with the requisite training and experience is critical. Training and orientation of the staff will be required to some degree but this cannot be substituted for the in-depth knowledge and experience of a professional staff with relevant experience. Specifically, the field ecologist should have expertise in the flora of the park and its environs. The PIs will require a background in natural science or ecology as well as photointerpretation.
>
> (2) The field ecology and PI staff must have a high level of interaction both in the field and in the office. Both groups bring special expertise to the project that must be integrated. It is expected that these two groups will provide each other a measure of cross training and will assist each other with specific tasks. The groups will be directed

to check each other's work for consistency and completeness. It is also an axiom that the more time the PI staff spends in the field, the better the work will be.

(3) The PI staff must have a high level of interaction and exchange of information among themselves. The only way to ensure a consistent approach to the photointerpretation is to have the PIs review each other's work in a systematic fashion. This can be programmed by assigning different PIs to work in adjacent areas and to assign in-process edits of each other's work.

(4) Systematic checking of the work and documentation of the process at several stages is mandatory. Senior staff will be required to check all work against specific checklists at the early and last stages of the process and they will provide direct feedback to the assigned staff. Field checking of the interpretation work while in the early stages of the process must also be part of the quality assurance program. Records will be kept of the errors to detect trends or any misunderstanding. Any designated corrective actions will be the responsibility of the interpreter and must be documented. In summary the important element of quality assurance are in-process edits, accountability, and coordination between the ecologist, PIs, and editors.

(5) Consistent work between parks is as important as consistency within a park. This is primarily achieved by a uniform set of guidelines and procedures, but is also supported by continuity in the PI/field teams. It is also recommended that an individual or individuals be assigned to the role of national consistency quality assurance. This position would have the advantage of a broad overview and could overcome the natural tendency to diverge in purpose and products.

6.5 Map Generation

The complete vegetation map of the entire park will be created by applying the decision rules developed from the sampled polygons. The map scale will be 1:24,000 with a minimum mapping unit of 0.5 hectares. The vegetation maps will represent every vegetation type that occurs throughout the mapping area if the polygons are greater than the minimum mapping unit. As a rule, every polygon will be attributed with one vegetation type from the NVCS (but see the National Vegetation Classification System document for a description of exceptions). The per-class accuracy of the maps will exceed 80 percent.

7.0 Validation and Accuracy Assessment

The objective of this section is to document the procedure for map validation and briefly describe the accuracy assessment procedures.

Validation and accuracy assessment are important steps in processing remote sensing data. They document the value of the resulting spatial products for the users and are used to increase efficiency of the methods. The use of the term "validation" for this report refers to the procedure that will be used to test the class accuracy of the preliminary vegetation maps and evaluate the methods used to create the maps. The validation procedures will detect significant errors within the maps and direct their correction. The term "accuracy assessment" refers to the procedures that will be followed to evaluate and document the thematic and spatial accuracy of the final map products for the U.S. Geological Survey/National Park Service vegetation mapping program.

7.1 Validation

The goal of the validation process is to identify and correct any errors on the preliminary map before the final map is produced. Once the preliminary map is created, it will be tested by selecting sample sites in the field and checking whether they have been accurately labeled using the vegetation descriptions and keys. Because of the high cost of field time, it may not be possible to do a statistically rigorous accuracy assessment of the preliminary map. Instead, a sampling procedure will be developed to detect error trends or sources in the map without doing a complete accuracy assessment. Steps can then be taken to alter procedures or provide feedback to the staff on the quality of work. Ideally the sampling procedure for map validation would be tested against a complete data set of known vegetation polygons in the field. Since these types of data sets are rare, this will not be possible. Instead, different sampling procedures for the map validation will be tested against the results of the accuracy assessment during the prototype phase of the program to develop the most efficient set of validation procedures.

The initial sampling methodology to be tested for map validation is described below. It follows closely methods for sample allocation described in **Section 5.3** above. The data analysis methods for the map validation will be similar to those delineated in the accuracy assessment report.

7.1.1 Sampling Approaches for parks of Different Sizes

The maximum amount of potential variation of each class will be tested during the validation process. The variation of the vegetation type will be sampled through stratification of sampling by biophysical cells and pattern variation in the photo signatures. This will increase the likelihood of finding an error in the map.

The approach for locating field sites for validation sampling will differ based on the size of the parks. The polygons to be tested must be large enough to allow characterization inside a 20 meter buffer strip around the polygon edge. Validation will not be necessary for small parks (<1 km^2) because all polygons will have been visited and most sampled during the field inventory stage. Vegetation polygons on medium parks (1–100 km^2) will be selected to test at least one sample per vegetation type per biophysical class across the entire park. The samples will be spread across the site and across the variation of the signatures for that type.
On the large parks (100–2,500 km^2) polygons will be selected to test at least one sample per vegetation type per biophysical class across the entire park. As with medium-sized parks, the polygons sampled will be spread across the site and across the variation of the signatures for that type. For very large parks (>2,500 km^2) which span different ecoregions, the environmental stratification will be applied to each ecoregion separately. Within the ecoregions, the very large parks will be sampled using the same methods as those used for large parks.

7.1.2 Number of Polygons to be Sampled

Generally, ten polygons of each vegetation type will be sampled during the map validation process. However, the number of polygons to be sampled will vary with the degree of environmental variability, the degree of inherent variability in the vegetation type, and the variability in the signature for the vegetation type. The different possible sampling scenarios are described below. **Table 4** shows the recommended sample sizes for validation.

Scenario A:

When a vegetation type has more than ten polygons distributed in more than ten environmental cells, one polygon per environmental cell type will be sampled. If the vegetation class shows a high signature variability in the aerial photos or is known to be particularly variable in species composition or structure, more sample plots may be taken in order to capture the variation.

Scenario B:

Where the type is found in fewer than ten biophysical cells, a minimum of ten polygons will be sampled across all biophysical cells of occurrence, other spatial distribution patterns, and differences in the spectral signatures.

Scenario C:

When a vegetation class has fewer than ten occurrences that were not sampled in the preceding vegetation sampling procedure, all those polygons will be validated for accuracy.

Table 4. Number of Validation Samples for Different Scenarios

Scenario	Descriptions	Number of Polygons	Number of Environmental Cells	Number of Samples
A	Class has many polygons that occur in more than ten environmental cells	≥ 10	≥ 10	Same as number of environmental cells*
B	Class has many polygons that occur in less than ten environmental cells	≥ 10	< 10	10*
C	Class has fewer than ten polygons	< 10	< 10	Sample all polygons

* More sample plots may be taken if the level of biological, environmental, or signature variability is high.

7.1.3 Validation of the Map in the Field

At each selected field site the vegetation on the ground will be identified using the vegetation keys and descriptions. The surveyors will need to know the polygon boundaries and the sample points but will not have knowledge of how the polygon has been labeled on the vegetation map prior to identifying it in the field. After the type has been classified by the validation team, it will be compared to the type labeled on the map. If the type was mislabeled, the surveyors will then identify the source of the error while they are still in the field.

7.1.3.1 Use of Vegetation Descriptions and Keys

The vegetation descriptions and keys will be used to complete both the map validation and accuracy assessment stages of this program. During both of these procedures the field teams will use these tools to the classify the vegetation in the map polygons that have been selected for field verification. They will then compare the classification determined during the verification process to the map label to determine whether the community type has been accurately identified on the map.

The manner in which the descriptions and keys in the field to determine the accuracy of labels on the vegetation map polygons will vary with the complexity of the mapped polygon. When the map polygon is a homogeneous patch of one vegetation type (or formally defined vegetation complex) which is larger than the minimum map unit, the vegetation keys, and descriptions will be used directly to label the vegetation map polygon.

As described ins Section 6.2.3 of the National Vegetation Classification document, there are several different situations where non-homogeneous mapping units will be labeled on the maps. How the vegetation descriptions and keys will be used to verify these non-homogeneous mapping units is described below.

> (1) Patches of vegetation larger than the minimum mapping unit which have inclusions of vegetation types which are smaller than the minimum mapping unit will be mapped as a single map polygon. These polygons will be labeled with the dominant vegetation type. During the map validation process the field teams will use the keys and descriptions to identify the dominant vegetation type, and they will not attempt to classify and inclusions that are smaller than the minimum mapping unit.
>
> (2) Vegetation types which occur together in a mosaic of patches each smaller that the minimum mapping unit will be mapped together in a single map polygon. The polygon will be labeled as a mosaic of both vegetation types. In these cases, the vegetation

descriptions and keys will be used to identify the mosaics composed of the component vegetation types. It will be critical that the field teams know where the boundaries have been drawn on the map to avoid including the vegetation from neighboring polygons as a component of the mosaic.

(3) Where transition zones between two vegetation types are larger than the minimum mapping unit, the zone will be mapped in a single polygon and will be labeled with the names of both communities and given the designation, "transition Zone." The vegetation descriptions and keys will be used to identify the "transition zone" type.

7.1.3.2 Data Collection

As a rule, plot data will not be collected during the map validation stage. The following information will be minimally recorded for validation sites. The Accuracy Assessment Field form (see **Appendix 12.0**) can be used with the exception that the staff will have previous knowledge of the labeled vegetation type.

(1) Unique Control #
(2) Actual Vegetation Type
(3) Labeled Vegetation Type
(4) Notes on sources of error for misidentified polygons
(5) Location

Detailed plot data will be collected using the standard field form when the vegetation type cannot be identified in the field through the vegetation descriptions and keys. These types will be evaluated and classified through a more thorough analysis of vegetation types in the area.

7.1.4 Data Analysis

The results of the validation exercise will represent the attribute accuracy of the preliminary map in the form of an error matrix. Data analysis will address both per-type users' and producers' accuracy in order to give as complete information as possible of the error properties of individual types in order to correct errors. The users' accuracy describes the probability that a sample from the classified data actually represents that category on the ground. It is computed by dividing the number of correctly classified samples by the total number of samples that were classified as belonging to that category. The producers' accuracy describes the probability that a reference sample has been classified correctly. It is computed by dividing the number of samples that have been classified correctly by the total number of reference samples in that class. **Section 5.2** of the "Accuracy Assessment Procedures" report for this project gives a detailed discussion of these two parameters.

7.1.5 Identification and Correction of Errors

Initially, there will be three options and associated actions that will follow the validation of the preliminary polygons.

(1) If the vegetation attribute for the polygon is validated through the vegetation key and description, this sample will be marked as correct.

(2) If the vegetation attribute for the polygon is not correct, the vegetation descriptions and keys will be used to determine the vegetation type that fits the field occurrence. The change in the vegetation type will be noted for the error matrix. If the error is significant, the vegetation map will be reviewed to assess the level of replication of this error across the map. If this is the case, the methodology will be refined, and the map will be reviewed and corrected.

(3) If the vegetation attribute for a polygon is not correct and it is not possible to find the correct type using the vegetation descriptions and key, a field plot will be completed to document the type. Standard procedures will be followed to determine whether this polygon reflects variation of an existing type or should be added to the vegetation list of the region as a new type. All polygons within this class across the entire vegetation map will be reviewed to assess whether the mislabeling represents a single anomaly or a pattern across the map. The methods will be revised to reflect the new information and the map will be fixed.

When the results of the map validation exercise demonstrate that particular classes cannot meet the 80 percent class accuracy standard for this project, three possible situations can arise (for more detailed descriptions of these situations, see the National Vegetation Classification System document):

(1) The accuracy for a particular class is less than 80 percent and NPS officials determine that the documented level of error for that particular class is acceptable.

(2) The accuracy for a particular class is less than 80 percent and the error is not acceptable. Supplemental correlation to environmental variables and further analysis of the photo signature will be required to elevate the accuracy level up to the program standard.

(3) The accuracy for a particular class is less than 80 percent and the error is not acceptable. Supplemental correlation to environmental variables and further analysis of the photo signature is not enabling a higher level of class accuracy. It will be necessary to classify this type at a coarser level in the classification hierarchy to meet the class accuracy requirements.

7.2 Accuracy Assessment of Final Products

After the final vegetation map has been completed, an assessment of class and positional accuracy across the park will be carried out. The accuracy assessment methods are fully described in a separate report in this series. The vegetation class accuracy will be determined through the stratification of sample points by class throughout the park. These assessment points will be spread randomly across the park. The final report will include a matrix documenting the per-class accuracy across the vegetation map. A sample Accuracy Assessment Field Form is included in **Appendix 12.1.1**.

8.0 Changing Technologies

Presently, there are new data collection and processing technologies available that offer considerable improvements over traditional methods. These include developments in integrated Global Positioning System/Geographical Information System, soft-copy photointerpretation, and data loggers with automated forms.

Furthermore, it is anticipated that over the life of the mapping program, additional and perhaps dramatic improvements in technology will occur. These new technologies offer the potential of cost savings and, in some cases more useful output or products. Nevertheless, new technology always presents risks that must be considered and then managed.

8.1 Integrated GIS/GPS and Data Loggers

One of the more promising new technologies is the automation of field data collection using integrated GIS/GPS. The convergence of GPS and GIS and document management technologies and the arrival of rugged and portable computers provide new means of collecting field data. Portable GIS with GPS will allow the rapid capture of information about features and phenomena, and the ability to map them in the field. The incorporation of automated forms packages and data logging software can speed data capture using menus and pick lists with predefined features, attributes, and space for numeric, or character value entry. (i.e., hydrologic regime or aspect). These automated forms packages can be customized with mathematical macros to perform some functions that would require a calculator, such as relative abundance calculated automatically by entering the species occurrence along a transect. These data can be automatically tagged to a GPS coordinate via connections to GPS receivers. Data collection templates can also be designed for quick transfer to relational databases or any SQL DBASE format. It is recommended that a data logging system built from off-the-shelf hardware and software be tested during the prototype stage. For additional discussion of GPS technology see **Section 7.1** in the Accuracy Assessment Methodology document.

8.2 Digital Orthophotography

The use of digital orthophotography (soft copy) in the photointerpretation process is also a very promising technology. It is still considered developmental for many applications, but recent advances have pushed it to the point where an investment in testing and evaluation is warranted.

Digital orthophotos are terrain-corrected images that can be used as precision basemaps, or they can be viewed on a screen as three-dimensional digital images for extracting and delineating features through a manual or partially automated process. The process involves scanning a film positive and then rectifying the image to a dense network of known points on a pixel-by-pixel basis. The digital terrain model (DTM) can be generated automatically in many systems following the standard photogrammetric steps of obtaining ground control and performing aerotriangulation. However, automated DTM feature extraction is far from perfected and it is often necessary to manually add breaklines and edit the DTM.

Once the orthophoto is created, it can be viewed on the screen in three dimensions (stereo) using special glasses, much like a mirror stereoscope except the display is heads-up and the operator can draw the digital line work directly on the image using a puck. Land base information can be added as well as thematic information. The advantages of the process are that certain steps, such as the transfer of line work and digitization of line work, are accomplished as the interpretation proceeds. It also means that the final products are highly accurate as the number of steps are reduced and the method is essentially photogrammetric. Additionally, if the original DTM is sufficiently dense, and the vertical as well as the horizontal control are field surveyed, then accurate NMAS topographic information, in the form of contours, can also be generated. This does mean additional expense.

Some of the disadvantages are the initial high cost of the software and hardware and the large size of the files created, particularly those associated with high resolution. Additionally, using the orthophoto for the land base means the polygon information will, in all likelihood, not register with other existing digital data tied to a USGS quadrangle without some manipulation. This could be a factor in the design of an overall multipurpose GIS.

However, the most basic concerns are whether photointerpretation can be accomplished as accurately on the screen as with the original diapositives and a high-powered mirror stereoscope, and does the use of the process significantly reduce total man-hours for a positive cost benefit ratio? It is proposed that these questions be tested during the prototype stage.

8.3 Strategy for Implementation of New Technology

The basic strategy for dealing with changing technology during the NPS mapping contract is to develop standards that will stand independently of the technology. That is to say the standards will not dictate how something is to be accomplished but rather define the content, accuracy, and documentation of the product. This will ensure that data being derived from the new technologies will not affect the utility of the existing data. Secondly, as new, promising technology becomes available, it will be evaluated first in benchmarks and then in prototype efforts to gauge its reliability, its cost-effectiveness, and, most importantly, whether or not it can perform to the documented standard.

9.0 Products

Multiple products will result from the implementation of the USGS/NPS Vegetation Mapping Program on a Park. The final products for a park will consist of the items detailed below.

9.1 Map Products

9.1.1 Vegetation Maps

The major product from this program will be the vegetation map for the park (and environs). The map will be available both in hard-copy and digital Geographical Information System formats. All vegetation polygons will be labeled with the vegetation type from the NVCS System and will have accompanying attributes concerning the vegetation type.

9.1.2 Map of the Biophysical Environment

The identification of pilot areas and the stratification of sampling for classification and validation will be based on a coarse biophysical characterization of the park. The environmental data will be available in digital or hard-copy format. The environmental data layers will be mapped individually and combined to produce a map of biophysical map units. Descriptive statistics on the distribution of the biophysical classes will also be available.

9.1.3 Map of Pilot Areas and Sampling Points

Map layers will be available delineating the pilot areas, sample points, and copies of the field sample forms.

9.2 Reports

9.2.1 Vegetation Descriptions and Field Keys

Descriptions for each of the vegetation types found in the park will be produced to accompany the vegetation map. The nomenclatural information about each vegetation type will include the scientific and common name, the name of this vegetation type in other classification systems, and the level of confidence in the classification unit. The vegetation descriptions will include the complete physiognomic classification for each type along with the abundant and diagnostic species associated with each strata. The environmental description will describe the physical and environmental location of the types in the landscape context. The distribution of each vegetation type will be described along with the conservation status throughout the range. Major references associated with the type will be listed.

Keys to each vegetation type will be developed for use in the field. The keys will provide the user a process to work through the structure, physiognomic characteristics, and the floristics to determine the vegetation type. These keys will be critical to support the identification of types during the map validation and accuracy assessment components of this program.

9.2.2 Park Inventory and Classification Methods

A brief report on the specific methodologies that were used on the project will be completed. This report will provide a log of the activities on the park, including a description of the planning process and resulting inventory approach. Reference will be made to the data collected, the participants in the mapping program, and the results that were generated.

9.3 Other Products/Benefits

The products listed above are in a tangible form as maps and reports. No less significant are the other, less-tangible products that include training, field samples, and the ability to assess the status and value of the vegetation types on the park in relation to the rest of the country.

10.0 Authors and Contributors

***** Identifies the major authors of this report. The other individuals listed contributed information and ideas or acted as reviewers.

Dennis Grossman*
Kathleen Lemon Goodin*
Xiaojun Li*
Cynthia Swinehart
The Nature Conservancy
1815 N. Lynn Street
Arlington, Virginia 22207

Don Faber-Langendoen*
The Nature Conservancy
Midwest Regional Office
1313 Fifth Street, SE, Suite 314
Minneapolis, Minnesota 55414

Mark Anderson*
Lesley Sneddon
The Nature Conservancy
Eastern Resource Office
11 Avenue de Lafayette
Boston, Massachusetts 02111

Alan Weakley
The Nature Conservancy
Southeast Regional Office
101 Conner Drive, Suite 302
P.O. Box 2267
Chapel Hill, North Carolina 27515

Patrick Bourgeron*
Marion Reid
The Nature Conservancy
Western Regional Office
2060 Broadway, Suite 230
Boulder, Colorado 80302

Kenneth Metzler
Connecticut Geological and Natural History Survey
Natural Resources Center
Department of Environmental Protection
State Office Building
Hartford, Connecticut 06100

Randy Vaughan*
Charles Convis
Anthony Curtis
Environmental Systems Research Institute, Inc.
380 New York Street
Redlands, California 92373-8100

Michael Goodchild
Frank Davis
National Center for Geographic Information Analysis
University of California at Santa Barbara
Santa Barbara, California 93106

11.0 Literature Cited

Allen, T.F.H. and T.B. Starr. 1982. Hierarchy: perspectives for ecological complexity. University of Chicago Press, Chicago, Illinois.

Austin, M.P. 1985. Continuum concept ordination methods and niche theory. Annual Review of Ecology and Systematics, 16: 39–61.

Austin, M.P. 1987. Models for the analysis of species response to environmental gradients. Vegetatio, 69: 35–45.

Austin, M.P. 1991. Vegetation theory in relation to cost-efficient surveys, pp. 17–22. C.R. Margules and M.P. Austin (editors). Nature conservation: cost effective biological surveys and data analysis. Commonwealth Scientific and Industrial Research Organization. Melbourne, Australia.

Austin, M.P. 1991b. Vegetation: data collection and analysis. C.R. Margules and M.P. Austin (editors). Nature conservation: cost effective biological surveys and data analysis, pp. 37–41. Commonwealth Scientific and Industrial Research Organization. Melbourne, Australia.

Austin, M.P. and E.M. Adomeit. 1991. Sampling strategies costed by simulation. C.R. Margules and M.P. Austin (editors). Nature conservation: cost effective biological surveys and data analysis, pp. 167–175. Commonwealth Scientific and Industrial Research Organization. Melbourne, Australia.

Austin, M.P. and T.M. Smith. 1989. A new model for the continuum concept. Vegetatio, 83: 35–47.

Austin, M.P. and P.C. Heyligers. 1989. Vegetation survey design for conservation: gradsect sampling of forests in northeastern New South Wales, 50: 13–32. Biological Conservation.

Austin, M.P. and P.C. Heyligers. 1991. New approach to vegetation survey design: gradsect sampling. C.R. Margules and M.P. Austin (editors). Nature conservation: cost-effective biological surveys and data analysis, pp. 31–36. Commonwealth Scientific and Industrial Research Organization. Melbourne, Australia.

Austin, M.P. and G.A. Yapp. 1978. Definition of rainfall regions of southeastern Australia by numerical classification methods. Archiv fur Meterologie, Geophysik und Bioklimatologie, Series B, 26:121–142.

Austin, M.P., R.B. Cunningham, and P.M. Fleming. 1984. New approaches to direct gradient analysis using environmental scalars and statistical curve fitting procedures. Vegetatio. 55:11–27.

Bailey, R.G. 1976. Eco-regions of the United States. U.S. Department of Agriculture, Forest Service, Intermountain Region. Ogden, Utah, USA.

Bailey, R.G., M.E. Jensen, D. Cleland, and P.S. Bourgeron. 1993. Design and use of ecological mapping units. M.E. Jensen and P.S. Bourgeron (editors). Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Belbin, L. and M.P. Austin. 1991. ECOSIM—a simulation model for training in cost-effective survey methods. In: C.R. Margules and M.P. Austin (editors). Nature conservation: cost effective biological surveys and data analysis, pp. 159–166. Commonwealth Scientific and Industrial Research Organization. Melbourne, Australia.

Bourgeron, P.S. and L.D. Engelking. 1993. A Preliminary Series Level Classification of the Western U.S. Unpublished report prepared by the Western Heritage Task Force for The Nature Conservancy. Boulder, Colorado, USA.

Bourgeron, P.S. and L.D. Engelking (editors). 1994. A Preliminary Vegetation Classification of the Western United States. Unpublished report prepared by the Western Heritage Task Force for the Nature Conservancy. Boulder, Colorado, USA.

Causton, D.R. 1988. Introduction to vegetation analysis. Unwin Hyman. London, England.

Christian, C.S. and G.A. Stewart. 1953. General report on the survey of Katherine-Darwin region, 1946. Land Res. Series 1. CSIRO. Melbourne, Australia.

Clements, F.E. 1936. Nature and structure of the climax. Journal of Ecology, 24:252–284.

Davis, F.W., D.A. Quattrochi, M.K. Ridd [and others]. 1991. Environmental analysis using integrated GIS and remotely sensed data: some research needs and priorities. Photogrammetric Engineering and Remote Sensing, 57:689–697.

Delcourt, H.R. and P.A. Delcourt. 1988. Quatenary landscape ecology: relevant scales in space and time. Landscape Ecology, 2:45–61.

DeVelice, R.L., G.J. Daumiller, P.S. Bourgeron, and J.O. Jarvie. 1993. Bioenvironmental representativeness of nature preserves: assessment using a combination of a GIS and a rule-based model. Proceedings, first biennial scientific conference on the Greater Yellowstone Ecosystem, September 1992. Mammoth, Wyoming: National Park Service: 51-58.

Fisser, H.G., D.C. Trueblood, and C.H. Butterfield. 1980. Soil–vegetation relationships on rangeland enclosures in the Overland Planning Unit of south central Wyoming. University of Wyoming Scientific Report No. 1042. Wyoming Agricultural Experiment Station, Laramie, Wyoming, USA.

Gauch, H.G., Jr. 1982. Multivariate analysis in community ecology. Cambridge University Press. Cambridge, England.

Green, R.H. 1980. Multivariate approaches in ecology: the assessment of ecological similarity. Annual Review of Ecology and Systematics, 11:1–14.

Gillison, A.N. and D.J. Anderson (editors). 1981. Vegetation classification in Australia. Commonwealth Scientific and Industrial Research Organization: Canberra, Australia.

Gillison, A.N. and K.R.W. Brewer. 1985. The use of gradient directed transects or gradsects in natural resource survey. Journal of Environmental Management. 20:103–127.

Godron, M. and R.T.T. Forman. 1983. Landscape modification and changing ecological characteristics. In: H.A. Mooney and M. Godron (editors). Disturbance and ecosystems: components of response. Springer-Verlag, pp. 12–28. New York, USA.

Gruell, G.E. 1983. Fire and vegetative trends in the northern Rockies: interpretations from 1871–1982 photographs, p. 117. U.S. Department of Agriculture, Forest Service, General Technical Report INT-159. Intermountain Forest and Range Experiment Station, Ogden, Utah, USA.

Hill, M.O. 1979. TWINSPAN - a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ecology and Systematics, Cornell University, Ithaca, New York.

Hill, M.O. and H.G. Gauch. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio, 42:47–58.

Helman, C. 1983. Inventory analysis of southern New South Wales rainforest vegetation. M.S. thesis. University of New England.

Jenkins, R.E. 1976. Maintenance of natural diversity: approach and recommendations. Pp 441–451. In: Transactions of the 41st North American Wildlife Conference, 4 March 1976, Wildlife Management Institute Washington, D.C., USA.

Jensen, M.E., W. Hann, R.E. Keane [and others]. 1993. ECODATA—a multiresource database and analysis system for ecosystem description and evaluation. In: M.E. Jensen and P.S. Bourgeron (editors). Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Deparment of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Jensen, M.E. and R. Everett. 1993. An overview of ecosystem management principles. In: M.E. Jensen and P.S. Bourgeron (editors). Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Deparment of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Kent, M. and P. Coker. 1992. Vegetation Description and Analysis. Belhaven Press, London, England.

Kovalchik, B.L. and L.A. Chitwood. 1990. Use of geomorphology in the classification of riparian plant associations in mountainous landscapes of central Oregon, USA. Forest Ecology and Management. 33/34:405–418.

Kuchler, A.W. 1988. Ecological vegetation maps and their interpretation. In: A.W. Kuchler and I.S. Zonneveld (editors). Vegetation mapping, pp. 469–480. Kluwer Academic Publishers. Boston, Massachusetts, USA.

Kuchler, A.W. and I.S. Zonneveld. 1988. Vegetation mapping. Kluwer Academic Publishers. Boston, Massachusetts, USA.

Lathrop, R.G. and D.L. Peterson. 1992. Identifying structural self-similarity in mountainous landscapes. Landscape Ecology 6:233–238.

Levin, S.A. 1992. The problem of pattern and scale in ecology. Ecology, 73:1,942–1,968.

Looman, J. 1980. The vegetation of the Canadian Prairie Provinces II. The grasslands, Part 1, Phytoceoenologia, 8:153–190.

Mackey, B.G., H.A. Nix, M.F. Hutchinson, and J.P. MacMahon. 1988. Assessing representativeness of places for conservation reservation and heritage listing. Environmental Management. 12:501–514.

Mackey, B.G., H.A. Nix, J.A. Stein, and S.E. Cork. 1989. Assessing the representativeness of the wet tropics of Queensland World Heritage Property. Biological Conservation. 50:279–303.

Milne, B. 1993. Pattern analysis for landscape evaluation and characterization. In: M.E. Jensen and P.S. Bourgeron (editions) Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Minshall, G.W. 1993. Stream-riparian ecosystems: rationale and methods for basin-level assessments of management effects. In: Jensen, M.E.; Bourgeron, P.S., (editions) Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology, p. 547. John Wiley and Sons, New York, New York, USA.

Nix, H.A. 1982. Environmental determinants and evolution in Terra Australia. In: Barker, W.R.; Greenslade, P.J.M. (editions) Evolution of the flora and fauna of arid Australia, Peacock, South Australia. pp. 47–66.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers. 77:118–125.

Orloci, L. 1978. Multivariate analysis in vegetation research. Second Editon. Dr. W. Junk Publishers. The Hague, Netherlands.

Orloci, L. and W. Stanek. 1979. Vegetation survey of the Alaska Highway, Yukon Territory: types and gradients. Vegetatio. 41:1–56.

Pielou, E.C. 1984. The interpretation of ecological data: a primer of classification and ordination, p. 263. John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore.
Pinay, G., Fabre, A. Fabre, P.H. Vervier, F. Gazelle. 1992. Control of C, N, P distribution in soils of riparian forest. Landscape Ecology. 6(3):121–132.

Pressey, R.L.; A.O. Nicholls. 1991. Reserve selection in the western division of New South Wales: development of a new procedure based on land system mapping. In: Margules, C.R., M.P. Austin, (editions) Nature conservation: cost-effective biological surveys and data analysis, pp. 98-105. Commonwealth Scientific and Industrial Research Organization: Melbourne, Australia.

Reed, R.A., R.K. Peet, M.W. Palmer, and P.S. White, 1993. Scale dependence of vegetation-environment correlations: A case study of a North Carolina piedmont woodland. J. of Veg. Sci. 4:329–340.

Rice, B. and M. Westoby. 1983. Plant species richness at the 0.1 hectare scale in Australian vegetation compared to other continents. Vegetatio, 52:129–140.

Rowe, J.S., J.W. Sheard, 1981. Ecological land classification: a survey approach. Environmental Management. 5:451–464.

Scott, J.M., B. Csuti, J.J. Jacobi, J.E. Estes. 1987. Species richness: a geographic approach to protecting future biological diversity. BioScience. 37:782–788.

Sellers, P.J., F.G. Hall, G. Asrar, [and others]. 1988. The first ISLSCP field experiment (FIFE). Bulletin of the American Meterological Society. 69:22–27.

Swanson, F.J., T.K. Kratz, N. Caine, R.G. Woodmansee. 1988. Landform effects on ecosystem patterns and processes. BioScience. 38:92–98.

ter Braak, C.J.F. 1990. CANOCA — a FORTRAN program for CANOnical Community Ordination by [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis, version 3.10. Microcomputer Power, Ithaca, New York, USA.

Turner, M.G., R.H. Gardner, R.V. O'Neill. 1993. Multiscale organization of landscape heterogeneity. In: Jensen, M.E.; Bourgeron, P.S., eds. Eastside Forest Ecosystem Health Assessment—Volume II: Ecosystem management: principles and applications. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon, USA.

Urban, D.L., R.V. O'Neill, H.H. Shugart, Jr. 1987. Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns. BioScience. 37:119–127.

Walter, H. 1973. Die vegetation der Erde I. Tropische and subtropische Zonen. Third edition. Fisher, Jena, Stuggart, Germany.

Walter, H. 1979. Vegetation of the earth and ecological systems of the geobiosphere. Heidelberg: Springer Verlag.

Weir, D.A. and J.B. Wilson, 1988. Micro-pattern in an area of New Zealand alpine vegetation. Vegetatio, 73:81–88.

Westhoff, V., E. Van der Maarel. 1978. The Braun-Blanquet approach. In: R.H. Whittaker, (editon) Classification of plant communities. The Hague: Dr. W. Junk Publishers: Chapter 20.

Whittaker, R.H. 1962. Classification of natural communities. Botanical Review 28:1–239.

Whittaker, R.H. 1977. Evolution of species diversity in land communities. Evolutionary Biology, 10:1–67.

Wiens, J.A. 1989. Spatial scaling in ecology. Functional Ecology. 3: 85–397.

Zonneveld, I.S. 1988b. Landscape (ecosystem) and vegetation maps, their relation and purpose. In: A.W. Kuchler, I.S. Zonneveld, (editions) Vegetation mapping, pp. 481–486. Kluwer Academic Publishers: 481-486. Boston, Massachusetts, USA.

Zonneveld, I.S. 1989. The land unit— a fundamental concept in landscape ecology, and its application. Landscape Ecology 3:67–86.

12.0 Appendixes

12.1 Field Forms

APPENDIX 12.1.1 NATIONAL PARK VEGETATION MAPPING PROGRAM: PLOT SURVEY FORM

IDENTIFIERS/LOCATORS

Polygon Code___________________________ Plot Code____

Provisional Community Name____

State _________ Park Name__________________________________ Park Site Name______________________

Quad Name____ Quad Code_____________________

Latitude___ ___ ___ ___ ___ ___ N Longitude___ ___ ___ ___ ___ ___ ___ W GPS Error________________

Survey Date_____________ Surveyors____

Directions to Plot

Plot length____________ Plot width____________ Plot Photos (y/n) ______ Plot Permanent (y/n) ________

Plot representativeness

ENVIRONMENTAL DESCRIPTION

Elevation ______________________ Slope _____________________ Aspect___________________

Topographic Position

Landform

Surficial Geology

Hydrologic regime

Tidal
___Irregularly Exposed
___Regularly Flooded
___Irregularly Flooded
___Unknown

Non-Tidal
___Permanently Flooded
___Semipermanently Flooded
___Seasonally/Temporarily Flooded
___Saturated
___Seasonally flooded/saturated
___Intermittently flooded

Salinity/Halinity modifiers
___Saltwater
___Brackish
___Freshwater

Soil Taxon/Description

Soil Texture
___ sand ___ sandy loam ___ loam ___ silt loam
___ clay loam ___ clay ___ peat ___ muck

Soil Drainage
___Rapidly drained
___Moderately well drained
___Somewhat poorly drained
___Well drained
___Poorly drained
___Very poorly drained

VEGETATION DESCRIPTION

Leaf Type
___Broad-leaved
___Needle-leaved
___Microphyllous
___Graminoid
___Forb
___Pteridophyte

Leaf phenology (of uppermost stratum having >10% cover)

Trees and Shrubs	Herbs
___Evergreen	___Annual
___Deciduous	___Perennial
___Cold-deciduous	
___Drought-deciduous	
___Mixed	
___Mixed evergreen - cold-deciduous	
___Mixed evergreen - drought-deciduous	

Strata	Height	% Cover	Diagnostic species (if known)
T1 Emergent	_______	_______	______________________________
T2 Canopy	_______	_______	______________________________
T3 Sub-canopy	_______	_______	______________________________
S1 Tall shrub	_______	_______	______________________________
S2 Short Shrub	_______	_______	______________________________
H Herbaceous	_______	_______	______________________________
N Non-vascular	_______	_______	______________________________
V Vine/liana	_______	_______	______________________________
E Epiphyte	_______	_______	______________________________

Cowardin System
___Upland ___Palustrine ___Estuarine
___Lacustrine ___ Riverine

Physiognomic class
___Forest ___Woodland ___Sparse Woodland ___Shrubland ___Sparse Shrubland ___Dwarf Shrubland
___Sparse Dwarf Shrubland ___Herbaceous ___Sparse vascular vegetation

Species/percent cover: starting with the uppermost stratum, list all species and % cover for each in the stratum. For forests and woodlands, list on a separate line below each tree species the DBH of all trees above 10 cm diameter. Separate measurements with a comma. Put an asterisk next to any species that are known diagnostics for a particular community in the classification

Species outside plot	Natural and Anthropogenic Disturbance	Animal Use Evidence

ACCURACY ASSESSMENT FIELD FORM

CONTROL#_____ PARK CODE_____ TEAM LEADER ___________________________
ORIGINAL SAMPLE SITE_____YES _____NO; REPLACEMENT FOR CONTROL#______
USGS 7.5"____________ DATE________________
LOCATION: LAT__________ LONG __________ _____GPS _____MAP

LOCATION
DESCRIPTION:____
____
____
____
____
____

GPS UNIT#__________ MODEL__________ EST. ERROR__________
SAMPLE TYPE: ______GROUND ______AIR OTHER_________
OBSERVATION AREA: _______ha.(approx.) SHAPE:_______________
GROUND PHOTOS ____YES ____NO (valid photos must have visible control # in scene)

CLASSIFICATION: ALLIANCE:________________________________
COMMUNITY:_____________________________

CONFORMANCE TO KEY/
COMMENTS:____
____
____
____
____
____
____
____
____

SPECIES	%COVER	STRATUM
________________	________________	________________
________________	________________	________________
________________	________________	________________
________________	________________	________________

APPENDIX 12.1.2 Instructions for NPS Vegetation Mapping Field Form

Polygon Code — Code indicating the vegetation polygon where the plot was taken.

Plot Code — Code indicating the specific plot within the vegetation polygon. This field will be used to track the data when more than one plot is taken within a vegetation polygon.

Provisional Community Name — Using the classification, assign the name of the vegetation type which most closely resembles this type. Enter the finest level of the classification possible. This is meant to be a field call of the vegetation classification and may change when the data are analyzed.

State — state where the survey was conducted.

Park Name — Name of the national park where the data were collected (if sampling outside of the park boundaries, list the name of the park and state from which the sample was taken outside of the boundaries.

Park Site Name — Provisional name assigned by field worker that describes where the data were collected; it should represent an identifiable feature on a topographic map.

Quad Name(s) — appropriate name/scale from survey map used; use 7.5-minute quadrangle if possible.

Quad Code(s) — code of quadrangle map.

Latitude — latitude in degrees, minutes, seconds (Use GPS, do not estimate.)

Longitude — longitude in degrees, minutes, seconds (Use GPS, do not estimate.)

GPS Error — enter the error inherent in the GPS type/model used.

Survey Date — date the survey was taken; year, month, day.

Surveyors — Names (and addresses, if appropriate) of surveyors, principle surveyor listed first.

Directions to Plot — precise directions to the site using a readily locatable landmark (e.g., a city, a major highway, etc.) as the starting point on a state or local road map. Use clear sentences that will be understandable to someone who is unfamiliar with the area and has only your directions to follow. Give distances as closely as possible to the 0.1 mile and use compass directions. Give additional directions to the plot within the site.

Plot Length and Plot Width — enter width and length dimensions for rectangular (or square) plots, or radius length for circular plots. Choose the appropriate plot size based on the following:

Forest:	200 – 500 m^2
Shrubland:	50 – 200 m^2
Grassland:	50 – 100 m^2
Dwarf-shrub heath:	10 – 25 m^2
Moss communities:	1 – 4 m^2
Lichen communities:	0.1 – 1 m^2

(Source: D. Mueller-Dombois and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons. New York.)

Plot Photos — Check off if photos of the plot have been taken at the time of sampling.

Plot Permanent — Check off if the plot has been permanently marked.

Plot Representativeness — Does this plot represent the full variability of the polygon? If not, were additional plots taken? Note additional species not seen in plot in the space provided below.

ENVIRONMENTAL DESCRIPTION

Elevation — elevation of the plot: specify whether in feet or meters (this will depend on the units used on the topographic map/DEMs being used).

Slope — measure slope degrees using a clinometer.

Aspect — enter slope aspect; use a compass (be sure to correct for the magnetic declination).

Topographic Position — Topographic position of the plot. NOTE: A comprehensive list of topographic positions is being developed. The list below provides an example of the topographic positions that might be included.

- INTERFLUVE (crest, summit, ridge): Linear top of ridge, hill, or mountain; the elevated area between two fluves (drainageways) that sheds water to the drainageways.

- HIGH SLOPE (shoulder slope, upper slope, convex creep slope): Geomorphic component that forms the uppermost inclined surface at the top of a slope. Comprises the transition zone from backslope to summit. Surface is dominantly convex in profile and erosional in origin.

- HIGH LEVEL (mesa): Level top of plateau.

- MIDSLOPE (transportational midslope, middle slope): Intermediate slope position.

- BACKSLOPE (dipslope): Subset of midslopes that are steep, linear, and may include cliff segments (fall faces).

- STEP IN SLOPE (ledge, terracette): Nearly level shelf interrupting a steep slope, rock wall, or cliff face.

- LOWSLOPE (lower slope, foot slope, colluvial footslope): Inner gently inclined surface at the base of a slope. Surface profile is generally concave and a transition between midslope or backslope, and toeslope.

- TOESLOPE (alluvial toeslope): Outermost gently inclined surface at base of a slope. In profile, commonly gentle and linear and characterized by alluvial deposition.

- LOW LEVEL (terrace): Valley floor or shoreline representing the former position of an alluvial plain, lake, or shore.

- CHANNEL WALL (bank): Sloping side of a channel.

- CHANNEL BED (narrow valley bottom, gully arroyo): Bed of single or braided watercourse commonly barren of vegetation and formed of modern alluvium.

- BASIN FLOOR (depression): Nearly level to gently sloping, bottom surface of a basin.

Landform — enter the landform that describes the site where the plot was taken. NOTE: A comprehensive list of landforms is currently being developed.

Surficial Geology — note the geologic substrate influencing the plant community (bedrock or surficial materials). NOTE: A comprehensive list of surficial geologic factors is being developed. The list below provides an example of the values that might be included.

- IGNEOUS ROCKS
  - Granitic (Granite, Schyolite, Syenite, Trachyte)
  - ioritic (Diorite, Dacite, Andesite)
  - Gabbroic (Gabbro, Basalt, Pyroxenite, Peridotite)
- SEDIMENTARY ROCKS
  - Conglomerates and Breccias
  - Sandstone
  - Siltstone
  - Shale
  - imestone and Dolomite
  - Marl
  - Gypsum
- METAMORPHIC ROCKS
  - Gniess
  - Schist
  - Slate and Phyllite
  - Marble
  - Serpentine
- GLACIAL DEPOSITS
  - Undifferentiated glacial deposit
  - Till
  - Moraine
  - Bedrock and till
  - Glacio-fluvial deposits (outwash plains, ice-contacted GF deposits, eskers, kames, pro-glacial deltas, crevasse filling, etc.)
  - Deltaic deposits (alluvial cones, deltaic complexes)
  - Lacustrine and fluvial deposits (glacio-fluvial, fluvio-lacustrine, freshwater sandy beaches, stony/gravelly shoreline)
  - Marine deposits (bars, spits, sandy beaches, old shorelines, old beach ridges, old marine clays, etc.)
- ORGANIC DEPOSITS:
  - Peat (with clear fibric structure)
  - Muck
  - Marsh, regularly flooded by lake or river (high mineral content)

- SLOPE AND MODIFIED DEPOSITS:
  - talus and scree slopes
  - olluvial
  - solifluction, landslide
- AEOLIAN DEPOSITS
  - dunes
  - aeolian sand flats
  - loess deposits
  - cover sands

Hydrologic Regime — Assess the hydrologic regime of the plot using the descriptions below. Hydrological modifiers used to identify wetland units at the formation level (adapted from Cowardin et al. 1979).

Tidal

Irregularly Exposed — Land surface is exposed by tides less often than daily; the area from mean low tide to extreme low spring tide. The area on NOS charts from seaward edge of light green (mean low water) to depth contour (often in blue tone) approximately extreme low water (includes some mangrove and/or bald cypress swamps).

Regularly Flooded — Tidal water alternately floods and exposes the land surface daily, from mean low (lower low on west coast) to mean high (higher high on west coast) tide (includes cordgrass low marshes).

Irregularly Flooded — Tidal water floods land surface less often than daily. The area must flood by tide at least once yearly as a result of extreme high spring tide, plus wind, plus flow. The area extends from mean high water inland to the maximum extent of tide plus the splash zone (includes salt hay meadows).

Unknown — The water regime is not known. Unit is described simply as "wetland."

Non-Tidal

Permanently Flooded — Water covers land surface at all times of year in all years. (includes many rooted emergent and floating aquatics)

Semipermanently Flooded — Surface water persists throughout the growing season in most years. Land surface is normally saturated when water level drops below soil surface (includes most bald cypress swamps, marshes).

Seasonally/Temporarily Flooded — Surface water is present during the growing season, but is absent by the end of the growing season in most years. The water table, after flooding, ceases to be very variable, extending from saturated to a water table well below the ground surface (includes floodplains and wet meadows).

Saturated — Surface water is seldom present, but substrate is saturated to surface for extended periods during the growing season (includes bogs and fens).

Seasonally Flooded/Saturated — The water table remains at or near the soil surface following flooding. Standing water can persist in depressions for much of the growing season; the soils are generally saturated when the water table drops below the soil surface (includes most wooded swamps).

Intermittently Flooded — Substrate is usually exposed, but surface water present for variable periods without detectable seasonal periodicity. This modifier was developed for use in arid Western United States to describe water regimes of playa lakes, and will apply to other areas as well. Inundation is not predictable to a given season and is dependent on highly localized rain storms. Playa lakes, intermittent streams, and dry washes are only considered to be wetlands if they support hydrophytes and/or have hydric soils.

Unknown — The water regime of the area is not known. The unit is simply described as "wetland."

Salinity/Halinity Modifiers — Enter the salinity/halinity modifiers of the hydrologic regime using the scale below.

Inland		Coastal Tidal
Saltwater	>30 ppt	Saltwater-tidal
Brackish	0.5–30 ppt	Brackish
No Equivalent	<0.5 ppt	Freshwater

Soil Taxon/Description — Provide the soil name and the name of the soil report/map from which the information was obtained. Also provide a basic description of the soils noting the most significant features with respect to classifying the vegetation. A soil core should be taken. Describe the soil horizons and note the depth, texture, and color of each. Note significant changes such as depth to mottling, depth to water table, root penetration depth, and depth of the organic layer. Also include a general description of the soil depth class (shallow, deep, very deep, etc.) pH, stoniness, erosion potential and type, etcetera. If it is not possible to take a soil core, as much information as possible should be recorded from the soil report and it should be noted that no core was taken.

Soil Texture — Using the key below, assess average soil texture.

Simplified Key to Soil Texture (Brewer and McCann, 1982)

A1 Soil does not remain in a ball when squeezed.. sand

A2 Soil remains in a ball when squeezed.. B

B1 Squeeze the ball between your thumb and forefinger, attempting to make a ribbon that you push up over your finger. Soil makes no ribbon.................................. loamy sand

B2 Soil makes a ribbon; may be very short..C

C1 Ribbon extends less than 1 inch before breaking..D

C2 Ribbon extends 1 inch or more before breaking..E

D1 Add excess water to small amount of soil; soil feels at least slightly gritty ....
....loam or sandy loam

D2 Soil feels smooth...silt loam

E1 Soil makes a ribbon that breaks when 1–2 inches long; cracks if bent into a ring....... F

E2 Soil makes a ribbon 2+ inches long; does not crack when bent into a ring.................G

F1 Add excess water to small amount of soil; soil feels at least slightly gritty ....
....sandy clay loam or clay loam

F2 Soil feels smooth...silty clay loam or silt

G1 Add excess water to a small amount of soil; soil feels at least slightly gritty ....
.... sandy clay or clay

G2 Soil feels smooth...silty clay

Soil Drainage — The soil drainage classes are defined in terms of (1) actual moisture content (in excess of field moisture capacity) and (2) the extent of the period during which excess water is present in the plant-root zone.

It is recognized that permeability, level of groundwater, and seepage are factors affecting moisture status. However, because these are not easily observed or measured in the field, they cannot generally be used as criteria of moisture status. It is further recognized that soil profile morphology, for example mottling, normally, but not always, reflects soil moisture status. Although soil morphology may be a valuable field indication of moisture status, it should not be the overriding criterion. Soil drainage classes cannot be based solely on the presence or absence of mottling. Topographic position and vegetation as well as soil morphology are useful field criteria for assessing soil moisture status.

- RAPIDLY DRAINED — The soil moisture content seldom exceeds field capacity in any horizon except immediately after water addition. Soils are free from any evidence of gleying throughout the profile. Rapidly drained soils are commonly coarse textured or soils on steep slopes.

- WELL DRAINED — The soil moisture content does not normally exceed field capacity in any horizon (except possibly the C) for a significant part of the year. Soils are usually free from mottling in the upper 3 feet, but may be mottled below this depth. B horizons, if present, are reddish, brownish, or yellowish.

- MODERATELY WELL DRAINED — The soil moisture in excess of field capacity remains for a small but significant period of the year. Soils are commonly mottled (chroma < 2) in the lower B and C horizons or below a depth of 2 feet. The Ae horizon, if present, may be faintly mottled in fine-textured soils and in medium-textured soils that have a slowly permeable layer below the solum. In grassland soils the B and C horizons may be only faintly mottled and the A horizon may be relatively thick and dark.

- SOMEWHAT POORLY DRAINED — The soil moisture in excess of field capacity remains in subsurface horizons for moderately long periods during the year. Soils are commonly mottled in the B and C horizons; the Ae horizon, if present, may be mottled. The matrix generally has a lower chroma than in the well-drained soil on similar parent material.

- POORLY DRAINED — The soil moisture in excess of field capacity remains in all horizons for a large part of the year. The soils are usually very strongly gleyed. Except in high-chroma parent materials the B, if present, and upper C horizons usually have matrix colors of low chroma. Faint mottling may occur throughout.

- VERY POORLY DRAINED — Free water remains at or within 12 inches of the surface most of the year. The soils are usually very strongly gleyed. Subsurface horizons usually are of low chroma and yellowish to bluish hues. Mottling may be present but at the depth in the profile. Very poorly drained soils usually have a mucky or peaty surface horizon.Simplified Key to Soil Texture (Brewer and McCann, 1982).

VEGETATION DESCRIPTION

Leaf Type — Select one value which best describes the leaf form of the uppermost stratum which contains at least 10% cover.

- BROAD-LEAF — Woody vegetation primarily broad-leaved (generally contributes greater than 50 percent of the total woody cover).

- NEEDLE-LEAF — Woody vegetation primarily needle-leaved (generally contributes greater than 50 percent cover).

- MICROPHYLLOUS — Woody cover primarily microphyllous.

- GRAMINOID — Herbaceous vegetation composed of more than 50 percent graminoid/stipe leaf species.

- BROAD-LEAF-HERBACEOUS (FORB) — Herbaceous vegetation composed of more than 50% broad-leaf forb species.

- PTERIDOPHYTE — Herbaceous vegetation composed of more than 50 percent species with frond or frond-like leaves.

Leaf phenology — Select the value that best describes the leaf phenology of the uppermost stratum which contains at least 10 percent cover.

- EVERGREEN — Greater than 75 percent of the total woody cover is never without green foliage.

- DECIDUOUS — Greater than 75 percent of the total woody cover sheds its foliage simultaneously in connection with the unfavorable season.

- COLD DECIDUOUS — Unfavorable season mainly characterized by winter frost.

- DROUGHT DECIDUOUS — Unfavorable season mainly characterized by drought, in most cases winter-drought. Foliage is shed regularly every year. Most trees with relatively thick, fissured bark.

- MIXED EVERGREEN – DECIDUOUS — Evergreen and deciduous species generally contribute 25–75 percent of the total woody cover.

- MIXED EVERGREEN – COLD DECIDUOUS — Evergreen and cold-deciduous species admixed.

- MIXED EVERGREEN – DROUGHT DECIDUOUS — Evergreen and drought-deciduous species admixed.

- PERENNIAL — Herbaceous vegetation composed of more than 50 percent perennial species.

- ANNUAL - Herbaceous vegetation composed of more than 50 percent annual species.

Strata/Lifeform, Height, Cover, Diagnostic Species — Visually divide the community into vegetation layers (strata). Indicate the average height of the stratum in the first column, and average percent cover (using the cover scale below) of the whole stratum in the second column. Trees are defined as single-stemmed woody plants, generally 5m in height or greater at maturity and under optimal growing conditions. Shrubs are defined as multiple-stemmed woody plants generally less than 5m in height at maturity and under optimal growing conditions. If species known to be diagnostic of a particular vegetation type are present, list them. Leave blank if the diagnostics are not known.

Cover Scale for Strata

01	0 - 10%
02	10 - 25%
03	25 - 60%
04	60 - 100%

Cowardin System — If the system is a wetland, enter the name of the USFWS system that best describes its hydrology and landform. Indicate "upland" if the system is not a wetland.

Physiognomic Type — Select the value that best describes the physiognomy. Definitions are modified from the 1973 UNESCO and 1984 Driscoll et al. Formation Classes and are defined by the relative percent cover of the tree, shrub, dwarf shrub, herbaceous, and nonvascular strata.

- FOREST — Trees usually over 5m tall with crowns interlocking (generally forming 60–100% cover). Shrubs, herbs and nonvascular plants may be present at any cover value.

- WOODLAND — Open stands of trees usually over 5m tall with crowns not usually touching (generally forming 25-60% cover). Shrubs, herbs, and nonvascular plants may be present at any cover value.

- SPARSE WOODLAND — Trees usually over 5m tall with widely spaced crowns (generally forming 10–25% canopy cover. Shrubs herbs and non-vascular plants may be present with any cover value.

- SHRUBLAND — Shrubs and/or small trees usually 0.5–5.0 meters tall with individuals or clumps not touching to interlocking (generally forming >25% canopy cover). Trees may be present, but with cover 10 percent or less. Herbs and nonvascular plants may be present at any cover value.

- SPARSE SHRUBLAND — Shrubs and/or small trees usually 0.5 to 5m tall with individuals or clumps widely spaced (generally forming 10–25% canopy cover. Trees may be present, but with cover 10 percent or less. Herbs and nonvascular plants may be present at any cover value.

- DWARF SHRUBLAND — Low growing shrubs and/or dwarf trees are usually under 0.5m tall (though known dwarf forms between 0.5 and 1m can be included), individuals or clumps not touching to interlocking (generally forming >25% cover). Trees and shrubs greater than 0.5m may be present but cover with canopy cover 10 percent or less. Herbs and nonvascular plants may be present at any cover value.

- SPARSE DWARF SHRUBLAND — Low growing shrubs and/or dwarf trees usually under 0.5m (though known dwarf forms between 0.5 and 1m can be included) with individuals or clumps widely spaced (generally with 10–25% cover). Trees and shrubs greater than 0.5m may be present, but with cover 10 percent or less. Herbs and nonvascular plants may be present at any cover value.

- HERBACEOUS — Graminoids and/or forbs (including ferns) generally forming >10% cover. Trees, shrubs, and dwarf shrubs may be present, but with cover 10 percent or less. Nonvascular may be present at any cover value.

- SPARSE VASCULAR VEGETATION/NON–VASCULAR — Vascular vegetation is scattered or nearly absent. The cover of each vascular lifeform (tree, shrub, dwarf shrub, herb) is at most 10 percent; in some cases the total cover of vascular vegetation may exceed 10 percent. Cover of nonvascular plants (mosses and lichens) may be absent to continuous.

Species/Percent Cover — Starting with the uppermost stratum, list all the species present and the percent cover (using the scale provided below) of each species in the stratum. For forests and woodlands, list on a separate line below each tree species and the DBH of all trees above 10 cm diameter. Separate the measurements with a comma and note whether in centimeters or inches. The first line of each stratum should be used to identify which stratum is being described. The codes from the stratum diagram in Number 48 can be used as an abbreviation. See the example below.

Cover Scale for Species Percent Cover

Code	**Range of Class**	**Class midpoint**
00	0 Cover	0
01	>0 – < 1%	0.3%
03	1 – < 5%	3%
10	5 – <15%	10%
20	15 – <25%	20%
30	25 – <35%	30%
40	35 – <45%	40%
50	45 – <55%	50%
60	55 – <65%	60%
70	65 – <75%	70%
80	75 – <85%	80%
90	85 – <95%	90%
98	95 – <100%	97.5%

NOTE: The cover scale used is that developed by Region 1 of the U.S. Forest Service for their ECODATA data management and analysis system (Jensen et al., FLAG date). The error rate of ±1 cover class is assumed for each estimate. For example, if the cover class entered is 35– <45% (cover code 40), the midpoint of the class that will be used in future analyses will be 40 percent. The error associated with the value is 25–55%.

Example of a completed species list.

T1	
Quercus alba	40
52, 37, 15, 27, 18, 48, 40 cm	
Acer rubrum	20
25, 16, 14, 16, 23	
T2	
Cornus florida	20
13, 16	
S2	
Vaccinium angustifolium	60
Corylus cornuta	03

APPENDIX 12.2 Example Applications of the Field Methods for Vegetation Mapping

12.2.1 The Gray Ranch, New Mexico

Detailed accounts of the two-stage gradsect sampling design and of the resulting data exist for the rainforests of southern New South Wales, Australia, (Helman 1983) and for a mixture of eucalypt and rainforests in northern New South Wales (Austin and Heyligers, 1989, 1991). In the United States, an opportunity to use gradsect methodology and to evaluate its efficiency in recovering ecological patterns arose as result of a request from The Nature Conservancy to survey the Gray Ranch in southern New Mexico. The goals were to characterize the vegetation patterns and their associated floristic variability in relation to the range of environmental variability within the ranch and to use this information to assess the conservation value of the area (Bourgeron et al. 1993, Engelking et al. 1993). The constraint was that resources were limited to only two weeks of field work and two crews of two surveyors each for a total area covering 340,000 acres. An existing regional vegetation classification was used to initiate the sampling design. Results of the survey were used to refine the classification and to create a map of existing vegetation using TM data. Accuracy assessment was conducted after the study was completed.

In the absence of a spatially referenced database containing defined attribute data for modeling and sampling the environment, variables and their classes were chosen according to information from previous studies, the decisions of a group of experienced ecologists and soil scientists, and the availability of suitable maps. The landscape level variables selected as among the dominant environmental variables influencing the distribution of species and plant communities at the Gray Ranch were (1) geology as an indicator of the nutrient regime, (2) elevation as an indicator of precipitation and temperature, and (3) soil type as an indicator of water availability. The variables were grouped into classes (Bourgeron et al. 1993, Engelking et al. 1993) and arranged in a factorial design. Each factorial combination (elevation x soil x geology) was consider to represent a physical environment. Class intervals were chosen to produce maps (1:100,000 scale) for each variable. These maps were overlaid to produce a map of the physical environments suitable for visual assessment of the environmental gradients.

Taking into consideration access roads, several positions for gradsects were established. Two main gradsects were chosen to contain as many of the physical environments as possible. After comparing the physical environments in the gradsects with those occurring in the Gray Ranch as a whole, two small additional gradsects were chosen specifically to capture those environmental combinations that did not fall into the two main gradsects. Some physical environments of very restricted extent were not represented at all in the gradsects. Given the time constraints, they were not targeted for sampling. For the purpose of the survey, the gradsects, including forty-nine of the fifty-five physical environments, were judged representative of the study area.

Geographical replication of similar environments allows to represent biological variation due to criteria other than those used to define the gradsects. Geographical replication was included twice in the design. First, the overlap between the environmental envelopes of the gradsects provides a degree of geographical replication of similar environments. Second, the main gradsects were each divided into three segments to further enhance geographic replication.

The following explicit sampling procedures were used to locate the sample sites. First, the total number of sample sites that could be visited during the two-week period was estimated to be one hundred. This number was increased to 120 to provide for flexibility during field work. Second it was decided to sample physical environments according to their representation at the Gray Ranch. A grid with .25-mile spacing was generated and overlaid on the map of the physical environments. Each grid point was assigned to one of the environments. From the number of grid points intercepted by each combination, a percentage (number of grid points for a given environment/total number of grid points) was calculated. The percentages are estimates of the spatial extent of each physical environment and were used to calculate the number of samples per combination. For example, the combination alluvium substrate x elevation class 1,250–

1,500m x argid soil suborder occurred on 11 percent of the Gray Ranch and should have received 11 percent of the total number of samples. Based on this rule, however, the environments representing less than 1 percent of the Gray Ranch would not receive a sample. It was decided to sample all physical environments present in the gradsects in order to cover as much of the range of environmental variability as possible. Therefore, one sample was assigned to each infrequent environment. This kind of decision can be made by the investigators in order to adjust the sampling scheme to meet the needs of the study.

All physical environments in the two short gradsects were infrequent (less than 1 percent of the total area) and were each allocated one sample (total = 11). Choice of the sample locations was simplified by the fact that, in many cases, these combinations were found in only one location. That left 109 samples for the two main gradsects. Each main gradsect was allocated samples in proportion to its surface area. Within a gradsect, each segment was allocated one third of the number of samples. The number of samples assigned to each physical environment in a segment was in proportion to its representation in the segment. The number of grid points intercepted by each environment within the segment was used again to calculate the percent of representation and a number of samples were assigned.

Actual sample location within each segment was chosen randomly for a given physical environment. Bias due to accessibility was made explicit by taking in to account the location of access roads. However, to decrease the effect of intense grazing and disturbance on vegetation patterns, the design was constrained so that plots were at least 0.5 miles from a road, water tank, or windmill, except for a few times when the sites were deemed of high quality. The design further allowed for alternative sample site selection within the same physical environment when the field survey showed the sites were too inaccessible (time constraint) or too severely impacted by cattle and/or other human activity.

At the local scale, variables other than those chosen for the sampling design may also have a strong influence on vegetation composition (i.e., slope, aspect, etc). Therefore a further stratification based on the response of the vegetation to the environment was imposed. Within each sample, 20 x 20m plots were located in each physiognomic type found (e.g., forest, shrubland, grassland), and/or in dominance types. Finally, at each sample site, the classes of the stratifying variables were verified (soil and geology) to compensate for errors due to the various map scales used in the sampling design. If an error was found, changes were made accordingly in the design to stay on track with the required number of samples for each physical environment.

After two weeks of vegetation survey, ninety seven plots were taken on the Gray Ranch. Thirty - six of the forty-nine physical environments occurring in the gradsects were sampled. The thirteen environments that were not visited were infrequent and scheduled to have only one sample. These types were often found only in hard-to-access areas requiring long hikes, which would have required too much time given the two-week survey period limitation. All unsampled physical environments occurring at the Gray Ranch were slated to be surveyed during the next field season.

12.2.2 The Yampa River

The study watershed (the Yampa River), over 19,000 km^2, is part of the Upper Colorado River Basin and spans northwestern Colorado and a small area of southcentral Wyoming. The major goal of the study initiated by The Nature Conservancy was to assess the environmental variability in the Yampa River Basin, the corresponding response of the riparian vegetation, and to use the resulting information to design a watershed-wide conservation strategy. The study was to be conducted within one year. As for the Gray Ranch, complete georeferenced databases were not available over the study area.

As in the Gray Ranch study described in **Section 7.5**, environmental factors used to characterize the environmental variability of the Yampa River were chosen based on previous riparian work in the central Rocky Mountains and after consultation with a group of experts. Additionally, a technical committee of land managers reviewed the decisions. The variables were as follows: (1) elevation as an indicator of the temperature regime, (2) geologic substrate as an indicator of the soil nutrient regime, (3) valley width/depth ratio as an indicator of the solar radiation regime, and (4) drainage basin length, strongly correlated with stream discharge, as an indicator of the moisture regime.

Values of each variable analyzed were divided into classes (**Table 4**), which were then arranged factorially (**Table 5**). Locations (perennial stream or river segments) that shared similar classes of selected environmental gradients were identified and mapped. The number of stream segments in each physical environment varied from one to over twenty. The areal extent of each physical environment was estimated by measuring the length of each stream segment and summing them up (**Table 5**) to get a total length in each physical environment.

The sampling design for the collection of data on riparian vegetation was based on the data on the areal extent of each physical environment. Gradsect methodology was modified for this study to reflect the fact that perennial streams constitute transects of their own. No stream segment or geographic area was excluded from possible sampling. This approach maximized geographic replication and enabled the sampling team to visit most of the study area. An important feature of the methodology is the sampling of all segments of variation of the environmental gradients according their actual areal representation (xxxx). This was accomplished by determining the proportion that each physical environment occupied of the total drainage basin length of the Yampa River watershed. Numerical criteria (**Table 7**) were developed to allocate sample sites according to the proportional representation of the physical environment.

Once the number of sample sites per physical environment was determined, the actual location of each site was selected randomly. Sampling at individual sites was designed to capture the local variation in environmental variables (e.g., aspect or topography) not included in the characterization of the physical environment but expressed by the vegetation. Plots were placed for quantitative sampling of floristic and environmental data (e.g., landform, distance to water, etc.) on each site; a total of eighty sites were visited, with 111 individual plots collected. **Table 8** summarizes the number of possible combinations of the variable classes, the number of existing and sampled combinations, and the number of kilometers (areal representation) of these.

The criteria developed for allocating sample sites deliberately allows for undersampling of common physical environments and oversampling of less common environments. The underlying assumption is that less common physical environments may support rare species combinations. The sampling success (or failure) for each physical environment can be tracked, allowing assessment to determine which portions of a particular gradient have been missed.