ECOLOGICAL SYSTEMS OF LATIN AMERICA AND THE CARIBBEAN

A WORKING CLASSIFICATION OF TERRESTRIAL SYSTEMS

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Front cover: Cushion plant community, Antisana Volcano, Ecuador. Photo © Hugo Arnal

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Executive Summary

Conservation of the Earth's rich diversity of life requires a sound understanding of the distribution and condition of the components of that diversity. Efforts to understand our natural world are directed toward different biological and ecological scales—from genes and species, to natural communities, local ecosystems, and landscapes. While scientists have made considerable progress classifying fine-grained species and communities on the one hand, and coarse-grained ecoregions on the other, land managers have identified a critical need for practical, mid-scale ecological units to inform conservation and resource management decisions. This report introduces and outlines the conceptual basis for such a mid-scale classification unit—*ecological systems*.

Ecological systems represent recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding. They are intended to provide a "meso-scale" classification unit that is readily mappable, often from remote imagery, and readily identifiable in the field.

NatureServe and its member programs, with funding from The Nature Conservancy, have completed a working classification of terrestrial ecological systems in Latin America and the Caribbean. This report summarizes the nearly 700 ecological systems that currently are classified and described, emphasizing the natural portion of the landscape. We document applications of these ecological systems for conservation assessment, ecological inventory, mapping, land management, and ecological monitoring.

Terrestrial ecological systems are specifically defined as a group of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. A given system will typically manifest itself in a landscape at intermediate geographic scales of tens to thousands of hectares and persist for 50 or more years. This temporal scale allows typical successional dynamics to be integrated into the concept of each unit. With these temporal and spatial scales bounding the concept of ecological systems, we then integrate multiple ecological factors – or *diagnostic classifiers* - to define each classification unit. The multiple ecological factors are evaluated and combined in different ways to explain the spatial co-occurrence of vegetation.

Summarizing across the range of natural variation, some 477 ecological systems types (69%) are from uplands, 199 types (29%) wetland, and 17 types (2%) are complexes of uplands and wetlands. Considering prevailing vegetation structure, 512 types (71%) are predominantly forest, woodland, or shrubland, and 198 types (28%) are predominantly herbaceous, savanna, or shrub steppe. Seventeen types (2%) are sparsely vegetated.

Terrestrial ecological systems represent practical, systematically defined units that provide the basis for mapping terrestrial ecosystems at multiple scales of spatial and thematic resolution. The working classification presented in this report will serve as the basis for NatureServe to facilitate the on-going development and refinement of the Latin America and Caribbean components of an International Ecological Systems Classification.

Introduction and Background

Attempts to understand and conserve our natural world have often been directed at different biological and ecological levels, from genes and species, to communities, local ecosystems, landscapes. Ecological conservation and resource management typically require the identification, description, and assessment of some or all levels of biodiversity within a given planning area or ecoregion. Practically speaking, the *focal elements* that define these levels need to be clearly specified to clarify exactly what is to be protected or managed (Groves et al. 2002).

Conservationists and resource managers now use a variety of approaches to assess biodiversity at different scales (Redford et al. 2003). Species and ecoregions have received a great deal of attention. Species approaches include a focus on rare or endemic species, key or umbrella species, and biodiversity hotspots. Ecoregional approaches include global prioritizations, such as the WWF Global 2000 ecoregions (Redford et al. 2003) or ecological land classifications (e.g. Albert 1995, Bailey 1996, Griffith et al. 1998). Community and local ecosystem approaches have been less-well developed, however with the development of national and international vegetation classifications (Hueck & Seibert 1972, Devillers & Devillers-Terschuren 1996, Grossman et al. 1998, Eva et al. 2002, Rodwell et al. 2002, Jennings et al. 2003), the community approach is now applicable at broader geographic scales. The local ecosystem approach has included mapping and assessment of fine-scaled landscape ecosystem units (e.g. see Barnes et al. 1998) or the definition of ecological system units within ecoregions (e.g. Neely et al 2001, Tuhy et al. 2002).

A common set of concerns of conservation or resource managers are a) the spatial scale of the focal element (the "grain"), b) the degree of consistency in the element definition or taxonomy, c) the extent to which they can be applied across multiple jurisdictions or even continents, and d) the extent to which information can be readily assembled to assess their distribution. The species approach may require that grain be assessed on a species-by-species basis. The degree of consistency is improving as taxonomies improve, but parts of the world are not well surveyed. World wide lists and Red Books are increasingly available, but information on many species is often difficult to obtain.

Ecoregional approaches often provide multiple levels of spatial scales, but typically the grain is quite coarse, and the units are typically unique subsets of the geographic space, with varying degrees of heterogeneity. They are either used as focal elements directly or as organizing units for focusing on more specific focal elements within the region. They are are now increasingly available around the world, and information can be readily assembled, depending on the features of the ecoregion being assessed.

Community approaches, often considered a more convenient focal element (the "coarse filter') , as compared to species (the "fine filter") (*sensu* Jenkins 1976), often have a fine grain, are relatively consistent, but are often not available world-wide. Their fine grain may hinder ability to assemble information and conduct assessment, limiting their practical value. Finally, the intermediate-scaled landscape ecosystems (e.g. USFS ECOMAP Land Type Associations) are often difficult to define consistently, and on top of it, may be rather heterogeneous with respect to biodiversity. They are not widely available across the country, or across continents, making regional/national assessments difficult.

Lacking in these approaches is a focal element that is more coarsely grained than the community approach, retains a standard of consistency that allows ready identification and application of the unit at local or regional scales, and that is widely applicable at continental or hemispheric levels. In addition, gathering information on such focal elements should not make excessive demands of conservation or resource managers. Here we describe a standardized terrestrial ecological system classification designed to meet these objectives. Our purpose is to demonstrate that these systems, though related to both community and landscape ecosystem approaches, provide a greatly improved set of focal elements for conservation and resource management. NatureServe's experience in application of the U.S. National Vegetation Classification (NVC) has indicated the need for standardized classification units that more fully integrate environmental factors into unit definition (e.g. see Anderson et al 1999). The same is true for Latin America, where many countries share ecosystems and/or ecoregions and each one has a different approach to vegetation or land cover maps, and where there are still large geographical gaps of this kind of information. There is also a need to define units somewhat more broadly than the NVC alliance and association units – i.e. allowing for a greater range of biotic and abiotic heterogeneity in type definition – without "scaling up" to the vegetation classification formation unit (Grossman et al. 1998, UNESCO 1973), which is defined solely through vegetation physiognomy and limited environmental factors.

Ecological Scope and Geographical Coverage of Classification

The emphasis of this classification is directed towards surficial terrestrial environments, encompassing both upland (*terra firme*) and wetland areas where rooted and non-vascular vegetation – as well as readily identifiable environmental features (e.g. alpine, coastal, cliff, sand dune, river floodplain, depressional wetland, etc.) - may be used to recognize and describe each type. We do not address subterranean environments where vertebrate and/or invertebrate species, along with environmental features could be used for type recognition and description. Nor do we address aquatic environments, either freshwater or marine, where aquatic animal and/or environmental features are often used for type recognition and description. Also, we focus here on ecological system types that can be considered "natural" or "near-natural," i.e., those that appear to be unmodified or only marginally impacted by human activities. We have made no attempt to describe agricultural ecosystems or urban ecosystems where human-caused elements are clearly novel. A given area could therefore be comprehensively mapped in terms of natural ecological systems and coupled with a classification of human-induced land use.

NatureServe is currently working towards a first-draft classification of terrestrial ecological systems across North, Central, South America and the Caribbean. As part of this report we provide a working list and descriptions of nearly 700 terrestrial ecological systems of Mexico, the Caribbean Islands, Central America, South America and their near-shore islands. Regions of South America such as Patagonia, the temperate Pampas, the Peruvian Chilean desert, and the Galapagos Islands, have not yet been classified and described under our approach, though we expect to complete their classification in the near future, adding around 150 more types to this first list of ecological systems.

The Iterative Nature of Classification

Ecological classifications are often portrayed as being "complete." Classification is more appropriately viewed as an ongoing process of stating assumptions, data gathering, data analysis and synthesis, testing new knowledge through field application, and classification refinement. A classification system provides a framework for this ongoing process and the resulting classification should continually change as new knowledge is gained. The effort documented here represents the first attempt to synthesize data and apply a standard approach to documenting natural upland and wetland ecological systems comprehensively across Latin America and the Caribbean. NatureServe will continue to provide a mechanism for ongoing development and dissemination of this classification.

Objectives of this Report

This report documents the development of terrestrial ecological systems, emphasizing the key issues and requirements of such a system in relation to other approaches. We review the criteria used to identify systems, and the standards that were used to develop, name, and describe them. We also describe the process for gathering information on these systems and summarize the results of this initial classification effort. We then describe the application of ecological systems for mapping and assessing occurrence quality or ecological integrity. Finally we address the next steps in the process of further enhancing the systems classification.

Key issues and decisions in developing Ecological Systems

Ecosystems have been defined generally as " a community of organisms and their physical environment interacting as an ecological unit" (Lincoln et al. 1982). Classification of ecological systems can be based on a variety of factors (e.g., vegetation, soils, landforms) at a variety of spatial and temporal scales (hectares to millions of kilometers and annual to millennial), and with varying degrees of concern over spatial interactions. A full review of the variety of classifications currently used is beyond the scope of this document. Rather, some key issues will be highlighted that includes discussions of other approaches.

Ecological Systems as Functional Units versus Landscape Units

Historically, ecological systems have been defined from a wide variety of perspectives, depending on the investigator, with some emphasizing ecosystem function and processes (nutrient cycling, energy flows); others the "physical" (land) factors that structure the system (Golley 1993, Bailey 1996). Odum (2001) emphasizes the functional perspective in his definition:

> *An ecological system, or ecosystem, is any unit (a biosystem) that includes all the organisms (the biotic community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined biotic structures and cycles of materials between living and non-living parts. An ecosystem is more than a geographic unit (or ecoregion); it is a functional system with inputs and outputs, and with boundaries that can be either natural or arbitrary.*

Emphasis on these studies is on energy flow and nutrient cycling, looking at how primary and secondary producers shape the flow of energy and materials through a system. By contrast, Bailey (1996) emphasizes the landscape ecosystem approach:

J. S. Rowe ... defined an ecosystem as "a topographic unit, a volume of land and air plus organic contents extending areally over a particular part of the earth's surface for a certain time." This definition stresses the reality of ecosystems as geographic units of the landscape that include all natural phenomena and that can be identified and surrounded by boundaries."

These definitions do not lead to mutually exclusive approaches to ecosystem studies. Many functional studies use watershed geographic units to define their ecosystems; and landscape ecosystem studies often emphasize functional properties within and across geographic units. Our decision was to emphasize a classification approach to ecosystems that does not rely on a fixed landscape map unit and which is still amenable to process-functional studies. We emphasize how processes on the landscape shape ecological systems, and define them through a combination of biotic and abiotic criteria.

Ecological Systems as Geo-Systems versus Bio-Systems

Given that ecosystems generally are defined as an ecological unit of both organisms and their environment, there are various approaches to choosing which set of factors to emphasize in a classification. The landscape ecosystem, or geo-ecosystems (Rowe and Barnes 1994), emphasizes the controlling factors of climate, soils, and topography over that of biota. The bio-ecosystems approach gives more emphasis to the controlling factors of biota (akin to the "biogeocoenosis" of Sukachev 1945, in Mueller-Dombois and Ellenberg 1974, or the biogeocene unit of Walter 1985).

The bio-ecosystem approach has recently received more widespread attention for conservation and resource management through the development of "biotope" units. A **biotope** (sometimes called "habitats") is a small to meso-scale ecosystem unit, defined as "a limited geographic area with a particular environment and set of flora and fauna" (Devillers et al. 1991). In Europe, biotopes have been defined at a variety of scales by the CORINE Biotope Manual, which defined and described hundreds of biotopes (Devillers et al. 1991). The same methodology used for the CORINE Biotopes typology, was applied to classify the habitats of South America, resulting in hundreds of types organized in a hierarchical arrangement where the biogeographical criterion was used in such a way that led to the definition of very localized, site scale, units.

Our decision was to take the approach of defining ecological systems using a "bio-ecosystem" approach. We also chose to classify these systems at a meso-scale (akin to the "biogeocene complex" unit of Walter 1985). This approach defines the boundaries of a system in part based on the combination of component plant communities and abiotic factors. The plant communities are based on existing vegetation, and so our systems are also based on "existing ecosystems," not potential systems.

Nonetheless, the geo-ecosystem approach has an important role to play in helping define the abiotic template on which ecological systems may be found.

Ecological Systems as Discrete Units versus Individualistic Units

Although there is continuous variation in species composition and environmental gradients, in some places the level of compositional and environmental change is low (e.g., within a readily recognizable plant community) whereas in other places the level of compositional change is high (e.g., across an ecotone).

The necessary consequence of these findings is that in most cases there are no clear and unambiguous boundaries between plant communities or ecological systems in nature, and species assemblages or ecosystem processes are not entirely predictable. Any decision as to how to divide the continuously varying and somewhat unpredictable phenomenon of community types and systems must be somewhat arbitrary with multiple acceptable solutions. Ecological classification only requires that it is reasonable to separate the continuum of variation in ecological composition and structure into a series of somewhat arbitrary classes (Whittaker 1975, Kimmins 1997). Furthermore, ecosystem factors are typically more temporally and spatially stable than vegetation factors on their own, facilitating repeated recognition of the same unit.

Our decision is to recognize that ecological systems do grade more-or-less continually across the landscape. We rely on a combination of diagnostic classifiers of both abiotic and biotic factors to create reasonable classes of units.

The Scale of Ecological Systems

In principle, ecosystems can be defined at any geographic scale, from a rotting log or vernal pond to the entire biosphere. Thus they range from <10 to 1,000,000s of hectares. They can also vary in the definition of their stability, from annual to 1,000s of years (Delcourt and Delcourt 1988). Recent classifications or regionalizations using the geo-ecosystem approach explicitly define a nested series of spatial scales, from broad ranging ecoregional units that span millions of hectares to "micro-ecosystem" land types that span 10s of hectares. The expectation is that these units are stable on the order of hundreds of years. Functional approaches work at a variety of temporal and spatial scales as well, depending on the processes being studied.

For the purposes of developing an ecological systems classification, our decision was to focus on the scale of greatest need. The micro-ecosystem level has not been comprehensively developed for all of Latin America and doing it consistently would require a long term, resourceful project. Good classifications however, exist at the macro-ecosystem level; vegetation formations (UNESCO 1973), a recent vegetation and land use map of South America (Eva et al. 2002), or ecoregions (Olsen et al. 2001) can be used. Spatially, these macro-systems often span continents. Temporally, formations reflect short to long-term stability (though the recognition of units tends to focus on the more stable units), and ecoregions emphasize stability on the order of 100s to 1000s of years.

Notably lacking, however, are good meso-scale units. For bio-ecosystems that utilize local plant communities for their definition, the conceptual "distance" between UNESCO formations and local community units is rather large, given that formations are defined solely through vegetation physiognomy and limited environmental factors. In Latin America, probably the most common type of classification applied at the national level has been the Holdridge Life Zone system, which due to its mathematical model, leaves out wetlands and many other “azonal” types related to special substrates or hydrogeomorphology. Nor is its use of latitudinal and altitudinal regions a good enough surrogate for the bio/phytogeographical criterion.

Conceptual Basis

A terrestrial ecological system is defined as a group of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. A given terrestrial ecological system will typically manifest itself in a landscape at intermediate geographic scales of 10s to 1,000s of hectares and persist for 50 or more years. Ecological processes include natural disturbances such as fire and flooding. Substrates may include a variety of soil surface and bedrock features, such as shallow soils, alkaline parent materials, sandy/gravelling soils, etc.. Finally, environmental gradients include local climates, hydrologically defined patterns in coastal zones, arid grassland or desert areas, or life zones such as montane, alpine or subalpine zones

In Latin America and the Caribbean, where classification at the floristic levels equivalent to the US NVC association and alliance is not available region-wide, multiple references on plant communities at local scale become the potential units to group through an iterative “bottom-up” and “top-down” process of information synthesis, where abiotic and environmental characterizations within a given geographic setting help to define the spatial criteria that bond these communities.

Given the relative ease of recognizing vegetative structure and composition, this approach is preferable to, for example, defining biotic components using animal species that are more difficult to consistently observe and identify. Ecological systems are defined using both spatial and temporal criteria that influence the grouping of communities.

In developing an ecological systems approach, we are mindful that in principle ecological systems can be defined in a number of ways. Indeed, there are so many different definitions, that perhaps the concept is in danger of losing its utility for ecological research and application. Recently, O’Neill (2001) made a number of suggestions to help improve the ecosystem concept; namely, that the ecosystem (1) be explicitly scaled, (2) include variability, (3) consider long-term sustainability in addition to local stability, and (4) include population processes as explicit system dynamics. Here we define our ecological system concept as follows:

1. We explicitly scale the unit to represent:
    a. spatial scales of 10s to 1000s of hectares.
    b. temporal scales of 50 to 100 years
2. We make explicit the variability in the system by describing them in terms of a consistent list of abiotic and biotic criteria and by linking ecological systems to a number of local references to plant community types that describe the biotic community variation within the system.
3. We propose to consider long-term sustainability and local stability by mapping and evaluating the occurrence of ecological systems at the local site and the regional level.
4. We do not formally include population processes as explicit system dynamics, but through knowledge of the component plant communities, it would be possible to at least describe the major plant species and their dynamics within the systems. Additional work could formalize the roles of additional biotic elements such as invertebrates and vertebrates.

Meso-Scale Systems

Our conceptualization of terrestrial ecological systems includes temporal and geographic scales intermediate between those commonly considered for local stand and landscape-scale analyses, which can range from 50 to 1,000s of years and 10s to 1,000s of hectares (Delcourt and Delcourt 1988). These "meso-scales" are intended to constrain the definition of system types to scales that are of prime interest for conservation and resource managers who are managing landscapes in the context of a region or state. More precise bounds on both temporal and geographic scales take into account specific attributes of the ecological patterns that characterize a given region.

Temporal Scale. The temporal scale we have chosen determines the means by which we account for both successional changes and disturbance regimes in each classification unit. Relatively rapid successional changes resulting from disturbances are encompassed within the concept of a given system unit. Therefore, daily tidal fluctuations will be encompassed within a system type. Some of the communities describing one system may represent multiple successional stages. For example, a given floodplain system may include both early successional associations and later mature woodland stages that form dynamic mosaics along many kilometers of a river. Many vegetative mosaics resulting from annual to decadal changes in coastal shorelines will be encompassed within a system type. Many forest and grassland systems will encompass common successional pathways that occur over 20-50 year periods. Selecting this temporal scale shares some aspects with the "habitat type" approach to describe potential vegetation, but differs in that no "climax" vegetation is implied, and all "seral" components are explicitly included in the system concept.

Of course, many environmental attributes, such as climate, continually change through time. We assume that a given "natural/near-natural" ecological system type will encompass continual change resulting from climatic patterns as they have occurred in recent millennia, with little or no human influence, and will continue to change into the future.

Pattern and Geographic Scale. Spatial patterns that we observe at "intermediate" scales can often be explained by landscape attributes that control the location and dynamics of moisture, nutrients, and disturbance events. For example, throughout the tropical Andes it is possible to see distinctions in vegetation along the elevation gradient, with the slope aspect adding complexity to the moisture patterns. In extensive plains such as the ones of the South American Chaco, micro topography and substrate induce clear distinctions in vegetation, going abruptly from wetlands to xerophylous types. Rivers provide moisture, nutrients, and scouring soil disturbance that regulate the regeneration of some plant species. In each of these settings we find a number of plant communities co-occurring due to controlling factors in the environment. The communities that co-occur may or may not share the same physiognomy or floristic characteristics that would place them in the same UNESCO formation. More often than not, we see mosaics of communities from different formations, such as woodlands, shrublands, and herbaceous meadows, occurring in a complex mosaic along a riparian corridor, and we can often predict that along riparian corridors within a given elevation zone, and along a given river size and gradient, we should encounter a limited suite of communities.

Having said this, we still define "intermediate" spatial scales within rather broad bounds of 10s to 1,000s of hectares. For the purposes of guiding field identification, mapping, and interpreting ecological relations among terrestrial ecological systems, it is often helpful to categorize ecological system types based on their typical patch type characteristics. Table 1 describes four categories for patch types that encompass all terrestrial ecological systems. These include "matrix-forming," "large patch," "small patch," and "linear." In each of these instances, an expected geographic scale (size of the patch) is included as initial guidance for identifying systems within a given area. Review of broad scale ecological pattern for a given region should result in an initial suite of ecological systems types that could fall into each of these categories. For example, matrix-forming forests, shrublands, and/or grasslands may dominate extensive uplands for a given regional landscape. Both large patch and small patch systems tend to appear nested within those matrix system types, while linear system types occur along riverine corridors, coastal areas, and major physiographic breaks (e.g. escarpments or cliff faces). Analysis of more local-scale patterns nested within the region's natural matrix clarifies the diversity of potential patch and linear system types, and similar evaluations of composition and correlated abiotic attributes may be used to differentiate system types.

Table 1. Categories for patch types used to describe ecological systems

Patch Type	Definition
Matrix	Ecological Systems that form extensive and contiguous cover, occur on the most extensive landforms, and typically have wide ecological tolerances. Disturbance patches typically occupy a relatively small percentage (e.g. <5%) of the total occurrence. In undisturbed conditions, typical occurrences range in size from 2,000 to 10,000s ha.
Large Patch	Ecological Systems that form large areas of interrupted cover and typically have narrower ranges of ecological tolerances than matrix types. Individual disturbance events tend to occupy patches that can encompass a large proportion of the overall occurrence (e.g. >20%). Given common disturbance dynamics, these types may tend to shift somewhat in location within large landscapes over time spans of several hundred years. In undisturbed conditions, typical occurrences range from 50-2,000 ha.
Small patch	Ecological Systems that form small, discrete areas of vegetation cover typically limited in distribution by localized environmental features. In undisturbed conditions, typical occurrences range from 1-50 ha.
Linear	Ecological Systems that occur as linear strips. They are often ecotonal between terrestrial and aquatic ecosystems. In undisturbed conditions, typical occurrences range in linear distance from 0.5 to 100 km.

The concepts of both "linear" and "small patch" types result in the definition of units that can only fall into either category. The same is not always true with "large patch" vs. "matrix" types. There are circumstances where an ecological system form the matrix within one part of its range, but then occurs as a "large patch" type in another part of its range. This likely results in differing dynamics of climate and related disturbance processes – and interactions with other systems – that vary in ways that are unique to each system type. For example, a savanna system may form the matrix of one ecoregion where landscape-scale fire regimes have historically been supported by regional climate. But an adjacent, more humid, ecoregion might support the same type of savanna system, where it occurs as patches within a matrix of forests. Importantly, we have established as a classification rule that this type of change in spatial character – between "large patch" and "matrix" categories across the range of a type - does not force the distinction of two system types. The environmental and disturbance dynamics that result in that variation can be described and addressed for conservation purposes without defining a distinct type. With these temporal and spatial scales bounding the concept of ecological systems, we may then integrate multiple ecological factors to define each classification unit.

Diagnostic Classifiers

As the definition for ecological systems indicates, this is a multi-factor approach to ecological classification. Multiple environmental factors – or *diagnostic classifiers* - are evaluated and combined in different ways to explain the spatial co-occurrence of natural communities. Diagnostic classifiers is used here in the sense of Di Gregorio and Jansen (2000); that is, the structure of the ecological systems classification is more "modular" than "hierarchical" in that it aggregates diagnostic classifiers in multiple, varying combinations, without a specific hierarchy. The focus is on a single set of ecological system types. This is in contrast to, for example, the framework and approach of most vegetation classification systems where the lower level units are grouped into the upper levels of the hierarchy based solely on floristic and/or physiognomic criteria. These hierarchies provide more of a conceptual aggregation with no presumption that communities co-occur in a given landscape. The ecological system unit links plant communities using multiple factors that help to explain why they tend to be found together in a given landscape due to similar ecological processes, substrates, and/or ecological gradients. Therefore, ecological systems tend to be better "grounded" as ecological units than most vegetation classification types and are more readily identified, mapped, and understood as practical ecological classification units. Diagnostic classifiers include a wide variety of factors representing bioclimate, biogeographic history, physiography, landform, physical and chemical substrates, dynamic processes, landscape juxtaposition, and vegetative structure and composition.

Biogeographic and Bioclimatic Classifiers. Ecological Divisions are sub-continental landscapes reflecting both climate and biogeographic history, modified from Bailey (1996 and 1998) at the Division scale (Figure 1). Continent-scaled climatic variation, reflecting variable humidity and seasonality (e.g. Mediterranean vs. dry continental vs. humid oceanic) are reflected in these units, as are broad patterns in phytogeography (e.g. Takhtajan 1986). These units were adapted and more precisely described using ecoregion lines established by The Nature Conservancy (Groves et al. 2002) and World Wildlife Fund (Olson et al. 2001) throughout the Western Hemisphere.

These regional units aid in organizing the classification and in describing the distribution of each ecological system type. Regional patterns of climate, physiography, disturbance regimes, and biogeographic history are well described by each Division. Examples of these Divisions include North-Central Moist Andes, South-Central Dry Andes, Orinoquia, Caribbean, Chaco, Patagonia, Peruvian-Chilean Desert. A “Chaco” ecological system type is predominantly found (>80% of it’s total range) within the Chaco Division. A “Meridional Chaco” ecological system type is limited in distribution to southern portions of the broader Chaco Division. In a few instances, ecological systems remain very similar across two or more Ecological Divisions. In these instances, the Domain scale of Bailey (1996) was used to name and characterize the distribution of types.

Subregional bioclimatic factors are also useful for classification purposes, especially where relatively abrupt elevation-based gradients exist, or where maritime climate has a strong influence on vegetation. We integrated global bioclimatic categories of Rivas-Martinez (1997) to characterize subregional climatic classifiers. These included relative temperature, moisture, and seasonality. They may be applied globally, so they aid in describing life zone concepts (e.g. ‘maritime,’ ‘lowland,’ ‘montane,’ ‘subalpine,’ ‘alpine’) in appropriate context from arctic through tropical latitudes.

Environment. Within the context of biogeographic and bioclimatic factors, ecological composition, structure and function in upland and wetland systems are strongly influenced by factors determined by local physiography, landform, and surface substrate. Some environmental variables are described through existing, standard classifications and serve as excellent diagnostic classifiers for ecological systems. For example, soil moisture characteristics have been well described in the United States by the USDA Natural Resource Conservation Service (NRCS 1998). Practical hydrogeomorphic classes are established for describing all wetland circumstances (Brinson 1993). Other factors such as landforms, specialized soil chemistry may be defined in standard ways to allow for their consistent application as diagnostic classifiers.

Ecological Dynamics. Many dynamic processes are sufficiently understood to serve as diagnostic classifiers in ecosystem classification. In many instances, a characteristic disturbance regime may provide the single driving factor that distinguishes system types. For example, many wetland systems are distinguishable based on the hydroperiod, as well as water flow rate, direction, and origin (Brinson 1993; Cowardin 1979). Once characterized in standard form (e.g. Frost 1998), these and other dynamic processes apply to multi-factor classification.

Landscape Juxtaposition. Local-scale climatic regime, physiography, substrate, and dynamic processes can often result in recurring mosaics. For example, large rivers often support recurring

Figure 1. Ecological Divisions of America used in organization and nomenclature of NatureServe Ecological Systems

patterns of levee, floodplain, and back swamps, all resulting from seasonal hydrodynamics that continually scour and deposit sediment. Many depressional wetlands or lakeshores have predictable vegetative zonation driven by water level fluctuation. The recurrent juxtaposition of recognizable vegetative communities provides a useful and important criterion for multi-factor classification.

Vegetation Structure, Composition, and Abundance. As is well recognized in vegetation classification, both the physiognomy and composition of vegetation suggests much about ecosystem composition, structure, and function. However, the relative significance of vegetative physiognomy may vary among different ecosystems, especially at local scales. For example, many upland systems support vegetation of distinct physiognomy in response to fire frequency and soil moisture regimes. In general, physiognomic distinctions such as "forest and woodland," "shrubland" "savanna," "shrub steppe," "grassland, " and "sparsely vegetated" are useful distinctions in upland environments. On the other hand, needleleaf or broadleaf tree species that are either evergreen vs. deciduous may co-occur in many combinations due more to phytogeographic history than current environmental conditions. Many wetland systems could support herbaceous vegetation, shrubland, and forest structures in the same location, again, based on the particular strategies of the species involved and local site history.

Therefore, while recognizable differences in vegetative physiognomy may initially suggest distinctions among ecosystem types, knowledge of vegetative composition should be relied upon more heavily to indicate significant distinctions. As in vegetation classification, we recognize beta diversity, or the turnover of species composition through space, as a primary means of differentiating ecosystem types. The task of classification is to recognize where that turnover is relatively abrupt, and explain why that abrupt change occurs on the ground.

In the absence of a standarized vegetation classification for Latin America and Caribbean, especially at the floristic level, we have relied on qualitative description and evaluation of non-standard classification units and on finer phytogeographic classifications below the level used for defining the Ecological Divisions, since they serve as a useful surrogate for detailed data on the physiognomy and floristics of vegetation across the region.

While beta diversity is a primary consideration, the relative abundance of vegetation can also be an important consideration. For example, many riparian and floodplain systems can share many plant species, due to their adaptation for dispersal along a seasonally flowing river. However, there may be substantial differences in the relative abundance of species between, for example, riparian systems with small, flashy stream dynamics and a large, well-developed river floodplain many kilometers downstream. Measurement of vegetation abundance, and the environmental factors that support it, are needed to adequately address this facet of ecological classification.

Methods of Classification Development

Ideally, ecological classification proceeds through several phases in a continual process of refinement. These phases could include 1) literature review and synthesis of current knowledge, 2) formulating an initial hypothesis describing each type, 3) establishing a stratified sampling design, 4) gathering of field data, 5) data analysis, 6) description of types, 7) establishing dichotomous keys to classification units, 8) mapping of classification units, and 9) refinement of classification, establishing relative priorities for new data collection. Our approach presented here is qualitative and rule-based, focusing on steps 1 and 2 above. We used existing information from other classifications as much as possible. National or regional vegetation or ecosystems maps were used, particularly to select the diagnostic classifiers at the division level and organize the process of defining systems. We utilized also the existing ecoregional frameworks provided by WWF (www.worldwildlife.org) and additional detailed information available for a few ecoregions. We also reviewed hundreds of references, thus our approach draws extensively on the existing literature available to us.

In the process of developing the classification we have consulted with several regional experts affiliated with a number of institutions (see list of Collaborators). Their participation was facilitated by the organization of three workshops carried out in Ecuador, Peru, and Bolivia, where draft versions of portions of the classification were discussed and reviewed. We consider their participation as a valuable and initial peer review process.

Classification Structure

As previously mentioned, the structure of the ecological systems classification could be described as "modular" in that it aggregates diagnostic classifiers in multiple, varying combinations. This approach has allowed us maximum flexibility in the definition of multi-factor units. For the landscape hierarchy, we emphasize the division level and the WWF version of the ecoregional level, because that level is being used for conservation planning by The Nature Conservancy.

However, it is possible that some type of hierarchy may be advantageous. With approximately 1,000 upland and wetland system types across Latin America and the Caribbean, a hierarchy would at least improve the organization of the units. But more importantly, a hierarchy may also allow us to further interpret the ecological patterns over a range of intermediate-scales. Hierarchical arrangements of biotopes or habitats in Europe (such as by EUNIS) may provide some guidance on establishing a hierarchy of ecological systems presented here.

Development of Diagnostic Criteria and Descriptions

Diagramming factors. Multiple diagnostic criteria may be arranged to allow for a visual expression of the combinations that define each ecological system unit. Figure 2 depicts a subset of upland ecological system types that are found in the South Central Dry Andes Division. The major break between "upland" and "wetland" was used as the initial stratifier. Global life zones of "montane" vs. "alpine/altiandino" vs. "lowland" and subordinate belts of "upper montane," "montane," "lower montane," and "subalpine" are usually the next level classifier in montane areas, which may then break in physiognomic types. Landscape position can affect soil drainage and exposure to wind, giving way to finer-scale bioclimate and landform/ substrate characteristics, which further set up constraints on the type of disturbance regimes and resulting vegetation that a given site will support. This type of diagramming allows for major diagnostic classifiers to be organized and visibly display the logic of how they were used. Subsequent description and qualitative analysis allow these initial assumptions to be tested, then built upon.

Qualitative description. Each type is described in a database that includes a summary of known distribution, environmental setting, vegetative structure and composition, and dynamic processes. A separate portion of the database allows any combination of classifying criteria to be selected, then attributed as a diagnostic classifier. This permits subsequent sorts and further evaluation of types using any combination of diagnostic classifiers (e.g. all riparian systems, all High Andean systems, all upper slope systems found in the Andean Divisions, etc.).

Attribution of Vegetative Communities. Numerous literature sources were used to identify, classify, and describe the ecological systems. Many of those besides describing the vegetation types or communities within a given region, go a step further and describe the relationship between a community type and a particular environment or environmental attribute. This is the type of reference that provides evidence of the correlation between vegetation types and specific (abiotic) diagnostic criteria. When a local terminology is used to name the vegetative communities, this information is added to the database. Units of existing vegetation maps at a scale similar or larger to that of the identified systems are also attributed to the system in the database.

<table>
<tr><td>General stratifier</td><td colspan="6">UPLAND</td></tr>
<tr><td>Life Zone</td><td colspan="6">AltiAndino (3600-) 3900 – 4900 m ASL</td></tr>
<tr><td>Landscape Position</td><td colspan="2">Upper slopes</td><td colspan="3">Upper slopes/Plateaus</td><td>Lower Slopes</td></tr>
<tr><td>Major Physionomy</td><td colspan="2">Forest & Woodland</td><td colspan="2">Grassland & Steppe</td><td>Sparse Vegetated</td><td>Grassland & Steppe</td></tr>
<tr><td>Landform/ Topography</td><td colspan="2">Side Slopes</td><td>Side Slopes</td><td>Side Slopes /Toe Slopes</td><td>Side slopes/ Flats</td><td>Internal Slopes/West aspects</td></tr>
<tr><td>Bioclimate</td><td>Pluvi-seasonal</td><td>Xeric</td><td>Desertic</td><td>Pluviseasonal</td><td>Xeric / Pluviseasonal (Frigorideserta)</td><td>Xeric / desertic</td></tr>
<tr><td>Local Phyto-geography</td><td>Boliviano-Tucumano province</td><td>Altiplano province</td><td>Altiplano province</td><td>Boliviano-Tucumano province</td><td>Altiplano province</td><td>Altiplano province</td></tr>
<tr><td>System Definition</td><td>East xeric Puna highandean Polylepis short forest</td><td>West xeric Puna highandean Polylepis short forest</td><td>South xeric Puna highandean grassland and scrub</td><td>North xeric Puna highandean grassland and scrub</td><td>Xeric highandean Puna open vegetation</td><td>West xeric Puna highandean thorn scrub</td></tr>
</table>

Figure 2. Sample decision matrix for classification of upland ecological systems in the South-Central Dry Andes Division

Nomenclature for Ecological Systems

The nomenclature for the ecological systems classification includes three primary components that communicate aspects of the Systems characteristics, including its regional distribution (predominant Ecological Division), vegetation physiognomy and composition, and/or environmental setting. The final name used is a combination of these ecological characteristics with consideration given to local usage and practicality (e.g., length of name).

Ecological Divisions. These Division-scaled units typically form part of each classification unit's name. Thus, a "Cerrado" ecological system unit is predominantly found (>80% of it's total range) within the Cerrado Division, but could also occur in neighboring Divisions. This nomenclatural standard applies for many ecological system units, except in those types that are more localized (>80% of the range) within a phytogeographic subunit of the Division (e.g. Xeric Puna, within the South Central Dry Andes Division), or span many several Divisions (e.g., some tidal or freshwater marsh systems).

Vegetation Structure and Phenology. Vegetation structure (e.g. Forest and Woodland, Grassland), and phenology (e.g. seasonal evergreen, deciduous) are commonly used in the name of a system. In sparse to unvegetated types, reference to characteristic landforms (e.g. cliff) may substitute for vegetative structure and/or composition. It will typically come after Ecological Division, but may come before or after Environment (see below).

Environment. Environmental factors (e.g., xeric, hygrophilous, montane) can be used in conjunction with Vegetative Structure and Phenology or on their own to name system types. This will typically come after Ecological Division, but may come before or after Vegetation Structure and Composition.

Results

Number and Distribution of Systems

This first iteration has resulted thus far in the identification and description of some 700 upland and wetland ecological system types within 19 of the 23 Divisions encompassed in Latin America and the Caribbean, and we expect to identify at least 150 additional types in the remaining divisions. This selection represents almost the full range of natural settings that can be encountered in the region, with the exception of the temperate grasslands of the Southern Cone, the Pacific Desert, and the unique environments of the Galapagos Islands.

A total of 694 types give the following preliminary results when grouped in different categories: some 477 types (69%) are uplands, 199 (29%) are wetlands, and 17 types (2%) are complexes of uplands and wetlands, these proportions may change slightly towards a reduction in the number of wetlands when some of these systems are more accurately classified as complexes of uplands and wetlands. Looking at prevailing vegetation physiognomy, some 512 types (71%) are predominantly forest, woodland, and/or shrubland, and some 198 types (28%) are predominantly herbaceous, savanna, and/or grassland. Only 17 types have been recorded as sparsely vegetated. Clearly this number does not represent the full diversity of these restricted, isolated, and usually rare types, and more detailed information is required in order to better represent them in the classification.

Figure 3 categorizes Ecological Divisions by the number of ecological systems. The first evident pattern is the habitat diversity of the Andes, an expected result given the broad altitudinal and latitudinal gradients encompassed in the cordillera. A perhaps less expected pattern is the comparatively poorer diversity of the rainforests of the tropical lowlands. Adding the systems of the two Andean divisions the total number is 202, with little overlapping, whereas the sum of the systems of all the typical tropical rainforest regions is 184 (Amazonia, Atlantic Forest, Guianan Eastern Lowlands, Guianan Uplands and Highlands, and Moist Meso America). Table 2 indicates the number of ecological systems within each ecological division.

Figure 4 illustrates the number of ecological systems by country. A direct correspondence exists between the number of divisions occurring in one country, and the number of ecological systems for the same country. This explains in part the unexpected large number of systems found to occur in Argentina or Bolivia, for instance. It is again important to recognize is that these figures reflects to some degree the availability of information, or rather, the level of detail of the available information, as well as geographical expertise of involved reviewers.

Table 2. Breakdown of ecological system types by Ecological Division

Division Name	Number of Ecological System Types	Division Name	Number of Ecological System Types
Amazonia	49	Moist Meso-America	37
Atlantic Forest	20	North-Central Moist Andes	126
Caribbean	53	Orinoquia	19
Caatinga	25	Sierra Madre	12
Cerrado	55	South American Pacific Maritime	19
Chaco	27	South-Central Dry Andes	76
Dry Meso-America	31	Mediterranean Chile	10+
Guianan Eastern Lowland	20	Madrean Semidesert	14
Guianan Uplands and Highlands	58	North American Warm Desert	50
Meso-American Seasonal Highlands	16		

Data Management and Access

The classification information is stored in a MS-Access database (*Systems2000.mdb*). The Access-based database includes descriptions of the approximately 700 systems types, their distribution by country and for a subset of systems, by ecoregions, correspondence with standard classifications (Central America and the Caribbean), and references of all available literature. It also includes the diagnostic classifiers used to define the ecological systems. The database is available in both Access 97 and Access 2000 versions, in both cases as a read-only database. An accompanying manual in MS-Word (*Systems database manual.doc*) documents its content, functionality, and reporting capabilities.

In the future, all of the Terrestrial Ecological Systems and their accompanying data will be converted into NatureServe's central data management system, *Biotics 4*. Once the system types and the data are stored in *Biotics 4*, the full data management, updating, and revision capabilities of that will be available for the continuing development and refinement of system types. In addition, the ecological systems will be served on-line via NatureServe's public website (www.natureserve.org).

Figure 3. Number of Terrestrial Ecological System types by Ecological Division

Figure 4. Number of Terrestrial Ecological System types by Country

Applications

Applications to Conservation Assessment

Conservation assessment occurs at varying spatial scales to serve the priority-setting needs of various users. Assessment at a regional scale is often necessary to evaluate status and trends in regional biodiversity. Places are then identified that capture ecological and genetic variation across a broad range of environmental gradients (Johnson et al. 1999). At these regional scales, planning efforts may identify networks of places that, taken together, fully represent characteristic biological diversity. One might then identify areas where more intensive natural resource development could take place in a compatible fashion. That network of places is sometimes referred to as a “portfolio,” because an ever-changing variety of approaches may exist to conserve biological diversity over time through on-the-ground actions. As knowledge expands, and the “market” for conservation changes, one can expect that new places will gain importance, while other places may contribute less to conservation goals. Much like a financial portfolio, a regional conservation network embodies this portfolio concept.

Assessments using ecoregions as a spatial planning framework have become increasingly common in recent years, and standardized classifications of ecological systems can serve a central role in these types of assessments. Ecoregions are regional landscapes, or relatively large areas of land and water defined by similar geology, landforms, climates and ecological processes. Further, ecoregions contain geographically-distinct assemblages of ecological systems that share a large majority of their communities, species, dynamics, and environmental conditions, and function effectively as a framework for conservation assessment at global and continental scales (Bailey 1996, Olsen et al. 2001). In most instances, upland and wetland ecological system units can be mapped comprehensively across ecoregions or any other regional planning area. Therefore they aid in evaluating the status and trends of numerous ecological phenomena, from trends in land conversion or wildlife habitats to creating repeatable metrics for landscape fragmentation.

An “element-based” approach to conservation assessment commonly establishes a suite of species, communities, and ecological systems that provide the focus for representing biodiversity. An additional suite of elements may also be included in the analysis to represent overall conservation value (e.g., those identified under environmental regulations, open space, scenic or cultural values.). The objective should be to select a limited set of elements that could serve as effective surrogates for all (or nearly all) biological diversity. Through conservation of these elements across the planning area, one seeks to efficiently secure the ecological environments and dynamic interactions that support the vast majority of species. Occurrences of these elements, as well as the relative quality of their occurrences, are used to characterize biodiversity value and identify specific locations for conservation action.

Three levels of biological or ecological organization: *ecological systems*, *communities,* and *species*, should be represented among selected elements*.* As these categories indicate, this reflects a "coarse filter/fine filter" hypothesis – i.e. the conservation of multiple, high-quality occurrences of all ecological systems will also support the majority of native biodiversity. Since this "coarse filter" on its own would be unlikely to represent all biodiversity, especially those communities and species that are rare and thus not reliably found within most examples of ecological systems, additional elements, those that are imperiled or vulnerable, are also needed – the "fine filter." Lambeck (1997) proposed a generic set of criteria for selection of focal species for conservation planning. Experience suggests that this combined "coarse filter/fine filter" approach is the most efficient and effective approach to capturing biodiversity in a network of reserves (e.g. Jenkins 1976, 1985; Noss and Cooperider 1994, Haufler et al. 1996, Groves et al. 2002, Kintsch and Urban 2002). The coarse filter/fine filter approach also helps us to minimize complexity and cost associated with strict species-based approaches (e.g. Scott et al 1987, Beissinger and Westphal 1998; Willis and Whittaker 2002) while allowing sufficient flexibility to integrate new approaches as technical hurdles are overcome (e.g. Fleishman et al. 2001, Carroll et al. 2001, Scott et al. 2002).

Careful element selection therefore provides appropriate focus for subsequent efforts to map and evaluate element occurrences, then establish specific conservation goals and objectives.

Applications to Element Occurrence Inventory and Mapping

Here we discuss the issues about identifying the systems on the ground and developing detailed information on their locations or occurrences ("element occurrence requirements"). In the *Applications to Management and Monitoring* section, we introduce the issue of assessing the ecological integrity of these occurrences.

Elements, then are the units of biodiversity, whether species, communities, or systems. Element occurrences are geographic locations of those elements on the ground. Specifically, NatureServe standards (NatureServe 2002) state that:

> *An element occurrences is an area of land and/or water in which a species, natural community, or ecological system is, or was, present. An occurrence should have practical conservation value for the Element…. For community Elements, the occurrence may represent a stand or patch of a natural community, or a cluster of*

stands or patches of a natural community. For system elements, the occurrence may represent a cluster of stands from different communities that are part of the system.

Occurrences constitute the principal source of detailed information about the distribution of the elements. The occurrences are typically mapped, but map scale can vary depending on the application.

Key to the identification and mapping process is establishing the criteria for a given occurrence. When is one occurrence of a system distinct from another occurrence of the same system? For example, a mesic forest system (such as the Tumbesian Dry Montane Forest) may occupy a series of ravines, and is distinct from either the riparian forests in the bottoms of ravines or the xeric scrubs that predominate on the warmer and drier upland slopes. How far apart do the dry forest stands need to be before they are treated as separate occurrences? And do small stands of only a 0.5 hectare patch get recorded as a separate occurrence from xeric scrubs that surround it? It is these questions about minimum patch size and separation distances between patches that are addressed by the "occurrence requirements," which ensure consistent application of the systems approach.

Defining Occurrences. For ecological systems (as for communities), occurrences represent a defined area that contains (or contained) a characteristic ecological setting and vegetation. Occurrences are separated from each other by barriers to species interactions or ecological processes, or by specific distances defined for each element across adjacent areas occupied by other natural or semi-natural community types, or by cultural vegetation. Occurrences can be created for both communities and systems. In some cases a system occurrence may encompass several community-level occurrences, either of the same community type (in cases where the separation distance requirement at the systems level is greater than at the community level) or several community types. Recommended minimum sizes for the system types will meet or exceed those of the component community types.

They are:

10 ha for matrix,
10 ha for upland large patch;
1 ha for wetland large patch;
0.5 ha for small patch;
100 m for all linear types.

Stands/areas below the recommended minimum size become difficult to judge in terms of community or system type characteristics, and, if isolated, become heavily influenced by edge effects. For conservation purposes, generally only larger sized occurrences of each community or system type are tracked and the threshold for minimum size is seldom approached.

Barriers and Separation Distances. Known barriers for Elements, either naturally occurring or manmade, should be described in the occurrence requirements. For community or system occurrences, barriers may be obstacles that limit the expansion or alter the function of these types. These barriers either separate populations of most of the component species within the community or system, thus obstructing or severely limiting gene flow and ecological interactions, or they obstruct or limit ecological processes that these species depend on. Barriers may be common for many wetland communities or systems, but are typically less common for many upland terrestrial communities or systems.

In addition to barriers that totally, or almost completely, prevent ecological processes and species interactions, there may be habitats between two stands of an element that partially restrict species interactions or ecological processes. Unlike barriers, their effect depends on the kind and extent of this intervening habitat and its effect on the stands. This leads to the issue of separation distance. The intent of assigning values for separation distances between two stands is to achieve consistency in the manner in which occurrences are defined and mapped. Smaller separation distances are used when the intervening habitat is highly restrictive to the ecological processes or species interactions the element depends, and greater distances are used when these habitats are less prohibitive to ecological processes or species interactions.

We use two broad categories of intervening habitats to define separation distances, namely – natural/semi-natural vegetation or cultural vegetation. Generally speaking, intervening natural and semi-natural vegetation will have less of an ecological effect between two stands of an occurrence than intervening cultural vegetation. Thus rather simplistically, we suggest that different separation distances be specified for these two kinds of situations. Typically, a shorter separation distance is specified when the intervening habitat is cultural vegetation than when it is natural/semi-natural. Minimum values for separation distances have been recommended to ensure that occurrences are not separated by unreasonably small distances, which would lead to the identification of unnecessarily splintered stands as potential targets for conservation planning or action. For communities or systems, the minimum separation distance for intervening areas of different natural or semi-natural communities is set at 1 km or greater, and for intervening areas of cultural vegetation, the distance is set at 0.5 km or greater (Table 3). These separation distances may, of course, be much larger. For communities or systems found primarily in mountainous regions, where habitat tends to be less fragmented, separation distances may be 5 km or more. A few elements may require separation distances that are less than the established minimum; in such cases, these distances should be justified in the occurrences.

Table 3. Recommended Minimum Separation Distances for Communities and Ecological Systems

Type of Separation	Minimum Separation Distance
Barrier	qualitatively defined
cultural vegetation	≥ 0.5 km
different natural or semi-natural communities or systems	≥ 1 km

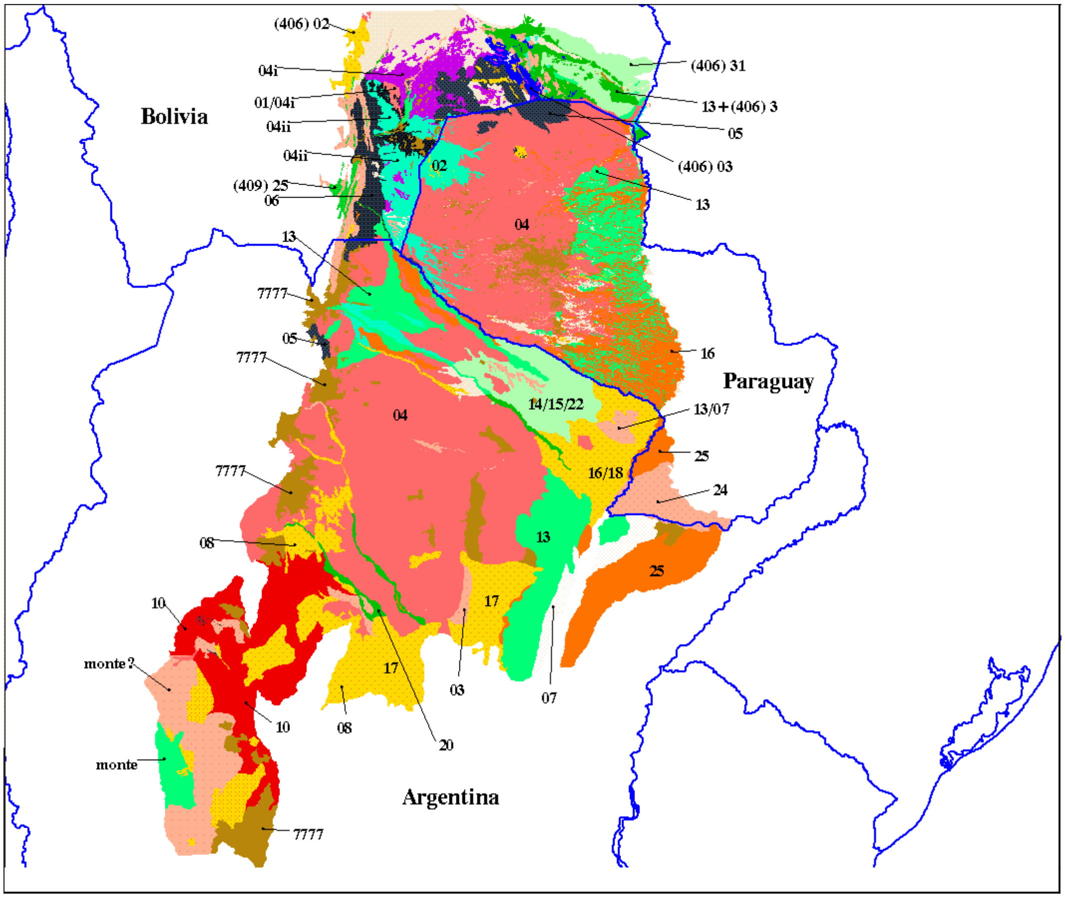
Mapping Applications

Vegetation forms one of the most readily observable natural features of the landscape. It provides an important measure of the current condition of natural systems and can serve as a cost-effective monitoring tool for ongoing management of those systems. Vegetation mapping is the process of integrating multiple sets of information. It often involves interpreting signatures from vegetation from remotely sensed data – sometimes integrating ancillary spatial data - then assigning each signature to a map unit. In order to ensure that each mapper bases his or her interpretation of those signatures on the same ecological perspective, a consistent classification is needed.

Given the inherent difficulties in achieving a consistently agreed-upon classification scheme, it may appear that classification should really be the end result of mapping; that is, the vegetation mapper is free to explore the vegetation patterns as they appear on the local landscape, and choose those features that are most relevant to the species combinations and environmental factors on hand (*a posteriori* classification). Indeed, Kuchler (1988) argued that this approach has much to recommend it. But Kuchler also pointed out that such *a posteriori* classifications have a major drawback – they are best applicable only in the mapped area or, at best, only short distances beyond the borders of the area. Since the scope of the NatureServe Ecological Systems Classification is hemispheric, basing the mapping on these classifications should allow any map produced to be compared to other areas in an integrated and consistent manner.

Only a few countries in Latin America have national vegetation maps based on remote sensing data and modern mapping tools. On the other hand, a contrasting situation occurs at the local level, where increasingly easier access to mapping tools (*i.e*. software) is causing a proliferation of ad-hoc legends for local vegetation maps and therefore increasing the difficulties in using those for spatial analysis of trends across entire ecosystems ranges.

The NatureServe ecological systems classification was utilized with the preparation of maps of ecological systems in four different regional planning areas that constitute subunits of NatureServe's Ecological Divisions and groupings of WWF ecoregions (e.g. Venezuelan Andes, Gran Chaco, Cordillera Real Oriental, and Equatorial Pacific). In these exercises existing vegetation maps, climatic maps, and interpretation of satellite imagery by experts were used to map the systems, and in cases, field trips have been conducted to identify the systems on the ground. At the time of this publication, these remained ongoing efforts, so we have not yet systematized the procedures followed, or performed map accuracy assessments. Figure 5 shows a preliminary map depicting ecological systems of the Chaco and a selection of the units, as an example. Not all of the 43 terrestrial ecological system units thought to occur in this region were depicted in this map with existing data. Those not depicted tend to occur as very small patches, or the ancillary information used was too coarse, such as in the Argentina side (Eva et al. 2002). These LAC maps have relied strongly on existing spatial vegetation information. As far as this information is available at a compatible scale it is a good alternative, otherwise resolution can be improved by bringing in biophysical variables such as elevation, landform, surface geology, soils, and hydrography in order to split coarse units in a number of systems. These variables should be used for modeling with the concept statements of each ecological system type in mind.



1. **Bosques de los arenales del Chaco septentrional occidental**.
2. **Sabanas arboladas de los arenales del Chaco septentrional occidental**.
3. Sabanas arboladas abiertas sobre paleocauces colmatados del Chaco septentrional.
4. **Bosques xéricos de las llanuras aluviales antiguas del Chaco septentrional occidental**.
   - **i. De la llanura aluvial antigua de los ríos Grande y Parapetí.**
   - **ii. De la llanura aluvial antigua del río Pilcomayo.**
   - iii. De la llanura aluvial antigua del río Teuco-Bermejo.

5. Bosques transicionales del Chaco septentrional a la Chiquitanía, sobre arenas.
26. Bosques transicionales del Chaco septentrional a la Chiquitanía, sobre cerros.
27. Bosques transicionales del Chaco septentrional a la Chiquitanía sobre llanura aluvial.
6. Bosques transicionales preandinos del Chaco septentrional occidental.
7. Bosques transicionales subhúmedos del Chaco septentrional oriental.
8. Bosques secundarios xéricos del Chaco septentrional occidental.
9. **Matorrales secundarios xéricos del Chaco septentrional occidental**.
10. Bosques xéricos del Chaco meridional.
11. **Vegetación saxícola de los acantilados del Chaco septentrional**.

Figure 5. Draft map of terrestrial ecological system units of the Gran Chaco and partial legend

Applications to Management and Monitoring

Having mapped ecological systems and established occurrences on the ground, we may then want to know if each mapped occurrence is of sufficient quality (viability or ecological integrity) or can be feasibly restored to such quality. This is the next essential step towards developing local-area management and monitoring objectives. Characterizing and evaluating the quality of an occurrence provides the basis for assessing ecological stresses—the degradation, or impairment—of element occurrences at a given site. There are three core components of occurrence evaluation that can be applied to *all focal conservation elements* in a conservation site of any scale – whether these are individual populations or species, assemblages of species, ecological communities, or ecological systems. These core components and their function are as follows:

1) **Key Ecological Attributes** – structure, composition, interactions and abiotic and biotic processes that enable the Element Occurrence to persist.

2) **Indicator** – measurable entity that is used to assess the status and trend of a Key Ecological Attribute.

3) **Indicator rating** – the point within a given expected range of variation one would rate each Indicator that describes its current status.

To assess the quality of element occurrences, one must first identify and document a limited number of key ecological attributes that support them (the terms "key ecological attribute" and "indicators" are comparable to the term "ecological attributes" and "indicator" used by TNC in Parrish et al. 2003 and by the EPA publication of Young and Sanzone 2002). After these are identified, a set of measurable indicators are established to evaluate each attribute and document their expected ranges of variation. For each indicator, we may then establish thresholds for distinguishing their current status along a relative scale from "Excellent" to "Poor."

Documentation of these basic assumptions about key ecological attributes, ranges of variation, thresholds, and indicators for measurement, are called "Element Occurrence Rank Criteria;" and form a central component of Heritage methodology. These criteria are needed to consistently assess whether the attributes exhibited for a given occurrence are within desired ranges or whether they will require significant effort to be maintained or restored to their desired status. Each key attribute is reviewed, rated, and then combined with others to rank each occurrence as A (excellent), B (good), C (fair), and D (poor). The higher the estimated viability or integrity of the occurrence, the higher is its occurrence rank and presumed conservation value. Table 4 lists the basic occurrence ranks assigned to each occurrence. The break between C and D establishes a minimum quality threshold for occurrences. D-ranked occurrences are typically presumed to be beyond practical consideration for ecological restoration. In subsequent management planning, these ranks and underlying attributes and indicators aid in focusing conservation activities and measure progress toward the local conservation objectives.

Table 4. Basic Element Occurrence Ranks

Occurrence **Rank**	**Description of Ecological Integrity**
A	excellent
B	good
C	fair
D	poor
E	verified extant (integrity not assessed)
H	historical (not recently located)
X	extirpated (no longer extant)

Because occurrence ranks are used to represent the relative conservation value of an occurrence as it currently exists, occurrence ranks are based solely on attributes that reflect the present status, or quality, of that occurrence. There are three generalized occurrence rank categories used to organize the various key ecological attributes. These are condition, size, and landscape context. They are combined further to arrive at an overall occurrence rank. Thus:

Condition+ Size + Landscape Context $\Rightarrow$ Estimated Viability or Integrity $\approx$ Occurrence Rank

For community and system Elements, the term "ecological integrity" is preferable to that of viability, since communities and systems are comprised of many separate species, each with their own viability. Ecological integrity is the "maintenance of…structure, species composition, and the rate of ecological processes and functions within the bounds of normal disturbance regimes[1]. More directly, occurrence ranks reflect the degree of negative anthropogenic impact to a

[1]From. Lindenmayer and Recher (in Lindenmayer and Franklin 2002). Similarly, Karr and Chu (1995) define ecological (or biological) integrity as "the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, and assemblages) and processes (mutations, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region.

community or system (*i.e.,* the degree to which people have directly or indirectly adversely or favorably impacted community composition, structure, and/or function, including alteration of natural disturbance processes).

It is not necessary to have knowledge of each of the three rank factors to develop occurrence rank criteria. The three EO rank factor categories and generalized key attributes are summarized in Table 5 below.

Table 5. Occurrence Rank Categories and Key Ecological Attributes

CATEGORY	GENERALIZED KEY ECOLOGICAL ATTRIBUTES (examples of indicators are noted within parentheses)	Species	Communities and Systems
Condition	reproduction and health (evidence of regular, successful reproduction; age distribution for long-lived species; persistence of clones; vigor, evidence of disease affecting reproduction/survival)	√	
	development/maturity (stability, presence of old-growth)		√
	species composition and biological structure (richness, evenness of species distribution, presence of exotics)	√	√
	ecological processes (degree of disturbance by logging, grazing; changes in hydrology or natural fire regime)	√	√
	abiotic physical/chemical attributes (stability of substrate, physical structure, water quality) [excluding processes]	√	√
Size	area of occupancy	√	√
	population abundance	√	
	population density	√	
	population fluctuation (average population and minimum population in worst foreseeable year)	√	
Landscape Context	landscape structure and extent (pattern, connectivity, *e.g.*, measure of fragmentation/ patchiness, measure of genetic connectivity)	√	√
	condition of the surrounding landscape (*i.e.,* development/maturity, species composition and biological structure, ecological processes, abiotic physical/chemical attributes)	√	√

Indicators. Key Ecological Attributes may be difficult or impossible to directly measure. Where this is the case, an indicator of the Attribute that may be reasonably and effectively measured should be identified. In a river floodplain system, for example, river flow dynamics may be an ecological process that is a Key Ecological Attribute, but it is not reasonable to expect that every possible parameter would be measured. A few parameters (e.g., flood seasonality and periodicity) can be selected that will give us an overall indication (indicator) of how the status of our Key Attribute (flow dynamics) is changing. So the indicator may be a subset of the variables defining the Key Attribute, or a more measurable substitute for the Attribute.

Any element's Key Ecological Attributes (and therefore their indicators) will vary over time in a relatively undisturbed setting. This variation is not random, but limited to a particular range that we recognize as either a) natural and consistent with the long-term persistence of each occurrence, or b) outside the natural range because of human influences (e.g., fire suppression in fire adapted systems).

Establishing Thresholds. In order to effectively evaluate occurrences relative to each other, overall ecological integrity ranks should establish a scale for distinguishing between "A", "B", "C", and "D" occurrences. This scale should usually spread from a lowermost limit (the "D" rank or minimum occurrence threshold) up through the threshold for an "A" rank. In addition, the threshold delineating occurrences with "fair" vs. "poor" viability or integrity must be identified. Figure 6 illustrates the rank scale for "A", "B", "C", and "D"-ranked occurrences.

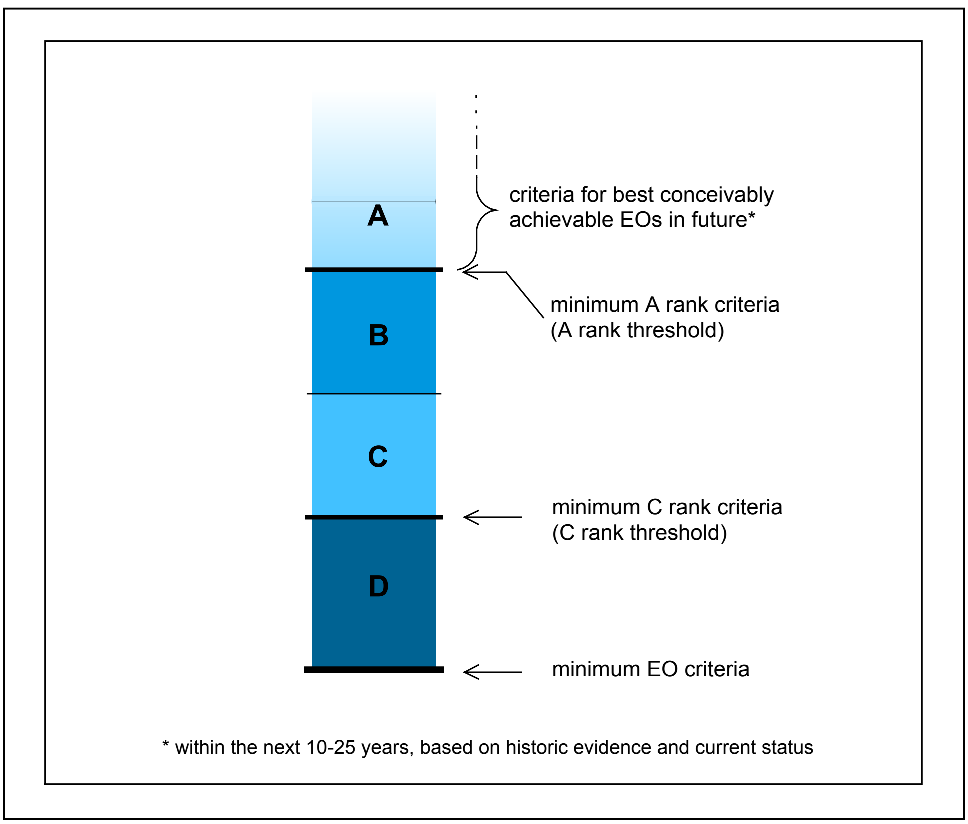


Figure 6. Rank scale for "A", "B", "C", and "D"-ranked Occurrences

Perhaps most critical for development of occurrence rank criteria is the establishment of the threshold between occurrence s with “fair” and “poor” viability or integrity (the minimum “C” rank criteria). As mentioned above, this clarifies whether or not one has a potentially restorable occurrence. Next the A-ranked criteria are established. Typically these are the best occurrences that are reasonably and conceivably achievable; generally, these will be the minimum “A” rank criteria unless the best reasonably achievable occurrences have only “fair” or “poor” viability or integrity. Finally, assuming the best occurrences that are reasonably and conceivably achievable are at or above the “A” rank threshold, one can identify minimum “B” rank criteria that achieve a spread between “A” and “C”-ranked occurrences.

An occurrence rank need not always be directly comparable to historical conditions. For example, some fire-adapted ecological systems historically supported fire on vast landscape scales that could not be feasibly repeated today. But under controlled conditions, many effects of those landscape scale fires could be reintroduced in smaller areas. These are the types of practical considerations that are documented in occurrence rank criteria. Further details are provided in NatureServe’s (2003) Element Occurrence Data Standards.

Future Applications

We envision this project as a point of departure to develop comprehensive mapping and continually updated databases on the nomenclature, distribution, ecological characteristics, and conservation status of terrestrial ecological system types throughout the western hemisphere. As stated previously, ecological classification may ideally proceed through several phases in a continual process of refinement. These phases could include 1) literature review and synthesis of current knowledge, 2) formulating initial hypotheses and tentatively describing each type, that support 3) establishing a field sample design, 4) gathering of field data, 5) data analysis and interpretation, 6) description of types, 7) establishing dichotomous keys to classification units, 8) mapping of classification units, and 9) refinement of the classification.

As noted by Jennings et al. (2003) and others before, a vegetation association or community represents a statistical and conceptual synthesis of floristic patterns. It can be a “useful abstraction,” representing a defined range of floristic, structural, and environmental variability. Ecological systems represent a similar kind of “useful abstraction” that encompasses the concepts of multiple vegetation associations, and emphasizes the environmental attributes that result in their co-occurrence on the ground. The definition of both associations and ecological systems as individual types is the result of a set of classification decisions based on field sampling, data analysis, and interpretation. What may begin as only an "abstraction" may become a truly "useful abstraction" when informed individuals can readily recognize units on the ground. Mapping ecological systems serves as an immediate practical test of classification concepts, ensuring that the mapped area is treated comprehensively by the classification, providing for a consistent use of multiple spatial data, and clearer distinctions between types.

We expect that further classification development will be a sustained process involving the participation of in-country experts net-working with NatureServe and international and local partner organizations to identify, map, and assess the condition of ecological systems occurrences, where NatureServe serves de role of "keeper" of this classification of terrestrial ecological systems.

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