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ECOLOGICAL CLASSIFICATION OF THE WESTERN HEMISPHERE

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ABSTRACT

Many geographical classifications of the world's continents can be found that depict their climate, landforms, soils, vegetation, and other ecological phenomena. Using some or many of these mapped phenomena, classifications of natural regions, biomes, biotic provinces, biogeographical regions, life zones, or ecological regions have been developed by various researchers. Some ecological frameworks do not appear to address "the whole ecosystem", but instead are based on specific aspects of ecosystems or particular processes that affect ecosystems. Many regional ecological frameworks rely primarily on climatic and "natural" vegetative input elements, with little acknowledgement of other biotic, abiotic, or human geographic patterns that comprise and influence ecosystems. The USGS EROS Data Center and the U.S. EPA NHEERL-WED initiated this project to develop an ecological classification and ecoregion map for the Western Hemisphere (North and South America) that is consistent with recent EPA and North American ecoregion frameworks. This report discusses some of the philosophical and methodological differences used in the development of ecosystem frameworks and how these differences can affect regional identification and boundary delineations. An understanding of these differences is important for interpretations of the regions and for applications of the frameworks to resource and ecosystem management issues.

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Introduction

"Is there any reason to produce a new classification for a natural world that has already been classified and reclassified by numbers of ecologists and geographers?" -- Raymond Dasmann, 1976

The world is awash with spatial data and geographic frameworks that can help us interpret and understand the resource patterns and ecological systems we are a part of. One challenge for ecological scientists and resource managers working across large areas of Earth is to collect, compile, interpret, synthesize, and display this abundance of disparate information to define meaningful areas or regions, in a hierarchical or scale-dependent manner, where the aggregate of ecological characteristics are relatively homogeneous. There is a proven need for a regional approach to address water quality problems, forest health concerns, biodiversity issues, and ecosystem management approaches in the aggregate. Regional frameworks can be useful for the development of strategies to create more viable and sustainable human economies and communities that maintain sound, healthy, and desired ecological characteristics and functions. They can help us understand ecological potential, historical states, current status, and attainable conditions.

Classifying and delineating ecologically homogenous areas is often considered a fundamental first step for ecosystem management, but there are, and will always be, numerous approaches to such an endeavor. Although there are some similarities among synthesized classifications such as natural regions, biomes, biotic provinces, biogeographical regions, life zones, and ecological regions, those researchers involved in the details of defining or using these frameworks tend to emphasize and magnify the differences. The differences in methods, materials, and philosophy do, however, lead to different results and regions. We have found that many ecological classifications emphasize climatic and "natural" vegetation elements, with little acknowledgement of other biotic, abiotic, or human geographic patterns that comprise and influence ecosystems. The different scientific approaches to ecological classification offer different insight and understanding. In addition, cultural and national perceptions influence classification results.

The aim of this paper is to review some of the ecological classifications of North and South America, highlight the differences in their objectives, approaches, and results, discuss some problems encountered in multi-national mapping efforts, and present a preliminary alternative classification for Central and South America. Why make another ecoregion map of North or South America? For the question posed above by Dasman, his own answer is to the point and forever applicable: "Examination of existing systems of classification revealed inadequacies," (Dasmann 1976).

Defining Ecosystems and Ecoregions

One's perception of "ecosystems" or how ecological regions should be defined is shaped not only by the agencies, institutions, or programs a person is associated with, but also by cultural background, educational training, and life experiences. Geographers, biologists, botanists, ecologists, landscape architects, soil scientists, regional planners, foresters, agronomists, and conservationists of all kinds each brings his or her own biased view on what the term ecosystem means to them. There is disagreement about whether ecosystems are abstract concepts or areas with geographical borders (Marin 1997, Rowe 1997, Blew 1996, Rowe and Barnes 1994). There is also the conceptual and philosophical issue of whether humans should be accepted as an integral part of ecosystems or are somehow a separate consideration. In general, definitions of the term "ecosystem" appear to have evolved from ones that centered just on the biota, to ones that comprised biotic and abiotic characteristics but in the absence of humans, to definitions that now more often consider humans as part of the biota.

Ultimately, most environmental researchers and managers become interested in some type of spatial framework of areas or regions within which the mosaic of all biotic and abiotic ecosystem components are different or exhibit certain patterns. The overall objective of the U.S. federal interagency effort to reach consensus on a hierarchical framework of ecoregions of the United States is to facilitate integrated research, assesment, and management of environmental resources between state and federal agencies and programs that have responsibilities for different resources for the same geographical areas. International organizations are interested in such frameworks to ensure that representation is maintained at an appropriate biogeographic scale for regional conservation planning. Although there will never be complete agreement among researchers and agencies about which is the most appropriate ecological framework, it is important to understand the differences in the purpose and development of these spatial classifications.

A Selective Review of Western Hemisphere Ecological Frameworks

In searching for "ecological" classifications of the Western Hemisphere, there are several that are small-scale as part of global classifications, and a few that are larger-scale but cover only an individual country. A review of these frameworks helps illustrate the differences and changes that have occurred in the concept and construction of ecological regions.

As reviewed by Bailey (1996), most efforts to divide the world into ecological regions have been based primarily on the distribution of climate or climate-vegetation zones. As one would expect with related phenomena of climate and vegetation, there has also been circularity and interdependence in the development of these types of classifications: Köppen used vegetation composition and distribution to help define his climatic units; Life zones, from Merriam to Holdridge, were defined on the basis of climate. Pointing out the difficulties of defining climate and differentiating zones, Walter and Breckle (1985) noted that, "...the border of a climatic zone is regarded as being identical with that of a vegetational zone, giving the impression that climatic and vegetational maps are in remarkably close agreement." They also note that, when proposing ecological subdivisions, it is a mistake to account for only one of the factors such as climate, soil, vegetation and fauna; but they contend that it is also impossible to consider all of those factors at the same time. As with many ecological frameworks, they suggest a stepwise process of subdivision with prioty given to each factor at a different level. Few attempts are made to consider all factors at the same time in developing ecological frameworks.

Kendeigh (1954) reviewed the early development of floristic, faunistic, biotic and biome concepts of communities for North America. He noted that one of the better efforts of regionalization in the 1800's was the work of J.G. Cooper who mapped natural provinces and regions in 1859 for the Smithsonian Institute. This work was more "bioecological" than many efforts that followed, and many of the names and boundaries that Dice (1943) would later use for biotic provinces were similar to Cooper's.

In the early part of this century, natural regions were mapped for the world by Herbertson (1905). Herbertson considered the distribution of a combination of characteristics in defining his natural regions, including human activities. Joerg (1914) reviewed North America classifications and discussed methods to be used to establish natural regions. He suggested that the primary elements or factors for regional delineation would change from one area to another and depend upon the subjective evaluation of their relative importance. "For this reason, it is not a question of whether a subdivision is right or wrong, as Hettner points out, but only whether it is expedient or not," (Joerg 1914, p.58).

In North America, the life zones of Clinton Hart Merriam and the biomes of Victor Shelford were the prominent biogeographic classifications in the early American ecological literature. The life-zone concept developed by Merriam (1898) was based on certain ideas about temperature and plant growth. The life zone studies by the U.S. Department of Agriculture's Division of Ornithology and Mammology (Merriam was chief of the Division) were prompted largely by economic motives, that is, knowledge of life zone boundaries was thought to provide a key to agricultural possibilities (Daubenmire 1938). Life zones are generally arranged in a regular sequence from the tropics to the poles or in elevation bands that ascend high mountains. In North America, these life zones included the Tropical, Lower Austral, Upper Austral, Transition, Canadian, Hudsonian, and Arctic. Although some of Merriam's proposed relationships of temperature and plant growth were incorrect (Kendeigh 1932, Shelford 1932, Daubenmire 1938), his application of the system to agricultural zones provided a useful framework in the United States. Biologists, geographers, and others found that such descriptive life-zone regionalizations of plant and animal associations had some value for classifying large areas. Convinced of the correctness and finality of his system, Merriam (1895) confidently boasted:

> "It appears, therefore, that in its broader aspects the study of the geographic distribution of life in North America is completed. The primary regions and their subdivisions have been defined and mapped, the problems involved in the control of distribution have been solved, and the laws themselves have been formulated."

Merriam's life zones were accepted by some mammologists and ornithologists but not as much by other zoologists and botanists (Kendeigh 1954). Many questioned the concept that distributional patterns conformed to latitudinal zones. Criticism also centered on the fact that the transcontinental life zone boundaries were not defined biotically but were made to agree with isotherms. Dice (1952) concluded that the life-zone method "does not seem to be suited for the classification of ecological communities."

The biome system of classification was developed in the early 1900's to define major ecological divisions based on the physiognomy of its climaxes or "climax" vegetation, ie grassland biome, deciduous forest biome, tundra biome, coniferous forest biome, etc. The development of the work in North America was based on Weaver and Clements (1929), and developed further by the botanist Clements and the zoologist Shelford (Clements and Shelford 1939). The biomes were divided into associations based on climatic climax community (Clements and Shelford 1939). The associations were divided into fasciations, and the fasciations into communities, although these lesser divisions were rarely mapped. Most of this work was concentrated in North America and was not developed enough for other continents to be useful for an international conservation-oriented classification system (Dasmann (1976). Global-scale biome maps are usually based on Köppen's climate classification.

Dice's (1943) biotic provinces are continuous geographic units based on climate, physiography, soils, and major natural communities (Dice 1952, Whittaker 1978). Dice (1943) defined 29 biotic provinces that "were characterized by the occurrence of one or more important ecologic associations that differ, at least in proportional area covered, from the associations of adjacent provinces." This system emphasises centers of specific evolution, geographic relation, and taxonomic differentiation. Biotic districts subdivided the biotic provinces, and life belts were vertical subdivisions of provinces, but a biotic province was never discontinuous. This is one of the differences from biomes, which are discontinuous. Dice (1952) suggested that biomes and biotic provinces should not be considered as mutually exclusive competing systems of ecological classification, but are supplementary to each other. Pitelka (1943) criticized Dice's work for "an excessive amount of arbitrariness" and a lack of discussion on the theoretical bases for the units that were delineated.

A bioclimatic classification of life zones was devised by Holdridge (1947, 1987) and has been used in Central American, Andean, and other countries to map vegetal based regions (e.g., Holdridge and Budowski 1956; Tosi 1958, 1960, 1969). The classification is based on a chart that differentiates life zones for the world according to latitudinal region, altitudinal belt, and humidity province (Holdridge et al. 1971). The life zone boundaries on the diagram are precisely defined by mean annual precipitation and mean annual biotemperature. Although defined by climatic elements such as precipitation, temperature, and potential evapotranspiration, the life zones use vegetation formation terms, and the mapped boundaries were delineated mostly from field observations of remnant "natural" vegetation (Parsons 1962). Although the life zone maps and documentation provide many useful regions and discussions of the land relative to human uses, the system has been criticized as providing hypothetical reconstructions that do not represent current conditions, and for not taking into account the length of day, seasonal distribution of precipitation and temperature, soil differences, variations in runoff, sparse or misleading climate data, or the role of human disturbance (Parsons 1962; Bennett 1967, 1968). Some of these issues were subsequently addressed by Holdridge et al. (1971) in their attempt to further develop life zone mapping.

The Holdridge approach has recently been used to map life zones of the conterminous U.S. (Lugo et al. 1998). While this work was an innovative use of recent precipitation models and other climate and digital elevation data, the end product remains essentially a map of climate-elevation units with attached vegetation formation names. The western U.S. has much complexity because of the elevational differences, and the eastern U.S. is quite simplified. Some researchers favor this system because it supposedly depicts the climatic conditions that regulate ecosystem function, and there appears to be less room for subjectivity (Lugo et al. 1998). The climatic emphasis, however, appears to be an ecological oversimplification that presents more problems than it solves.

For defining useful geographical units for cataloging the distribution of species as well as for the conservation of ecological areas, Dasmann (1972, 1973) suggested a hierarchical system of geographic areas that was intended to unite faunistic and floristic regional systems of classification. This work for the IUCN Commission on Ecology aimed to extend the biotic province system of Dice in North America to the rest of the world (Dasmann 1976). These biogeographic provinces (Udvardy 1976) are basically subdivisions of biomes based on animal and plant distributions. As renamed by Udvardy (1975): biogeographical realms correspond to the kingdom of the florist and the region of the faunist; biogeographical provinces generally correspond to the regions of the florist and the faunal province of the faunist and the biotic province of Dice (1943). Each province is characterized by the major biome or biome-complex (e.g., tropical humid forests, temperate needle-leaf forests and woodlands, warm deserts and semideserts, temperate grasslands, etc.). The reliance on vegetation for classification was indicated by Udvardy (1975, p.14): "Ideally biogeographic provinces ought to be delimited on faunal, floral and ecological bases. Lack of source material and data caused, as already intimated, that more often than not ecological, i.e. vegetational knowledge, was the only source material available."

Dasmann (1976) asserted that the usefulness of the province concept extends beyond plant and animal species conservation:

> "They represent areas within which ecological conditions are relatively uniform, with certain natural potentials and limitations. During human history societies and cultures developed within certain provinces and adapted to their potentials and limitations....Many serious land use blunders could have been avoided if people had not tried to transplant land-use practices developed within one biotic province to the differing ecological conditions of another."

Brown and others (Brown 1994; Brown et al. 1980, 1985, 1998) have defined a hierarchical classification system for biotic communities in North America. They emphasise the need for a universal standard for a system that addresses "evolutionary-based ecosystems" and a hierarchical classification system that is able to be expanded or modified. Originally developed for the southwestern area of North America, the system considers the limiting effects of moisture and temperature minima as well as evolutionary origin on the structure and composition of plant and animal communities. The hierarchy includes biogeographic realm, hydrologic regime/vegetation (upland, wetland, cultivated, or natural), formation type, climatic zone, biome or regional formation, series (community of generic dominants), association (community of specific dominants), and composition-structure phase. This biotic system has an emphasis on vegetation and climate with disproportionate attention given to arid/semi-arid and subtropical/tropical portions of the continent than to temperate and colder regions.

Bailey's (1989) ecoregions of the continents was intended to "supplement the Udvardy (1975) system of biogeographical provinces with a treatment of higher resolution." Influenced by Crowley's (1967) classification system of domains, divisions, and provinces, Bailey used macro-features of the climate and vegetation, primarily Köppen's climate system as modified by Trewartha (1968), as well as areas from a world map of natural landscape types (Gerasimov 1964) to delineate the continental regions. In his approach, Bailey analyzed those factors that appeared to control ecosystem size at varying scales in a hierarchy and used the significant changes in those controls as the boundary criteria (Bailey 1996, 1998). Climate was the prime controlling factor in his system. "At each successive level, a different aspect of the climate and vegetation is assigned prime importance in placing map boundaries," (Bailey 1996, p.49). Bailey's approach has been criticized by some academics because it, "...stems from a view of ecosystems in which biological components are secondary outcomes of linear developmental processes, controlled by the particular combination of abiotic factors and culminating in predictable, stable endpoints," (Griffin 1997). The concept of constraints rather than controlling factors is seen as a better method for addressing the complexities, feedbacks, and multiple outcomes of dynamic ecosystems.

The Nature Conservancy (TNC Ecoregional Working Group 1997) and World Wildlife Fund (Ricketts et al. 1997) have also developed frameworks of ecoregions. In each of these cases, the mapping process was guided by a specific organizational goal, but also relied heavily on a particular federal agency framework for the North American portion. The TNC framework for the continental United States was based in part on Bailey's and other USFS (ECOMAP) frameworks (Bailey et al. 1994), but was modified in several respects. The goal of the TNC was to define large areas within which there are similarities in the structure and function of biological communities, with the size and number of the these regions being influenced by organizational capabilities (TNC Ecoregional Working Group 1997).

For North America, the WWF adopted many of the regions and digital boundaries from the CEC (1997) framework that was developed from the US EPA (Omernik 1995), Gallant et al. (1995), and Environment Canada (Ecological Stratification Working Group 1995) ecological regions. According to WWF, they "...chose these as foundations because their published maps approximate well documented patterns of biodiversity in North America," (Ricketts et al. 1997). The WWF combined some regions and sprinkled on a few other small areas of interest, such as scattered pieces of Florida Sand Pine Scrub, South Florida Rocklands, and Great Basin Montane Forests. Biological distinctiveness and conservation status were supposedly the two essential discriminating considerations in the determination of the World Wildlife Fund ecoregions (Ricketts et al. 1997). A vegetational interest or bias is also apparent in their modification of regional names, e.g., Sierra Nevada becomes Sierra Nevada Forests, East Central Texas Plains becomes East Central Texas Forests, Flint Hills becomes Flint Hills Tall Grasslands, Copper Plateau becomes Copper Plateau Taiga, and so on.

The WWF, with funding from the World Bank and contributions from an extensive list of individuals and institutions, developed a framework of Latin American and Caribbean ecoregions (Dinerstein 1995). These ecoregions are often based heavily on vegetation, with some areas defined apparently by patching together vegetation coverages. The result is some inconsistency in patterns and scale from one country or area to another.

The TNC has also adopted the WWF ecoregions for Latin America. When this framework is attached and compared with the TNC's U.S. ecoregions based on Bailey's work, the discrepancies also become apparent. The conceptual differences are also interesting in joining these frameworks. In contrast to Bailey's domains based on climate groups (polar, humid temperate, dry, humid tropical), the first level of the

WWF system in Latin America, major ecosystem types, reflects the vegetation interest (tropical broadleaf forests, conifer/temperate broadleaf forests, grasslands/savannas/shrublands, xeric, mangroves).

Other Latin America Ecoregion Schemes

In addition to the global and contintental ecoregion frameworks mentioned above, there are several other ecoregion frameworks, mostly national, that have been developed within Latin America. (References for this section are found in Appendix 2). In Peru, for example, a comparison was made of the natural regions of Peru developed by Dr. Javier Pulgas Vidal, with the ecoregions of Peru (Penaherrera del Aguila 1989). Ecological regions that are directed more toward agricultural potential have been defined in Argentina (Fundación Agro Palermo 1983) and Brazil (Ministério da Agricultura e Reforma Agrária 1993). Also in Argentina, biogeographic regions, domains, and provinces have been defined (http://www. surdelsur.com/flora/biogeogr/promap.htm), as well as the earlier phytogeographic regions based on the work of Angel Lulio Cabrera. For the South American continent, Aziz Ab'Sáber (1977) delineated morphoclimatic and phytogeographic domains.

Hierarchical Levels and Other Problems in Mapping Multi-Nation Ecoregion Frameworks

In mapping continental or global frameworks with methods that depend on a variety of national source materials and collaboration with individuals from different countries, there are difficulties in achieving agreements on conceptual approaches and attaining a consistent product. This is due not only to the wide variation in the quality and quantity of available information, but also by personal and national perceptions of the topic being mapped. A researcher from a small Central American country, for example, who is used to viewing detailed divisions of his country in national frameworks, might have difficulty accepting that the entire country falls within one or maybe two general regions at a particular hierarchical level. This discussion on hierarchical levels and detail of mapping may help illustrate some of these problems.

There are conceptual and cartographic problems and dilemnas in delineating different hierarchical levels of ecological regions. The different approaches to this problem result not only in differences in the appearance of the mapped boundaries, but also affect the existence and extent of the regions that are defined.

Bailey's (1989, 1994) generalized, smooth lines at the highest hierarchical levels affect regional and boundary placement at the lower levels. It is mostly a top-down approach where divisions fit within the domains, and provinces within the divisions etc. Because a different ecosystem component is used at each successive level, however, a relatively homogeneous region might be subdivided by a higher level domain or division line based on a climate zone boundary that is actually quite fuzzy.

The World Wildlife Fund's scheme for Latin America and the Caribbean appears conceptually top-down, but the cartographic portrayal and their regional or ecosystem definitions reflect a more bottom-up approach. Major ecosystem types, major habitat types, bioregions, and ecoregions comprise the hierarchy from high to low. The boundaries of the higher levels, such as bioregion and major habitat type, are from delineations of the lower level, the ecoregion. In this bottom-up aspect, the bioregions consist of contiguous ecoregions, "designed to better address the biogeographic distnctiveness of ecoregions," (Dinerstein et al 1995, p.123). The WWF states that the major habitat types are not geographically defined units, and are roughly equivalent to biomes (Ricketts et al 1997). But these major habitat types, as well as biomes, *are* often portrayed and used as boundary-delimited units or areas.

The CEC (1997) map of North America was developed in a collaborative effort by teams of Canadian, U.S., and Mexican researchers. As with many international mapping efforts, there were different approaches, methods, biases, and perceptions among the different members and teams that contributed to a product that is not entirely consistent across political borders. While Canada and the U.S. had existing ecological frameworks, and their methods were generally similar, there were still differences in the hierarchical levels that created problems for creating a North American product.

Mexico did not have a similar ecological framework that could be easily modified to join with the U.S. and Canadian schemes. A draft framework for Mexico at levels I, II, and III that was sketched out as “straw-man” regions by a U.S. researcher was deemed unacceptable by the Mexican colleagues, especially for being too general and with insufficient regions to depict the ecological complexity of Mexico. It was difficult to come to agreement on the level of detail to portray the regions at the coarsest level (level I) in the hierarchy. The initial goal was to show the smallest number of regions possible, for very general continental assessment and reporting purposes -- a level that would show the broadest type of ecological regions on a page size map. This handful of regions would each have considerable variability, but each would be generally similar in environmental issues, capacities, and potentials to allow reporting and extrapolation at the broadest of levels. The initial level I draft contained nine ecological regions for North America, five of which occurred in Mexico. The coarseness of the first approximation of level I for North America was unacceptable to the Mexican participants, probably because it had little meaning to them from their national perspective. The Mexican team then began development of a new ecological regionalization for Mexico, using a biophysical approach that relied heavily on vegetation, climate, and physiography. The Mexican team would accept no less than six regions for Mexico at level I, and the final map contained 15 regions for North America, seven of which occurred in Mexico.

Decisions regarding the degree of detail of a particular hierarchical level of regionalization must recognize scale differences that transcend political boundaries and regions of personal familiarity. Inconsistency in perceptions between countries at coarse levels of regionalization can have a cascading effect on the delineation of more detailed hierarchical levels. The inconsistency in the approach between the Mexican and U.S. system is especially apparent at the level III. Mexico, for example, included coastal wetlands and mangrove systems at level III, while in the U.S. EPA’s system, these would be delineated at level IV or V. The WWF also recognizes mangroves at the very coarsest level (major ecosystem type), but these are difficult or impossible to depict cartographically at the small-scale pagesize maps typically used to portray regions at the broadest levels.

Addressing “The Whole Ecosystem”

Is an ecoregion map more than a climate or soils or vegetation or biotic regions map? If there is general agreement that ecosystems are some type of three dimensional space composed of biotic and abiotic, terrestrial, aquatic and atmospheric features and all of their interactions, structure, and processes, then a process to define ecological regions should attempt to address and consider as many of these features as possible in a holistic, integrated manner. As Box (1994) stressed, one of the key requisites to implementing ecosystem management is “...shifting from reductionistic and disciplinary work to synthesis and interdisciplinary analysis of systems.” Approaches that purposely separate individual characteristics hierarchically by perceived importance, or that rely only on one or two mapped features seem to be counter to the nature of the item being defined, i.e., the ecological region. As Denevan (1984) discussed for biotopes (areas with relatively uniform landform, climate, soil, and biota), “It is with such units of nature that individual humans interact, not with a polymorphous ‘tropical forest’. ”

The Synthesizing Approach to Ecological Regionalization

"...any attempt to divide the world involves subjective judgment, not merely in the determination of the limits of individual factors, but in deciding which of several factors is to be regarded as most important."
R. Hartshorne, 1939. The Nature of Geography. p.296-297.

The approach used by the EPA (Omernik 1987, 1995) and Environment Canada (Wiken 1986, 1996) recognizes that the quantity and quality of environmental resources that make up ecosystems, and the way they are interrelated, vary infinitely in space and time. This is still compatible, however, with Bailey's (1998) assertion that "...the distribution of ecoregions is not haphazard; they occur in predictable locations in different parts of the world and can be explained in terms of the processes producing them." In order to determine the regions within which there is spatial coincidence in the geographic phenomena that cause or reflect regional differences in ecosystems, one must filter through the maps and other materials that represent the geographic nature of each characteristic (Omernik 1995). The relative importance of each characteristic varies from one region to another at all scales. A major strength of this approach lies in the scrutiny and analysis of multiple geographic phenomena that are thought to cause or reflect differences in the mosaics of ecosystems. Maps of particular characteristics, such as physiography, geology, vegetation, and soils, are simply representations of aspects of those characteristics. Each map is different in the purpose, level of generality (even if at the same scale), relative accuracy, and classification used. In the compilation of all maps, subjective determinations must be made concerning the classification to be used, the level of generality, and what can and cannot be represented, regardless of whether the map is computer generated or hand drawn. In this approach to regionalization, expert judgement is applied throughout the selection, analysis, and classification of data to form the ecological regions, basing judgements on the quantity and quality of source data and on interpretation of the relationships between the data and other environmental factors.

Bailey (1996, p.27) has called this approach a "gestalt method" of regionalization and suggests that it is not "objective" or explicit compared to other methods.

> "The philosophy of this method seems to be that no rules exist for recognizing regions; they vary depending on location....These schemes eventually evolve into nothing more than 'place-name regions,' which are identified primarily by the places themselves rather than by objective criteria that define particular types of regions."

Bailey's characterization of this method is limited and misleading. That there are methods that are more explicit or objective is not questioned; that frameworks resulting from those methods are more useful than those derived from a synthesizing approach is the more important question.

The application of computer-assisted mapping technology to map synthesis has invigorated the debate over "subjective" and "objective" mapping methods. The distinction between the two is not so clear cut, however, and in fact no map can be wholly objective. The use of statistics, mathematics, and computers does not eliminate subjectivity from many of the decisions in scientific research or the regionalization process. Judgements are required about the usefulness of data sets, variables to choose, weights to assign, methods to apply, and theories from which to operate. Despite the earlier zeal of geographers to replicate their regions, there will always be subjectivity in so-called objective methods (Johnston 1968). As Brown (1994, p.13-14) has pointed out for biomes: "The delineation of biomes is, therefore, somewhat subjective; although not usually determined through measured criteria, the communities depicted are based on natural criteria and are subject to quantitative assessment." If the concern is for developing a framework that is a closer approximation of what is actually on the ground rather than an explicit, easily replicable, quantifiable method of mapping, then logic, professional judgement, and knowledge of relationships and associated distributions are essential for putting geographic sense into the regionalization process.

Reinforcement concerning the merits of this type of approach comes from the variety of researchers from around the world that tend to agree with its logic and practicality. Although the U.S. EPA and Canadian researchers were initially defining ecological frameworks separately, they later found that their method and philosophy were not that dissimilar (Omernik 1995, Wiken 1986, Wiken et al. 1997) and that the ecoregions, with some modifications, could be joined at the border (Wiken and Lawton 1995, Wiken and Gauthier 1996, CEC 1997). While a framework of ecoregions in Australia has been collaboratively defined with the states and territories (Thackway and Cresswell 1995), one of the regional researchers there has found that a more quantitative approach that was pursued for many years has proven less satisfactory than a more synthesizing approach (R. Thackway, Australian Nature Conservation Agency, personal communication). A shared perspective and interest in defining an international framework using this approach is also encountered in Russia (N. Denisov, Moscow State University and UNEP GRID-Arendal, personal communication).

Ecoregions of Central and South America - First Approximation

While there is a need to have an ecological framework that is based on a variety of environmental characteristics, many frameworks for Latin American countries tend to be single-theme frameworks to address concerns such as forest resources or agricultural potential. Continental frameworks, as mentioned previously, also tended to rely on particular aspects or processes of ecosystems. How might a framework based on a synthesizing approach differ from, or be similar to, the frameworks completed by the WWF or Bailey, for example? To develop an ecoregional classification for the Western Hemisphere (North and South America) that was consistent with recent U.S. EPA and North American ecoregion frameworks, we delineated a preliminary classification for Central and South America. The methods used were similar to those described by Omernik (1995) and Gallant et al. (1989, 1995). Maps and information of environmental characteristics of Central and South America and the Caribbean were collected from several U.S. university libraries, the EROS Data Center, the Library of Congress, the USGS Cartographic Information Center in Reston, and the U.S. State Department map library. Many of these references are listed in Appendix 2.

In addition to the variety of information from these thematic maps and descriptive texts, regional patterns were also assessed from the global land cover characteristics database obtained from 1-km Advanced Very High Resolution Radiometer (AVHRR) data (Loveland and Belward 1997; Loveland et al. 1998; Brown et al. 1993). Seasonal land cover regions derived from the AVHRR data are composed of relatively homogeneous land cover associations (for example, similar floristic and physiognomic characteristics) which exhibit distinctive phenology (that is, onset, peak, and seasonal duration of greenness), and have common levels of primary production. The classification process used to develop the land cover regions database is not automated, but more closely resembles a traditional manual image interpretation philosophy. There is a reliance on the skills of the human interpreter to make the final decisions regarding the relationship between spectral classes defined using unsupervised methods and landscape characteristics that are used to make land cover definitions. A convergence of evidence approach is used to determine the land cover type for each seasonal land cover class: All available documentation, including the region attributes, image maps, atlases, other existing land cover/vegetation maps, and any other relevant materials are consulted and compared to the spatial distribution of each region (Global Land Cover Characteristics Database Readme File, http:// edcwww.cr.usgs.gov/landdaac/glcc/globdoc1_2.html). This convergence of evidence approach, therefore, has some similarities to the synthesizing approach used to define ecological regions.

The initial delineation of ecoregions was based on analysis of multiple types and scales of thematic maps including geology, physiography, soils, potential and existing vegetation, climate, landcover and agricultural uses, other ecological frameworks, and from other regional descriptive documents. Draft sketches at several different small scales (ranging from small, 1:30,000,000-scale page-size maps to larger 1:8,000,000-scale maps) were made during the regionalization process for discussion purposes among NHEERL geographers. We delineated and digitized the ecoregion boundaries on 1:5,000,000-scale mylar base maps and created geographic information system coverages with ARC/INFO software.

For Central and South America and the Caribbean, we delineated 12 level I regions (Figure 1), 35 level II regions (Figure 2), and 121 level III regions (Figure 3 and map insert). This compares to North America (CEC 1997), where there were 15 level I regions, 52 level II regions, and approximately 202 level III regions. These counts may include some overlapping regions from North America to Central America.

Conclusions and Recommendations

This purpose of this project was to develop a first approximation of ecological regions of Central and South America that would be relatively consistent with the purpose and methods of the already completed CEC framework for North America. Although advancements were made in defining and delineating three hierarchical levels of ecological regions for the southern portion of the western hemisphere, there remains substantial work to finalize the framework. In considering the hierarchy of regions, we found that the level III ecoregions of Central and South America appeared generally more acceptable to us. Our debates and discussion within an internal group of geographers about the level I regions were the most difficult, with a divergance of opinion on what should be represented. We mapped several alternative scenarios for level I, each having some merit and logic, but also including shortcomings relative to the lumping of disparate ecological areas. There is obviously a great need for collaboration with and review by experts from Latin America and other researchers with hemispheric and global perspectives.

The CEC effort was a commendable attempt to produce a consistent framework for three countries of North America, however, it was not defined within the viewpoint of a global framework. Questions remain not only about how best to tie the level I regions for North and South America, but also how these might relate to a global classification. In light of the fact that several researchers from different parts of the world are tending to embrace this type of regionalization method, there appears to be an opportunity to improve these frameworks and address many of the issues and questions from a broader and more diverse perspective.

Despite the difficulties of multi-nation and multi-perspective involvement in ecological mapping, if utility is a goal, such involvement becomes essential. A successful ecological framework cannot be developed singularly or in isolation.

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APPENDIX 1

Central and South American Ecoregion Maps

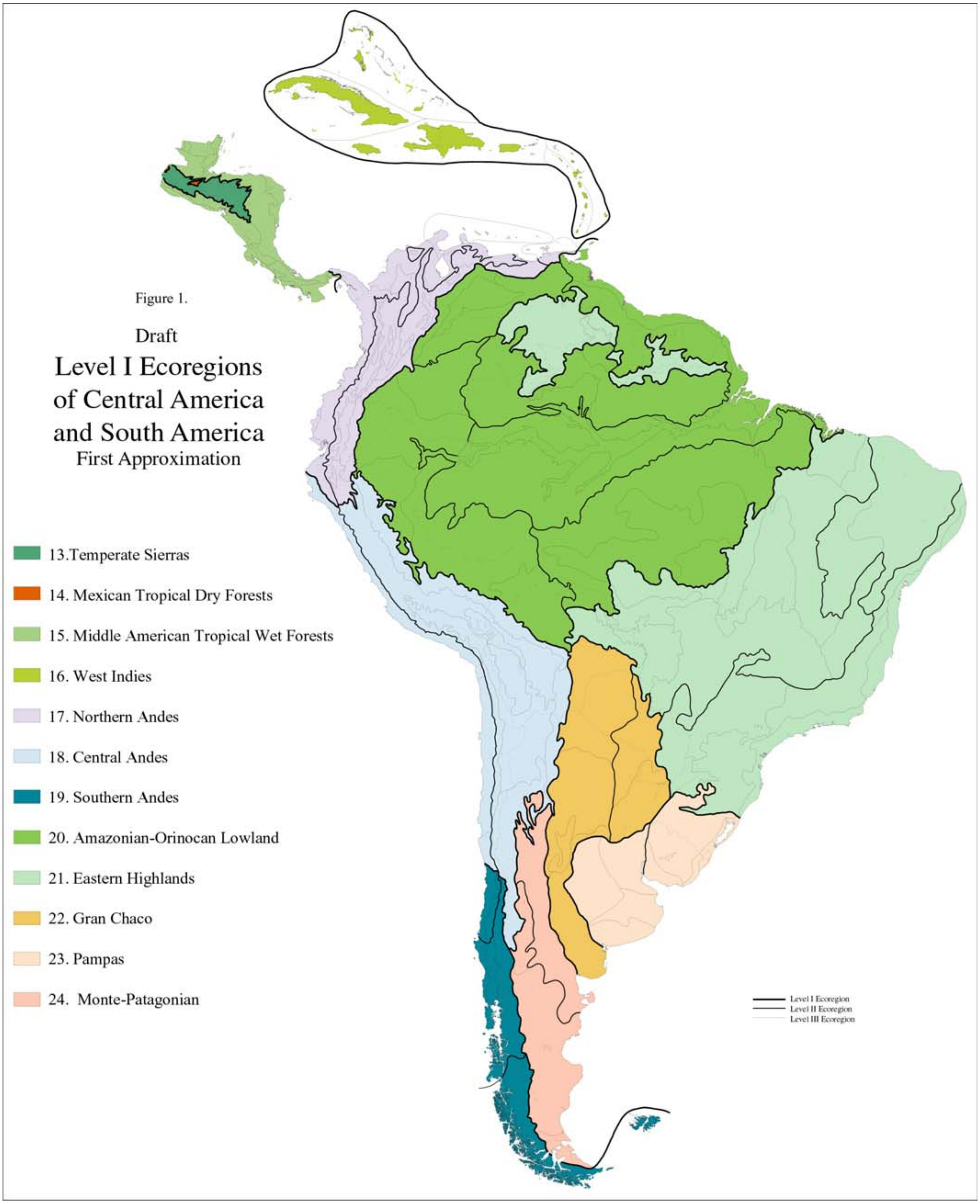
Figure 1.
Draft
Level I Ecoregions
of Central America
and South America
First Approximation
13.Temperate Sierras
14. Mexican Tropical Dry Forests
15. Middle American Tropical Wet Forests
16. West Indies
17. Northern Andes
18. Central Andes
19. Southern Andes
20. Amazonian-Orinocan Lowland
21. Eastern Highlands
22. Gran Chaco
23. Pampas
24. Monte-Patagonian
Level I Ecoregion
Level II Ecoregion
Level III Ecoregion

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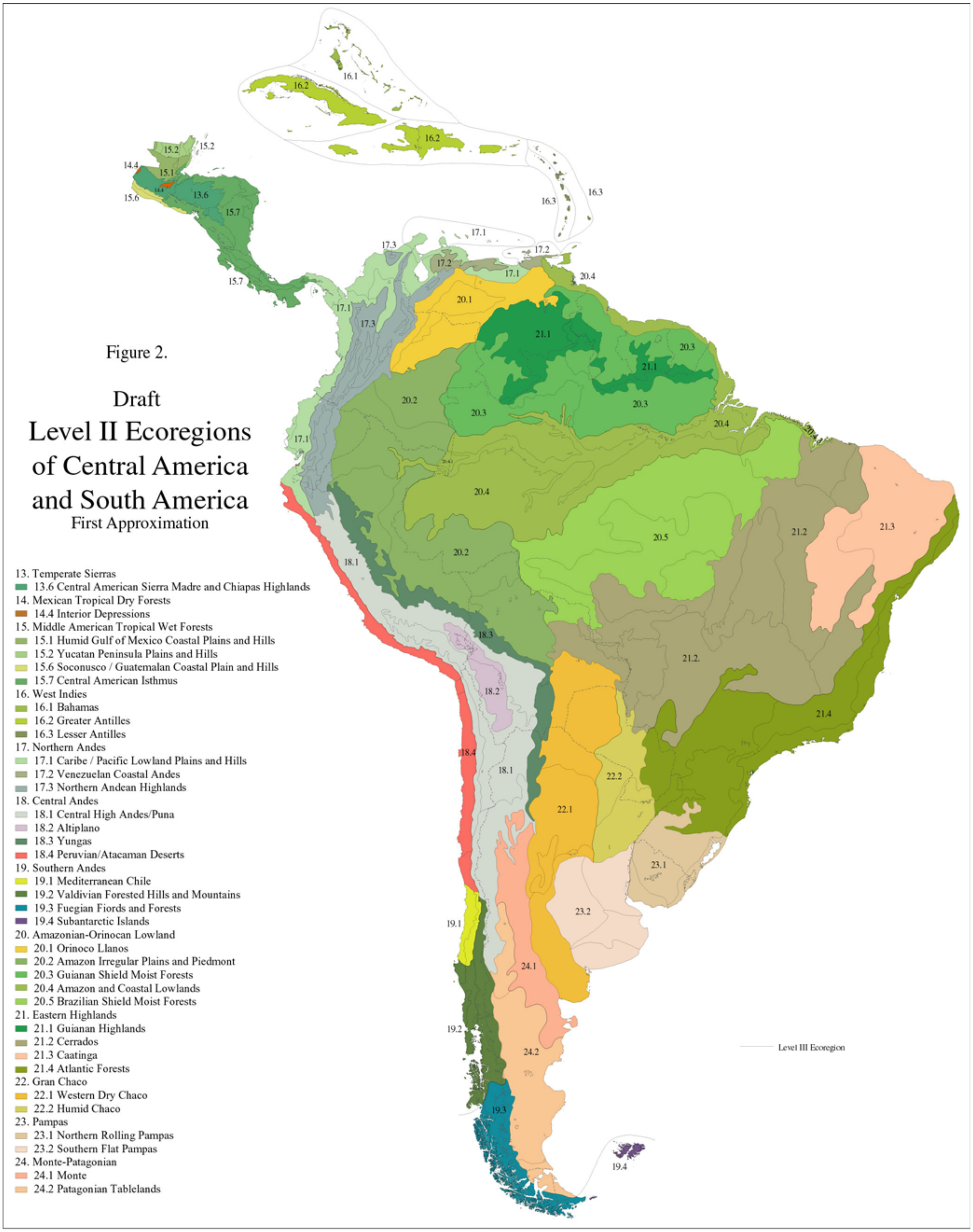
Figure 2.
Draft
Level II Ecoregions
of Central America
and South America
First Approximation
13. Temperate Sierras
13.6 Central American Sierra Madre and Chiapas Highlands
14. Mexican Tropical Dry Forests
14.4 Interior Depressions
15. Middle American Tropical Wet Forests
15.1 Humid Gulf of Mexico Coastal Plains and Hills
15.2 Yucatan Peninsula Plains and Hills
15.6 Soconusco / Guatemalan Coastal Plain and Hills
15.7 Central American Isthmus
16. West Indies
16.1 Bahamas
16.2 Greater Antilles
16.3 Lesser Antilles
17. Northern Andes
17.1 Caribe / Pacific Lowland Plains and Hills
17.2 Venezuelan Coastal Andes
17.3 Northern Andean Highlands
18. Central Andes
18.1 Central High Andes/Puna
18.2 Altiplano
18.3 Yungas
18.4 Peruvian/Atacaman Deserts
19. Southern Andes
19.1 Mediterranean Chile
19.2 Valdivian Forested Hills and Mountains
19.3 Fuegian Fiords and Forests
19.4 Subantarctic Islands
20. Amazonian-Orinocan Lowland
20.1 Orinoco Llanos
20.2 Amazon Irregular Plains and Piedmont
20.3 Guianan Shield Moist Forests
20.4 Amazon and Coastal Lowlands
20.5 Brazilian Shield Moist Forests
21. Eastern Highlands
21.1 Guianan Highlands
21.2 Cerrados
21.3 Caatinga
21.4 Atlantic Forests
22. Gran Chaco
22.1 Western Dry Chaco
22.2 Humid Chaco
23. Pampas
23.1 Northern Rolling Pampas
23.2 Southern Flat Pampas
24. Monte-Patagonian
24.1 Monte
24.2 Patagonian Tablelands
Level III Ecoregion

20

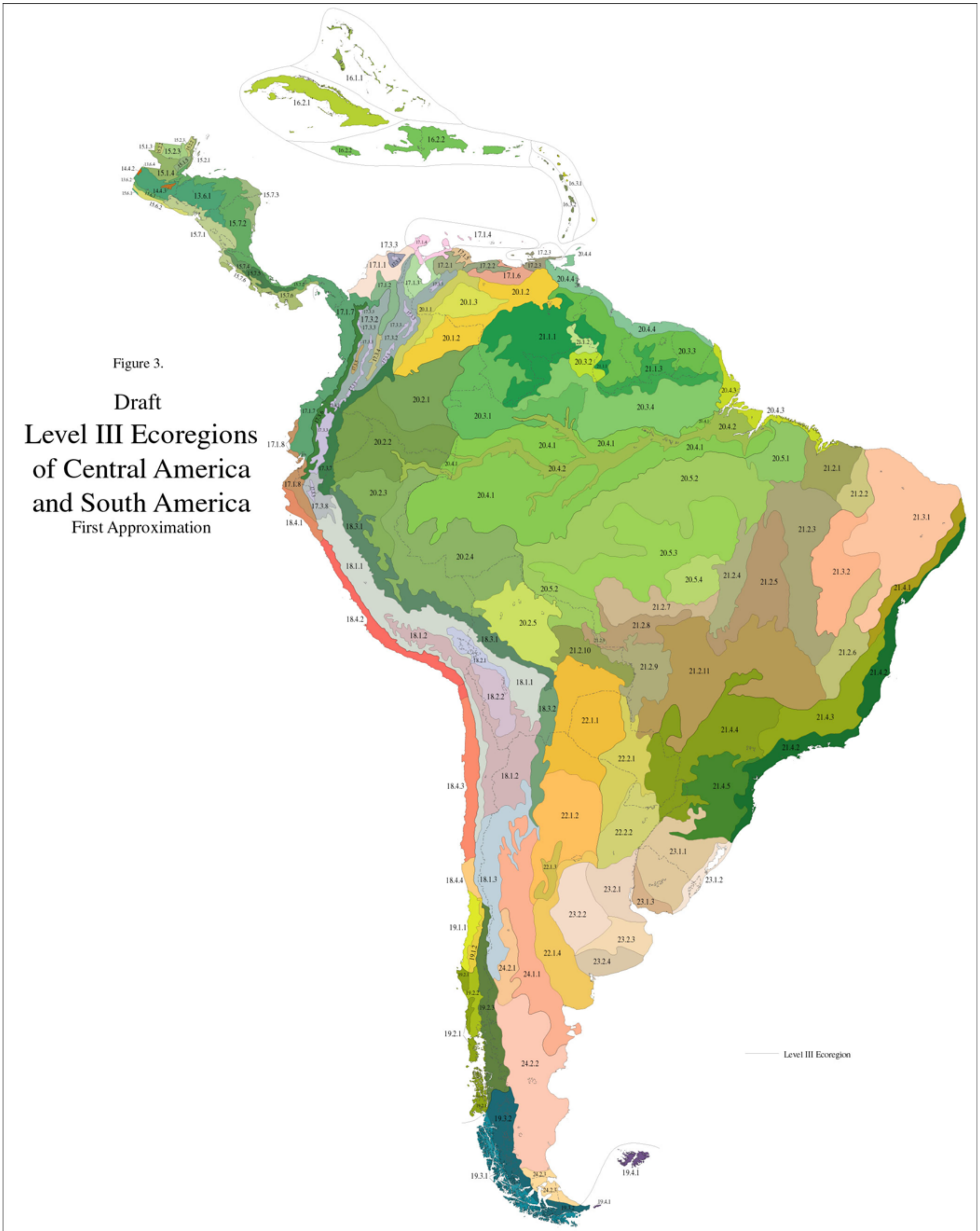
Figure 3.
Draft
Level III Ecoregions
of Central America
and South America
First Approximation
Level III Ecoregion

21

- 13. Temperate Sierras
  - 13.6 Central American Sierra Madre and Chiapas Highlands
    - 13.6.1 Northern Central American Highlands
    - 13.6.2 Southern Mexican Sierra Madre
    - 13.6.4 Altos de Chiapas con bosque mesófilo
- 14. Mexican Tropical Dry Forests
  - 14.4 Interior Depressions
    - 14.4.2 Chiapas Depression
    - 14.4.3 Motagua Valley
- 15. Middle American Tropical Wet Forests
  - 15.1 Humid Gulf of Mexico Coastal Plains and Hills
    - 15.1.4 Humid Gulf of Mexico and Southern Petén Hills
    - 15.1.5 Maya Mountains
  - 15.2 Yucatan Peninsula Plains and Hills
    - 15.2.1 Quintana Roo / Belizean Wet Coastal Lowland
    - 15.2.2 Yucatán Karst Plains
    - 15.2.3 Central Yucatán / Petén Hills and Karst Plains
  - 15.6 Soconusco / Guatemalan Coastal Plain and Hills
    - 15.6.2 Soconusco / Guatemalan Coastal Plain
    - 15.6.3 Soconusco Hills / Guatemalan Piedmont
  - 15.7 Central American Isthmus
    - 15.7.1 Pacific Volcanic Lowlands
    - 15.7.2 Caribbean Coastal Plains and Hills
    - 15.7.3 Miskito Lowland Pine Savanna
    - 15.7.4 Guanacaste / Central Volcanic Uplands
    - 15.7.5 Talamanca and Panama Central Cordilleras
    - 15.7.6 Costa Rica-Panama Pacific Plains and Hills
- 16. West Indies
  - 16.1 Bahamas
    - 16.1.1 Bahamas
  - 16.2 Greater Antilles
    - 16.2.1 Cuba
    - 16.2.2 Mountainous Greater Antilles
  - 16.3 Lesser Antilles
    - 16.3.1 Limestone Low Islands
    - 16.3.2 Volcanic High Islands
- 17. Northern Andes
  - 17.1 Caribe / Pacific Lowland Plains and Hills
    - 17.1.1 Sinú / Magdalena Dry Plains
    - 17.1.2 Magdalena Wet Plains
    - 17.1.3 Maracaibo Lowlands
    - 17.1.4 Guajira/Paraguaná Peninsulas
    - 17.1.5 Chichiriviche Coastal Plain
    - 17.1.6 Unare Plains
    - 17.1.7 Pacific Plains and Hills
    - 17.1.8 Guayas-Tumbes-Piura Dry Hills
  - 17.2 Venezuelan Coastal Andes
    - 17.2.1 Segovia Highlands
    - 17.2.2 Central Coastal Cordillera
    - 17.2.3 Eastern Coastal Cordillera
  - 17.3 Northern Andean Highlands
    - 17.3.1 Sierra Nevada de Santa Marta
    - 17.3.2 Colombian / Venezuelan High Cordilleras
    - 17.3.3 Paramo / Alto Andina
    - 17.3.4 Upper Magdalena Valley
    - 17.3.5 Upper Cauca Valley
    - 17.3.6 Pacific Western Cordillera Montane Forest
    - 17.3.7 Eastern Cordillera Montane Forest
    - 17.3.8 S. Ecuador / N. Peru Transitional High Andes
- 18. Central Andes
  - 18.1 Central High Andes/Puna
    - 18.1.1 High Andes / Humid Puna
    - 18.1.2 Dry Puna / Puna de Atacama
    - 18.1.3 Southern Central Andes
  - 18.2 Altiplano
    - 18.2.1 Titicaca / Northern Altiplano
    - 18.2.2 Southern Arid Altiplano
  - 18.3 Yungas
    - 18.3.1 Northern Yungas
    - 18.3.2 Southern Yungas
  - 18.4 Peruvian/Atacaman Deserts
    - 18.4.1 Northern Peruvian Desert
    - 18.4.2 Garua-Loma Desert
    - 18.4.3 Northern Chilean Desert
    - 18.4.4 Transitional Subdesert Matoral
- 19. Southern Andes
  - 19.1 Mediterranean Chile
    - 19.1.1 Coastal Ranges
    - 19.1.2 Llano Central
  - 19.2 Valdivian Forested Hills and Mountains
    - 19.2.1 Valdivian Coastal Range
    - 19.2.2 Central Depression
    - 19.2.3 Valdivian High Andes
  - 19.3 Fuegian Fiords and Forests
    - 19.3.1 Magellanic Moorland and Rainforest
    - 19.3.2 Fuegian High Andes / Ice Caps
  - 19.4 Subantarctic Islands
    - 19.4.1 Falklands / Islas Malvinas
- 20. Amazonian-Orinocan Lowland
  - 20.1 Orinoco Llanos
    - 20.1.1 Piedmont
    - 20.1.2 High Plains or Dissected Plains
    - 20.1.3 Alluvial Overflow Plains / Wet Plains
  - 20.2 Amazon Irregular Plains and Piedmont
    - 20.2.1 Colombia Rock Mesa Amazon
    - 20.2.2 Napo / Putamayo Moist Forests
    - 20.2.3 Ucayali / Marañon Lowland
    - 20.2.4 Southwestern Amazonian Irregular Plains
    - 20.2.5 Llanos de Mojos / Beni Savanna
  - 20.3 Guianan Shield Moist Forests
    - 20.3.1 Upper Rio Negro / Campinas area
    - 20.3.2 Boa Vista Depression / Rupununi Savanna
    - 20.3.3 Guianan Forested Plains and Hills
    - 20.3.4 Amapá / Roraima Plains and Tablelands
  - 20.4 Amazon and Coastal Lowlands
    - 20.4.1 Amazon Flat Plains
    - 20.4.2 Várzea / Igapó
    - 20.4.3 Amazon Estuary and Coastal Savannas
    - 20.4.4 Guianan Coastal Lowland
  - 20.5 Brazilian Shield Moist Forests
    - 20.5.1 Gurupi Plains and Low Tablelands
    - 20.5.2 Amazon Upland Irregular Plains
    - 20.5.3 Mixed Forest Plains and Tablelands
    - 20.5.4 Upper Xingu Depression
- 21. Eastern Highlands
  - 21.1 Guianan Highlands
    - 21.1.1 Guianan Uplands and Tepuis
    - 21.1.2 Roraima and Grand Savannas
    - 21.1.3 Suriname / Guyana Low Mountains
  - 21.2 Cerrados
    - 21.2.1 Northern Maranhão Plains
    - 21.2.2 Northern Piauí Plains
    - 21.2.3 Northeastern Cerrado
    - 21.2.4 Araguaia Depression
    - 21.2.5 Tocantins Hills and Tablelands
    - 21.2.6 Espinhaço / Diamantina Hills and Low Mountains
    - 21.2.7 Mato Grosso Savanna Tablelands
    - 21.2.8 Upper Paraguai / Guapore Plains and Hills
    - 21.2.9 Pantanal
    - 21.2.10 Chiquitos-Velasco Forested Hills and Plains
    - 21.2.11 Southern Cerrado Tablelands
  - 21.3 Caatinga
    - 21.3.1 Northeastern Caatinga
    - 21.3.2 Western Caatinga
  - 21.4 Atlantic Forests
    - 21.4.1 Agreste / Caatinga Transition
    - 21.4.2 Brazilian Atlantic Coastal Forests
    - 21.4.3 Eastern Inland Atlantic Mixed Forests
    - 21.4.4 Western Inland Atlantic Mixed Forests
    - 21.4.5 Araucaria Tablelands
- 22. Gran Chaco
  - 22.1 Western Dry Chaco
    - 22.1.1 Northern Dry Chaco
    - 22.1.2 Southern Dry Chaco
    - 22.1.3 Sierras of Cordoba and San Luis
    - 22.1.4 Pampa Seca / Espinal
  - 22.2 Humid Chaco
    - 22.2.1 Northern Humid Chaco
    - 22.2.2 Southern Humid Chaco
- 23. Pampas
  - 23.1 Northern Rolling Pampas
    - 23.1.1 Campos / Northern Pampas
    - 23.1.2 Brazil / Uruguay Coastal Pampa
    - 23.1.3 Southern Uruguay Lowland
  - 23.2 Southern Flat Pampas
    - 23.2.1 La Plata / Uruguay Lowland
    - 23.2.2 Inland Pampa
    - 23.2.3 Low Argentine Pampa
    - 23.2.4 Southern Pampa
- 24. Monte-Patagonian
  - 24.1 Monte
    - 24.1.1 Monte
  - 24.2 Patagonian Tablelands
    - 24.2.1 Northern Patagonia
    - 24.2.2 Southern Patagonia
    - 24.2.3 Magellan Grasslands

22

APPENDIX 2

Central and South American Ecoregion Notes

Central and South American Ecoregion Notes

13. Temperate Sierras

- major Mexican mountain system of mixed geology
- mostly conifer and oak

13.6 **Central American Sierra Madre and Chiapas Highlands**

13.6.1 **Northern Central American Highlands**

- “cool” tropical highlands; Cw and Cf climates compared to A climate lowlands
- conifer/oak and cloud forest veg.; southern extent of many conifer species
- mostly volcanic, metamorphic and intrusive rocks
- more shallow, rocky soils than surrounding regions

14. Mexican Tropical Dry Forests

- low deciduous and subdeciduous forest and shrub, now mostly agriculture and grazing
- 5-8 month dry season

14.4 **Interior Depressions**

- deciduous and thorn forests; xeric shrubland
- commercial (irrigated) and traditional agriculture, grazing

14.4.2 **Chiapas Depression**

14.4.3 **Motagua Valley**

- semi-arid climate compared to surrounding more humid tropical
- dry thornscrub (mimosas, acacias, cacti) and savanna

15. Middle American Tropical Wet Forests

- wet, warm climate with broadleaf evergreen or subdeciduous forest
- mostly lowland plains and hills; some mountains

15.1 **Humid Gulf of Mexico Coastal Plains and Hills**

15.1.4 **Humid Gulf of Mexico and Southern Petén Hills**

- hills and plains on marine carbonates and marine clastic sediments
- medium to tall broadleaf evergreen forest, some oak-subdeciduous forest
- more hilly and wetter than Yucatán regions to the north

15.1.5 **Maya Mountains**

- metamorphic and intrusive granite rocks & shallow, rocky soils
- max. elevations 3000-4000 feet

15.2 **Yucatán Peninsula Plains and Hills**

- soils from limestone residuum & colluvium, generally of low fertility & poor drainage

15.2.1 **Quintana Roo / Belizean Wet Coastal Lowland**

- beach ridges of sand and shell; coral and limestone reefs and islands; mangrove

15.2.2 **Yucatán Karst Plains**

- mostly forested, some shifting cultivation
- tall to medium broadleaf evergreen forests; some subdeciduous
- areas of seasonal inundation

15.2.3 **Central Yucatán / Petén Hills and Karst Plains**

- slightly more hilly and relief than Yucatan Karst Plains, 15.2.2
- more tall forest than in Yucatan Karst Plains, 15.2.2

15.6 **Soconusco/Guatemalan Coastal Plain and Hills**

- semi-deciduous forest and savanna original cover
- volcanic and coastal alluvial soils
- prime and mixed use agricultural land

15.6.1 **Humedales** (Mexican coastal wetlands &mangrove -not appropriate at level III)

15.6.2 **Soconusco/Guatemalan Coastal Plain**

- fertile volcanic soils similar to Piedmont, but warmer, drier, and flatter
- mostly commercial agriculture; cotton, sugarcane, rice, cattle

15.6.3 **Soconusco Hills / Guatemalan Piedmont** (Boca Costa)
- originally tall, wet tropical broadleaf forest; more rain than in coastal plain
- fertile volcanic soils
- Guatemala's principal commercial agriculture (lower Piedmont 350-1500ft.) and coffee area (upper Piedmont, 1500-5000 feet)

15.7 **Central American Isthmus**

15.7.1 **Pacific Volcanic Lowlands**
- 5-6 month dry season; drier than Caribbean side
- originally semideciduous to deciduous forest & savanna
- mostly cropland (commercial & traditional) and pasture; coffee, cotton, corn
- lower mountains than regions north or south

15.7.2 **Caribbean Coastal Plains and Hills**
- hotter, more humid than Pacific side; short to no dry season
- dense broadleaf evergreen forest; more forest cover than drier Pacific region
- mostly sedimentary & some volcanic rocks; poorly drained, unfertile soils
- cattle, bananas, subsistence agriculture

15.7.3 **Miskito Lowland Pine Savanna**
- flat, lowland coastal plain of quartz sands and gravels
- pine (*Pinus caribaea*) savanna (bunch grasses)
  with saw palmettos, scrub hardwoods, extensive mangroves

15.7.4 **Guanacaste/Central Volcanic Uplands**
- includes densely populated Valle Central or Meseta Central
- wetter with higher peaks than volcanic region to the north, 15.7.1

15.7.5 **Talamanca and Panama Central Cordilleras**
- high elevation with paramo
- shorter dry period and more cloud forest veg. than highlands of northern C.A.
- Talamanca: non-volcanic- sedimentary and intrusive granitic batholith
- Panama: volcanic
- could be lumped with 15.7.4 at level III?

15.7.6 **Costa Rica-Panama Pacific Plains and Hills**
- similar to 15.7.1 but different mosaic of wet and dry climates and geology
- wetter than 15.7.1with shorter dry season and some areas of dense forest
- Panama's principal agricultural area

16. West Indies or Caribbean Islands
- could be included with 15
- great variety and complexity of physical and cultural island geography

16.1 **Bahamas**
- 700 islands and long barrier reef
- generally low plains of recently emerged limestone, with coral, shell detritus
- somewhat drier than Greater Antilles
- tourism economy; some fishing, pine forests, little arable land

16.2 **Greater Antilles**
- 90 % of land area of West Indies
- west-east areas of folded and block mountains
- mostly mountainous, except Cuba plains

16.2.1 **Cuba**
- could be defined at level II and subdivided at level III
  (Sierra Maestra/Baracoa Mtns.; Trinidad/Escambray Mtns.; Santa Clara Hills; Organos/Rosarios Mtns.; Zapata Swamps, Cuban Plains and Hills...)
- greater extremes of temperatures than other West Indies islands
- extensive cropland; sugar, tobacco, rice, fruit, corn, pasture

16.2.2 **Mountainous Greater Antilles**
- generally more mountainous, less agriculture compared to Cuba

16.3 **Lesser Antilles**

- north-south trending arc of small islands
- double line of submarine volcanoes; outer, n.e. arc older, eroded, submerged

16.3.1 **Limestone Low Islands**
- low relief, porous limestone,
- lack of streams,water deficient, ~45 inches annual rain
- cattle, sheep, goat grazing; fishing; some sugar; tourism

16.3.2 **Volcanic High Islands**
- high mountains, volcanos, north-south mountain axis
- abundance of streams, rainfall >200 in.
- forests; rich volcanic soil, variety of crop specializations

17. Northern Andes
- higher humidity/precip. and primary productivity than Central Andes
- east and west flanks are climatically more similar to each other than in central or southern Andes
- upper limit of cultivation about 3200m (10,500 ft), about 1000m lower than Central Andes

17.1 **Caribe/Pacific Lowland Plains and Hills**
- lower and flatter than Coastal Andes and Highland Andes

17.1.1 **Sinú / Magdalena Dry Plains**
- dry to semi-humid with thorn and dry forest
- more humid than Guajira/Paraguaná Peninsulas; drier than Magdalena Wet Plains

17.1.2 **Magdalena Wet Plains**
- generally flat, braided-river corridor of mostly Quaternary sediments
- more forested than upper Magdalena Valley 17.3.4
- swamps, marshes, ciénagas in lower, northern part
- oil fields;

17.1.3 **Maracaibo Lowlands**
- alluvial plains of Quaternary sediments
- more arid to the north; mostly dry forest/savanna but humid forest in south
- wetlands and swamp forest in southwest
- oil fields; subsistence agriculture

17.1.4 **Guajira/Paraguaná Peninsulas**
- plains and hills with arid & semi-arid climate; xerophytic and spiny vegetation
- could be grouped with a deserts region at higher level
- oil refineries and export terminals

17.1.5 **Chichiriviche Coastal Plain**
- lower, flatter plains & river valleys compared to surrounding hills & mountains
- deciduous and subdeciduous forest; heavier forest cover than the shrub/brush and xeric veg. of Segovia Highlands & Guajira/Paraguaná Peninsulas

17.1.6 **Unare Plains**
- mostly plains but drier than Llanos to the south
- dry forest and xeric shrublands

17.1.7 **Pacific Plains and Hills**
- dense evergreen rainforest in hot, wet climate; one of the wettest areas in S.A.
- mix of plains, hills, and low mountains
- wide area of mangroves in S.Colombia

17.1.8 **Guayas-Tumbes-Piura Dry Hills**
- dry woodland with succulents on hills and low mountains
- more woody and more rain than desert to south

17.2 **Venezuelan Coastal Andes**
- lower and drier than Northern Andean Highlands 17.3

17.2.1 **Segovia Highlands**
- semi-arid hills with irrigated agriculture in river valleys
- cocoa, sugar, sisal, pineapples; some coffee in the south

17.2.2 **Central Coastal Cordillera**
- higher & wetter in parts with different geologic mix than Eastern

Coastal Cordillera 17.2.3

- crystalline granites, gneisses, schists in sierra; alluvial basins
- short rainy season (Nov.-Dec.);
- scrub veg. with some moist forest at higher elevation
- high population density
- Valencia basin: productive agricultural area - cocoa, coffee, sugar, cotton, cattle

17.2.3 **Eastern Coastal Cordillera** (Sierra de Cumana)

- dissected upland of folded sandstone and limestone
- more arid to west and along coast

17.3 **Northern Andean Highlands**

- higher and wetter than Coastal Andes 17.2

17.3.1 **Sierra Nevada de Santa Marta**

- could be combined with 17.3.2, but its isolation creates some biotic distinction

17.3.2 **Colombian/Venezuelan High Cordilleras**

17.3.3 **Paramo / Alto Andina**

- mostly above 3000m
- annual precipitation evenly distributed
- grazing lands for sheep and cattle
- grasses, herbs, dwarf shrubs, rock, snow, (some high elevation cloud forest?)

17.3.4 **Upper Magdalena Valley**

- spiny scrub cover with irrigated cropland
- less forested than upriver or downriver
- permeable Tertiary volcanic sediments

17.3.5 **Upper Cauca Valley**

- level valley floor of Quaternary sediments from old lake bed
- one of most productive agricultural areas of Colombia
- more narrow valley than Magdalena

17.3.6 **Pacific Western Cordillera Montane Forest**

- high diversity, very wet tropical rainforest & mountain cloud forest

17.3.7 **Eastern Cordillera Montane Forest**

- high diversity wet tropical rainforest & mountain cloud forest

17.3.8 **S. Ecuador / N. Peru Transitional High Andes**

- slightly lower than mountain regions to the north or south
- drier than region to the north, more humid than region to the south
- mostly dry tropical forest, thorn forest, deciduous forest, drier towards the west

18. Central Andes

- wider, and generally higher than northern and southern andes with plateau areas
- drier climate than north, with short rainy season
- dense human population on more humid plateau areas; highest pre-Conquest pop.density
- upper limit of potato cultivation about 4200 m

18.1 **Central High Andes / Puna**

- highest elevations of Central Andes
- drier than forested Yungas 18.3; more grass and scrub than desert region 18.4

18.1.1 **High Andes / Humid Puna**

- mostly dry and cold, but some summer rains (Nov. to April)
- more humid, more agriculture and humans than Dry Puna and Atacama Puna

18.1.2 **Dry Puna / Puna de Atacama** *(should not be lumped?)*

- dry and cold, some grass or bare ground, thorn puna
- saline and soda lakes
- dry puna has greater seasonal contrast compared to wet puna
- desert puna - lower temperatures/greater diurnal range than dry/wet puna

18.1.3 **Southern Central Andes**

- bunch grasses and alpine grasses; scrub veg. at lower elevations
- wetter than dry puna areas to the north; lack of trees compared to S.Andes

- includes Mt. Aconcagua 22,381 ft (6,959 m), highest peak in the Americas

18.2 **Altiplano**

18.2.1 **Titicaca / Northern Altiplano**
- more humid than to the southern arid altiplano, with grasses and shrubs
- lake affected climate: reduced diurnal and seasonal temp. range
- dense population with agriculture of maize, wheat, barley, potatoes

18.2.2 **Southern Arid Altiplano**
- more arid than northern altiplano with saline, wet and dry lakes
- low human population
- sheep and llama pastoralism, mining

18.3 **Yungas**
- warm, wet, forested, species-rich, windward mountain slopes

18.3.1 **Northern**
- dense, wet forests, high species richness, endemism, diversity
- subsistence farming; coffee, tea, coca crops

18.3.2 **Southern**
- dry valleys compared to Northern Yungas,
- moist forests compared to very most in northern region
- forest mix: evergreen rainforest, transitional mesophytic, subhumid montane

18.4 **Peruvian/Atacaman Deserts**
- arid to semi-arid climates
- xerophytic vegetation or no vegetation

18.4.1 **Northern Peruvian Desert**
- occasional heavy rains and rainy years (El Niño)
- different vegetation, more woody species?

18.4.2 **Garua-Loma Desert**
- the fog and lomas more extensive (see Dillon)
- high relative humidity because of garua fog
- lomas vegetation formations in scattered areas
- more settlement/cropland in valleys than Chilean Desert

18.4.3 **Northern Chilean Desert**
- areas of extreme aridity
- plants and cacti on ocean facing slopes / barren leeward slopes
- coastal escarpment, hills, coalescing piedmont plains, interior basins
- historical nitrate mining - depletion of *tamarugo* tree for use as fuel

18.4.4 **Transitional Subdesert Matoral**
- cyclic semi-arid climate
- thorn scrub and shrubland

19. Southern Andes (Southern Andean Temperate Forests)
- rugged mountains with ice fields, fiords, glacial lakes
- reversed aridity pattern compared to central andes with wet west and dry east sides
- evergreen forest, deciduous to north; stunted bush, bare rock on exposed areas
- lower elevations than Andes to the north

19.1 **Mediterranean Chile**
- mild Mediterranean climate with dry summer season
- sclerophyll shrub and scrub vegetation
- diversified cropland; urban/industrial development
- northern boundary is a relatively wide transitional zone, ie 18.4.4

19.1.1 **Coastal Ranges** (or Cordillera de la Costa, or Central Coastal Plateaus and Hills)
- sclerophyllous shrub, chaparral; some scattered acacia trees
- littoral plain and coastal hills and low mountains
- grazing and pasture land

19.1.2 **Llano Central** (Central Plain or Central Valley)
- irregular plains, alluvial fans; crossed by Andean streams

- Chile’s most important irrigated agriculture, urban/ industrial region

19.2 **Valdivian Forested Hills and Mountains**
- wetter, more forested than Med. Chile 19.1 to the north
- Ultisols rather than Alfisols to the north

19.2.1 **Valdivian Coastal Range**
- more hilly and forested than Central Depression; islands and fiords
- Valdivian rainforest, laurel and *Nothofagus* forests

19.2.2 **Central Depression**
- relatively flat with Quaternary sediments: glacial moraines & debris
- glacial lakes along eastern boundary with mountains
- higher precipitation, no summer drought compared to Llano Central
- mostly unirrigated cropland: wheat, oats, hay, apples, potatoes, peas

19.2.3 **Valdivian High Andes**
- Valdivian rainforest, deciduous *Nothofagus* forest, alpine grass, rock, ice

19.3 **Fuegian Fiords and Forests**
- lower elevation and colder climate than Valdivian region to north
- more swamp forests, bogs, moors

19.3.1 **Magellanic Moorland and Rainforest**
- outer coastal islands, generally lower elevation than inland
- heath/moorland, swamp forest, evergreen *Nothofagus*

19.3.2 **Fuegian High Andes/Ice Caps**
- high elevations with glaciers and ice caps
- some areas of deciduous forest or mixed forest
- drier areas east side of mountains

19.4 **Subantarctic Islands**

19.4.1 **Falklands / Islas Malvinas**
- mostly treeless rolling to hilly grassland with bogs and moors

20. Amazonian-Orinocan Lowland

20.1 **Orinoco Llanos**
- savana grassland and brush with gallery forests covering low-gradient rivers
- relatively flat, low-relief plain between highland areas
- cattle grazing and ranching
- dry winter/wet summer humid tropical Aw climate

20.1.1 **Piedmont**
- on alluvial fans and terraces with better drained soils than alluvial plains region
- more forested (semi-deciduous tropical; dry forests in north, moist to the south);

20.1.2 **High Plains or Dissected Plains**
- in east: more clays and shales; major area of tropical deciduous forest in Llanos

20.1.3 **Alluvial Overflow Plains** *or Wet Plains or Flooded Plains*
- depression area, wetter soils, inundated for 3-4 months
- some of best grazing land

20.2 **Amazon Irregular Plains and Piedmont**
- near-Andes piedmont; higher elevation and wetter than more eastern Amazon regions

20.2.1 **Colombia Rock Mesa Amazon**
- more undulating plain with steeper slopes and mesa-like rock islands
- different general soils and geology
- heavy all-year rains in south-southeast part

20.2.2 **Napo / Putamayo Moist Forests**
- mostly flat plains , lacking outlier hills/mesas of 20.2.1

20.2.3 **Ucayali / Marañon Lowland**
- fluvial area on Quaternary sediments
- many areas of flooded grasslands and swamp forest with palms

20.2.4 **Southwestern Amazonian Irregular Plains** *(name?)*

20.2.5 **Llanos de Mojos** *(Llanos del Mamoré or Beni Savanna)*

- flat plains of Quaternary sediments
- seasonally flooded grassland/wetland savanna; square lakes
- differs from Pantanal by the several blackwater, Amazonian-type rivers that cross
- cattle production, some cropland
- *?should Beni Moist Forests be separate region or included in this?*

20.3 **Guianan Shield Amazonia**

- slightly drier, more seasonal rainfall pattern than 20.2
- igneous-metamorphic bedrock compared to deeper alluvium of 20.2&20.4

20.3.1 **Upper Rio Negro / Campinas Area**

- campinarana vegetation
- sandy soils of igneous-metamorphic origin from Guiana Shield
- area of black water rivers especially to the south

20.3.2 **Boa Vista Depression / Rupununi Savanna**

- mostly Quaternary sediments (on Brazil side)
- cerrado-like grass and park vegetation
- longer dry season than amazon regions to south and west

20.3.3 **Guianan Forested Plains and Hills** *or Guianan Moist Forests*

- dense forest cover over crystalline plateau of granites, gneisses
- timber and mining activities: bauxite, diamonds, gold, manganese

20.3.4 **Amapá / Roraima Plains and Tablelands**

- rolling, irregular plains, some hills or low mountains
- forest products, brazil nuts; tree plantations, mining

20.4 **Amazon and Coastal Lowlands**

- sedimentary basin of kaolinitic clays and quartz sands
- jute, black pepper crops; rubber and Brazil nuts important gathering products

20.4.1 **Amazon Flat Plains** or **Central Amazon Lowland**

- acidic, nutrient poor soils & waters
- lower in fauna and different flora patterns compared to adjacent upland areas

20.4.2 **Várzea/Igapó**

- annually flooded or occasionally flooded riparian areas
- historically more human activities than 20.4.1:
  Indigenous settlement patterns showed preference for rivers that came from Andes , avoiding areas and rivers of less fertile 20.4.1

20.4.3 **Amazon Estuary and Coastal Savannas**

- high water table, often saline

20.4.4 **Guianan Coastal Lowland**

- alluvial coastal plain; swampy, clay soil, sand ridges, mangroves near coast
- sea-borne mud from mouths of Amazon by equatorial current
- two wet seasons Apr.-Aug., Dec.-Jan.; two dry seasons Sept.-Nov., Feb.-Mar.
- narrow belt of agriculture: tidal land reclamation and alluvial valleys
- sugar, rice, bananas, oilpalm, vegetables, citrus

20.5 **Brazilian Shield Moist Forests**

- more open, seasonal, semi-deciduous forests than Amazon regions to north and west

20.5.1 **Gurupi Plains and Low Tablelands**

- more lattosols, less fertile than 20.5.2
- denser forests than 20.5.2 and 20.5.3, many cleared areas

20.5.2 **Amazon Upland Irregular Plains**

- rolling to irregular plains
- mix of open and dense forest

20.5.3 **Mixed Forest Plains and Tablelands**

- more varied elevation, relief, and forest types than 20.5.2
- more savanna areas and seasonal forests than 20.5.2

20.5.4 **Upper Xingu Depression**

- Pleistocene sedimentary basin
- distinctive riverine soils and gallery forests

21. Eastern Highlands

21.1 **Guianan Highlands**

21.1.1 **Guianan Uplands and Tepuis**
- a complex mix of valleys, high-relief plateaus/sandstone mesas, hills & mountains
- montane wet tropical broadleaf forests, lowland forests and savannas...
- high number of endemic species

21.1.2 **Roraima and Grand Savannas**
- upland savanna compared to Boa Vista Depression / Rupununi Savanna
- savannas and seasonal swamps on white sands from Roraima sandstones
- elevations generally 2000 - 4000 feet
- narrow definition of Gran Sabana to exclude most of high tepuys

21.1.3 **Suriname/Guyana Low Mountains** *(need better name)*
- (includes Serra Caruma, Serra Arapy, Serra Acaraí, Tumuc-Humac Mountains)
- generally higher, hillier, wetter? than surrounding forested land
- historically mapped as savannas, but appears mostly forested
- elevations mostly 1000-3000 feet

21.2 **Cerrados**
- a natural region, a phytogeographic province, a series of plant formations
- plateau and high tablelands, deeply dissected and fragmented
  (high plains or serras separated by wide interfluves)
- strong dry season during southern winter
- savannas on uplands (grass to shrubs to woodland); gallery forests in lower wide valleys;
  generally more woody than other S.A. savannas
- species-rich, 160,000 species of plants, animals, & fungi
- pasture for cattle; crops of soybeans, corn, rice; charcoal for steel industry

21.2.1 **Northern Maranhão Plains**
-transitional region from Amazonian moist forests to cerrado
- savannas with babacu palms to the west
- some moist tropical evergreen forest in west, deciduous to south

21.2.2 **Northern Piauí Plains** *(combine with N. Maranhão Plains?)*
- transitional region from cerrado to caatinga
- more caatinga and cerrado vegetation than N. Maranhão Plains

(Northern Cerrado regions-more woody? than southern; mostly unimproved grazing)

21.2.3 **Northeastern Cerrado** *(Sao Francisco / Meio-Norte Chapadas)* or .....?
- mostly Cretaceous to Triassic rocks compared to older rocks to west
- more sandy quartz soils compared to west; sandy tablelands
- lower primary productivity and different cover shown by AVHRR

21.2.4 **Araguaia Depression**
- lowland area of Quaternary sediments
- hydromorphic soils region & macroagroeco region
- park vegetation and gallery forests

21.2.5 **Tocantins Hills and Tablelands**
- slightly lower depressional area than Northeastern Cerrado
- a mix of Paleozoic and Precambrian rocks; different soils from NE

21.2.6 **Espinhaço / Diamantina Hills and Low Mountains**
- more hilly than tablelands to the west, many inselbergs
- more tropical deciduous forest; drier to the north

21.2.7 **Mato Grosso Savanna Tablelands** *(or Parecis/Mato Grosso Cerrado)*

21.2.8 **Upper Paraguai / Guapore Plains & Hills** (Cuiaba / Caceres Plains & Hills)
-

21.2.9 **Pantanal**
- flat plains of Quaternary sediments surrounded by Precambrian hills/tablelands
- mostly seasonally flooded grassland & cerrado vegetation; high water Dec.-Apr.

- “world’s largest wetland” ...with jaguars, giant ant-eaters, caymans, marsh deer, giant otters, an estimated 650 species of birds, 240 varieties of fish and more than 90,000 types of plants
- between three and eight million cattle have historically grazed the Pantanal.

21.2.10 **Chiquitos-Velasco Forested Hills and Plains**

(or Chiquitos Irregular Plains or Bolivian Lowland Dry Forests...)
- more irregular plains with some hills
- semi-deciduous forests
- “may be among the richest dry forest ecosystems in the world” (?)

21.2.11 **Southern Cerrado Tablelands**

-more grassy than northern cerrado regions
- improved grazing and cropland compared to mostly unimproved grazing in north
- charcoal in eastern section

21.3 **Caatinga**

- semi-arid climate; scanty, fluctuating rainfall, 8 months or more dry season;
- scrub vegetation, succulent plants, cacti; few grasses except after rains
- some cotton, sisal, castor beans
- intermittent streams and rivers

21.3.1 **Northeastern Caatinga**

- plains with widely spaced hills & mountains; some tablelands & low mountains
- different vegetation / landcover mosaic from western region (see AVHRR)

21.3.2 **Western Caatinga**

- a transitional region to the cerrado
- more deciduous forest and savanna-forest mix than in northeast
- different geology and soil mosaic from northeast
  (Sao Francisco depression and surrounding hills and scarps)

21.4 **Atlantic Forests**

- more heavily forested than cerrado or caatinga; although now greatly deforested
- diverse forest types distinct from Amazon forests
- mostly upland areas (hills, low mountains, tablelands) but some coastal lowlands

21.4.1 **Agreste / Caatinga Transition**

- drier than coast, with deciduous and semi-deciduous forests
- thinner, sandier, rockier soils than coastal forests
- more diverse land use & smaller land holdings than to the humid east or drier west

21.4.2 **Brazilian Atlantic Coastal Forests**

- Tropical moist broadleaf forests on coastal plains and uplands
- higher rainfall than inland mixed forests
- crops of sugar cane, coconuts, cocoa, bananas

21.4.3 **Eastern Inland Atlantic Mixed Forests**

- more deciduous and semi-deciduous forests than coastal forests
- geology, soils, physiography break divides from western region

21.4.4 **Western Inland Atlantic Mixed Forests**

- more deciduous and semi-deciduous forests than coastal forests
- better agricultural land than eastern region; coffee, cotton, sugar cane...

21.4.5 **Araucaria Tablelands**

- historically, a distinctive Parana pine (*Aruacaria angustifolia*) forest area
- more temperate or sub-tropical climate compared to tropical Atlantic forests
- more evenly distributed precipitation compared to dry season of Inland Forests
- some occasional snow at highest elevations

22. Gran Chaco

- vast alluvial/colluvial nearly flat plains
- dry scrub woodland vegetation
- mostly Quaternary sediments compared to surrounding geology mix; saline and alkali soils

22.1 **Western Dry Chaco**

- mostly flat plains; some scattered hills

- drier, hotter than Humid Chaco 22.2
- drought-deciduous woodland and scrub

22.1.1 **Northern Dry Chaco** / Chaco Boreal
- drier, warmer climate & greater summer maximum temp. than in south?
- more irregular plains with Tertiary rocks closer to the surface

22.1.2 **Southern Dry Chaco** / Chaco Austral
- flatter, lower elevation than to the north

22.1.3 **Sierras of Cordoba and San Luis**
- hills and mountains
- mountain grassland with woody species

22.1.4 **Pampa Seca / Espinal**
- drier than humid pampa with more woody species; summer rainfall
- plains and low scattered hills; sandy soils and loess soils
- agriculture and livestock

22.2 **Humid Chaco**
- grassland with palms, dry to semi-humid forests, gallery forests

22.2.1 **Northern Humid Chaco**
- mostly flat plains
- some cotton, cattle

22.2.2 **Southern Humid Chaco** or Mesopotamian Chaco
- more gallery forests and seasonally flooded land
- more low brush and grass compared to Dry Chaco
- mesopotamic parkland compared to Northern Humid Chaco
- AVHRR difference from Northern Humid Chaco
- some rice, citrus, mixed livestock

23. Pampas
- former tallgrass prairie and other grassland types
- warm, temperate Cfa climate compared to drier, B climate areas to the west
- relatively flat plains; some irregular plains and low hills in Uruguay, S. Brazil
- dense human settlement; important agricultural and industrial region

23.1 **Northern Rolling Pampas**
- rolling, irregular plains and hills over granitic and basaltic rocks

23.1.1 **Campos/Northern Pampas**
- more hilly, ie granite ridges&hills (cuchillas), basaltic plateaus
- more grazing of sheep and cattle, less crop production than southern pampas
- some wheat, soybeans, grapes, tobacco
- could be subdivided: nw area of intrusive rock, more elevated, dissected

23.1.2 **Brazil/Uruguay Coastal Pampa**
- flat, low plain of Quaternary sediments
- dunes, lagoons, and mangrove

23.1.3 **Southern Uruguay Lowland**
- more hilly and rocky than La Plata/Uruguay Lowland in Argentina

23.2 **Southern Flat Pampas**
- flat plains of Quaternary loess and silt sediments with more cropland than in north
- the largest area of fertile soil in South America

23.2.1 **La Plata/Uruguay Lowland**
- alluvial deposits, some loess
- more cropland than Northern Pampas

23.2.2 **Inland Pampa** or western pampa
- mostly flat and lacking a stream network
- good drainage with sandy soils, some dunes; also marshes, salty ponds
- drier climate, coarser soils than other Pampas regions

23.2.3 **Flooding Pampa or Low Argentine Pampa**
- lower elevations and relief than nearby regions

- poor drainage with periods of extensive flooding; ponds and lakes
- more suitable for cattle and sheep grazing than cropland

23.2.4 **Southern Pampa** (or combine with inland pampa)

- some hills, mesa-like forms and rock outcrops

24. Monte-Patagonian

24.1 **Monte** *(could be put with Chaco?)*

- (biotic influence/origin from Chaco thorn forest)
- physiognomically similar to Sonoran Desert

24.1.1 **Monte**

- semideciduous or evergreen shrubland, floristically richer than Patagonia
- most of rainfall in summer
- pastoral subsistence; vine, vegetable, fruit crops

24.2 **Patagonian Tablelands**

- cold semi-desert
- mostly winter rainfall with some snow

24.2.1 **Northern Patagonia** *or Payunia*

- plains with widely spaced hills & mountains
- different AVHRR pattern than southern region
- transitional region from Patagonia to Monte

24.2.2 **Southern Patagonia**

- dissected tablelands
- deciduous shrubland compared to Monte semideciduous or evergreen shrubland

24.2.3 **Magellan Grasslands**

- wetter and colder? than Southern Patagonia
- tundra-like vegetation
- different AVHRR landcover

APPENDIX 3

Central and South America Ecoregion References

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