AN ABSTRACT OF THE THESIS OF

Isaac Brewer for the degree of Master of Science in Geography presented on May 6, 1999. Title: The Conceptual Development and Use of Ecoregion Classifications.

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Philip L. Jackson

This thesis explores the genesis of the ecoregion concept, examines the conceptual development of ecoregion classification systems, investigates applications of ecoregion classification systems for a broad range of purposes, and discusses the prospects for the further evolution of this concept. An ecoregion is an area that exhibits patterns of homogeneity in specified criteria such as soils, vegetation, climate, geology, physiography, land use, and hydrology. Ecoregions provide a unifying spatial framework for environmental research, assessment, management, and monitoring and are appropriate tools at continental, national, and state planning levels.

Recent years have seen marked interest in the development, use, and application of ecoregion classifications. A literature review provides a thorough look at the geographer's concept of regions and regionalization, and identifies ecoregion classifications in use today, including Bailey's, the EPA's, and others' frameworks in the context of their specialized perspectives, purposes, and differences. The contemporary uses, applications, and trends of ecoregion classifications are also discussed.

Conclusions are made regarding the proliferation of ecoregions to meet diverse information needs, trends in expanded use, and concerns about the information value of ecoregion

classification frameworks. This analysis has shown that ecoregions have been used effectively for a wide array of applications, including broad-based holistic resource analysis, development of biological criteria for water quality standards, evaluation of protected area representativeness, wetland mitigation, and calibration of remote sensing data. Over 40% of all ecoregion uses between 1976 and 1998 were for water quality management; however, recent trends indicate ecoregions are being used for more holistic assessment of terrestrial, aquatic, abiotic, and biotic resources with increasing interagency collaboration. Ecoregion theory has developed rapidly within the past thirty years, and this thesis identifies the current utility of ecoregion classifications in the international arena.

Master of Science thesis of Isaac Brewer presented on May 6, 1999.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Isaac Brewer, Author

The Conceptual Development and Use of Ecoregion Classifications

by

Isaac Brewer

A THESIS

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The Conceptual Development and Use of Ecoregion Classifications

Chapter I

Introduction

"Society has allocated responsibility for the study of areas to geography; this responsibility is the justification for our existence as a scholarly discipline,"
(Hart, 1982; 1).

Environmental issues transcend political boundaries. To date, public land management agencies have tended to focus on individual resources rather than entire ecosystems. Changes in US environmental policy spurred the need for the development of regional-scale ecological classifications to provide information for environmental monitoring and management. Ecoregions were developed to meet these requirements.

An *ecoregion*, or *ecological region*, is an area with relative homogeneity in ecosystems within which the mosaic of ecosystem components, biotic and abiotic, as well as terrestrial and aquatic, is different than that of adjacent regions (Omernik and Bailey, 1997).

The ecoregion concept, introduced by Crowley (1967), is based on the notion that such homogeneous ecosystem regions exist in nature and can be delineated and classified. This concept is not new, but is merely a new name for old ideas developed in scientific and geographic theory. The ecoregion concept, or theory, is used to create classifications and frameworks that depict ecoregions.

The US Congress passed the National Environmental Policy Act (NEPA) (Pub. Law 91-190, 1970) and created the Environmental Protection Agency (EPA) in 1970. NEPA mandated that all Federal agencies "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decision making which may have an impact on man's environment" (Pub Law 91-190, 1970; 2). This requirement created the need for vast amounts of information to set environmental goals, to guide rational decisions, and to enforce legal standards. The ecoregion classification was consequently designed to help agencies organize and achieve these goals.

The stimuli to develop ecoregional frameworks within individual federal agencies differed. Ecoregions of the United States (Bailey, 1976) was prepared by the Forest Service in cooperation with the Interior Department's Fish and Wildlife Service to aid in the National Wetlands Inventory, and to conduct assessments required by the 1980 Resources Planning Act (Bailey, 1978). For the EPA, the need to assess existing and attainable surface water quality was the impetus for ecoregion classification (Omernik and Griffith, 1991; Gallant et al., 1989). A Science Advisory Board Report recommended to the EPA that ecoregions were useful for water quality assessment and environmental management, and promoted development of the concept (USEPA, 1991).

These developments have caused other governmental agencies and non-governmental organizations (NGOs) to develop new ecoregion classifications to meet their environmental mandates. The frameworks are receiving widespread use in environmental management. Private industry, government agencies, international environmental organizations, and academic researchers are using the ecoregions in environmental assessment, monitoring, and management.

The widespread use and acceptance of the ecoregion concept could result in misleading information and confusion due to the development of many different ecoregion classification systems, each designed for a specified purpose (Omernik and Griffith, 1991). A careful examination of the development and use of ecoregions should aid researchers by enumerating and describing the features of ecoregion frameworks presently in existence.

1.1 Statement of the Problem

This thesis explores the genesis of the ecoregion concept, examines the conceptual development of ecoregion classification systems, investigates applications of ecoregion classification systems for a broad range of purposes, and discusses the prospects for the further evolution of this concept.

1.2 Objectives

The objectives of this thesis are: to conduct an historical examination of the concept of natural regions and the influence of early geographical classifications on modern ecoregion theory; to catalog, compare, and contrast the ecoregion classifications that have been developed; to evaluate the varied uses and applications of the ecoregion classifications; and finally, to describe the current proliferation of new ecoregion classification systems in the context of information and communication concerns.

1.3 Organization

Chapter I identifies the problem, defines terms, and introduces the topic, and Chapter II traces the progression of regionalism in geography from its earliest roots to current discussions surrounding different ecoregionalization methodologies. Quantitative, qualitative, reductionistic, and holistic regionalization techniques are examined. Frameworks depicting "natural regions" or "biomes" (Herbertson, 1905; Austin, 1972; Hunt, 1974; and Udvardy, 1975) built the foundation for mapping ecological regions. The conceptual and methodological reasons for the transition to contemporary ecoregion classifications are examined.

Section one of chapter III catalogs the international ecoregion frameworks that were developed during the thirty-two year period from 1967 to 1999 (Crowley, 1967; Bailey, 1976; Omernik, 1987). The terrestrial and aquatic ecoregion schemes developed by Bailey and the Forest Service (1976), Omernik and the Environmental Protection Agency (1987), the Commission for Environmental Cooperation (CEC) (1997), the World Wildlife Fund (WWF) (Rickets et al., 1997), The Nature Conservancy (TNC), the Sierra Club, and other frameworks representative of the contemporary use of the ecoregion concept are compared and contrasted.

Section two of chapter III analyzes difficulties encountered during ecoregion delineation including disagreements over boundary width and boundary change over time. In this regard, the relationships among institutional goals, policy requirements, information needs, and ecoregions are discussed.

The applicability of a framework is a good test of its validity and usefulness. Chapter IV identifies the various uses and applications of ecoregions. All known uses of the term 'ecoregion' are specified, compiled, and discussed. Specific attention is placed on categorization of individual uses. Categories include the use of ecoregions as an indicator of location, a basic mapping unit boundary, and for stratifying water quality information.

Graphic displays illustrate the use of ecoregions in society. Included are time series and distribution graphs of ecoregion publications. Areas of growth in the international arena are also identified. Controversies surrounding the use of qualitatively defined ecoregional frameworks are also examined.

Finally, in Chapter V, new insights into the future of ecoregions for environmental management applications are presented.

1.4 Methods

A literature review of geographical and ecological literature was conducted in order to trace the genesis of the ecoregion concept in geography. Papers pertaining to theories of regions, natural regions, and ecoregions were collected.

The ecoregion classifications were identified during the literature search, and cataloged in Chapter III. The most recent classifications were obtained from the World Wide Web. To compare and contrast the frameworks, the classifications' methodologies were obtained from the literature review; however, not all classifications denoted explicit methodological processes. For the EPA's interagency classification, interviews with regional geographers were used to identify the most important criteria for ecoregion delineation.

All known references to ecoregion classifications were identified and discussed in the context of conceptual frameworks. The classifications developed by Bailey and the EPA were back-referenced to identify all known citations utilizing the published frameworks. The Science Citation Index was used as an initial guide to referenced citations. Bibliographic references not appearing in the Science Citation Index but cited within other documents were also obtained. Recent uses and applications of ecoregions were obtained from the Current Contents database and personal communication with ecoregion developers. During the course of the research, applications of other ecoregion frameworks were encountered and included.

Undoubtedly, a few ecoregion citations remain unidentified. Non-peer reviewed departmental and governmental literature, as well as recent publications, represent the most likely categories of use that might have been overlooked. Regardless, every attempt was made to ensure that the dataset was as accurate as possible and that any omissions were not deliberate.

The uses were categorized by discipline, and applications significant to the evolution of ecoregion theory were presented. A citation was classified as a use when it appeared in a published study--book, peer-reviewed journal, or internal document--that incorporated ecoregions. The uses were divided into separate categories denoting broad generalizations of use. Trend analyses of the findings were graphically portrayed in the final chapter. The graphs were discussed, and concerns were raised.

1.5 Definitions

A universal definition of ecoregions does not exist and will not likely exist in the near future. Researchers tend to describe ecoregions as large portions of the Earth's surface over which ecosystems have common characteristics. Beyond such a common definition, areas of contention arise.

Researchers designing classifications for conservation purposes describe ecoregions as areas of extreme biodiversity or environmental uniqueness. Some scientists refer to ecoregions as climatically defined areas while still others contend the regions are based on the integrated spatial relationships of all environmental phenomena. The greatest area of contention is whether to include humans as a part of the biotic realm.

Differing opinions over terminology is not a new problem for regional geographers. A similar problem arose in the definition of regions. Richard Hartshorne wrote:

> The validity of an hypothesis cannot be made to depend on the use of any particular word; on the contrary, if it appears to depend upon a term that is never precisely defined, it is for that very reason suspect. If an areal section of the earth's surface, delimited in some particular way to constitute a 'region,' can be demonstrated to be a corporeal thing, a concrete unit whole, it must be that by whatever name

> we call it. If we wish our logical demonstration to be clear, we will avoid words whose lack of clarity is likely to lead to dubious conclusions. If area and region are regarded as inadequate by some because geography is not to include everything in an area but only its material features, it would be better to invent a term such as 'geographic region,' that could be precisely defined to mean that, since it has not established meaning in common thought." (Hartshorne, 1939; 263)

The developers of the ecoregion concept learned from the mistakes of early regional geographers and coined interchangeable terms-ecoregion and ecological region. Ecoregion researchers from the United States tend to use the former (Omernik and Bailey, 1997; Ricketts et al., 1997) while Canadian researchers use the latter (CEC, 1997).

Whether to consider humankind's ability to erect cities, transform grasslands into agricultural areas, and mine the earth for minerals as factors important to the ecoregional boundary determination remains an area of contention. Some definitions include anthropogenic change while others consider only environmental phenomena. Several researchers and environmental managers have stressed the need to develop an agreeable definition, but due to the differing paradigms, goals, methodologies, and philosophies of ecoregion developers, a standardized definition remains elusive.

The following diagram (Figure 1.1) depicts a visual interpretation of an ecoregion. The US Forest Service representation also portrays the other scales of the agency's ecoregion classification hierarchy.

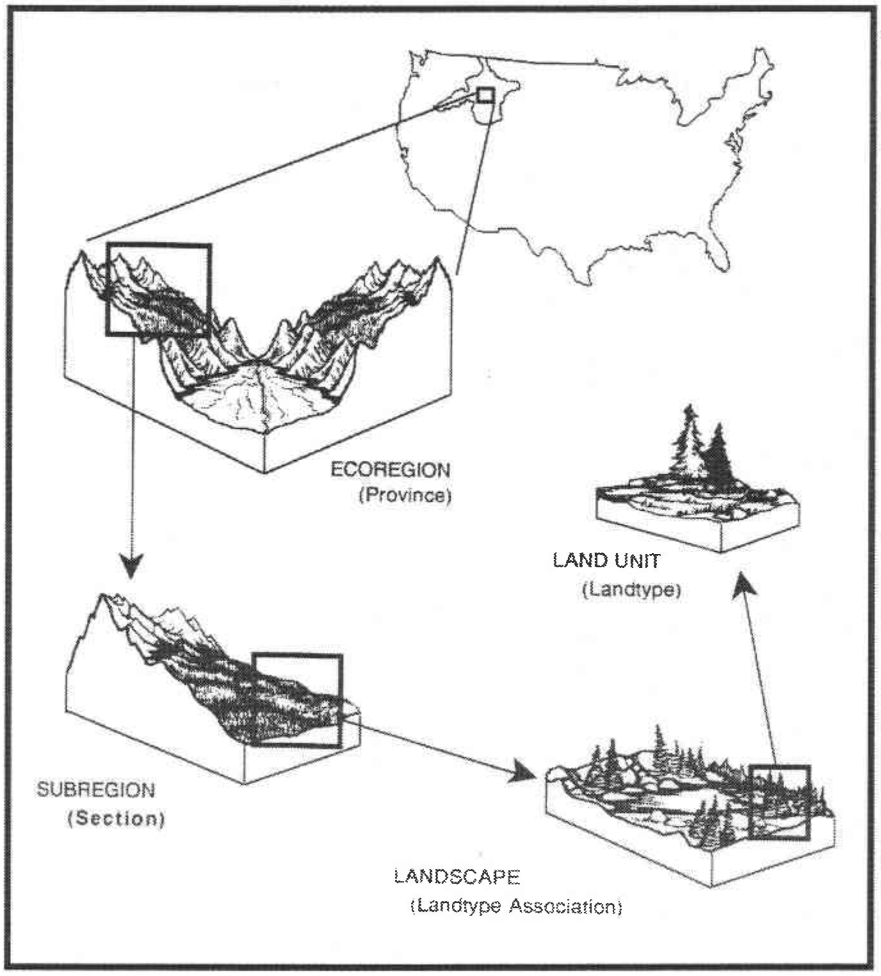

Figure 1.1 Visual diagram of an ecoregion
(McNab and Avers, 1994; 1)

Variations in delineation and definition of landscape units, or ecoregions, are rooted in early historical geographic science. Chapter II investigates the historical and conceptual development of natural landscape classifications.

Chapter II

The Historical Development of Ecoregions

**"Regionalism was never a coherent movement,
but a hodgepodge of people and ideas.
(Hart, 1982; 10).**

2.1 Holistic Regionalization

A primary task of the geographer is to synthesize a wide array of information gathered from distinctively different sources into a holistic idea. The region, a tool used by geographers to divide the world into manageable pieces, has played an integral part in the development of geography. Geographers have long debated the creation and use of the region as a spatial tool and this debate continues today. Scientists, on occasion, have divided the world into such finite, intricate, and detailed areas that they have lost sight of the complete, comprehensive system. The Bridge at Courbevoie, a painting by the French impressionist who invented pointillism, Georges Seurat, helps illustrate this point. The first three images, significantly enlarged, appear as groups of colorful dots. Only when the image is viewed from a distance does the nature of the painting become comprehensible. The series of four illustrations (Figures 2.1 & 2.2) is an allegorical representation of the type of complications that can result when landscapes and ecosystems are examined too closely.

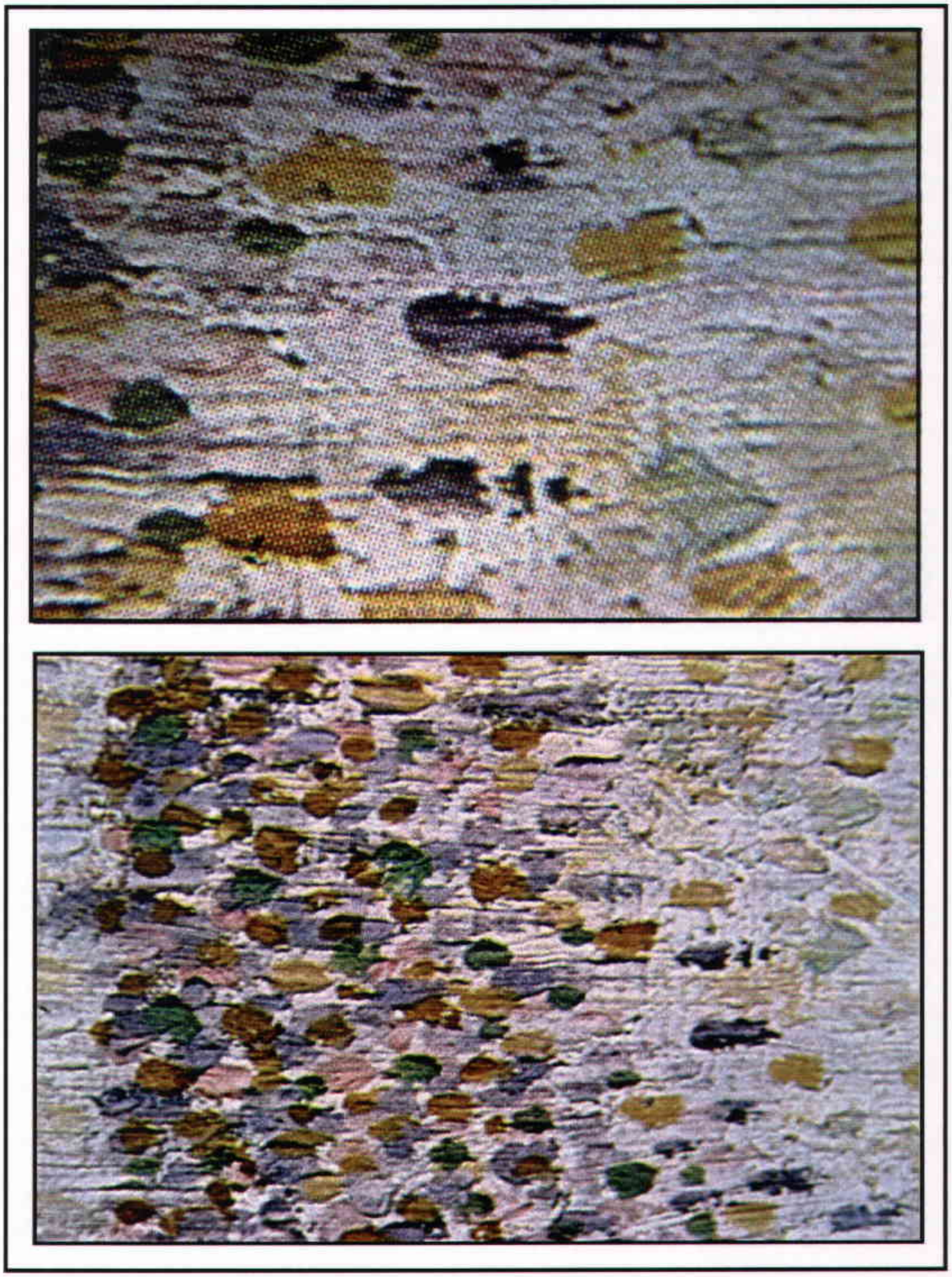

Figure 2.1 Portion of The Bridge at Courbevoie by G. Seurat 1886-7
(Harden, 1999)

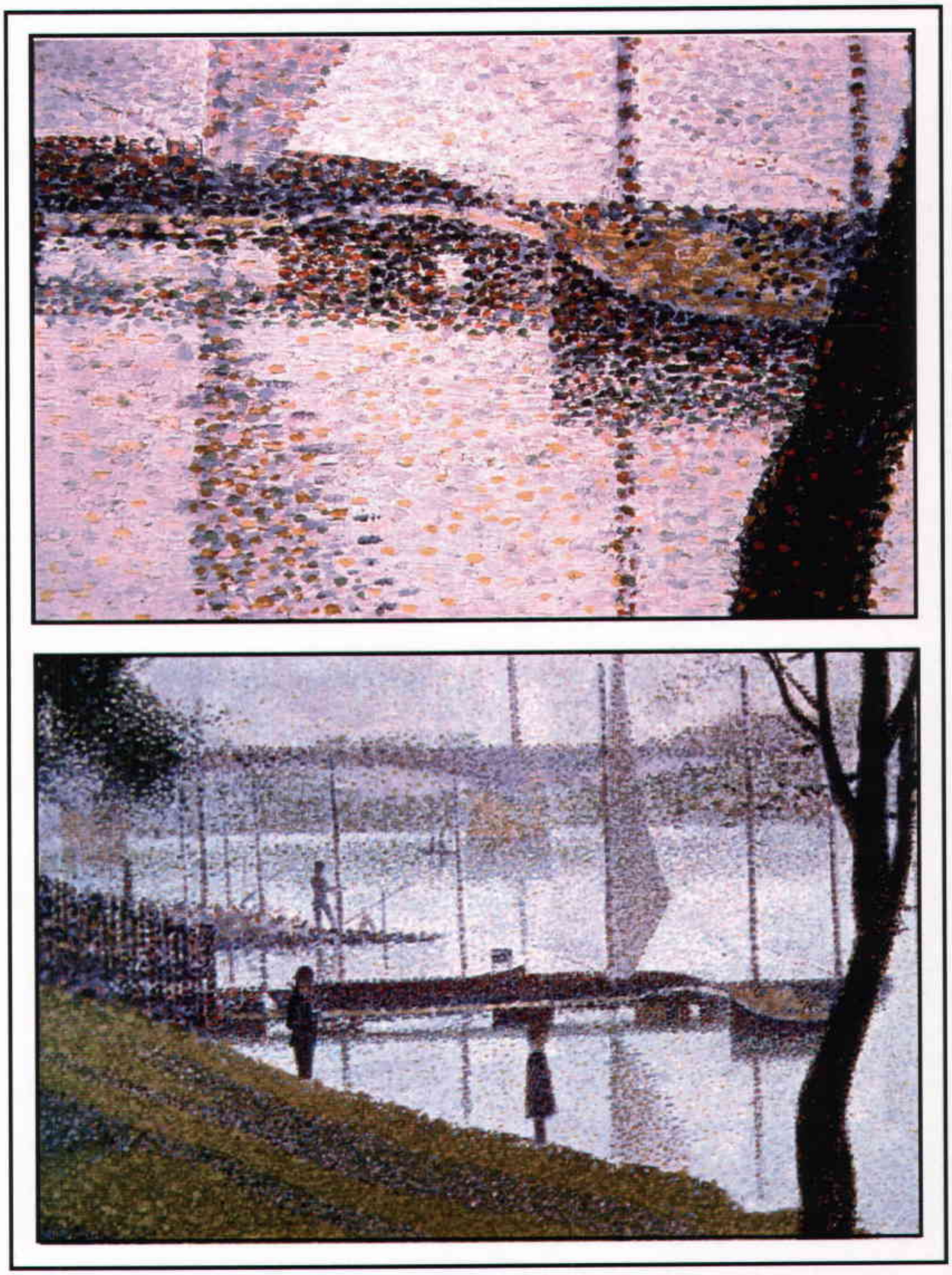

Figure 2.2 The Bridge at Courbevoie by G. Seurat 1886-7
(Harden, 1999)

The M.C. Escher lithograph, Relativity, further illustrates the need for holistic regionalization strategies. The linear assumption is based on the premise that one can understand the whole by studying the individual parts. Such sequential linear thinking assumes that the whole is equal to the sum of its parts. Music can aid in the explanation of this point. Though Johann Sebastian Bach and Wolfgang Amadeus Mozart created compositions comprising a myriad of individual notes, the true nature of the musical score could not be understood by knowing the pitch and duration of each individual note. The individual notes do not impart the listener with the complete package of rhythm, melody, harmony, and tone inherent in musical compositions. Landscapes, also, cannot be understood by examining the individual parts; the entire region must also be investigated.

The M.C. Escher print was divided into several pieces (Figure 2.3). Each piece was labeled with a division of the physical or biological sciences. To the observer, each piece appears upright, and normal within the context of its own boundaries. The theory, terms, and paradigms of the individual fields have allowed the scientist(s) to examine and define the "piece of the puzzle" according to his or her individual standards.

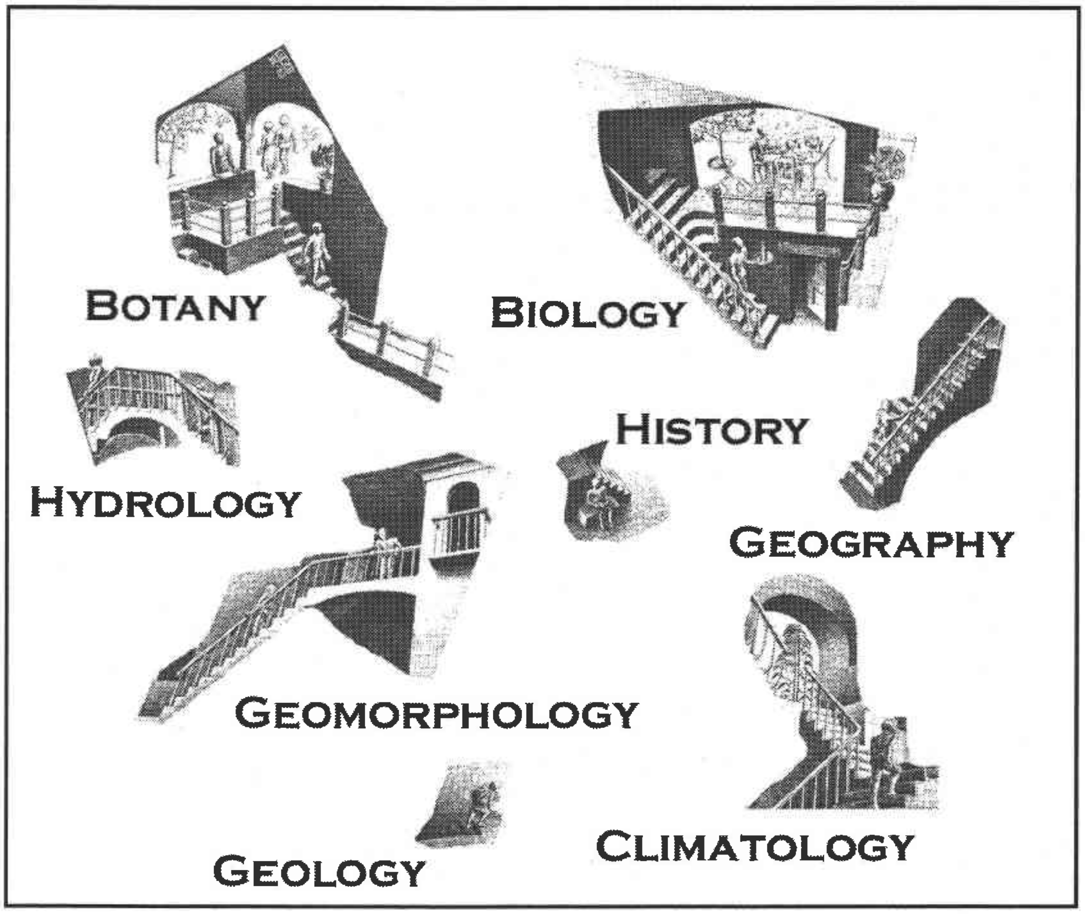

Figure 2.3 Adapted from Relativity by M.C. Escher
(Trent Graphics, 1999)

When the print is reassembled (Figure 2.4), however, the shape that appeared correct when analyzed using only one paradigm becomes incomprehensible. The entire picture, the holistic view of the system, cannot be examined with the same set of rules. Thus, the theories fall apart, and the big picture fails to make sense. When dealing with large-scale studies of the earth's ecosystems, this need for holistic thinking becomes obvious.

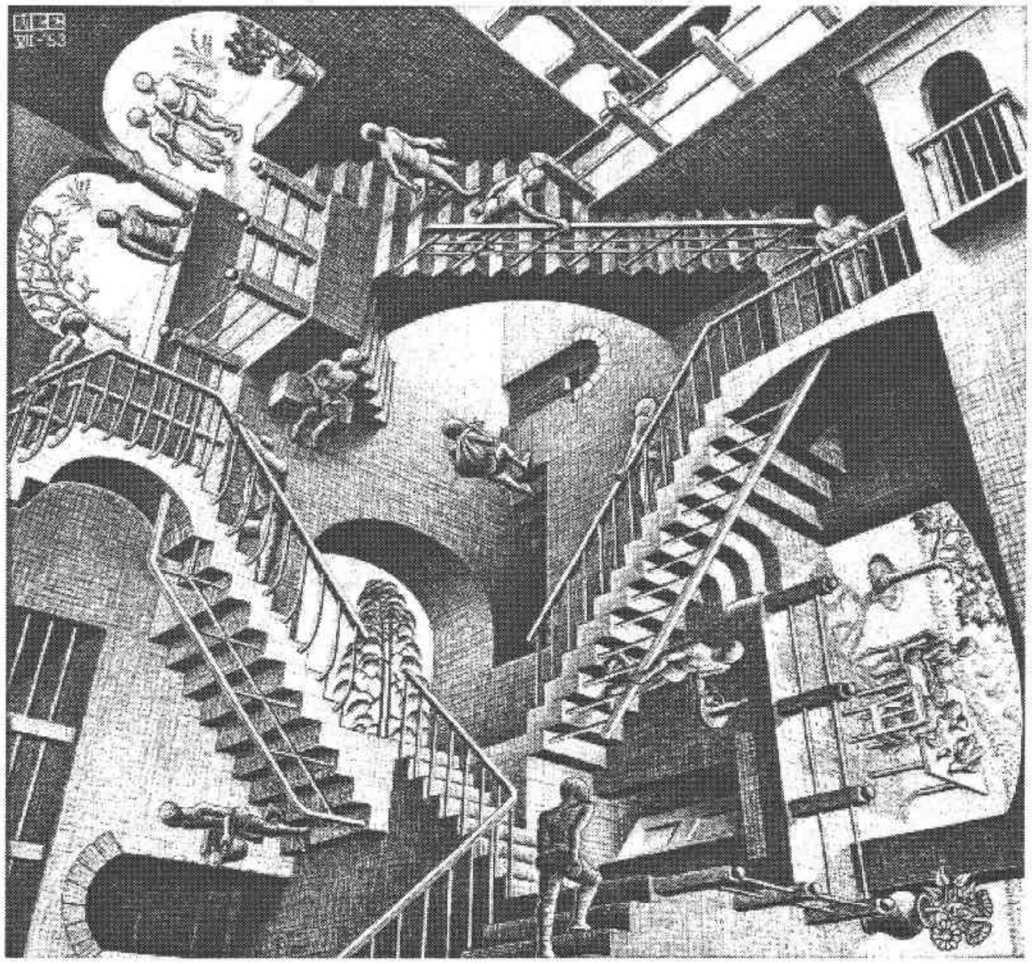

Figure 2.4 Relativity by M.C. Escher (Trent Graphics, 1999)

Holistic scale studies require the scientist to examine the system as the *sum* of its parts, as opposed to a narrow focus on one piece of the system. There is another point to be made from this illustration. The earth is an extremely complex system. Any scientist alive today would have difficulty explaining the total of the earth's variance. That is why it is necessary to study the earth as discrete, observational units. A researcher must be careful when dividing the earth into such "manageable" pieces. Instead of applying an individual field's paradigms, terms, and theories to the new region, the holistic scientist must always consider the system. The central tenet to a holistic study must always be the way the smaller piece will fit back into the system. Therefore, each of the areas surrounding the studied section must also be taken into consideration.

Ecoregions are an attempt to break the earth into such smaller, manageable pieces. Most ecoregional classifications take into account the complexity of the system, but some do not. The correct use of ecoregions requires large-scale, interdisciplinary holistic reasoning.

2.2 Formation of the Regional Concept in Geography

A region is an area on the earth having one or more distinguishing characteristics that separate it from the surrounding areas. Without the unifying characteristics, a place is considered merely an area. The American Heritage Dictionary defines a region as "a large continuous segment of a surface or space" or "a part of the earth characterized by distinctive animal or plant life." Geographers have molded this definition into several forms; there is no universal agreement on the true definition of a region.

The concept of a 'region' existed prior to the appearance of the term. The Greek scholar Aristotle classified the world into three 'regions': the torrid zone, the frigid zone, and the *Ekumene*, or inhabited portion of the earth (Martin and James, 1993). Though referred to as zones, Aristotle's divisions represent one of the first documented examples of humans' attempts to classify the world into manageable regions.

The division of the earth into regions began in ancient times, continued during the Renaissance, and became a part of modern science. Several scholars adopted regionalism, as an area of study, in America in the 19th and 20th centuries. The use of the terms 'regional' and 'regionalism' to describe distinctive areas developed slowly through the 19th century and became widespread in American geographic literature beginning in the 1920s (Simpson, 1989; 1). Regionalism transformed the field of geography.

Regionalization has been a dominant tool for classification and generalization of phenomena, and geographers have used regions for a variety of studies. Ecoregions, a form of regional classification, are a relatively recent creation based on ideas that originated during the early twentieth century. Though the term ecoregion did not appear until 1967, the concept of ecological regions existed earlier. The first ecological regions were labeled with names such as biomes and natural regions.

In the mid-1700s, geographers attempted to create a scientific geography. Johann Christoph Gatterer made an instrumental first step in the development of regionalism in 1773. Gatterer replaced the traditional division of the world by political units with a division of "natural regions." His work was based on the theory of a continuous network of mountains spanning the entire globe (Hartshorne, 1939). The development of natural units would significantly influence other contemporary scholars such as Alexander von Humboldt, Immanuel Kant, and Karl Ritter. Kant coined a term that changed geographic theory and marked the beginning of regional geography-- *Länderkunde* (Hartshorne, 1939).

Karl Ritter (1779-1859), the German geographer who helped initiate the classical period in geography, made the first attempt at regional divisions in modern times (Martin and James, 1993). Ritter recognized the need to divide the world into regions based on the universal consideration of all features. Ritter's philosophy was based on the teleological view that dominated scholars of that period.

The middle to late 1700s and early 1800s was a dramatic period of change in regional theory. Hartshorne wrote:

> "Few of the writers of that period-or indeed any later period-distinguish clearly between the concept of unity of all phenomena at any particular place or area, in what we may call vertical totality or unity, and the horizontal unity of the area as an individual unit distinct from neighboring units," (Hartshorne, 1939; 44).

The development of regional geography in Germany, pioneered by Ritter, was continued by Ferdinand von Richthofen (1833-1905). Richthofen developed a special geography that required descriptive regional study followed by more detailed study of unique features. He supported the use of direct field observation to identify distributions of phenomena. He coined the term *chorology*--regional study (Martin and James, 1993). Richthofen also identified the need for integrated holistic and detailed study of the earth's surface. Richthofen's methodologies required field observation from the general to the more specific. He also defined the word *Erdkunde*—

which came to be regarded as the study of the region of the earth where the lithosphere, hydrosphere, atmosphere, and biosphere contact one another (Martin and James, 1993). This method of hierarchical regional study remains a significant part of modern ecoregional geography.

During the mid-1800s, a movement occurred in which the earth was thought of as a terrestrial organism. Continents were considered organs, and the smaller areas, or regions, were organisms. Karl Ritter (1779-1859) and Fredrick Ratzel (1844-1904) occasioned the idea of the earth as an organism. Ritter stated that the phenomena of the earth, animate and inanimate, material and immaterial were precise statements of regional character (Martin and James, 1993). Their ideas would have a significant influence on the development and definition of natural regions and eventually ecological regions.

2.3 "Natural" Regions

The concepts of unity and regional distinctiveness remain areas of contention in modern regional geography. Geography would not have evolved to its present state without an important transition that occurred during regional geography's infancy--the movement from state units defined by clear political boundaries to "natural" units. Supposedly equally definite and determined by nature, these units represented a clear break in tradition: political boundaries had long been the standard unit of separation for geographic study.

Examples of these so-called natural divisions of the world were the mountain networks, the seas, and the drainage basins separated by mountains (Hartshorne, 1939). As exploration of the earth's surface increased geographer's knowledge, the problem of finding natural boundaries for areas denoted as 'natural units' became more difficult to the early regional geographer (Hartshorne, 1939).

The use of the term 'natural' in defining regions of the earth's surface would hinder the developments in regional geography. Heated debates about what phenomena were natural or unnatural ensued, and scientific progress stagnated during the late 1800s (Hartshorne, 1939).

Though the concept of natural regions had been formed in 1773, formal consideration of each of the earth's divisions as individual, natural units did not surface until 1805. Heinrich Gottlots Hommeyer developed the concept of composite unity among land surface form and the topographic surface. Composite unity was defined as the integrated total of all areal phenomena into an individual unit that is distinct from neighboring areas. August Zeune and Wilhelm Butte also adopted and developed the concept of composite unity (Hartshorne, 1939). Butte's greatest contribution was the consideration of individual lands and districts as organisms, animate and inanimate, including humans. "The unit areas assimilate their inhabitants and the inhabitants strive no less constantly to assimilate their areas." (Butte in Hartshorne, 1939; 45). This idea--of active coexistence of humans and the landscape--was an important development in regional geography.

However, the concept of 'natural regions' was not without opposition. In 1811, Rühle von Lilienstern disputed the delineation of natural regions, citing the impracticability of establishing definite boundaries. In the 1820s, Heinrich Wilhelmi and Friedrich Selten pointed out other obstacles to the delineation of natural regions. They acknowledged that the boundaries of natural units could not be determined by only one kind of phenomena. They also identified the inherent difficulty in defining areas where the boundaries were gradual and failed to coincide (Hartshorne, 1939). Wilhelmi wrote, "Nevertheless, the forms of nature are clear and distinctly separated as soon as we regard the particular constitution (of the total of all factors in any area) in its full form rather than the boundary or transition zone," (Wilhelmi in Hartshorne, 1939). Despite the recognition of difficulty in delineation, Wilhelmi still believed that distinctive "natural" areas did exist, and could be identified. The contentions and arguments raised in the early 1800s persist today.

A powerful argument against the delineation of natural regions was raised by August Leopold Bucher in 1927. Bucher contended that the search for true natural regions was futile and that political boundaries were not effective regional divisions either. Bucher believed that regional studies could be arbitrarily bounded as needed for the convenience of user and use (Hartshorne, 1939). Bucher's argument took hold, and the skepticism gave rise to numerous regional frameworks with varying methods and criteria for boundary establishment. Today, ecological regionalization is plagued with Bucher's cavalier notion of individual ecoregional delineation. Such arbitrary ecological regionalization has led to the development of "ecoregion frameworks" that are nothing more than individual faunal distributions, soil regions, or climatic zones. Ecoregion users should be aware of the fact that Bucher's idea remains, and carefully select an appropriate ecoregion framework.

The skepticism of late 19th century scholars led to a period of decline in regional studies. However, with the dawning of the 20th century, a rebirth in regional geography appeared. Regions were again considered as definite, concrete, natural units (Hartshorne, 1939).

> The region, or Landschaft, is said to constitute a definite individual unit that has form and structure, and is therefore a concrete object so related to others like it that the face of the earth my be thought of " as made up of a mosaic of individual landscapes or regions." Further, for some students, in this country as well as in Germany, the region is an organic object, comparable to biological organisms, (Hartshorne, 1939; 250).

Thus geographers had turned the region into the major unit for geographical study; a unit equivalent to the species divisions of biologists. Despite this rebirth, the consideration of regions as independent organisms would help stymie the development of regional geography.

Walther Penck (1888-1923), a German geomorphologist, shattered the idea of the region as an independent organism. He argued that organisms were essentially indivisible, whereas regions could be divided into smaller and smaller units (Martin and James, 1993; Hartshorne, 1939). Another point of contention was that organisms grew from a common origin, but regions grew from a combination of factors. Penck also aided regional study by identifying the link between the observable features of the landscape and the climatic classification of the earth's surface (Martin and James, 1993). Penck's discovery of feature interelatedness would appear in later integrative landscape classifications.

German geographers also brought musical terms into regional geography. Harmony, dynamics, and rhythm were terms used to discuss regional relationships in reference to the concept, *Landschaft.* The great geographer of the Classical period, Alexander von Humboldt (1769-1859) agreed with the ideas of harmonious regions, although he rejected the idea of the region as an organism. Humboldt believed that harmony was simply the concatenation of all phenomena in a region. Rhythm was thought of as the harmony of regional change (Hartshorne, 1939). Even though these early philosophical debates seem senseless to modern, systematic geographers, the discussion was necessary to further the conceptual development of regional studies.

Not only did geographers have difficulty defining the terms of regional geography; but also, they had even more trouble delineating the boundaries of regions. Hartshorne (1939) pointed out the difficulties encountered even when boundary delineation was based on a single factor.

Siegfreid Passarge (1867-1958) assisted in the development of a methodology for the division of natural (non-human) elements. Passarge developed a system of *landschaftskunde.* In his system, *Landschaft* areas were not considered complete units such as animals or plants, but were specific concrete objects. The unit areas developed by Passarge were based primarily on vegetation (closely related to climate) and land forms (Hartshorne, 1939), and areas of natural vegetation were often confused with climatic zones. Passarge noted that, at times, it was necessary to arbitrarily select 'lines of convenience' when the zones of transition between regions were unclear (Passarge in Hartshorne, 1939; 269). Disagreements over boundary determination were prevalent early in regional geography.

At the turn of the Twentieth Century, a few geographers continued the work of early, regional scholars. In 1897, Hettner championed the ideas of Ritter and Richthofen, and developed an inductive method of classification based on the combined characteristics of small, individual areas. Hettner and his contemporary German scholars maintained the tradition of Ritter, and associated individual regions into larger realms and continents (Hartshorne, 1939). Hettner elaborated on Richthofen's concept of chorology. To Hettner, chorology required comprehension of the interrelations of regional characteristics within different realms, and the arrangement of the earth into continents, regions, and places (Martin and James, 1993). Hettner also promoted geographical study that integrated the study of general and specific elements.

Hettner suggested that reformulating the subject as a science of regions would help geography overcome the cultural geophysical dualism that burdened it. He contended that the geophysical component was too remote from the subject's traditional concerns, and, instead, urged that regional synthesis become the central focus of geography (Livingstone, 1992). Hettner argued in favor of inductive reasoning. He believed that only the chorological principle could allow geography to retain the physical *and* human components of geographic study because the character of regions was based on the integration of both factors (Livingstone, 1992). Hettner's methodology, *Länderkunde Schema,* followed a strict procedure of sequential observation of geology, relief, climate, natural resources, zoogeography, and, finally, settlement (Livingstone, 1992). Hettner's methods emphasized the physical environment while still considering the influences of the cultural landscape.

Other geographers believed the emphasis should rest on cultural factors. Otto Schlüter, a student of Richthofen, opined that the emphasis of geographical inquiries was the study of landscape change based on cultural phenomena (Livingstone, 1992). Schlüter placed emphasis on the cultural landscape as opposed to the natural landscape. The debates prompted by Hettner and Schlüter would continue throughout the first quarter of the twentieth century. In the end, the concept of *Landschaftskunde* became a more holistic, integrative concept based on the intricate relationships between humans and the land (Livingstone, 1992). Geography, a science of synthesis, was expanding.

Although the contributions of the German geographers to regionalism were remarkable, the monumental breakthrough in regional study sprang from the British school of geographical study. Patrick Geddes (1854-1932), influenced by the French geographers, attracted British scholars to the study of the region as a geographical unit (Livingstone, 1992).

Enter Andrew J. Herbertson. Herbertson (1865-1915) replaced the famous political geographer, Halford J. Mackinder (1861-1947), as the director of the Oxford School of Geography (Martin and James, 1993). Herbertson distanced himself from the

American teachings of William Morris Davis and the idea that geography was a science of the physical environment, and, instead, emphasized the study of regions (Livingstone, 1992). Because he was interested in improving geographical teaching, Herbertson rejected the use the earth's political unit divisions, and instead supported a framework based on natural regions in the traditions of Penck and Passarge (Martin and James, 1993).

Herbertson's classification of the landscape, published in 1905, was the first of its kind. He believed that geography was concerned with the distribution of *all* elements on the Earth's surface, not just one element. Herbertson wrote, "The recognition of natural regions gives the historian a geographical foundation for his investigations into the development of human society, such as he has not hitherto consciously possessed," (Herbertson, 1905; 309).

The natural regions developed by Herbertson (Figure 2.5) were based on configuration (physiography and geology), climate, and vegetation. Vast oceans, mountain ranges, and deserts defined his ideal boundaries. He warned that lines on the map were transition zones where regions melted into the characteristics of other regions (Herbertson, 1905).

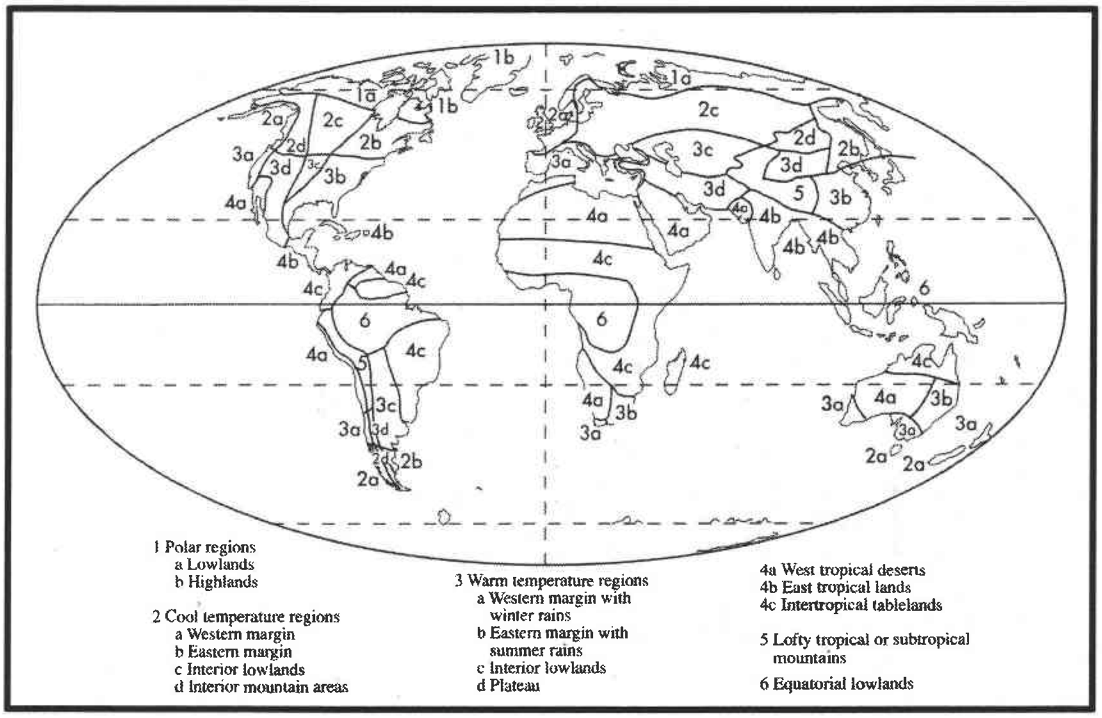

Figure 2.5 Herbertson's Natural Regions (Bailey, 1998a)

Herbertson's classification was unique because he considered the natural regions as specimens--types--that could be associated even when separated by vast distances. Hartshorne wrote, "his system was therefore a classification of regions regardless of location and association in space, in contrast with an areal division of the world into major parts, these each sub-divided into subdivisions which are contiguous and together form an associated whole," (Hartshorne, 1939; 293).

Herbertson's scheme was given the term *generic*—a comparative classification based on internal character as opposed to *specific*—an outline of the actual areal relations. In a *specific* division, the sub-regions could be added to form a true, single region, but in a *generic* system, sub-regions could not be combined (Hartshorne, 1939). Modern ecoregion geographers use both the *generic* and *specific* methods of regional division.

Herbertson stated his system would educate, as well as be useful in the fields of economics and politics. Despite Herbertson's claims, other geographers immediately questioned the usefulness of his system. Most geographers believed that *chorography* should be the dominating foundation for geographical education. Herbertson's use of climate in his subdivision was shunned. One scholar stated that because one classification could not satisfy all of the members of geographical science, the field should rely on the always-dependable degree-net, coastline, and contour lines for division of the earth's surface. Yet another scholar agreed that it was an instructive inquiry, but doubted the system's usefulness in teaching (Herbertson, 1905). These same arguments, established in 1904, remain today. The British cartographer Earnst Ravenstein (1834-1913) suggested that, for all practical purposes, Herbertson's natural regions could not serve as guides because they were not universally accepted geographical regions.

Despite the initial negative attitudes towards Herbertson's regions, his idea would eventually spread to England, Germany, and the United States. Hettner related that all classifications prior to Herbertson's were "artificial." The prior classifications were only useful because they had helped develop the infantile science of regional geography (Hettner in Hartshorne, 1939).

Herbertson's natural regions were strongly based on climate. Herbertson claimed, "no circumstance has a greater influence . . . than climate," (Herbertson in Livingstone, 1993; 281). Herbertson, thus, helped establish environmental determinism as a major factor of regional study ultimately causing severe problems for regional geographers in the mid-1900s.

Herbertson also developed a solution to the terminology dilemma of natural versus unnatural. He suggested removing the qualifier 'natural' and instead refer merely to regions. If this method were not sufficient, the regions could be labeled "geographic regions." Either way, the debates surrounding the use of the term "natural" would be eliminated (Hartshorne, 1939). Unfortunately, Herbertson's nomenclature did not take hold, and terminology debates continued.

Hettner pointed out another problem with the term natural. He contended that, regardless of the methods of division or application, the regions were based on so many subjective decisions that they could never be considered "natural," (Hettner in Hartshorne 1939, 297).

Some geographers have accepted the use of natural when referring to all of the phenomena observed outside the observer's mind. This definition was the one preferred by Alexander von Humboldt and several of his predecessors.

One 19th century movement defined natural as the study of non-human phenomena. Nature was considered independent of human influence (Hartshorne, 1939). This line of thinking later prompted James to begin using the word fundament when discussing relations between humans and the earth (Hartshorne, 1939).

Several new schemes of "natural regions" were developed following the pioneering work of Herbertson. For instance, C. Hart Merriam, Vernon Bailey, E.W. Nelson, and E. A. Preble created a map of the zoogeographical provinces of North America in 1910. The ten regions were produced for the American Ornithologists Union, but were based on altitude and other environmental factors. C.R. Dryer constructed a map of the natural regions in 1911 for use in his high school geography textbook. The "provinces" and "types" were based on soils and vegetation. Dryer identified five provinces and twelve "types" for North America. Banse (1912) fabricated a system with sixteen separate natural regions for North America; Fischer and Geistbeck (1912) also delineated a system with sixteen natural regions (Joerg, 1914).

Wolfgang L.G. Joerg created a system of natural ecological regions for the United States in 1914 (Figure 2.6). Natural regions were defined as any portion of the earth's surface whose physical conditions were homogenous (Joerg, 1914; 56). With a methodology adapted from Herbertson, Hettner, and Passarge, Joerg determined that structure, relief, climate, and vegetation were the most appropriate elements of regional delineation; anthropogenic factors, however, were not deemed suitable criteria.

Joerg emphasized that human activity could be better interpreted if the surrounding environment was first recognized. He used the inductive method based on direct field observations to further subdivide the natural regions into smaller units, relying on deductive, systematic descriptions only when necessary (Joerg, 1914). Joerg was also a firm believer that the real value of the system depended on its usefulness.

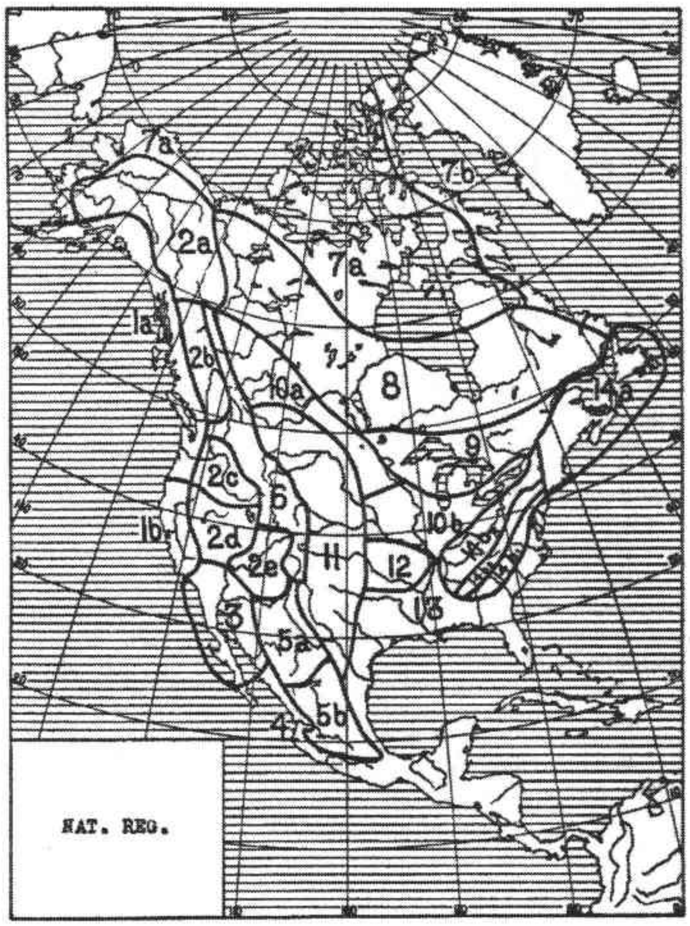

Figure 2.6 Natural Regions of North America (Joerg, 1914)

Researchers opposed to regional geography argued that regions were subjective entities that were extremely hard to comprehend. The argument was that regions were not equivalent to plants, animals, minerals, or other concrete objects (Hartshorne, 1939). A region could not be held or examined in the same manner one examines a mineral specimen. Not only did the researchers have trouble with regions as concrete entities, but also the problems spilled over into the general public. Laymen could not distinguish or identify a "concrete region." Nevertheless, George T. Renner asserted that "regions are genuine entities," (Renner in Hartshorne, 1939; 251). However, Hartshorne pointed out that Renner's statement was in reference to the collective belief of several contemporary regional experts (Hartshorne, 1939).

Though several regional scholars believed that regions were indeed complete entities or homogenous units, few scholars agreed on the definition, delimitation, or essential character of regions; therefore, terminology differences were a major hindrance to the growth of regional geography. The discordance of the early 1900s continues to plague modern regional geography as well.

American geography underwent significant changes during the years preceding World War II. Following the movement toward environmental determinism in the 1920s, geographers began to remove realms of discordance. Although practitioners of geography were still battling between the human and physical realms, new geographies were being created. Regional geography, the science of *chorology*, represented one of the four major areas of geographic study in the first half of the 20th century. Another significant occurrence was the development of applied geography, which utilized geographic concepts that strayed from traditional academic studies and, instead, answered practical economic, social, and political questions (Martin and James, 1993). Modern ecoregion geography is a mixture of chorology and applied geography.

Richard Hartshorne (1899-1992) made significant contributions to regional geography with his 1939 publication, The Nature of Geography. He identified a parallel between regions and research theses contending that geographers' searches to identify regions were comparable to the student's task of writing a thesis. Hartshorne wrote that no one had made an attempt to show that a thesis was a necessary product of research studies, nor demonstrated that the thesis had value explaining relationships that could have been explained without it (Hartshorne, 1939). Regional researchers, too, had not demonstrated the necessity or importance of the region to geography. "We are concerned, therefore, with a hypothesis that is neither self-evident nor the product of geographic research, but is constructed by what for lack of a better term we may call philosophic thinking about geography," (Hartshorne, 1939; 251).

Hartshorne instituted the idea of the region being an intellectual construction as opposed to a statement of obvious fact, a product of research, or a concrete entity. Research in regional geography continued. Hartshorne emphasized that because nature did not create obvious, individual concrete objects for geographic study like those for astronomers and zoologists, geographers must intellectually construct their regions (Hartshorne, 1939).

Given that regions were mere intellectual constructions, one might logically ask the questions, "What is the value of a region?" "For what purposes are regional studies useful?" Early geographers identified the value of the region as an area of relative homogeneity of phenomena.

Johannes Granö believed that the geographic region was an observable piece of reality. Granö suggested that geographic researchers needed to construct the "whole units" that were needed (Grano in Hartshorne, 1939). Wellington Jones expressed the need for extensive study prior to holistic regionalization:

> "The determination of areas of homogeneity inevitably must come late in an investigation. Only after an ample and sound body of data has been gathered, and the significant relations between various categories of data have been ascertained, can the important or essential homogeneities of areas be determined. And only after such homogeneities have been established can boundaries of areas of homogeneities be drawn with any approach to precision," (Jones in Hartshorne, 1939; 253).

Holism was, and is, an integral part of regional studies. To be of use, the intellectual constructs known as regions had to be delineated in a holistic fashion based on the integrated entirety of the world's phenomena.

The proponents of regional geography were not only developing the tools of geographers; they also sought to elevate geography to a higher order within the scientific community. There was a real need among many geographers to make the discipline a true, systematic science. Other "higher sciences" had objects of study, therefore regional geography was viewed as the method for creating such objects (Hartshorne, 1939).

Carl Sauer, regarded as the "father of regional geography," was guilty of referring to regions in terms similar to other sciences. He described regional areas as having form, structure, and function. He even stated that geographers could study the anatomy of areas. "We regard the geographic area as a corporeal thing," (Sauer in Hartshorne, 1939; 257). Again, the idea of a region as a living organism would be the central tenet of many debates among regional geographers.

After accepting a professorship at the University of California, Berkeley in 1923, Sauer began to specialize in regional geography, considering the chorological concept as the core of geography (MacPhearson, 1987). Two years later, Sauer published <u>The Morphology of Landscape</u> in which he attempted to distance geography from environmental determinism. Sauer's influence on other American geographers was extensive, and he helped establish the study of regions as a fundamental aspect of geographic study (Martin and James, 1993).

Vernor C. Finch (1883-1959) furthered the concept of regions as living entities. "A Geographic region, or even an arbitrarily-chosen portion of the earth's surface, may be thought of as having some of the qualities of a human being. It is a thing...with physical and cultural elements so interwoven as to give individualism to the organism," (Finch in Hartshorne, 1939; 257). Other famous geographers agreed with the concept of regions as organisms. Glen Trewartha (1896-1984) wrote that regions were functioning organisms comparable to plants, and Preston James (1899-1982) also referred to regions as organisms (Hartshorne, 1939).

Defining "natural" regions remained a problem in regional geography. Much of the dilemma was rooted in the process of delineation. Regionalization required subjective decision making, and some geographers found this process unacceptable. Any attempt to define "natural" areas came under extreme scrutiny. Geographers could not agree on a hierarchy of importance (Hartshorne, 1939). Was climate a more important factor than topography, or rainfall more important than soils? These questions plagued early regionalists.

Similarly, the use of the term 'natural' was a source of contention among regional scholars. Some geographers used the term to indicate the basis of a division found in nature, including humans, as opposed to a regional scheme based on one element, such as a system of climatic regions or vegetation regions. Hartshorne used the term in another manner. Natural regions were, "regions on a basis of real conditions" or more simply, "real regions," (Hartshorne, 1939; 297).

Not only did geographers disagree on what is natural, the dictionaries of the world also contain contrasting definitions. According to Webster, nature is defined as "the external world and its entirety," (Mish et al., 1983; 789). Natural refers to "a classification based on features existing in nature," (Mish et al.., 1983; 788). These definitions position humans within the realm of nature. The Oxford dictionary provides a different interpretation. Something is natural only if it is uncultivated, wild, and not artificial (Abate et al., 1996). A universal definition of the term "natural" remains equivocal.

2.4 Humans as Agents of Change

Certain geographers contended that natural regions were delineated based on their non-human elements. However, such a system exists only in theory. The world does not consist of a simple system of natural regions; instead it is a complex combination of independent, natural elements. There is no basis for the delineation of regions based on non-human elements; nature does not establish levels of environmental significance.

Human influences on environmental systems complicate the regionalization process. The ubiquitous human race has significantly altered the environment. Emily Russell pointed out three major factors that can impact regional studies. By studying the current conditions, researchers cannot detect the exact cause of landscape change if the past human changes left a residual effect. Anthropogenic changes are also cumulatively superimposed upon each other, often masking the conditions that might have existed. Climate also changes and must be considered. Finally, because human activities are so widespread, it is nearly impossible to find ecosystems unaffected by human change (Russell, 1997).

Humans have become a major geographic agent of change. In 1864, humans' ability to make extreme modifications on the environment was formally addressed. George Perkins Marsh wrote, "Not all the winds, and storms, and earthquakes, and seas, and seasons of the world, have done so much to revolutionize the earth as Man, the power of an endless life, has done since the day he came forth upon it, and received dominion over it," (Marsh in Russell, 1997).

Prior to Marsh's publication, Man and Nature, most people assumed that human changes resulting from logging, mining, soil erosion, or siltation were not major modifications, but only minor, temporary side effects. The major problems such as declining agricultural productivity or overfishing were attributed to natural causes and climatic change (Russell, 1997). Marsh changed the worldview by demonstrating that logging, overgrazing, and poor agricultural practices had led to long-term environmental degradation. He even suggested that logging and mining had altered mesoclimates (Russell, 1997).

To deal with the issues of human's ability to modify the environment, the concept of climax vegetation was created. Climax vegetation should occur in all areas of the earth's surface unaltered by humans. A discussion of the difficulties stemming from the use of the climax concept for ecoregion delineation appears in Chapter III.

Due to humankind's vast ability to alter the face of the planet, it would seem foolish not to consider humans when delineating natural or ecological regions. Although anthropogenic change has occurred for millennia, research suggests that humans considerably altered the physical 'pristine' environment over 5,000 years ago (Russell, 1997). The changes imparted on the landscape are so diverse and extensive, it would be fallacy to ignore anthropogenic effects. For instance, no researcher could definitively say that every inch of Africa had not been impacted at some point or another by humankind (Hartshorne, 1939). Passarge, in his attempt to identify natural vegetation of the planet, wrote "Man in his work practices such a determining influence on the landscape that, not only is its appearance completely changed, but it becomes actually an important and difficult problem to reconstruct the original landscape," (Passarge in Hartshorne, 1939; 304).

In 1934, V.C. Finch helped amalgamate humans and regional geography, diversifying the science. He wrote that the science of regional geography rested upon " the conviction that the observable phenomena of the inhabited earth ultimately shall be capable of analysis and classification," (Finch, 1934; 113). In addition, Finch attested to the inclusion of physical *and* cultural aspects of a chosen portion of the earth's surface in geographical regionalization. By integrating humans and nature, Finch continued the broadening of the regional concept among scholars.

Despite the ubiquitous presence of humankind and its actions as an agent of global change, some researchers still refused to include humans in their regional systems. They, instead, desired a system based on some virginal state that existed prior to humankind's arrival. The geographers' failure to consider human impact appears to be an oversight of the regional geographers. What value lies in the identification of a natural landscape that will never exist again? Perhaps approximations of the native, prehistoric landscape could be helpful for historical reconstructions of ancient battlefields or agricultural settlements. A Las Vegas casino designer might be interested in an ancient landscape in order to help design gardens of plastic plants for a "Jurassic Casino." Beyond such extravagant pursuits, the applicability of a framework that disregards humans seems negligible. The majority of modern researchers would find such a system a profligate endeavor.

With so many conflicting perceptions natural regions and how humans fit into the system, a conceivably better way of delineating a natural region might be to mention the item(s) to which the regions refer. Hartshorne pointed out that a regional system based on mosquitoes would be entirely different from one based on sequoias (Hartshorne, 1939). To create useful natural divisions, the geographer had to reference the classification to an ulterior concern and tailor the system for user and use. Herbertson perhaps said it best--natural regions are "regions based on natural conditions as significant to man," (Herbertson in Hartshorne, 1939; 300).

The natural and unnatural argument is a fundamental tenet of the dichotomy existing in historical and modern geography. Just as the cultural and physical nature of geography has been a source of debate for years, so has the definition of naturalism.

2.5 Problems with Delineation

Not only have geographers had difficulty identifying natural landscapes, but they have also had trouble drawing the boundaries. Passarge helped develop the methods of natural landscape delineation. He suggested that through observation of nature, one could find a basis for a division of the earth. The individual spaces could be combined according to a set of rules in "landscape spaces," (Hartshorne, 1939). Of course, delineation by observation carried certain problems with it. The regional geographer still must determine the amount of difference that is significant enough for regional boundaries to be broken out. Passarge believed that vegetation, affected by climate, landforms, and soils, was the most important division (Hartshorne, 1939). However, one could argue that the difference between mountainous areas and the surrounding plains was a more significant difference than that of a forest and a desert.

Another problem associated with regional delineation based on field observation was the subjective nature of the system. Regions were based on a hypothetical landscape that no living person had ever seen--the "natural landscape" (Hartshorne, 1939). Moreover, each person, depending on his or her training, would view a "natural landscape" in a different light. These uncertainties in regionalization, identified early in the nineteenth century, remain in current ecoregionalization attempts.

Several factors slowed progress in geographical regionalization of environmental areas. Hartshorne outlined four important conditions:

1.) A minimal relationship between climatic divisions and land forms,
2.) Soils and land surface forms are based primarily on past climate and vegetation rather than present conditions,
3.) The discordance of transport or circulatory phenomena, (atmospheric and hydrologic cycles)
4.) Faunal and floral regions, dependent upon climate, landforms, and soil, may be different because of geographical separation by natural barriers. (Hartshorne, 1939; 271)

Hartshorne believed that the interrelations of natural elements were not to be thought of as simple formulae, but were highly variable phenomena. Natural regions were individual and distinct unit areas determined *primarily* by non-human elements. He believed that the nature of the earth's surface was a result of a great number of varying causes that had nothing to do with each other. Hartshorne was steeped in the uniformitarian (gradual, smooth landscape change over time) viewpoint of his period. He believed that landscapes were based not on present influences but on the influences of the past (Hartshorne, 1939; 271-2).

On the other hand, Hartshorne also clearly understood the profound effects humans impart on their environment. Consideration of humans as part of the natural environment continued to be a topic of contention among the regional scholars of the early twentieth century. The difficulty in delineating regions that incorporate human influence caused Finch and Trewartha to abandon their prior definition of geographical regions as physical and cultural organisms (Hartshorne, 1939). They redefined their idea of regions to only consider the natural elements of the environment. A duality was developing among regional geographers.

To Hartshorne, the delineation of 'natural' regions without considering humans was impossible. An environment without human influence was, he believed, only an intellectual construct. Hartshorne wrote:

> Even if it were possible to reconstruct with certainty the fundament which existed before man, which is far from the case, that would not represent correctly the present natural environment, since natural elements have changed in some degree since the time of early man," (Hartshorne, 1939; 272).

Furthermore, Hartshorne believed that unity based on the natural environment that failed to consider humans had no reality. Natural and cultural features vary immensely and usually do not correspond. Therefore, attempts to include cultural features met with extreme difficulty.

In addition, Hartshorne pointed out the difficulty in defining boundaries depicting the location at which the area of one homogenous phenomenon ended and another began. Areas where two natural elements, such as climate and relief, showed significant correspondence and uniformity could be considered organic units.

Resolution of the arguments afflicting regional geography would not occur. However, several geographers identified the need for regional studies. Though the number of researchers undertaking regional studies waxed and waned throughout the Twentieth century, several famous geographers continued researching in the area.

In 1952, Preston James published an article discussing the regional concept and its relationship to geography. James said, "The regional concept constitutes the core of geography," (James, 1952; 195). He stated that the regional concept is based on the fact that the earth can be separated into areas of distinctive character. These areas are composed of complex patterns and associations of phenomena which possess a "legible meaning as an ensemble, which added to the meanings derived from a study of all the parts and processes separately, provides additional perspective and additional depth of understanding," (James, 1952; 195). According to James, geographers could only acquire a complete understanding of the earth by focusing individualized study on particular places.

James and his fellow scholars also tackled issues regarding degrees of generalization and the scale at which regionalism could be carried out. The region was considered a geographic generalization. By grouping information about an area into various categories, a better understanding of the place could be developed. The key to generalization was to simplify the issue enough so that the elements of the problem were illuminated. If, on the other hand, the region created obscured the factors of a problem, then the regional scientist had made a mistake (James, 1952).

James established guidelines for the scale at which areas should be classified into regions--microlevel, intermediate, and macrolevel (James, 1952). He also wrote about the distribution patterns of two different landscape elements. Figure 2.7 displays his idea of how elements could be related to one another.

Interrelationships and scale considerations were only some of the important issues for regional geographers. The methodology for delineation was also extremely important. Early regional geographers contemplated the idea of objective versus subjective methods of delineation. The German political geographer, Otto Maull (1887-1957) developed a solution to the problem of subjective boundary delineation (Martin and James, 1993). Maull suggested drawing a series of borders for each significant element. The bundle of lines formed what he termed a "boundary girdle," (Maull in Hartshorne, 1939; 269).

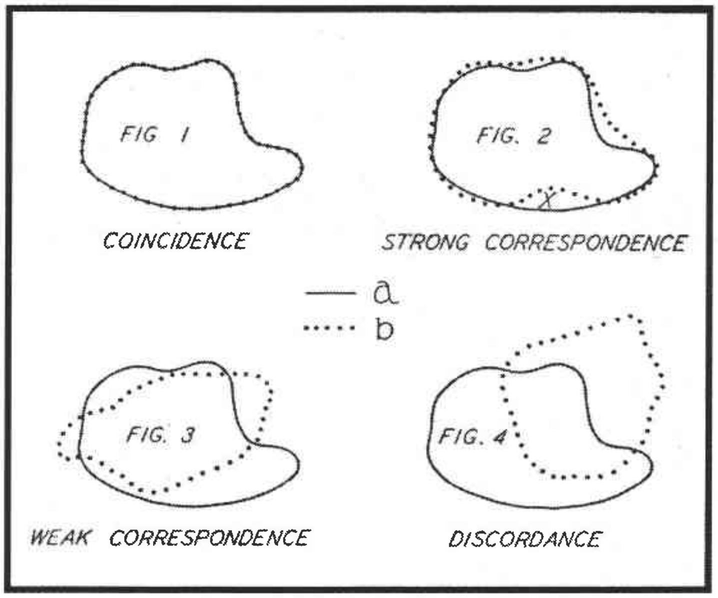

Figure 2.7 Spatial Interrelationships (James, 1934; 83)

Maull's boundary girdle methodology was used to divide the Balkans into various regions. Nevertheless, the method was not strictly objective. To divide the boundaries, a subjective decision was required for reducing the wide zone of boundaries into one single boundary.

Regional delineation using boundary girdles required subjective decisions. Wide zones of different boundaries not only had to be condensed into a single boundary; the criteria for compressing the lines had to be determined. Since education and training would likely differ among regional geographers, researchers also had to consider the irregular levels of influence that come from contrasting landscape factors, and not merely accept the geometric average of the lines. Some geographers 'fixed' this problem by defining clear rules of procedure, thus making the delineation method 'objective.'

In the 1950s, climatologists used a form of boundary girdling to determine where climatic boundaries should be placed. One application was based on average rainfall amounts for various climatic years. Figure 2.8 depicts the process of boundary girdling.

The average of the lines was used to determine the new climatic boundary. Though this attempt does not specifically apply to integration of different landscape phenomena, it does illustrate the girdling concept. Subjectivity is still associated with the selection of determining criteria.

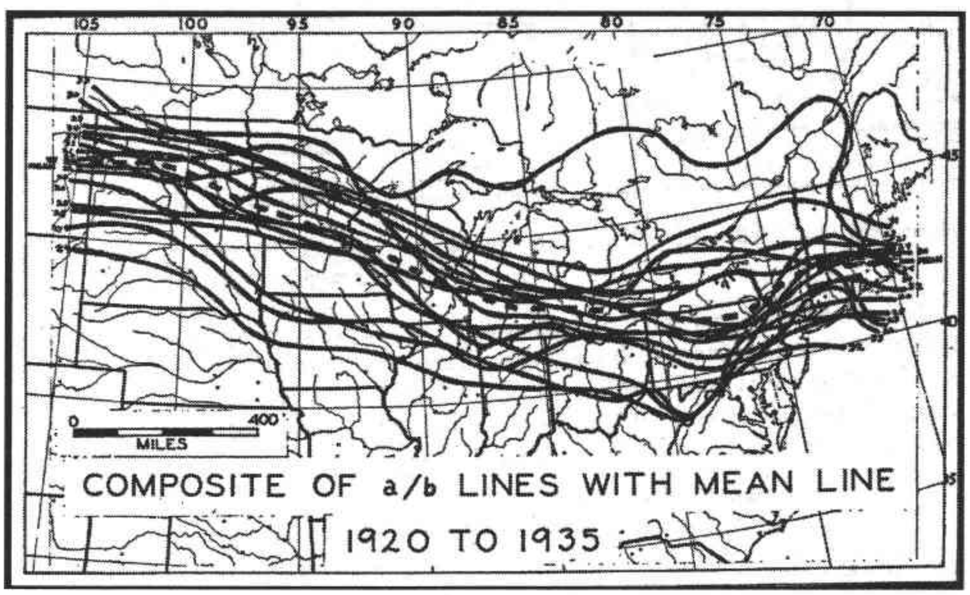

Figure 2.8 Example of Boundary Girdling (Villmow, 1952)

Passarge used another method for delineating regions, a method that was, in essence, an early form of the modern GIS overlay procedure. He superimposed transparent maps of different features and drew regional divisions based on line coincidence. Finding the method unsatisfactory, Passarge began using a method of "inspection" to determine the nature of the areal portion of regional landscapes. The method, which was employed by Passarge, is similar to the method used by the United States Environmental Protection Agency for delineating ecoregions.

Regardless of the method prescribed to, Hartshorne emphasized the importance of scale. Geographic techniques must support delineation from smaller to larger units *and* from larger to smaller units while adopting compromises between scales (Hartshorne, 1939).

2.6 Quantitative versus Qualitative Delineation Techniques

Several scholars in the early 1800s recognized the virtually impossible task of objectively delineating regional entities based on several observed, environmental factors. However, some researchers believed that the subjective element could be reduced to a minimum with increased study and expert knowledge (Hartshorne, 1939.) Delineation of landscape regions by qualitative or quantitative methods is still a topic of extensive debate.

Kurt Bürger stated that the many differences of opinion over the boundaries of regions were "no worse that the varying views of the limits of historical periods," (Bürger in Hartshorne, 1939; 275).

The German geographer Erich Obst emphasized that the more often and more conscientiously a region was studied, the greater the agreement of the dominating factors (Obst in Hartshorne, 1939; 275). Regardless of the views, geographers who believed regions could be discovered were conceding the fact that regions could be established within a degree of uncertainty.

Regional geography differs significantly from systematic biology in that the subdivision of the world is a "top-down" approach as opposed to a "bottom up" approach. Biologists study individual species, group them into genera and form the tree of life. Geographers, on the other hand, must first consider the earth as a whole and break it down into subsections, always considering the larger picture (Hartshorne, 1939; 291). "The most that we can say is that any particular unit of land has significant relations with all the neighboring units and that in certain respects it may be more closely related with a particular group of units than with others, but not necessarily in all respects." (Hartshorne, 275).

Regions constructed in such fashion were mental constructions, existing only as entities within an individual's thought processes. Because of the inherent difficulties, Hartshorne believed there was no hope for solving regional boundary arguments.

The quantitative revolution in geography sought to subjugate regional geography into a lower class of scientific endeavor. Quantitative techniques were not developed to apply to natural region delineation. The techniques also were not suitable for holistic integrative studies. Therefore, when the quantitative movement occurred during the 1950s, 1960s, and 1970s, regional geography fell from the forefront as a worthwhile endeavor among the young geographers of the period.

Today, quantitative techniques have advanced to such a degree that they actually assist regional geographers. Multivariate techniques can be applied to test the validity of regional frameworks, and remote sensing of the environment can aid in the identification of land use and land cover as well as human-environment relationships.

Qualitative and quantitative techniques can be utilized in harmony for regional studies. Most of the modern ecoregion frameworks incorporate qualitative delineation techniques; quantitative techniques are employed to test the validity of the frameworks. The quantitative-qualitative dichotomy remains an area of heated contention. Quantitative supporters would argue that the subjective nature of ecological regions requires that they be disregarded as science, while qualitative scientists would support the regions, citing the importance of expert and tacit knowledge and holistic thinking. Resolution of these differences in not likely.

The real issue surrounding ecoregions is that regardless of the delineation techniques, qualitative or quantitative, the regions seem to make sense. A drive from the Pacific Coast of North America, across the Cascade Range, and into the high desert validates this point. Along the drive, it would be difficult to point out the individual mile marker where the transition from coastal plain to mountains, mountains to valley, or mountains to desert occurred, however, one definitely realizes that they have crossed distinctly different landscapes. Thus, ecoregion boundaries, even when qualitatively defined, should be regarded as areas of transition. At times, the boundaries will be sharp; other times they will represent broad transition zones. Nevertheless, the landscape changes exist, and one would be hard-pressed to claim that no difference occurred.

2.7 Regional Geography Today

Regional delineation remains an arduous task. The first regional geographers recognized the extreme difficulty confronting geographers-the integration of the human and natural world. One group of researchers might be interested in one element or set of elements of the natural, non-human, landscape, whereas another group might be interested in the association of cultural elements and artifacts in other areas. However, the refusal of humans to conform to the natural environment created a dualistic system. Geographers have the difficult task of explaining all of the features in a particular part of the world that are distinctive in regard to the other features in the same location (Hartshorne, 1939). Geography as a science has assumed a responsibility that some feel is impossible. Hartshorne emphasized that the regional geographer had the laborious task of integrating varying phenomena according to concordance and non-concordance. The task of the regional geographer was not to discover regions that actually existed but to develop an intelligent and useful method for dividing the world into regions (Hartshorne, 1939).

In developing a useful division of the world, geographers must choose the criteria used for defining regional boundaries. Just as modern ecoregion frameworks are delineated differently, early regional geographers used a variety of criteria for defining the boundaries of "natural regions." Hettner pointed out that the choice of criteria must be made by the geographer, "according to his subjective judgement of their importance," (Hettner in Hartshorne, 1939; 290). Hettner also argued that regions should not be judged as true or false divisions, but instead as 'purposeful or non-purposeful.' "There is no universally valid division, that serves justice to all phenomena; one can only endeavor to secure a division with the greatest possible advantages and the least possible disadvantages," (Hettner in Hartshorne, 1939; 290).

Despite the tumultuous past, regional geography is thriving at the end of the millennium. The resurgence of regional studies is partly a result of the increase in ecoregional studies. J.M. Crowley coined the term ecoregion in 1967, and initiated interest in a new geography. The methods for this new study were backed by a long history of developments. The next chapter will catalog today's ecoregional frameworks and identify their similarities and dissimilarities.

CHAPTER III

Analysis of Ecoregion Frameworks

"Regions are subjective artistic devices and they must be shaped to fit the hand of the individual user. There can be no standard definition of a region, and there are no universal rules for recognizing, delimiting, and describing regions. Far too much time can be wasted in the trivial exercise of trying to draw lines around 'regions,'"
(Hart, 1982; 21-2).

This quote by John F. Hart (1982) describes some of the problems associated with contemporary ecoregion geography. While the developers of modern ecoregion systems tend to view ecoregions as areas of relative homogeneity in environmental phenomena, they fail to agree upon one mutually exclusive definition of the term. The greatest discrepancy involves the inclusion of humans as part of the biotic realm. Without terminology agreement, it is likely that the developers are, in fact, delineating areas of disparate phenomena. Ecoregion developers also employ varied methodologies when delineating boundaries. But, as Hart (1982) stated, there can be no standard system for defining regions. Therefore, it becomes necessary to analyze and compare the ecoregion frameworks in use today.

It is important for users to understand the similarities and differences among ecoregion classifications; therefore, the majority of this chapter (3.1) investigates the numerous contemporary ecoregion classifications. The frameworks are compared according to methodological interrelations and variances among delineation criteria. The final section (3.2) focuses on the problems facing ecoregion developers and possible ways to resolve discrepancies.

3.1 Ecoregion Frameworks

Regional geography laid the groundwork for the evolution of the ecoregion concept. Borrowing the methods and systems used during the early 1900s, several geographers began to develop classifications of ecological regions-termed ecoregions. Revisions of the earliest frameworks are still in wide use today. In fact, the development of ecoregion classifications has increased significantly in the last fifteen years. In the late 1980s federal agencies began to recognize a need for broad-scale ecosystem management approaches (U.S. GAO, 1994; Omernik and Griffith, 1999), a need, which further spurred development of the ecoregion concept. This section will examine the evolution of ecoregion classification systems.

3.1.1 The First Ecoregions

In 1967, when delineating an ecological classification for Canada, Crowley coined the term ecoregion. His intention was to promote the study and development of biogeography as a sub-field of geography in Canada. Crowley suggested that biogeography could become the geographic study of ecosystems by integrating the study of plants, animals, soils, climate, and geomorphology. His ecoregion classification (Figure 3.1) represented the basic units for biogeographical inquiries.

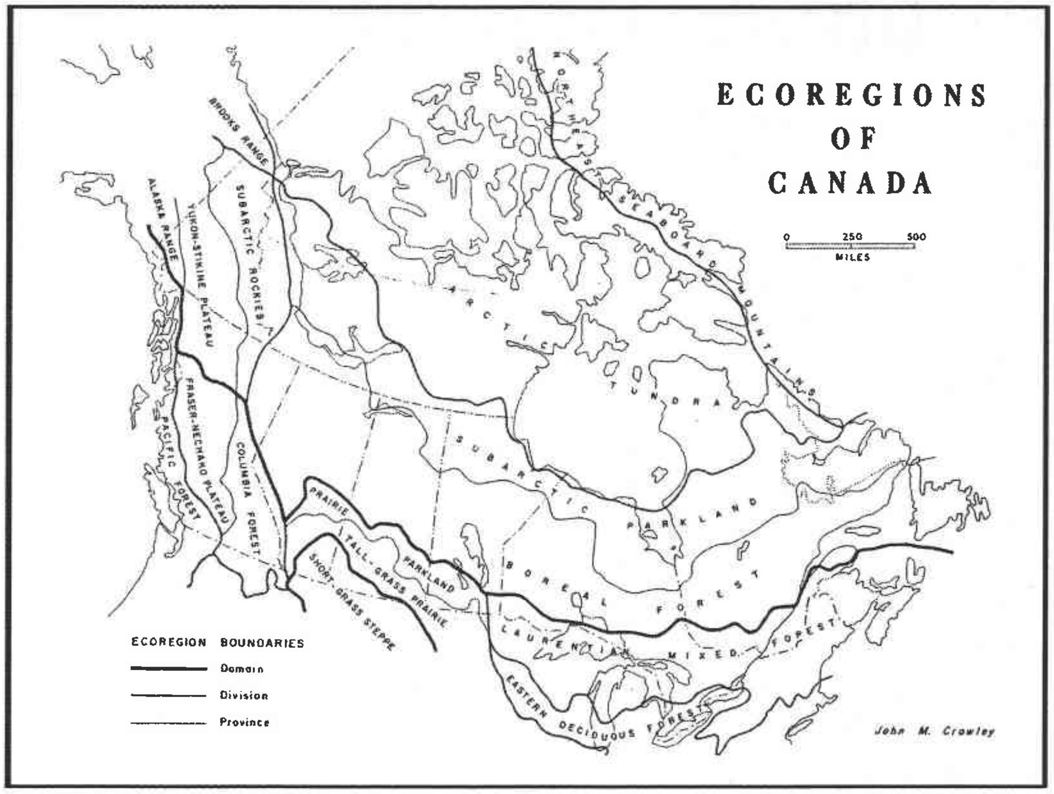

Figure 3.1 Ecoregions developed by Crowley (1967)

Crowley's ecoregions of Canada were divided into three hierarchical levels: domains, divisions, and provinces. Provinces, the smallest areal unit, represented broad areas with similar vegetation and climate that supported one or two zonal soils. Divisions were groups of provinces that had definite vegetational affinities and the same regional climate (e.g. Marine West Coast, Humid Subtropical, etc). Domains were groups of divisions based on vast climatic expanses. Crowley's ecoregions were thus based primarily on climate, vegetation, and regional soils.

The classification was to be used for broad scale studies. Researchers were to shift their focus from individual landscape components such as vegetation, soil, or landforms to studies utilizing entire ecosystems. Crowley championed such broad-scale, ecosystem studies as a major source locus of growth in Canadian and American biogeography. His approach laid the foundation for future investigations utilizing ecosystem regions.

3.1.2 R. G. Bailey and the U.S. Forest Service

Robert G. Bailey recognized the need for a comprehensive system for classifying ecosystems to aid regional and national long-range land management and planning. In 1976, Bailey, working for the United States Forest Service, published a map titled "Ecoregions of the United States," (Bailey, 1978). This map was published for the Interior Department's Fish and Wildlife Service to aid in the National Wetlands Inventory. In 1978, he published a supplement that contained detailed descriptions of the various ecoregions depicted on the original map.

Bailey's methodology closely paralleled the work of Crowley. He defined ecoregions as geographical zones that represented geographical groups or associations of similarly functioning ecosystems (Bailey, 1983). By analyzing environmental factors that acted as selective forces for the creation of ecosystems, Bailey constructed a 1:7,500,000-scale map of the United States' ecoregions. A detailed explanation of the delineation methods was published in 1983.

Ecoregions, according to Bailey, divided the landscape into variously sized ecosystem units that had significance for development of resources and conservation of the environment. Landscape analysis helped identify ecoregions which were defined as broad areas where one would expect to find similar vegetation and soil associations (Bailey, 1983).

Bailey proposed two important management functions that could be derived from an ecoregion classification. The map suggested the areal extent of productivity relationships derived from experiments and allowed users to apply individual experience. Ecoregion maps also provided a geographical framework that would allow recognition and prediction of similar responses from correspondingly defined sites (Bailey, 1983).

Climate, in Bailey's delineation methodology, became the most important reflection of zonality. Second was surface configuration, or land surface form. Vegetation regions based on Dasman (1969) and Küchler (1973) represented the next level of subdivision. Bailey established a hierarchical order based on sub-continental domains that were defined by broad climatic similarities. The fairly heterogeneous domains could be divided into divisions, which correspond to definite vegetational classifications such as prairies or forests. Zonal soils were given consideration at this level. The next class was the province level, based on climax plant formations. Soil zones also were important for province level delineation. The base level of classification was the section level, based almost entirely on Küchler's potential natural vegetation regions (Bailey, 1983).

Bailey recognized the difficulty of delineating ecological systems in mountainous regions. Thus, mountainous regions became one, separate ecological unit, called highland provinces. Boundary discrepancies were corrected by visual examination of the various primary map sources and subsequent line revisions. Bailey's complete regional hierarchy is depicted in the following diagram (Figure 3.2).

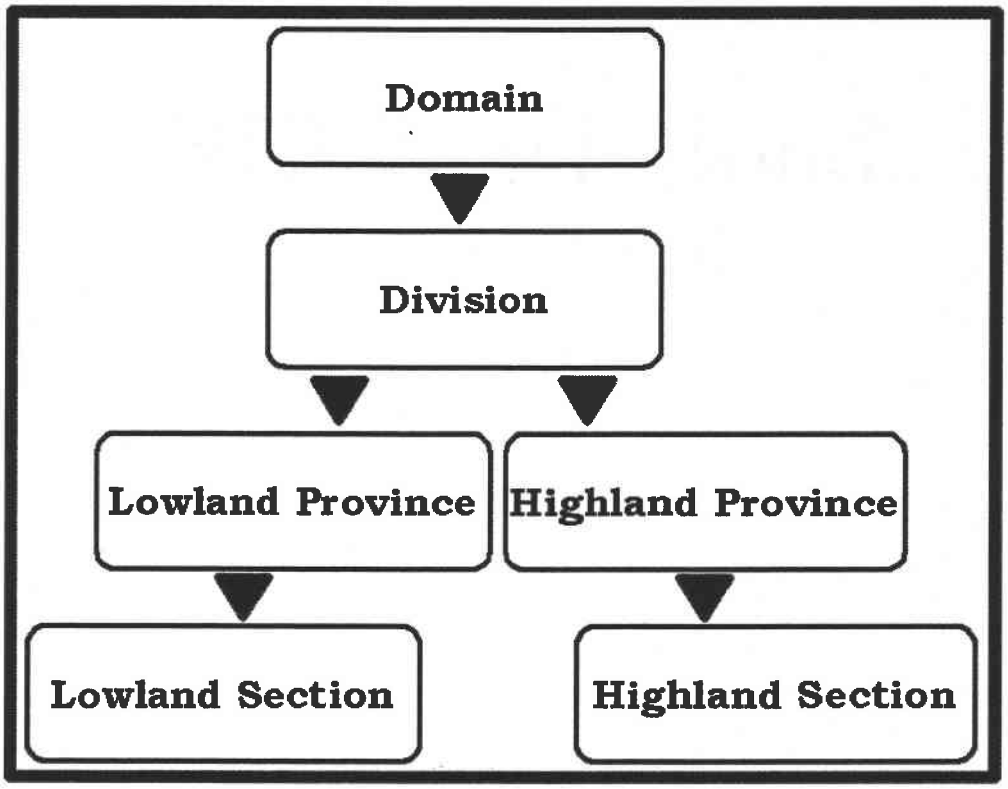

Figure 3.2 Bailey's Ecoregion hierarchy (Bailey, 1983)

Bailey drew the boundary limits wherever changes in climate, vegetation, and soil were most pronounced or significant when compared to adjacent areas. He stated that such lines were only approximations of the location of change, but detailed analyses would make local variation become clear.

Bailey's methodology is known as the controlling factors method. An alternative method, map-overlay, (used by the EPA researchers) integrates all factors, but some scientists have found the system too complex. Therefore, the controlling factors method was created to reduce the number of variables used when defining regions. The method is based on the dominance of one particular environmental controlling factor (Bailey, 1996). Bailey uses climate, land-surface form, and vegetation, respectively, as controlling factors. A criticism of the controlling factor method appears in section 3.5.

3.1.2.1 *Ecoregions of the United States*

Bailey's first classification was of the conterminous United States. This classification contained four Domains, 12 Divisions, 30 Provinces, and 45 section level regions (Figures 3.3 & 3.4).

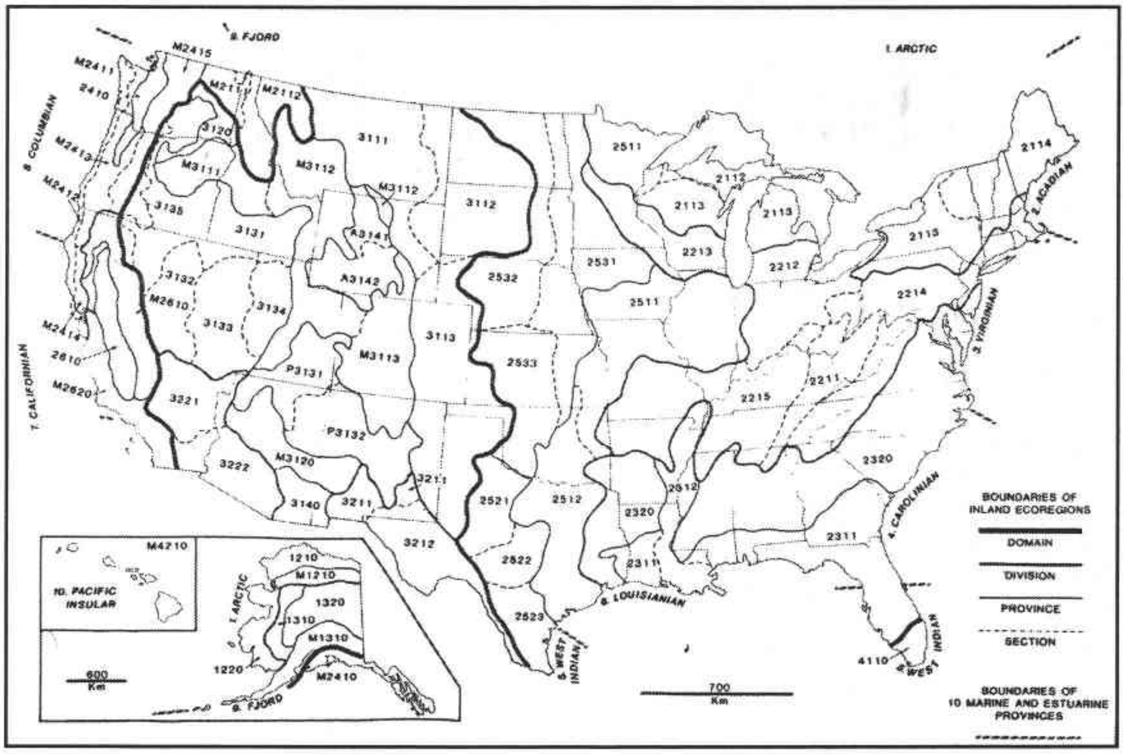

Figure 3.3 The Fourth-order Ecosystem Regionalization of the United States (Bailey, 1983)

- 1000 Polar Domain
  - 1200 Tundra Division
    - 1210 Arctic Tundra Province
    - 1220 Bering Tundra Province
  - Highlands[1]
    - M1210 Brooks Range Province
  - 1300 Subarctic Division
    - 1310 Yukon Parkland Province
    - 1320 Yukon Forest Province
  - Highlands[1]
    - M1310 Alaska Range Province
- 2000 Humid Temperate Domain
  - 2100 Warm Continental Division
    - 2110 Laurentian Mixed Forest Province
      - 2111 Spruce-fir Forest Section
      - 2112 Northern Hardwoods-Fir Forest Section
      - 2113 Northern Hardwoods Forest Section
      - 2114 Northern Hardwoods-Spruce Forest Section
  - Highlands[1]
    - M2110 Columbia Forest Province
      - M2111 Douglas-fir Forest Section
      - M2112 Cedar-Hemlock-Douglas-fir Forest Section
  - 2200 Hot Continental Division
    - 2210 Eastern Deciduous Forest Province
      - 2211 Mixed Mesophytic Forest Section
      - 2212 Beech-Maple Forest Section
      - 2213 Maple-Basswood Forest + Oak Savanna Section
      - 2214 Appalachian Oak Forest Section
      - 2215 Oak-Hickory Forest Section
  - 2300 Subtropical Division
    - 2310 Outer Coastal Plain Forest Province
      - 2311 Beech-Sweetgum-Magnolia-Pine-Oak Forest Section
      - 2312 Southern Floodplain Forest Section
    - 2320 Southern Mixed Forest Province
  - 2400 Marine Division
    - 2410 Willamette-Puget Forest Province
  - Highlands[1]
    - M2410 Pacific Forest Province
      - M2411 Sitka Spruce-Cedar-Hemlock Forest Section
      - M2412 Redwood Forest Section
      - M2413 Cedar-Hemlock-Douglas-fir Forest Section
      - M2414 California Mixed Evergreen Forest Section
      - M2415 Silver Fir-Douglas-fir Forest Section
  - 2500 Prairie Division
    - 2510 Prairie Parkland Province
      - 2511 Oak-History-Bluestem Parkland Section
      - 2512 Oak + Bluestem Parkland Section
    - 2520 Prairie Brushland Province
      - 2521 Mesquite-Buffalograss Section
      - 2522 Juniper-Oak-Mesquite Section
      - 2523 Mesquite-Acacia Section
    - 2530 Tall-grass Prairie Province
      - 2531 Bluestem Prairie Section
      - 2532 Wheatgrass-Bluestem-Needlegrass Section
      - 2533 Bluestem-Grama Prairie Section
  - 2600 Mediterranean Division
    - 2610 California Grassland Province
  - Highlands[1]
    - M2610 Sierran Forest Province
    - M2620 California Chaparral Province
- 3000 Dry Domain
  - 3100 Steppe Division
    - 3110 Great Plains Short-grass Prairie Province
      - 3111 Grama-Needlegrass-Wheatgrass Section
      - 3112 Wheatgrass-Needlegrass Section
      - 3113 Grama-Buffalograss Section
    - 3120 Palouse Grassland Province
    - 3130 Intermountain Sagebrush Province
      - 3131 Sagebrush-Wheatgrass Section
      - 3132 Lahontan Saltbush-Greasewood Section
      - 3133 Great Basin Sagebrush Section
      - 3134 Bonneville Saltbush-Greasewood Section
      - 3135 Ponderosa Shrub Forest Section
    - 3140 Mexican Highlands Shrub Steppe Province
  - Highlands[1]
    - M3110 Rocky Mountain Forest Province
      - M3111 Grand Fir-Douglas-fir Forest Section
      - M3112 Douglas-fir Forest Section
      - M3113 Ponderosa Pine-Douglas-fir Forest Section
    - M3120 Upper Gila Mountains Forest Province
    - P 3130 Colorado Plateau Province
      - P 3131 Juniper-Pinyon Woodland + Sagebrush-Saltbush Mosaic Section
      - P 3132 Grama-Galleta Steppe + Juniper-Pinyon Woodland Section
    - A3140 Wyoming Basin Province
      - A3141 Wheatgrass-Needlegrass-Sagebrush Section
      - A3142 Sagebrush-Wheatgrass Section
  - 3200 Desert Division
    - 3210 Chihuahuan Desert Province
      - 3211 Grama-Tobosa Section
      - 3212 Tarbush-Creosote Bush Section
    - 3220 American Desert (Mojave-Colorado-Sonoran) Province
      - 3221 Creosote Bush Section
      - 3222 Creosote Bush-Bur Sage Section
- 4000 Humid Tropical Domain
  - 4100 Tropical Savanna Division
    - 4110 Everglades Province
  - 4200 Rainforest Division
  - Highlands[1]
    - M4210 Hawaiian Islands Province

Figure 3.4 Descriptions of the Fourth-order Ecosystem Regionalization of the United States (Bailey, 1983)

An interesting characteristic of the ecoregion classification is the temporal change over time. Bailey's newest edition of the ecoregions of the United States (Figure 3.5) is significantly different from its original predecessor.

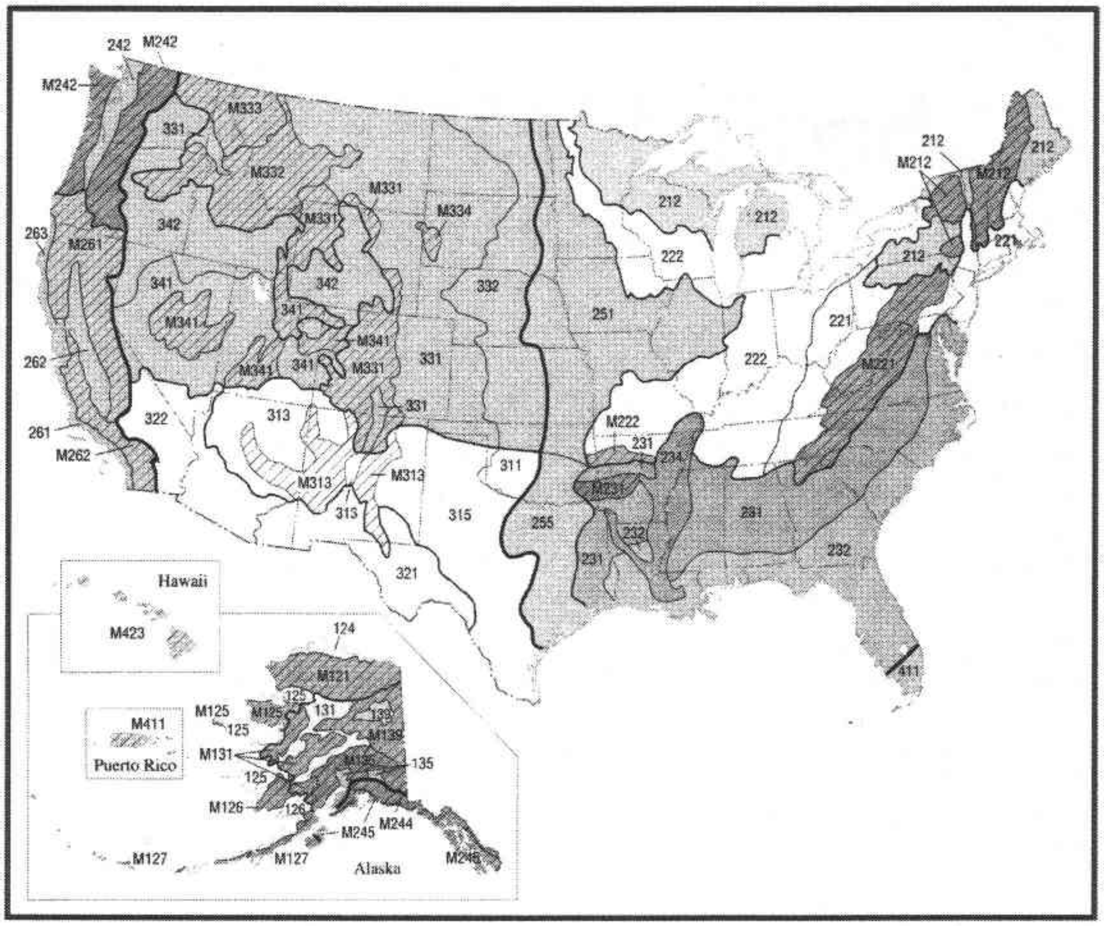

Figure 3.5 Revision of United States Ecoregions (Bailey, 1998b)

3.1.2.2 Ecoregions of North America

In 1981, with the help of the U.S. Fish and Wildlife Service, Bailey expanded the map of the United States to include all of North America. The boundaries and numeric ecoregion codes were modified and refined based on the ecoregions of Canada (Crowley, 1967) and of the United States (Bailey, 1976)

The new map identified continental scale ecosystem regions based on macroclimatic factors, regarded as the most significant factor affecting landform, vegetation, and wildlife distributions. With macroclimatic change, soils, topography, and other environmental landscapes are altered as well. The broadest domains and divisions are based primarily on Köppen's system of climatic zones which was modified by Trewartha in 1968 (Bailey, 1998b).

The macroclimates are composed of smaller areas known as climatic subtypes that correspond to major plant formations. Provinces are based primarily on the plant formations, with highland areas separated into mountain provinces.

The 1981 ecoregions of North America map (1:12,000,000) contained 4 domains, 22 divisions, and 56 provinces; the section level classification was eliminated.

A 1997 revision of the map (1:15,000,000) was created to replace the outdated 1981 version. The new classification contained 4 domains, 28 divisions, and 62 provinces. The new edition was published in 1997 through the cooperative efforts of the Nature Conservancy, the USDA Forest Service, and the U.S. Geological Survey.

The reasons for revisions on both the Ecoregions of the United States and Ecoregions of North America maps are not entirely clear. A noticeable change between versions is the number of hierarchical levels. The new maps contain three hierarchical levels, as opposed to the previous four. The subsection level was deleted from both classifications.

The revisions might be a result of a change in primary delineation criteria. In his first maps, Bailey used climate for the first division and landforms for the second. In 1996, Bailey stated that at each level, different aspects of the climate *and* vegetation were assigned prime importance for placing map boundaries (Bailey, 1996). Thus, vegetative features might have been given priority over landform boundaries on the newer classifications.

Other revisions may reflect the larger role taken by the US Forest Service in delineating the process. The USDA Forest Service adopted a policy of ecosystem management in 1992 and has since modified Bailey's ecoregion maps (McNab and Avers, 1994; Keys et al., 1995). The Forest Service framework adopts Bailey's names and hierarchical methodology. The maps have been further modified to include smaller landscape units (Bailey, 1996; McNab and Avers, 1994). Agency goals might have influenced the changes between classifications.

3.1.2.3 Ecoregions of the World

Bailey was also instrumental in the development of the first global ecoregion classification. Not to discredit the earlier work of

Herbertson (1905), who developed the natural regions of the world, and Udvardy (1975), who created a classification of the world's biogeographical provinces, as well as, Gerasimov (1964), who created a system of natural landscape types, but Bailey was the first scientist to create a global 'ecoregion' framework. The original map (Bailey and Hogg, 1986) has undergone revisions, but remains similar to the current version.

Bailey's system of world ecoregions (Figure 3.6) was developed using the same set of techniques used for his previous ecoregion class-ifications. He indicated that the United Nations Environment Programme (UNEP) and the International Union of Forestry Research Organizations (IUFRO) had expressed interest in worldwide ecoregion mapping (Bailey and Hogg, 1986). Bailey also noted that the map would be useful for national level policy analysis, environmental monitoring, transfer of agricultural technology, improvement of remote sensing-based systems for monitoring environmental conditions and agricultural activities, estimation of vegetative biomass from satellite imagery, and selection of areas for biological conservation (Bailey and Hogg, 1986).

By creating the ecoregions of the continents, Bailey initiated a significant movement in the evolution of the ecoregion concept. Prior to this point, ecoregion classifications had been confined to North America. In the 1990s, other researchers (Dinerstein et al., 1995; Griffith et al., 1998b) would follow Bailey's lead and develop ecoregion frameworks for other continents.

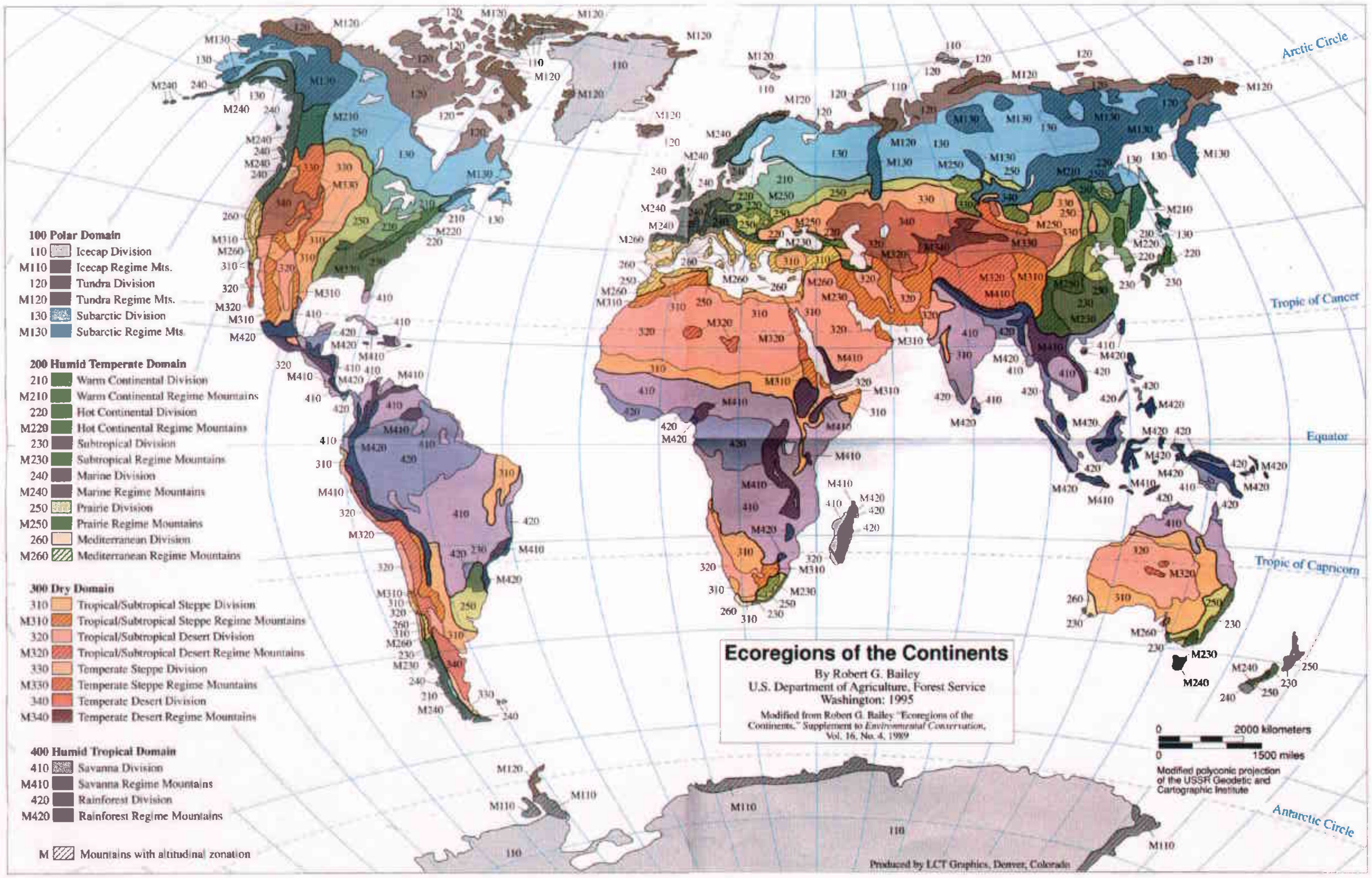

Figure 3.6 Ecoregions of the Continents (Bailey, 1996)

3.1.2.4 Ecoregions of the Oceans

Bailey continued his pioneering efforts in ecoregion classification by developing the world's first ecoregion classification of the oceans in 1995 (Figure 3.7). The delineated, oceanic regions he created were based on differences in physical and biological characteristics resulting from the interaction of oceanic macroclimates and large-scale oceanic currents (Bailey, 1998a).

There are two levels of oceanic ecoregions, broad-scale domains and a smaller-scale divisions. Domains identify homogenous areas of oceanic circulation, life forms, color, temperature, and salinity (Bailey, 1996). The broad-level regions are largely the same as the world's system of latitudinal zonation--polar, temperate, and tropical.

Within the domains are divisions, based on broad natural regions defined by Dietrich in 1963 (Bailey, 1996). At the division level, more detailed oceanic information, such as the spatial location of zones of upwelling, were used as delineation criteria. The descriptive names of the oceanic divisions such as Equatorward westerlies, Trade winds, and Equatorial countercurrent suggest that the divisions were defined by the prevailing winds of the oceanic areas.

Oceanic ecoregions were delineated to improve understanding of oceanic and climatic influence on the continental ecoregions map. Though the ocean ecoregions have not been widely used in ecoregion geography, they represent an area of future expansion. A detailed description of the oceanic regions appears in Bailey (1998).

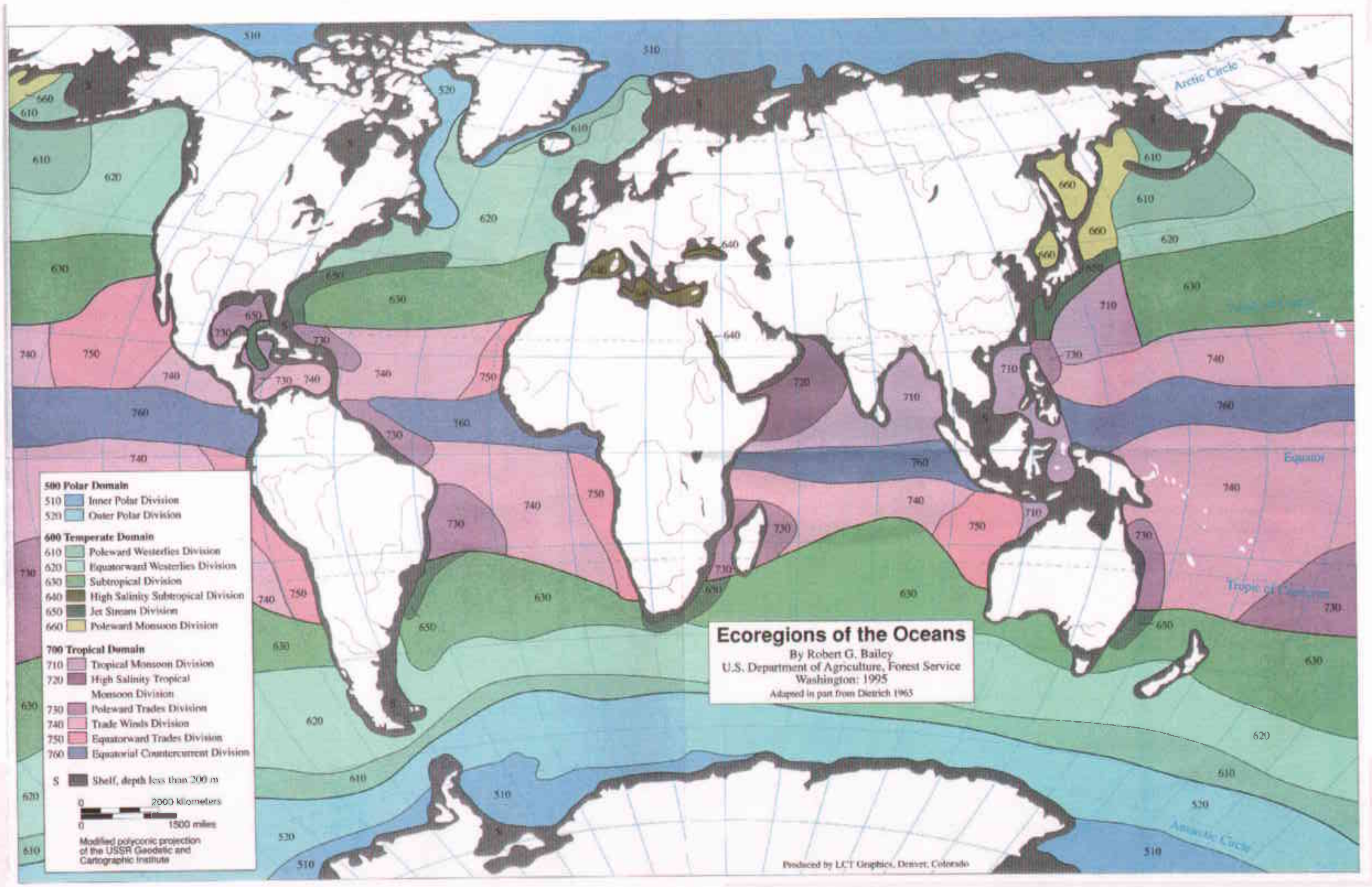

Figure 3.7 Ecoregions of the Oceans (Bailey, 1996)

3.1.3 Ecological Land Classification in Canada

Canadian scientists developed a significant portion of ecoregion theory. The Sustainable Development Branch of Environment Canada began an Ecological Land Classification Series in 1976. The series of publications presented national standards, terminology, methodological examples, and perspectives for ecological land survey and classification in Canada (Wickware and Rubec, 1989a).

In 1979, a national "Ecoregions of Canada" project was initiated. The project prepared computerized databases and maps of ecoregions and ecodistricts at various scales for the country. The ecological resource classification was intended for use in planning, management, and environmental impact assessments. The Canadian government initiated a national requirement to develop an ecological framework for the assessment of resources at risk because of long-range air pollution and deposition in order to meet the requirements of the Canada-United States Memorandum of Intent of Transboundary Air Pollution (Memorandum of Intent, 1981). This international memorandum called for risk evaluation and modeling of landscapes sensitive to acidic deposition (Wickware and Rubec, 1989a).

The interdisciplinary ecoregion and ecodistricts approach, a system with ecosystems nested within one another in a spatial hierarchy, later became known as Ecological Land Survey (ELS) (Wickware and Rubec, 1989a). The objective of ELS was to map and describe ecologically distinct areas of the earth's surface at varying levels of generalization based on biotic and abiotic criteria (Wickware and Rubec, 1989a).

The Canadian researchers cite developments in the 1950s and 1960s by Angus Hills as the origin of the modern system. Hills developed site regions, areas with similar vegetation, landforms and climate. The data made available by the LANDSAT satellite beginning in 1972 aided the national classification system. LANDSAT, which provided a consistent and uniform base for mapping the Canadian provinces, helped spur development of the Ecological Land Survey system (Wickware and Rubec, 1989).

Stan Rowe and John Sheard of the University of Saskatchewan pioneered research in the integrated landscape approach (Rowe and Sheard, 1981). They created a system of classification that was not bound to formal rules, but, instead, recognized awareness of levels of organization and the interconnectedness of parts and wholes. The system contained four hierarchical levels of regionalization: mid boreal, high boreal, low subarctic, and high subarctic (Rowe and Sheard, 1981).

Rowe and Sheard also believed that a search for one "true" classification was a waste of time and attempts to justify classifications by quantitative measures or the repeatability of the methods were misplaced. They argued that the primary aim of ecological land classification was the definition of functionally similar and dissimilar ecosystems as areal components of the biosphere (Rowe and Sheard, 1981). The theory they developed considered the landscape as a composition of ecosystems, large and small, within one another in a hierarchy of spatial sizes. Regions were identified by a system of "pattern recognition" of integrated environmental factors. Landforms provided the *a priori* means of identifying functional land units, but soils, climates, and biota were also important for identification of the regions. The theory and methods developed by Rowe and Sheard (1981) influenced later revisions of ecological land classification systems in Canada and the United States (Bailey, 1983; Omernik, 1987; Wiken et al., 1989).

Ed Wiken also worked on the holistic ecoregionalization of Canada in 1986. His expanded classification, Terrestrial Ecozones of Canada, would become the dominant ecological classification system. Wiken wrote:

> Ecological land classification is a process of delineating and classifying ecologically distinctive areas of the Earth's surface. Each area can be viewed as a discrete system, which has resulted from the interplay of the geologic, landform, soil, vegetative, climatic, wildlife, water and human factors which may be present. The dominance of any one or a number of these facts varies with the given ecological land unit. This holistic approach to land classification can be applied incrementally on a scale-related basis from very site specific ecosystems to very broad ecosystems (Wiken, 1986 as cited in CEC, 1997).

Canada's classification system was comprised of seven separate levels of generalization.

ECOZONE—an areas of the earth's surface of very generalized, large ecological landscape units adjusting to the mix of distinctive and interrelated abiotic and biotic factors present at any given time.

ECOPROVINCE – an area of the earth's surface characterized by major structural or surface forms, faunal realms, vegetation, hydrological, soil and climatic zones

ECOREGION – a part of an ecoprovince characterized by distinctive ecological responses to climate as expressed by vegetation, soils, water, and fauna

ECODISTRICT – a part of an ecoregion characterized by a distinctive pattern of relief, geology, geomorphology, vegetation, soils, water and fauna.

ECOSECTION – a part of an ecodistrict throughout which there is a recurring pattern of terrain, soils vegetation, water bodies, and fauna.

ECOSITE – a part of an ecosection having a relatively uniform parent material, soil and hydrology, and a chronosequence of vegetation.

ECOELEMENT - a part of an ecosite displaying uniform soil, topographical, vegetative, and hydrological characteristics.

Table 3.1 Levels of Generalization for Ecological Land Survey (Wickware and Rubec, 1989a)

The diversity of the Canadian system's generalization hierarchy represented a new development in ecoregion classification theory. Other publications helped promote ecoregion classification in Canada (Ecoregions Working Group, 1989; Gilbert et al, 1985; Wickware and Rubec, 1989b; Wiken et al., 1989). As the methodology for ecological classification evolved, the Canadian researchers began to consider humans and their impacts on the environment when delineating ecoregions (Wiken, 1995). The Canadian system appears in the Figure 3.8.

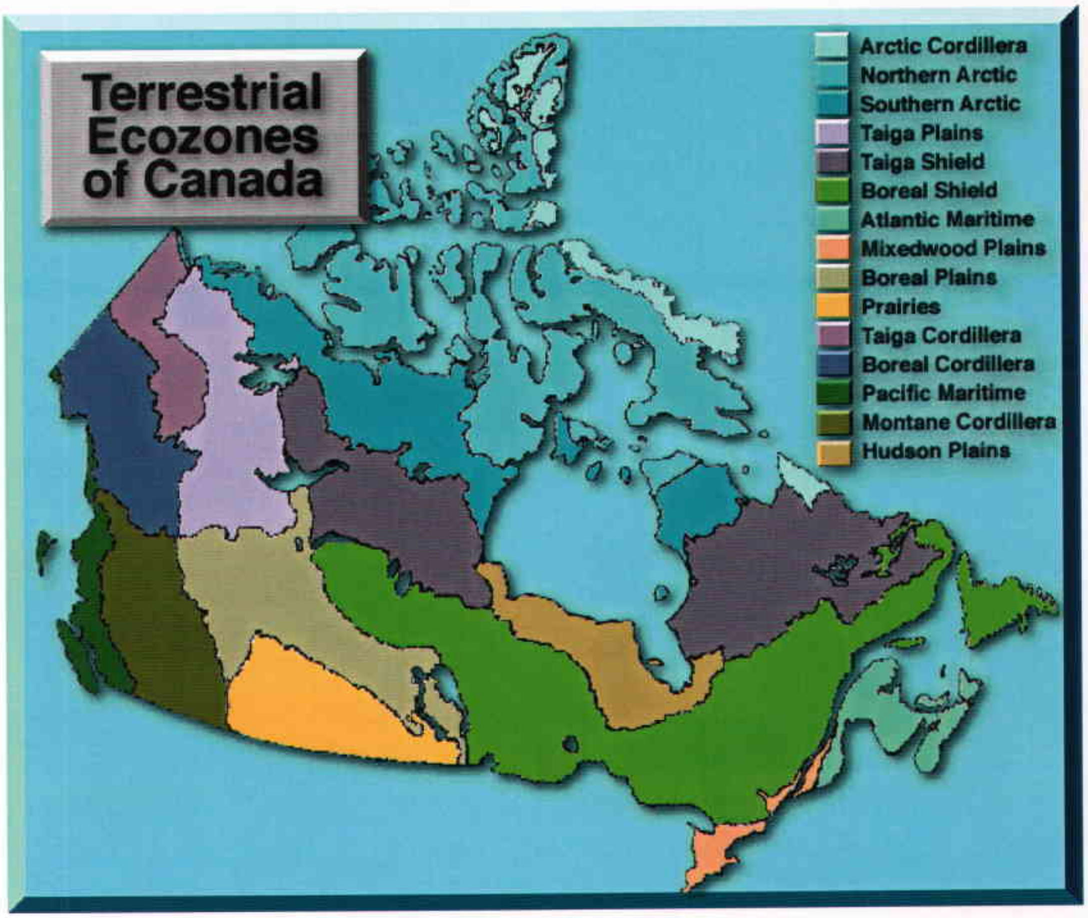

Figure 3.8 Ecological Stratification Working Group Ecozones (Environment Canada, 1998)

Broad scale ecosystem management is growing in Canada and has even been incorporated in the international ecological classification developed by the Commission for Environmental Cooperation for all of North America (CEC, 1997) (See 3.1.6). Inhabitants of northern Canada have been exposed to transcontinental pollution, eastern Canadians have been plagued by acid rain deposition, and western Canadians have witnessed the destruction of the prairies and forestland and the associated biodiversity (Wiken and Gauthier, 1996). The vastness of the Canadian landscape and the environmental problems facing its inhabitants has encouraged public acceptance of ecoregions (Wiken and Gauthier, 1996).

3.1.4 The Environmental Protection Agency Classification

Jim Omernik of the United States Environmental Protection Agency's Western Ecology Division found the hierarchical, climatically-driven classification developed by R.G. Bailey and the Forest Service inadequate for water quality monitoring and assessment. Omernik began developing a system of ecoregions for the EPA. The ecoregion framework was first published in the *Annals of the Association of American Geographers* in 1987. Today, several maps have been published of state and national EPA ecoregion boundaries. The EPA's classification, with over 170 citations in recent literature, represents the most widely used contemporary ecoregion framework.

The EPA developed the ecoregion classification to meet environmental legislation mandates and to conform to the following factors:

1. Holistic, broad-based regional analysis and assessment of resource management.
2. Inventory and assessment of environmental resources.
3. Establishment of resource management goals.
4. Wetland classification and management.

5. Development of biological criteria for water quality standards.
6. Refinement of chemical water quality standards.

(Griffith et al., 1994)

Omernik's first classification of regions was based on themes designed to address water resource concerns (Gallant et al., 1989). The approach stemmed from an effort to classify streams for effective water resource management. Omernik and his associates found that the USDA Major Land Resource Areas (US Department of Agriculture, 1981) as well as Bailey's framework of ecoregions were not sufficiently useful for classifying areas of different water quality. He was encouraged by his associates to create a new classification.

The newly formed EPA approach for defining ecoregions was based on a hypothesis that ecosystems and their components display regional patterns reflected in spatially variable combinations of causal factors, such as climate, mineral availability (soils and geology), vegetation, and physiography (Omernik, 1987). A map of United States ecoregions was compiled at the 1:3,168,000 scale and published at the 1:7,500,000 scale (Omernik, 1987). Other maps with increasing levels of detail followed at the 1:2,500,000 scale.

Three component maps, as well as several USDA soil maps, greatly influenced the boundaries of the first ecoregion framework: Major Land Uses (Anderson, 1970), Classes of Land-Surface Form (Hammond, 1970), Potential Natural Vegetation (Küchler, 1970) (Omernik, 1987). The component maps were analyzed to create a mental overlay of important features. Regions that were relatively homogenous in soils, land use, land surface form, and potential natural vegetation were then sketched. Some boundaries were clearly delineated while others were less distinct (Omernik, 1987).

The first ecoregion map was intended to allow comparisons of land and water relationships, help establish water quality standards, locate regional reference sites for environmental monitoring and management, provide an extrapolation unit to expand data from existing site-specific studies, and predict the effects of changes in land use and pollution controls (Omernik, 1987).

3.1.4.1 EPA Level III and IV Ecoregions

Since its creation, the USEPA ecoregion framework has undergone numerous changes. Among the most profound alterations is the stratification of ecoregions into four hierarchical levels. Level I represents the coarsest level, represented by 15 ecological regions for North America, and level II comprises 52 separate classes. Both level I and II boundaries (Figure 3.12) are nearly identical to the ecoregion boundaries that appear in the international framework developed by the CEC (1997).

Level III ecoregions are similar in scale to the original framework published in 1987; however, the boundaries have been adjusted as environmental knowledge has expanded and more state-level projects have been conducted. The current map of the conterminous United States (Figure 3.9) contains 84 separate level III ecoregions; the original map contained 76 aquatic ecoregions of the United States. Alaska has been mapped with an additional 20 level III regions (Gallant et al., 1995). The ability to adjust and refine the ecological boundaries has been considered an important aspect of ecoregion mapping (Omernik, 1987; Bailey, 1983; Rowe and Sheard, 1981).

Development of regional biological criteria and water quality standards for managing and monitoring nonpoint source pollution required a more detailed, level IV ecoregion classification (Figure 3.10) of individual states.

To better understand the nature of the EPA's classification techniques, a questionnaire (Appendix 1) was given to the five current researchers working on the EPA's ecoregion framework. The regional geographers were asked to rank important criteria for delineating ecoregion boundaries. Most of the researchers found the quantitatively based questionnaire to be an inappropriate and irrelevant method for describing the EPA's process of delineation.

Omernik did not complete the questionnaire. He pointed out that the qualitative and artistic nature of ecoregion delineation prevented a hierarchical quantification of delineation techniques.

> "The characteristics useful in defining ecological regions vary from one place to another, as do the types of materials useful in making the delineations. Ecoregions are intended for ecosystem management. They allow agencies and programs who have different interests and missions regarding the assessment, inventory, research, and management for the same geographical areas to integrate their activities," (Omernik, 1999).

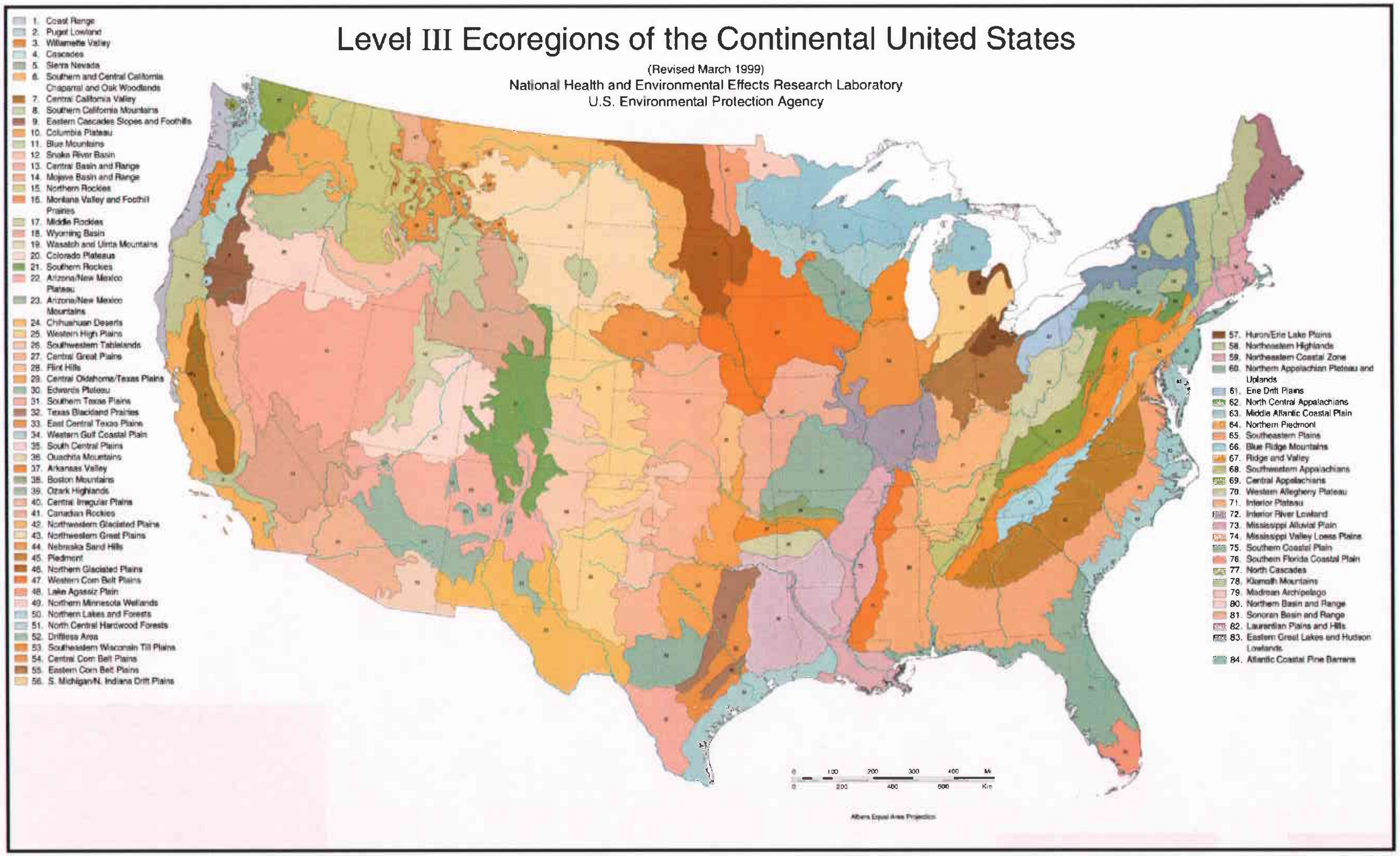

Figure 3.9 EPA's Level III Ecoregions of the Conterminous United States (USEPA, 1999)

Figure 3.10 EPA's Level III and IV Ecoregions of the Pacific Northwest (Pater et al., 1998)

Omernik's reply was similar to a statement made by J. F. Hart. "Geography is a science, but it is also an art, because understanding the meaning of area cannot be reduced to a formal process," (Hart, 1982; 3). Due to the artistic nature of the EPA's classification methodology, the techniques could not be described as a quantitative, formal process.

The other researchers replied in similar fashion. One researcher found all elements to be equally important in delineation; others were able to rank the criteria. Nearly all of the completed questionnaires identified user's objectives, political boundaries, federal agency jurisdictions, and the presence of microclimates and urban areas as relatively unimportant factors for delineating ecoregions.

EPA ecoregions are defined by identifying areas of coincidence among *all* landscape characteristics. The hierarchy of characteristics depends on the significance of features in a given area and changes among locations. Therefore, it was impossible for the researchers to pinpoint the most important criteria used for delineation. This integrative approach is known as the map-overlay method (Bailey, 1996). It is based on the premise that several environmental component maps, pertinent to ecosystem regions, can be correlated to one other by identifying areas where the lines coincide. This process is similar to the boundary girdling method developed by Maull in the 1920s. Researchers have often rejected this method because of the difficulty in synthesizing such broad ranges of criteria (Bailey, 1996).

The EPA specialists generally agreed on one definition of an ecoregion: areas with relative homogeneity in ecosystems within which the mosaic of ecosystem components, biotic (including humans), abiotic, terrestrial and aquatic is different than that of adjacent regions.

The researchers were also asked to identify concerns associated with the development of ecoregion frameworks. The use of different landscape variables among frameworks was identified as an extremely important area of concern. Other concerns were the lack of formal methods for selecting regional reference sites, the use of watersheds as an ecological framework, professional and agency bias toward particular delineation characteristics, and frameworks developed by committee that use different delineation methods in different parts of the country.

Level IV ecoregion classifications are currently being designed for several states. The following diagram (Figure 3.11) shows the current status of Level IV ecoregion mapping. The EPA's ultimate goal is to extend the Level IV ecoregion classification to every state.

The EPA ecoregion classification system has significantly evolved since the first classification was published in 1987. Today, the classification is based on the combined efforts of several governmental agencies, including the EPA.

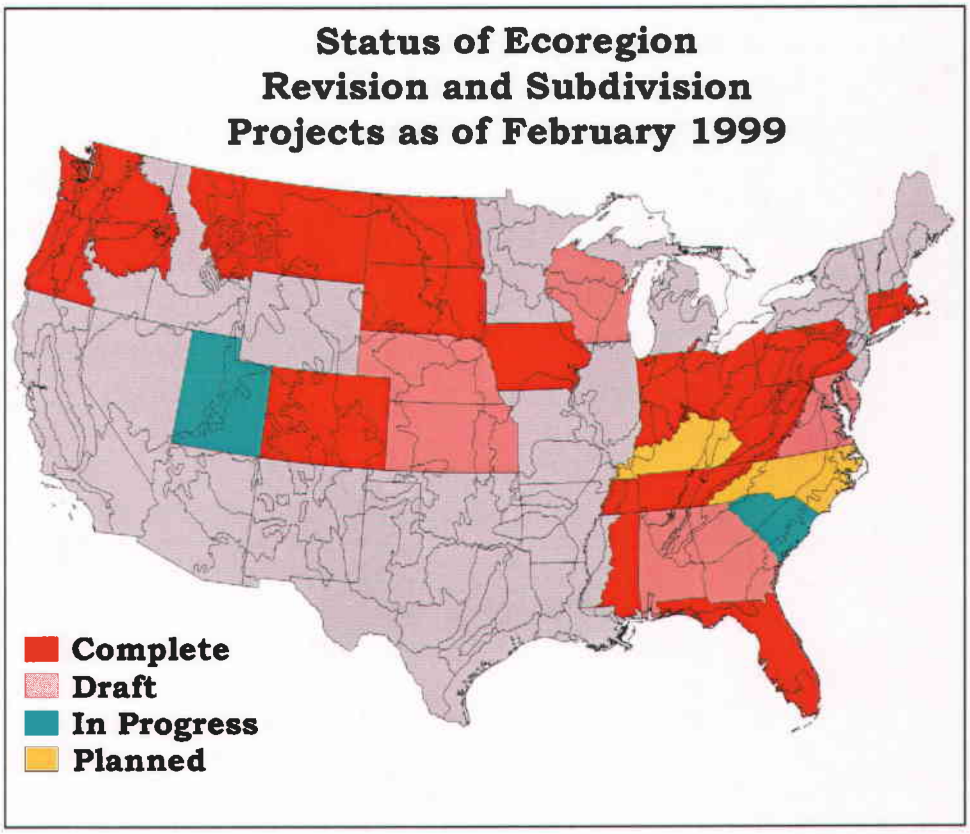

Figure 3.11 Status of E.P.A. Level IV Ecoregion Projects (USEPA, 1999)

3.1.4.2 Interagency Ecoregion Work

The newest EPA frameworks are delineated based on the integration of research by several scientists and agencies requiring a large number of individuals to agree on boundary placement in order to proceed with the publication of the map. The EPA, the US Forest Service, the Natural Resources Conservation Service (NRCS), the United States Geological Survey (USGS), and state and regional agency specialists all collaboratively define the level III and level IV ecoregion boundaries for the conterminous United States. Local and regional experts provide important assistance at the numerous meetings that take place during the delineation process. Though each agency has different interests and applications for the framework, cooperatively, they all manage to create these general-purpose regions. Interagency collaboration is an important advantage of this ecoregion classification.

The interagency framework has encountered difficulties during delineation as well (See 3.2.2). Despite the differences, one of the true hallmarks of ecoregion classification is its ability to integrate the inputs of multiple agencies during the delineation process.

The interagency framework attempts to do what Hart (1982) said was impossible-create a universal regional classification. The system allows resource agencies to 'read from the same page' when creating environmental policy and managing resources in an ecosystem framework. This integrative partnership represents a milestone of achievement for multi-agency collaboration for ecosystem management.

3.1.5 The Great Lakes Ecoregion Classifications

United States Department of Agriculture Forest Service researcher, Dennis Albert, and B.V. Barnes, from the School of Natural Resources at the University of Michigan, developed a regional landscape classification for Michigan (Albert et al., 1986). This classification incorporated methods similar to Bailey's ecoregion classification. The system used three hierarchical landscape units, Regions, Districts, and Sub-districts. Macroclimate and physiography dictated the boundaries of Regions and Districts, physiography and soils determined Subdistricts, and vegetation validated the climatic and geomorphologic boundaries (Albert et al., 1986). The approach was modeled after German biogeographers and the holistic concept of forest ecosystem regions developed by Hills (1960) in Ontario.

Bailey's 1976 and 1983 Ecoregions of the United States were similar in nature. However, where Bailey divided Michigan into three domain level ecoregions, Albert and his fellow researchers identified four Landscape Ecosystem regions. The researchers indicated that the two classifications were complementary frameworks, and differences might have resulted from varying scales used for delineation. The Michigan classification provided climatic and physiographic detail at a smaller scale and also added two more detailed levels, and was expanded in 1995 (Albert, 1995) to include Minnesota and Wisconsin. Bailey's ecoregion maps were not used in the development of the map and classification; however, the boundaries of both frameworks were coincident at the province and section level.

The ecoregions defined by Albert (1995) were used in yet another ecoregion classification of the Great Lakes system (Reid and Holland, 1997). Reid and Holland developed a holistic landscape level ecosystem approach for the Great Lakes in order to assess the adequacy of natural area protection along the coastal margin (Reid and Holland, 1997). The system required international and interagency collaboration during development and was used as a part of a gap-analysis program for the Great Lakes nearshore terrestrial ecosystems (Reid and Holland, 1997).

3.1.6 Commission for Environmental Cooperation Classification

The Commission for Environmental Cooperation is an international organization comprised of member nations: Canada, Mexico, and the United States. The CEC was created to address regional environmental concerns and help prevent potential trade and environmental conflicts, and to promote the effective enforcement of environmental law (CEC 1997). The CEC identified a need to develop a framework for the study of North American ecological regions that would facilitate continental cooperation for environmental protection, resource sustainability, and human impacts on ecosystems.

The CEC developed continental ecological regions (Figure 3.12) that would enhance the capabilities of governmental and non-governmental organizations for assessment of natural conditions and trends within the major North American ecosystems. The authors offered the regions to professionals and the public in hopes that the classification would be used as an educational tool, focused on the sustainability and conservation of resources.

The boundaries were based upon the integration and coincidence of environmental features, and human features were considered as factors in the delineation process. The ecological boundary lines for Canada were determined by Ed Wiken and four

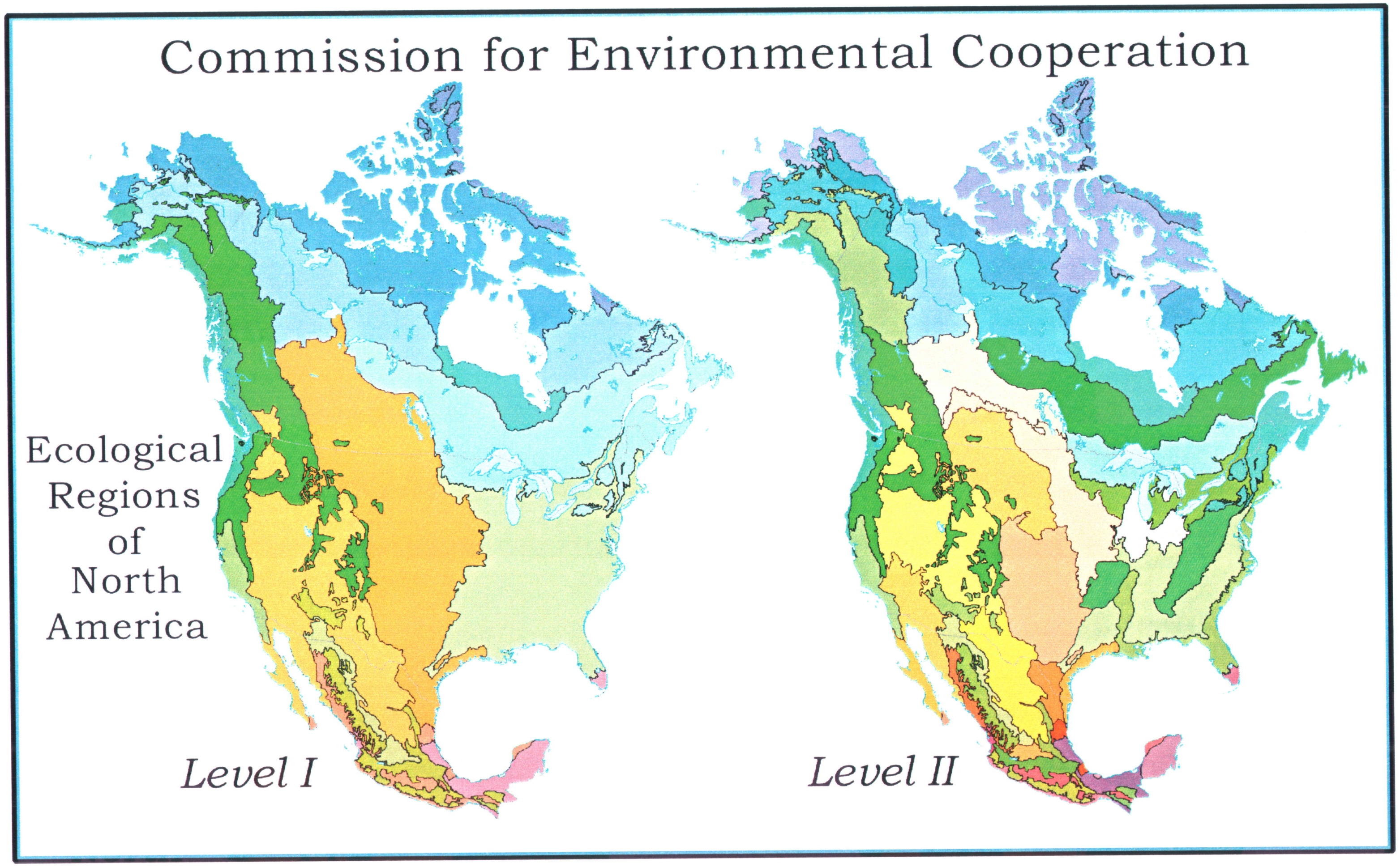

Figure 3.12 CEC Ecological Regions of North America Level I & Level II (CEC, 1997)

other Canadian researchers. Glenn Griffith, Tony Olson, and Jim Omernik of the Environmental Protection Agency, and Tom Loveland from the United States Geological Survey represented the United States research effort. Five researchers representing separate Mexican agencies identified the ecoregions of Mexico (CEC, 1997).

Canada and the United States had existing ecoregion frameworks with similar delineation strategies. The ecoregion boundaries for Canada are nearly identical to lines depicted by the Ecological Stratification Working Group (Figure 3.8), and the ecoregion boundaries of the United States follow the EPA boundaries (Figure 3.9).

Mexico did not have a system of ecological regions that could be easily joined with the US and Canadian systems. The American researchers developed a draft of levels I, II, and III ecoregions of Mexico that fit with the Canadian and US systems, but the Mexican scientists considered the regions far too general for effective representation of Mexico's ecological complexity (Griffith et al., 1998b).

The Mexican researchers ultimately created a system of ecoregions by using a biophysical approach, relying heavily on vegetation, climate and physiography. In the end, no less that six regions were acceptable for Mexico at level I. The final map contained fifteen regions for North America, and seven of these occurred in the smallest country, Mexico (Griffith et al., 1998b).

A cursory examination of the ecological boundaries indicates the presence of these varying levels of generalization. Of course, the different backgrounds, techniques, and perspectives of the regional geographers working on the project were factors that affected the location of the boundary lines. Working through international differences represents a necessary obstacle for ecoregion geography to overcome. The intracontinental differences, though obvious, do not discredit the integrative efforts of the researchers.

The CEC provided examples of possible applications of the ecological classification, stating that the ecological regions would be useful for forestry management of the North American temperate rainforests, aquatic resource management in basins extending across political boundaries, biodiversity conservation in the North American Arctic, bi-national cooperation for data access and resource monitoring to promote public awareness (CEC, 1997)

The cooperative ecoregion map represents a positive step in the development of ecoregional management. International cooperation during delineation of the ecological regions yielded distinct advantages. Not only did it promote cooperative resource management, it also provided a continental framework for management discussion. Greater efficiency should occur since international researchers will each have one system on which to base research (CEC, 1997).

The future potential for international applications of the classification is intriguing, yet there remains a distinct need for further delineation of continental subregions at level III. The increased detail should allow a wider array of applications and uses of the framework. Discrepancies between delineation strategies within Mexico, the US, and Canada should also be resolved.

3.1.7 World Wildlife Fund Classification

Environmental conservation organizations have adopted the ecoregion concept as a framework for preserving areas of environmental biodiversity. The system developed by the World Wildlife Fund (WWF) is well established within the organization's structure. The WWF recognized a need to create an objective framework that represented all ecosystem and habitat types at a landscape level to aid in biodiversity conservation. Without such a classification that assesses conservation status and biological distinctiveness, land donors could overlook preservation of seriously threatened areas of biodiversity (Dinerstein et al., 1995).

The WWF sought to undertake a long-term effort to conduct conservation assessments of the terrestrial, freshwater, and marine ecoregions of the world. The plan began with a biodiversity assessment in Russia (Krever et al., 1994), and was continued with a study in Latin America and the Caribbean (Dinerstein et al., 1995). Ecoregion assessments then moved to North America and plans are underway to develop systems for Asia and Africa (Ricketts et al., 1997).

The project has evolved into a map of the Global 200 Ecoregions--a collection of the Earth's most outstanding and diverse terrestrial, freshwater, and marine habitats. The ecoregion focus stemmed from the recognition that biological diversity is not evenly distributed or defined by political boundaries, and includes regions of varying levels of biodiversity importance (What is the Global 200? 1999).

The WWF defined ecoregions as relatively large areas of land or water that share a large majority of their species, dynamics and environmental conditions. The inclusion of species as a primary factor for ecoregion delineation differs from other ecoregion frameworks. Researchers evaluated the bioregions based on biological distinctiveness and conservation status at a regional scale. The organization identified four important goals of ecological regionalization:

1.) To develop a scientific approach to aid the land donor's decision making process as opposed to an ad hoc approach.
2.) To shift their priorities from individual species preservation to a broader focus on ecosystem and habitat conservation
3.) To integrate conservation biology and landscape ecology into decision making.
4.) To ensure funding was channeled into seriously threatened ecoregions rich in biodiversity (Dinerstein et al., 1995).

The World Wildlife Fund's ecological regions for North America (Figure 3.13) were based primarily on the boundaries delineated by the EPA and the CEC. Some of the EPA's plains ecoregions were aggregated into larger units. They also identified small regions of particular interest, such as portions of the Florida Sand Pine Scrub, South Florida Rocklands, Great Basin Montane Forests, and the Coastal Redwoods (Griffith et al., 1998b).

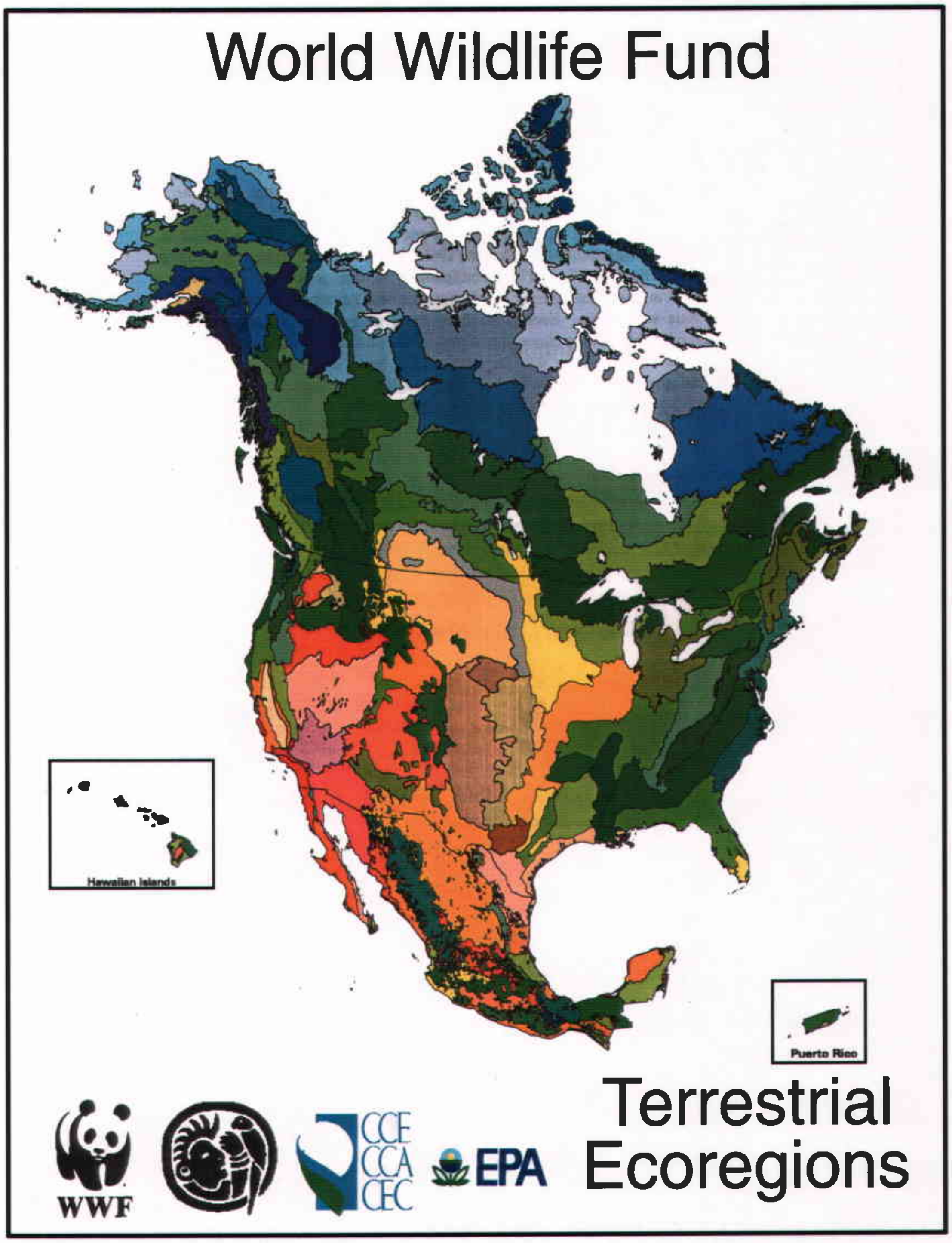

Figure 3.13 WWF Terrestrial Ecoregions (Ricketts et al., 1997)

One of the primary differences between the WWF ecoregions and the EPA ecoregions is the use of two indices, Biological Distinctiveness Index (BDI) and Conservation Status Index (CSI) for ecoregion identification. The Biological Distinctiveness Index (BDI) is based on species richness, species endemism, global rarity of habitat, and rare ecological or evolutionary phenomena. Globally important habitats and high levels of beta-diversity were among the classification factors. Conversely, beta-diversity is the measure of turnover or replacement of a species with distance or along ecological gradients. It provides an important indicator of the level of effort needed to conserve an ecoregion. High beta-diversity numbers require multiple protected areas across the ecoregion (Ricketts et al., 1997).

The WWF ecoregion framework employed a biotic emphasis in its definition, delineation, and ecoregion nomenclature. A bias towards vegetation types is apparent in the renaming of the EPA's Sierra Nevada ecoregion to Sierra Nevada Forests, and the Flint Hills Ecoregion to the Flint Hills Tall Grasslands (Griffith et al., 1998b). Nearly all of the EPA ecoregions were renamed with vegetational descriptions.

The Conservation Status Index (CSI) was designed to estimate the current and future ability of an ecoregion to meet three goals of biodiversity conservation: maintaining viable species populations and communities, sustaining ecological processes, and responding effectively to both short and long term environmental change. The index was based on habitat loss, remaining habitat enclaves, degree of fragmentation, degree of protection, and future environmental threat (Ricketts et al., 1997).

Ecoregions were ranked on a scale ranging from globally outstanding to regionally outstanding, bioregionally outstanding to nationally important. Upon ecoregional assessment, conservation strategies and resources could be more efficiently channeled to unprotected, globally outstanding regions (Ricketts et al., 1997).

While the CEC (1997) framework contains varying levels of intracontinental generalization, the WWF framework has varying levels of intercontinental generalization. And, the North American ecoregions (Rickets et al., 1997), based on the EPA's framework, differs significantly from the South American framework (Dinerstein et al., 1995). The South American ecoregions are based heavily on vegetation. Some of the areas were defined by combining considerably different vegetation coverages, creating inconsistencies in pattern and scale (Griffith et al., 1998b). The WWF's boundaries for the South American ecoregions are methodologically different from the boundaries for North America.

Users of the WWF ecoregion framework should realize the role of the organization's need to create a popular conservation strategy. The different methods employed for delineation of North America and South America are also an important consideration. Nevertheless, the World Wildlife Fund's ecoregion conservation program represents a rapidly growing realm of ecoregion geography.

3.1.8 The Nature Conservancy Framework

The Nature Conservancy (TNC) has also developed an ecoregion framework to help meet its goal of conserving the world's areas of biodiversity. The Conservancy's mission is the preservation of the Earth's diversity of life. In order to combat the current extinction episode, The Nature Conservancy shifted its management strategy focus from political units to ecological units.

In 1993, Steve McCormick and Deborah Jenson identified a system of ecoregions, developed by Robert Bailey, as an acceptable framework for agency management. The Nature Conservancy defined ecoregions as areas that follow living boundaries laid down by climate and natural ground cover within which lives a cohesive collection of living things. The regions contain a characteristic cover of plants and animals adapted to the terrain, seasons, and the natural trials of wildfire, drought and flood (Stolzenburg, 1998a). TNC's definition of an ecoregion is similar the Ritter's and Ratzel's idea of the earth as a terrestrial organism (See 2.2).

Incorporation of the ecosystem concept helped the TNC realize that its goal of saving the world's species could be accomplished on an ecoregion by ecoregion basis as opposed to random, point source management plans. The Conservancy's system uses 62 ecological regions borrowed from Bailey's ecoregion map for the United States. Within each region, locations of troubled species were marked, and preserves were located based on the species distributions.

The Conservancy uses the ecoregions to isolate biological "hot spots" and to buy land located in those regions. Sites that harbored species already established in another preserve were discarded. The final selection of sites left the Conservancy with 52 areas for which preservation was necessary. TNC considers the ecoregion management system to be the total solution to conservation. Gary Bell, the director of conservation in the New Mexico chapter said, "Ecoregional conservation is the only thing that makes sense," (Stolzenburg, 1998a; 16).

The Nature conservancy recognized the fallacy of attempting to protect the entire geographical expanse of an ecological region. Vast expanses that extend over several state boundaries cannot be protected in their entirety, but within each region there are tracts of habitat that represent the whole. Such diverse tracts are the regions the Conservancy would place in preserves.

The Nature Conservancy cites Bailey's ecoregion map as the basis for the ecoregion divisions, but the boundaries often deviate substantially from Bailey's ecoregion classification. The Great Lakes ecoregion (Figure 3.14) is an example of these differences.

The Great Lakes ecoregion comprises the coastal margin surrounding all five of the Great Lakes. Despite crossing several different climate, soil, landscape, and vegetation zones, the area is considered a homogeneous ecoregion. Even at Bailey's coarsest level, the Domain level, two regions separate the Great Lakes, and at the level equivalent to TNC's ecoregion map, the Great Lakes are surrounded by five separate regions (Bailey, 1998b). The inclusion of all of the Great Lakes in one region most likely reflects TNC's goals or operational capabilities as opposed to ecological criteria. No other ecoregion framework considers the coastal expanse of the Great Lakes as a homogeneous unit.

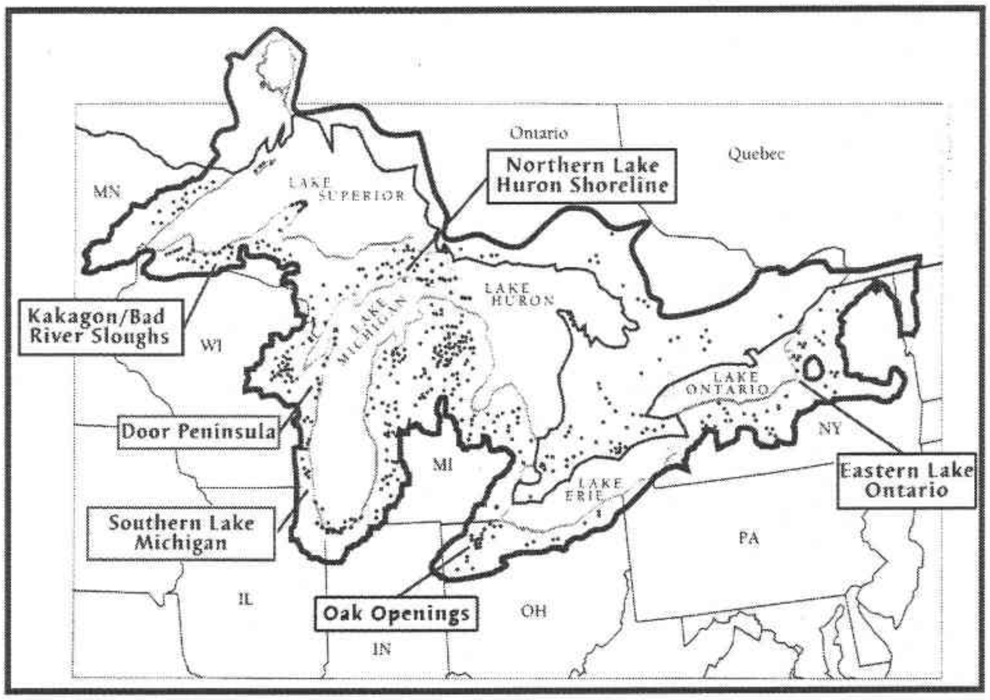

Figure 3.14 The Nature Conservancy's Great Lakes Ecoregion (Kinch, 1997)

3.1.9 The Sierra Club Critical Ecoregions Strategy

Recognizing the interelatedness of environmental problems, the Sierra Club decided to stop treating problems and places in isolation. They instead created a comprehensive, integrated plan to save the global environment—the Critical Ecoregions Program (Critical Ecoregions, 1998).

The Critical Ecoregions Program was focused on 21 ecosystem regions (Figure 3.15). The goal of the program was to support ecosystem health and to improve volunteer and public understanding by shifting the organization's focus from isolated systems to a more holistic view.

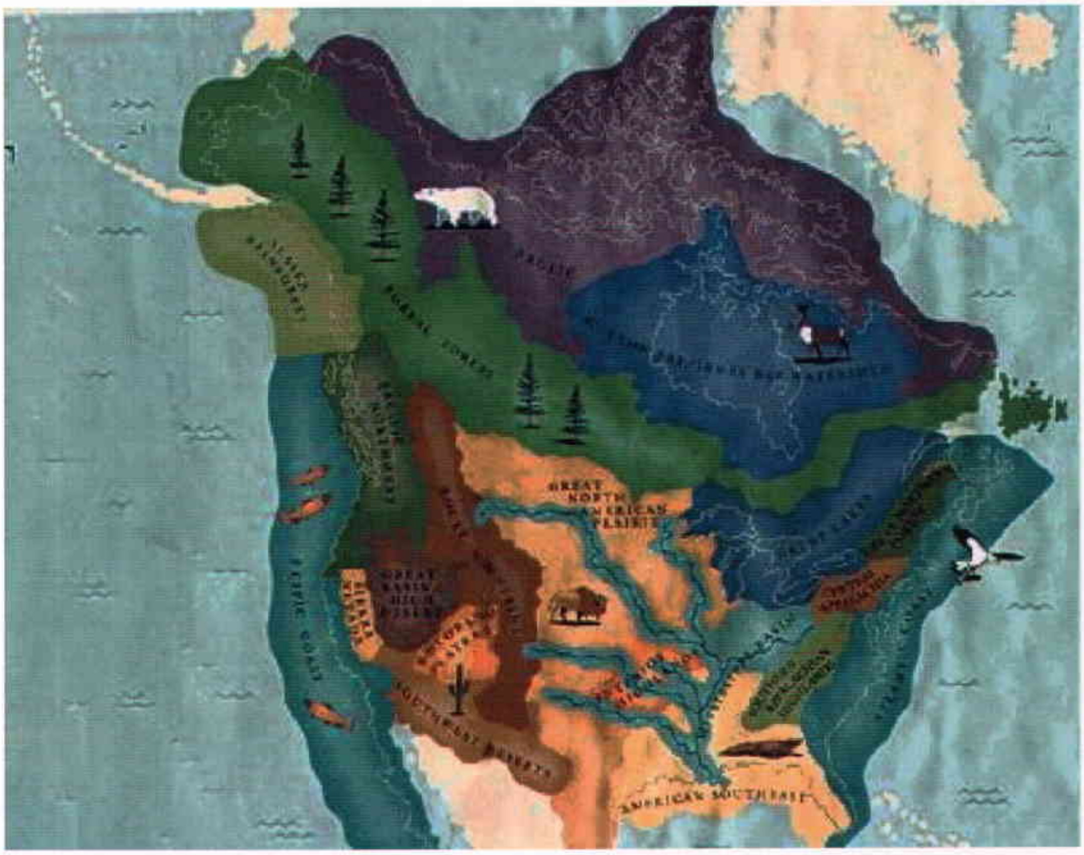

Figure 3.15 The Sierra Club's Critical Ecoregions (Critical Ecoregions, 1998)

A cursory examination of the Figure 3.15 indicates the unique nature of the Sierra Club's ecoregion classification. The Sierra Club's ecoregions are quite different from the other frameworks that have been described, since the delineation of boundaries was based on entirely different criteria than any other ecoregion framework. Ecoregions were tailored to coincide with jurisdictional operations of the Sierra Club's regional chapters and the "natural" areas of the earth's ecosystems.

The Sierra Club identified several ecoregions including the Great Lakes, the Great North American Prairie, The Ozark, the Black Hills, and the Hawaiian. Information distributed through the Sierra Club bulletin is organized to match this classification (Critical Ecoregions, 1998).

An interesting example of a Sierra Club ecoregion occurs in the Pacific Coast ecoregion. This ecoregion is defined on the west by the path of the migrating gray whales, the Pacific Flyway marks the center, and US Interstate Highway 5 represents the eastern boundary. British Columbia marks the northern extent, and Baja California the southern (Critical Ecoregions, 1998). This unique system of ecoregion boundaries is strikingly different than other classifications since the path of the migrating gray whales would be a difficult boundary to depict on a static map, and I-5 is hardly an ecological formation. Nevertheless, the Sierra Club has found this classification useful for the organization's individual conservation projects.

3.1.10 Other Frameworks

The National Park Service recently created a system of ecoregions to promote environmental sustainability (Figure 3.16). The Park Service's goal is to increase public education about ecosystems and ecoregional scale environmental conservation.

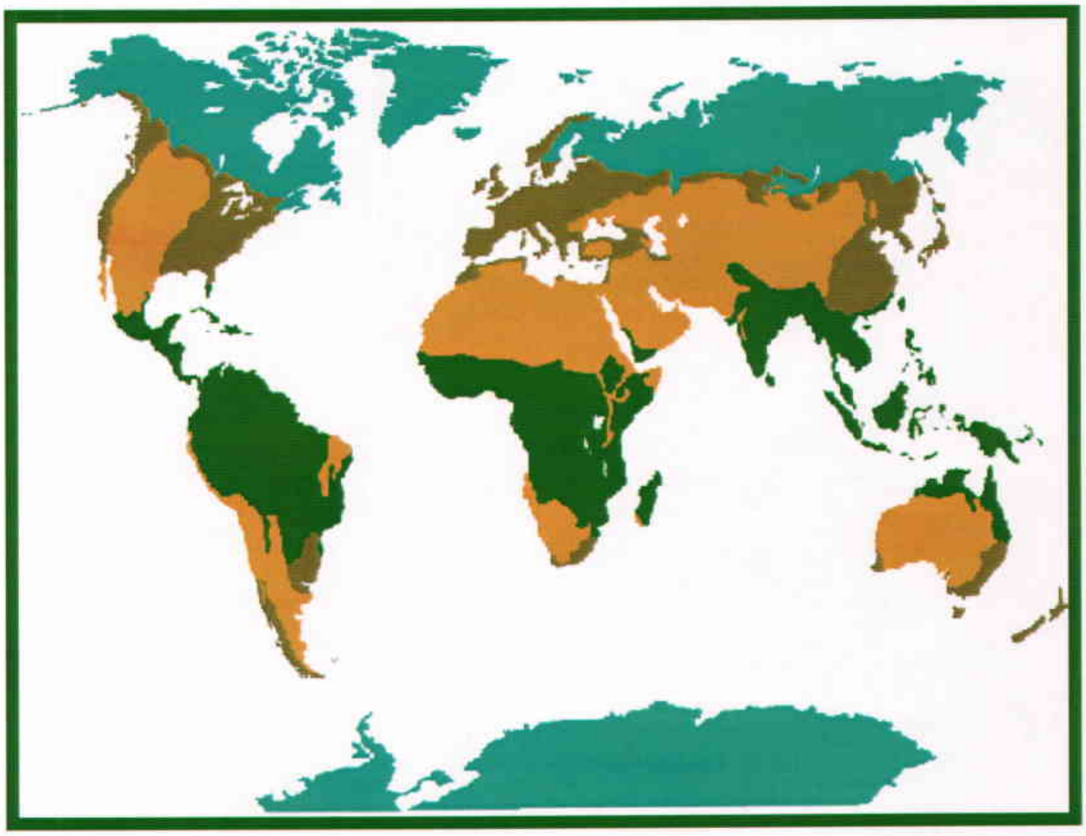

Figure 3.16 National Park Service World Ecoregions (NPS, 1999)

Such ecoregion classifications are becoming increasingly common, and delineation techniques and criteria are becoming exceptionally diverse. One of the largest areas of growth has occurred within conservation and preservation organizations. The Internet has become the preferred media for distribution of such information, and a search for the term ecoregion will yield thousands of websites. As public awareness of ecoregions increases, so will the number of frameworks. This proliferation of the concept could lead to problems in the future.

For one thing, ecoregions have been touted as a useful classification because of their integrative, multidisciplinary, and comprehendible nature. However, when countless organizations create their own ecoregion classification systems, potential users could be discouraged by the resulting confusion. For example, a conservation organization located in central Texas, The Hill Country Wild, developed an ecoregion framework that could be confusing to uninformed users. Using a Geographic Information System, members of the organization delineated a unique classification of ecoregions (Figure 3.17).

The Hill Country Wild was founded to preserve and restore the native species and ecological processes of the Central Texas hill country. The boundary of the 'Hill Country' ecoregion is nearly identical to the Edward's Plateau ecoregion developed by the EPA. Within the Edward's Plateau ecoregion are the four ecoregions of the organization's classification. The boundaries vary significantly, as the Balcones Canyonlands are extensively crenulated, whereas the other boundaries are more smooth. Such differing levels of cartographic generalization could create problems for potential users. The organization did not mention the process used for delineation, but personal communication with John Andrews, an officer in the organization, revealed the group's philosophy (Andrews, personal communication, 1999).

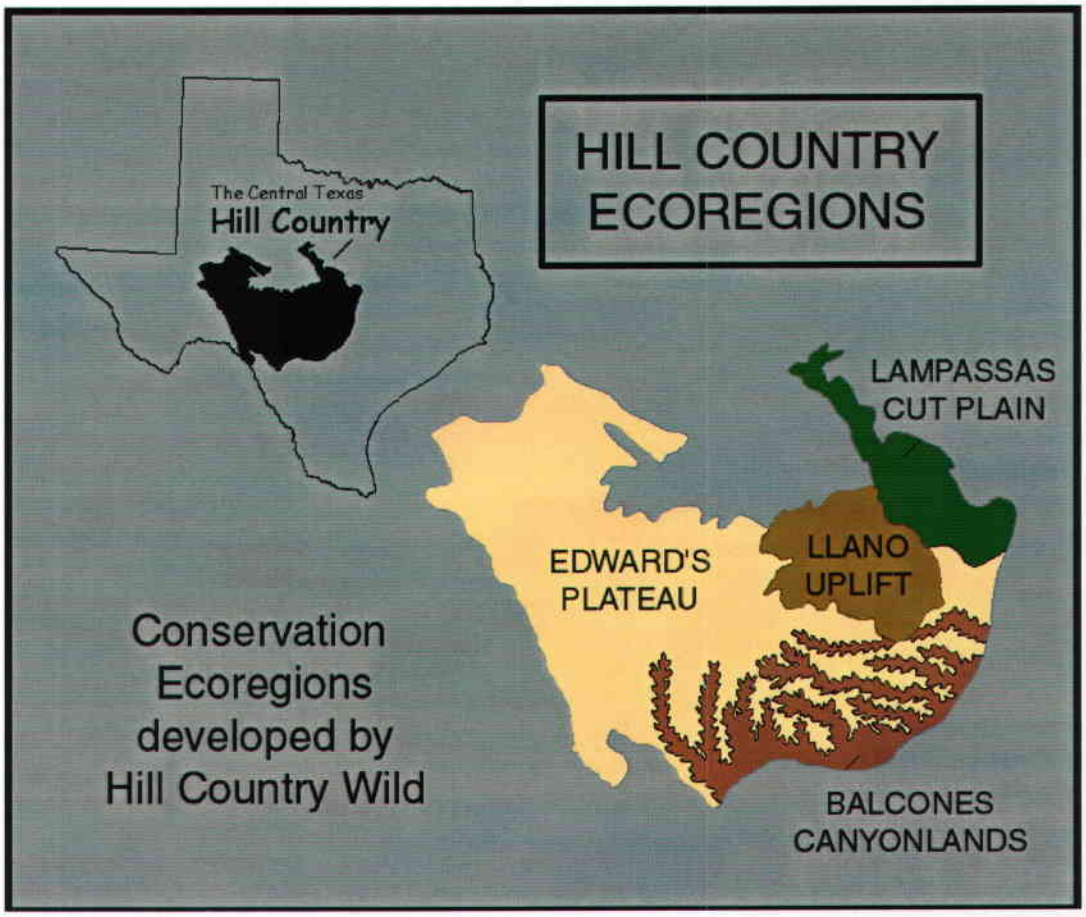

Figure 3.17 Hill Country Wild Classification (Sybert et al., 1998)

The Hill Country Wild organization believed that ecoregions were "known entities" and never considered the procedure for delineation of boundaries. In response to the question of criteria used for boundary delineation, Andrews replied, "It's not really something we've worried over too much; we consider it a very general boundary," (Andrews, personal communication, 1999). Andrews touched on an important issue; how important are the boundaries? Section 3.2 will further investigate some of the challenges facing ecoregion classification.

3.2 Ecoregion Delineation Challenges

With the numerous ecoregion classifications available, some scientists and conservationists have expressed concern that there is not one map for all of North America (Ricketts et al., 1997). The EPA's interagency work represents a consensus among several federal agencies and environmental professionals, but it is not a universal ecoregion framework.

3.2.1 Ecoregion Boundaries: Definite Breaks or Broad Transition Zones?

Although ecoregion boundaries are often defined by a single line, in reality, they are usually transition zones of varying widths (Clarke et al., 1991). In an attempt to better describe the boundaries between ecoregions, Clarke and others (1991) assigned lines of varying thickness to the EPA's ecoregions of Oregon. The lines indicated the width of the transition zone between ecological boundaries. Three transition widths were used: 1-5km, 5-15km, and 15-50km. They found that this explicit portrayal of transition width was useful. For example, the fault block ridges in southeastern Oregon showed abrupt (1-5km) change, while the transition from the western Cascades to the Klamath Mountains was a gradual transition (15-50km) (Clarke et al., 1991).

The EPA researchers also attempted to deal the issue of transition zones by creating 'fuzzy boundary' maps for Ohio, Massachusetts, Mississippi, and Alabama. This method was ultimately rejected because the increased complexity decreased the maps' utility for surface water quality management.

The ecological boundaries depicted on all ecoregion maps should be viewed as zones of transition. In areas where landforms create a significant change in the environment, the boundaries are easily defined. In other areas, where climate or vegetation change is the major factor for delineation, the boundary will be a broad transition zone. Using lines of varying width was an attempt to resolve this issue, but the system has yet to be used on a national ecoregion map. Ecoregion developers continue to use narrow lines on the maps to depict ecological boundaries, but they warn users that the lines actually represent zones of transition, or in statistical terms, confidence intervals.

3.2.2 Reasons for Boundary Refinement

Ecoregion classifications undergo boundary adjustments from time to time. Although the reasons for adjustment are as diverse as the regions they depict, the most common impetus for boundary alteration is the acquisition of new environmental knowledge.

The EPA's ecoregion map has been changed for several reasons including acquisition of new information on surface water quality, biota, and overall environmental patterns that has led to the restructuring of ecoregion boundaries.

Interagency collaboration (see 3.1.4.2) and the compromises required for such integrative work has also created a need for changes. The following diagram (Figure 3.18) displays current areas in which researchers have not been able to agree on boundary limits.

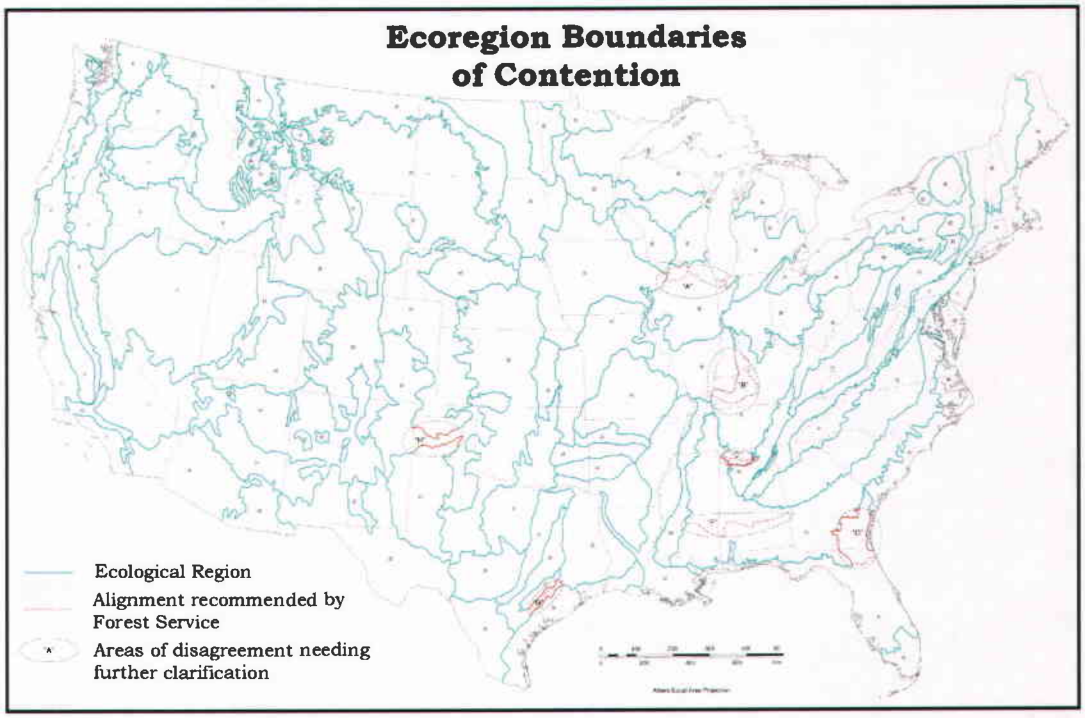

Figure 3.18 Interagency Lines of Contention
(Omernik et al., 1999)

For the EPA, Level IV mapping has also been a catalyst for boundary restructuring. The researchers' knowledge of the area increases proportionately with the amount of time spent delineating ecoregions, creating the need for boundary realignment.

Landscape alteration could also create a need to change the regional boundaries. As aquifers are drawn down from excessive ground water mining, the capacity of the entire region might undergo vegetative and faunal alterations. A region that was once homogeneous would need to be depicted as two separate regions. In the future, large-scale anthropogenic change, such as surface and sub-surface mining, landscape conversion or a nuclear reactor meltdown, might create the need for boundary realignment.

Climate change could foreseeably alter the boundaries of ecoregions, although the extent to which climate change might alter boundaries remains unknown. Any rapidly changing climate will be an issue in need of resolution in the future. It is important for ecoregion users to realize that even though ecoregions are printed as static maps, they are constantly changing and evolving.

3.2.3 Problems with Climax Stage Vegetation

Temporal considerations are important when delineating ecoregions. Paleoecological research suggests that minimally impacted ecosystems constantly change at a variety of scales, from decadal stand-level responses to local disturbances such as windstorms to long term climatic change (Russell, 1997). These temporal variations, according to Russell, would thwart any attempt to identify a typical "climax" type of vegetation at a regional scale. The constant reshuffling of species under climatic change, species migration, and microevolutionary influences magnified by human influences would prevent the delineation of a static framework (Russell, 1997; 18).

The controlling factor method used by Bailey for delineating ecoregions is limited by its narrow view of the role of biota within the ecosystem. The method views ecosystems as entities in which biological components are secondary outcomes of linear developmental processes, controlled by a particular combination of abiotic factors and culminating in predictable, stable endpoints (Griffon, 1997).

The emerging view of ecosystems recognizes biota as primary players in evolutionary processes, with rich feedbacks *between* hierarchical levels. Biota are capable of producing multiple, probabilistic outcomes rather than strictly determined results (Griffon, 1997). "Both the processes and their outcomes are seen as being constrained by higher levels, but not being controlled by them," (Griffon, 1997; 114). In Bailey's hierarchical system, climate controls the landscape and biota, and is not considered a constraining factor.

3.2.4 Institutional Influence on Ecoregion Delineation

Individual researchers, governmental and private agencies, and the goals and agendas of users influence ecoregion delineation. The EPA ecoregions incorporate more water quality considerations for delineation than other frameworks. Bailey's ecoregions consider climate and vegetation quite important due to the effect on forests.

The WWF identifies areas of extreme species biodiversity as separate ecoregions. TNC and The Sierra Club delineate boundaries based on their operational abilities. It is safe to say that every agency would delineate a separate set of ecological regions with fluctuating boundaries.

CHAPTER IV

The Use of Ecoregions

"The idea of the region provides an integrating philosophical theme for the disparate subject matter of geography, and regions can be useful areas for testing the theories generated by systematic studies in geography," (Hart, 1982; 19).

4.1 Applications of Ecoregions

Chapter III demonstrated that ecoregions have the potential to be used in numerous environmental studies. The use has steadily expanded to incorporate studies of biological, hydrological, geological, and environmental nature. To examine use of ecoregions, the classifications developed by Bailey and the EPA were back-referenced to identify all known citations utilizing the published frameworks

The following discussion of the various uses is limited to the developments and uses that represent significant advances in ecoregion theory. It would have been useful to mention each of the 350 plus citations individually, but in an attempt at brevity, the number of applications included has been significantly reduced. However, every citation was included in the bibliography for evaluation as needed. The ultimate goal of this chapter is to provide a general understanding of the types of studies in which ecoregions have been useful. Not all studies found ecoregions useful; in fact, some researchers rejected ecoregions due to various factors; these instances have also been presented.

Twenty-one separate categories of use were defined. The categories denote broad generalizations of use, and all of the studies were easily classified into their respective categories. The ecoregion frameworks of Bailey and the E.P.A. have been used more than any other ecoregion classification; Bailey's classification was cited 145 times, the EPA's classification was used on 172 separate occasions,

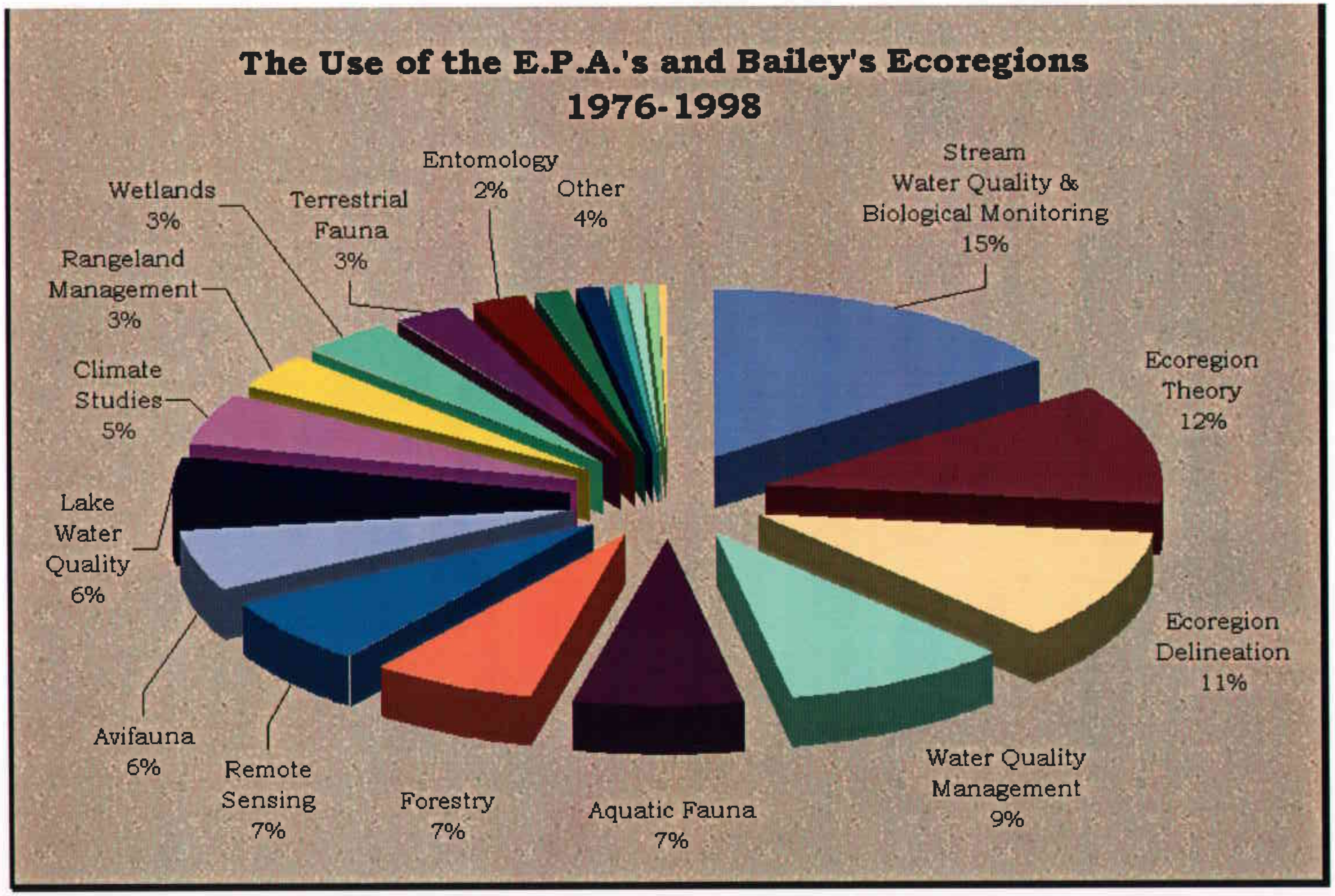

Figure 4.1 The Use of the EPA's and Bailey's Ecoregion Framework: 1976-1998

and 28 studies cited both frameworks. The uses of the two classifications are displayed in Figure 4.1.

4.2 Location and Description

Using ecoregions to describe or define the boundaries of a study area represents one of their most common applications. This category does not appear on the graph; instead, the uses for location were combined with the other investigations included in their respective fields. Twenty-six separate studies were found that utilized the EPA's ecoregions to describe the location of particular research areas.

Sixteen of the studies focused on water quality issues. Ecoregions represented the means for grouping the streams. Typical citations appeared as follows: "The study area was located in the Western Allegheny Plateau and Interior Plateau ecoregions," (Sanders, 1992), or "The study area is physiographically and ecologically diverse, encompassing portions of four ecoregions," (Davis, 1997). These types of studies tended to accept ecoregions as definite areas in which to conduct environmental research.

Studies of wetland pollution, amphibian distributions, forestry, remote sensing, avifaunal distributions, entomological distributions, and wilderness preservation were among the other ten citations that used ecoregions to describe location.

Not all researchers merely mentioned the location of the ecoregions; several scientists used the descriptions of the ecoregion frameworks. For example: "The refuge area is in Omernik's Central

Irregular Plains ecoregion, which has a parkland mosaic of bluestem prairie and oak/hickory forest as the potential natural vegetation," (Allen et al., 1995).

The use of ecoregions for location and description has been useful to researchers in that it helps familiarize researchers with the location and environmental surroundings of the various study areas.

4.3 General Water Quality Management

Forty percent of all studies utilizing ecoregions between 1976 and 1998 were focused upon some aspect of water quality monitoring or management. The water quality management category represents studies that used ecoregions for the expansion of water quality management theory, or for broad-based water quality management issues. Water quality issues that focused on wetlands, aquatic fauna, or riverine and lotic systems were classified separately.

Thirty-two studies (9% of all studies) used ecoregions for general water quality management. Eighty four percent of those studies used the EPA's classification. This percentage should not be surprising due to the water quality oriented nature of the Environmental Protection Agency's policies and management responsibilities.

State water quality researchers in Arkansas successfully incorporated the ecoregion approach into the preparation of Use Attainability Analyses (UAA). The Department of Pollution Control and Ecology (DPC&E) conducted brief field surveys on streams where land use change was proposed. The data that characterized the stream was compared to the data from the least-disturbed reference streams in the same ecoregion (USEPA, 1986).

The Arkansas program demonstrated the utility of ecoregions to develop and to evaluate water quality standards, particularly standards associated with dissolved oxygen content and the designation of fisheries. Arkansas also began using the ecoregion framework for testing water pH, hardness, and the presence of toxic pollutants. The study became the impetus for future statewide applications of the ecoregional framework in water quality management (USEPA, 1986).

Hughes and Larsen (1988) demonstrated the utility of ecoregions for determining chemical and biological goals of surface waters. The EPA ecoregion map was used to stratify the naturally occurring variance in water quality and biological communities in Oregon, Ohio, Arkansas, and Minnesota. Relationships between ecoregions, water quality patterns and fish assemblages were discovered. The analysis of the case studies demonstrated the value of the ecoregional approach for evaluation of aquatic ecosystem data.

Hughes and Larsen (1988) indicated that ecoregion classifications could serve as a bridge between national scale and site-specific approaches. The ecoregional approach along with appropriate statistical tests could provide precise expectations about large numbers of water bodies that would not be possible in site-specific research or river basin surveys.

Gannon et al. (1996) suggested a water quality-based, ecoregional approach as opposed to a technology-based perspective for dealing with water pollution. The ecoregional spatial framework was proposed as the basis for establishing non-point source pollution water quality standards. Research had shown that the natural landscape caused changes in water quality within basins. The researchers suggested that ecoregions, based on the natural landscape features that influence water quality, should be used to modify and refine water quality standards.

The CEC researchers who produced the international framework suggested ecoregions would be useful for aquatic resource management in basins that overlap political boundaries. Locations where such a system would be applicable included nutrient management in the different ecoregions of the Red-Assiniboine River basin from Saskatchewan and Manitoba to Minnesota and North Dakota, and water quality management in the contrasting ecoregions of the Rio Grande for the United States and Mexico (CEC, 1997).

The successful studies could lead one to believe that ecoregions were a panacea for water quality managers, but Karr (1991) was not so optimistic. Karr, an advocate for biological monitoring and assessment, stated that despite the adoption of ecoregions by several state water quality management agencies, the ecoregion boundaries should not be accepted without first examining other classifications such as river basins and physiographic provinces. Karr's statement suggests that ecoregions might not be the only choice for landscape stratification in water quality management. Research in this area has continued to expand, and ecoregions have remained an important part of broad-scale water quality studies.

4.4 Stream Water Quality Management & Biological Monitoring

This category contains only those studies that focused on stream water quality, selection of regional reference sites, or biological monitoring. Many of the studies also aided the development of ecoregional water quality management theory. Fifty-three different studies focused on stream water quality management between 1976 and 1998, and all but two of those studies used the EPA's ecoregion framework. Stream water quality monitoring and management applications were generally focused on selection of regional reference sites or determination of biological criteria.

Regional reference sites are used to quantify the health of ecosystems and establish benchmarks and standards for stream comparisons. Researchers have found that ecoregions are an effective means for the selection of representative reference sites on undisturbed streams (Hughes et al., 1986; Warry and Hanau, 1993; McCormick and Cairns, 1994).

The dearth of reliable historical information about the ecological conditions of aquatic organisms forced researchers to use regional reference sites to assess the extent of ecosystem deterioration. Thus, minimally impacted reference streams could be used as benchmarks to gauge the condition of other streams in the same ecoregion (McCormick and Cairns, 1994).

Hughes et al (1986) determined that regional reference sites offered a rational means to compare stream ecosystems over large areas. Of seven classification systems, the EPA's map of ecoregions was found to be the most appropriate system for classifying aquatic ecoregions because of the integrative ecological, versus technological and reductionist, way it was developed (Hughes et al., 1986).

The Hughes et al. (1986) study identified advantages and disadvantages of using ecoregions for selection of regional reference sites. Ecoregions were advantageous because regional reference sites could provide examples of the attainable community structure, dominant and intolerant species, species richness, habitat conditions and the spatial variation of those variables within each region. Managing agencies could determine how to monitor water quality standards and regulate point-source discharge. The sites could also be used to refine biological use classifications and ecological standards by providing empirical, regional examples of existing biota and habitat conditions. The use of a few regional reference sites would allow logical extrapolation of various conditions to the entire region.

The problems of the ecoregion reference site concept relate several factors including scale variability between large and small rivers and location of reference sites on anomalous streams. Another confounding variable is that undisturbed reference sites do not represent pristine systems; they represent the baseline conditions of *least altered* systems. The sites might also not realistically represent the attainable conditions of highly degraded systems because of the resources required to improve those systems. In addition, not all species would reveal regional patterns at the ecoregion scale of resolution, such as the distribution and abundance of rare or ubiquitous species. Finally, managers should not presume greater homogeneity within regions than actually exists. The sites would serve as attainable benchmarks in a broad context and would still require sound biological judgements and scientific stream surveillance.

The regional reference sites aid researchers attempting to establish biological criteria for stream water quality. Barbour et al. (1996) tested an ecoregion classification for use as a basic geographic unit for establishing reference conditions for biological monitoring in Florida streams. Ecoregions were considered useful as the basic geographic unit for establishing reference conditions because the water chemistry and stream biology were known to differ among ecoregions.

Four classification systems were evaluated using a discriminate function analysis. The objective was to identify the classification model that had the lowest discriminate misclassification rate of Florida streams according to the biological attributes of macroinvertebrate assemblages. An aggregated ecoregion approach had the lowest percentage of misclassification (8%) compared to the other models (25%, 29% and 33%) (Barbour et al., 1996). These findings suggested that the ecoregional framework was a suitable resource classification system for determining reference conditions for broad-scale biological assessment for Florida streams. Research in other locales has produced similar results (Hughes 1989a; 1989b; Hughes et al., 1990; 1994).

The use of ecoregions for establishment of regional reference sites and biological criteria continues today. Most states for which

Level IV ecoregions have been developed incorporate ecoregions in their water quality management plans. The ecoregion framework is a cost effective method for water quality monitoring (Hughes, 1989a). Of over 350 studies utilizing ecoregions, 15% fell into stream water quality management category, representing the highest proportion of use.

4.5 Lotic Water Quality Management

Nineteen citations, approximately 6%, involved the use of ecoregions to aid in lake water quality management, and all but one study used the EPA's classification. Not surprisingly, ecoregional strategies for lotic water quality management were developed in Minnesota.

The seven distinct ecoregions of Minnesota were used to assess regional patterns in watershed characteristics and in lake parameters such as phosphorus concentration, Secchi transparency, and lake mixing pattern. Ecoregions were utilized because the researchers believed that regional patterns of lake productivity and trophic status existed. Typical lotic productivity levels vary as functions of the combined interactions of climate, topography, soil, geology, land use, and other factors (Heiskary et al., 1987).

A sampling strategy for the thousands of glacial lakes in Minnesota would be utterly impossible. Therefore, roughly 10% of Minnesota lakes were sampled, and the findings were extrapolated across the ecoregions. This regional approach was preferable to a time consuming, resource intensive, lake-by-lake analysis (Heiskary et al., 1987).

The researchers encountered regional patterns in total phosphorus levels, phosphorus chlorophyll relationships, trophic status, fisheries composition, lake mixing patterns, and chemical watershed characteristics. Moreover, the findings indicated that the aquatic ecoregion approach was a valid method for grouping lake data and identifying spatial patterns of lake characteristics. The researchers also found that no single total phosphorus concentration could be used as a statewide standard. Regional standards are required for effective lake management, and the aquatic ecoregion approach helps identify and determine standards.

Other studies of lotic water quality using the ecoregional approach include Heiskary and Walker (1988), USEPA, (1988), Allen-Gil et al., (1995), Young and Stoddard (1996), Omernik et al., (1991), and Koutnik and Padilla, (1994).

Heiskary and Wilson (1989) also sampled user perceptions of water quality according to recreational suitability and physical appearance for Minnesota lakes. The chemical and subjective data were used to help define swimmable conditions and to assist goal setting by lake resource managers. Determination of regional lake swimmability was a unique use of the ecoregion framework. The researchers suggested a future use of the approach would be an assessment of lake trophic status within various subregions. This analysis would help refine regional total phosphorus criteria (Heiskary and Wilson, 1989).

The researchers reported that without the ecoregion framework, the state of Minnesota could not provide valid yardsticks for evaluating lake water quality, defining user perceptions of water quality, developing reasonable criteria for protecting water quality, and setting attainable goals for improving water quality (Heiskary and Wilson, 1989).

4.6 Wetlands

Twelve studies used ecoregions for wetland classification, management, or mitigation. The EPA's and Bailey's classifications were used equally for wetland studies. Ecoregions were generally used to locate or describe the particular wetland.

To aid in the development of a scientific foundation for wetland cumulative impact assessment, Bedford and Preston (1988) emphasized the need for a shift to larger temporal, spatial, and organizational scales in wetland management. Their study summarized current understanding and examined the generic assessment framework in terms of implications for research and regulation pertinent to building a stronger scientific base for both long-term and short-term wetland regulation.

The authors concluded that the EPA's ecoregion classification was an effective basis for wetland cumulative impact assessment. Minimal effort would be needed to develop a wetland regionalization that integrated USGS hydrologic units and ecoregions (Bedford and Preston, 1988). The scheme could be evaluated against various criteria and modified as needed. The ability to extrapolate results to other wetlands within the system was cited as the greatest advantage of the ecoregion framework (Bedford and Preston, 1988).

The EPA's ecoregion scheme and the USGS hydrologic units could be used to identify the natural boundaries of watersheds and drainage basins. The boundaries of the two systems would overlap since delineation features vary. The most comprehensive framework for wetland mitigation decisions would consider both ecoregions and hydrologic units (Bedford, 1996).

In a similar study (Bedford, 1996), the goal was to create a conceptual framework for establishing criteria for judging whether or not replacement wetlands were hydrologically equivalent to those lost. The research suggested that a shift in the scale of regulatory criteria from the individual project to broader landscape goals was necessary and that ecoregions provided the spatial context for decision makers to evaluate the potential cumulative effects of mitigation projects on broad-scale patterns of wetland diversity (Bedford, 1996). Bedford supported integration of the ecoregion and hydrologic unit frameworks for decisions regarding freshwater wetland mitigation.

4.7 Ecoregion Theory

Ecoregion theory has developed quite rapidly within the last quarter of the century. Applications within this category range from new developments in qualitative and quantitative ecoregion classification and delineation to the integration of ecoregion concepts with other fields or methods. Often the original developers of ecoregion frameworks conducted the theoretical developments. Forty citations, twelve percent, involved some aspect that furthered ecoregional theory. Bailey's framework represented 50% of the theoretical studies, the EPA comprised 25%, and both frameworks were cited for the remaining 25%.

Gonzalez (1996) suggested that ecoregions should be revised to include a third dimension during delineation that included air and water distribution and transport. Gonzalez argued that emphasis should be placed on functionality, which would include patterns of water flow and airflow and their linkages to the landscape. The ecosystem would be delineated based on the functional attributes of volumes of land, air, and water. His conceptual model incorporated groundwater in aquifers, and the upper air layer of the atmosphere, into the delineation process. Upper air currents undergo seasonal fluctuations and the water table adjusts with changes in rainfall and land use demands, but the study did not investigate the feasibility of integrating such ephemeral conditions (Gonzalez, 1996); however, it did introduce a third dimension to ecoregional theory.

Another study suggested the use of ecoregions for hazard and disaster assessment. Ecoregions could be useful in reducing uncertainty if the classification scale was appropriate to the hazard (Hunsaker et al., 1990). The authors indicated that ecoregions could be an effective means for determining data uncertainty but warned that further investigation is needed. Classification or aggregation of data could mask spatial heterogeneity that would be significant to the evaluation of the hazard.

A further development in ecoregion theory resulted from an integrated research endeavor by Omernik and Bailey (1997). The two pioneers of ecoregion classification attempted to reduce confusion surrounding applications of ecoregion and watershed frameworks, and the use and misuse of ecoregions. On a broad scale, ecoregions were intended to provide a spatial framework for ecosystem assessment, research, inventory, monitoring, and management. Because ecoregional schemes consider all aspects of the environment, the most useful applications would be as extrapolation mechanisms (Omernik and Bailey, 1997).

Ecoregions were not designed for regionalization of a particular characteristic. The authors cited five studies (Lyons, 1989; Inkley and Anderson, 1982; Poff and Alan, 1995; Poff and Ward, 1989; Spindler, 1996) that compared ecoregions to faunal assemblages or specific hydrologic characteristics. The studies often found correlation, but other characteristics were found to be more helpful. Omernik and Bailey (1997) stressed that the failure to recognize the purpose of ecoregions led to this "misuse." Ecoregions were considered useful for structuring research, assessment, and management of *all* environmental resources but might or might not be useful for examining one particular resource.

The authors also discussed the integrated use of watersheds and ecoregions and the benefits that result from such applications. Ecoregions and watersheds were both considered necessary for development of a system of regional reference sites in water quality management. Ecoregions and watersheds were referred to as complementary tools; an ecoregion framework, when used in conjunction with watersheds, provide the method for extrapolation of reference conditions (Omernik and Bailey, 1997). Each tool was designed for a specific purpose, and by emphasizing the positive attributes of each system, researchers could produce superior studies. The holistic, top-down nature of the ecoregion scheme could be coupled with the focused, bottom-up nature of watershed analysis.

Other theoretical developments attempted to create classifications that were objective and repeatable, as opposed to the qualitative ecoregion classifications. Host et al. (1996) contended that the existing ecoregional classification systems required numerous subjective decisions about the relative importance of different data layers. The classifications often contain unit boundaries defined by a consensus of various agencies. The researchers stated that such methods, based on *subjective* decisions for regional classification that were later treated as *objective* landscape entities, were often not repeatable.

Host et al. (1996) attempted to create a quantitatively based framework that would be more objective and repeatable than existing ecological land classifications. The framework was based on the integration of climatic and physiographic classifications using a GIS overlay operation. Lines were shifted to coincide when the boundaries were divergent. Besides objectivity and repeatability, an advantage to the quantitative approach was the application of classification criteria across ownership boundaries, whereas classifications developed by specific agencies tended to focus on data collected within single ownerships.

Other researchers have attempted to develop a quantitative classification of ecosystem units as well; however, no classification has been widely accepted, and the qualitative ecoregion boundaries remain in wide use by several public and private agencies.

4.8 Ecoregion Delineation

Delineation and revision of ecosystem regions accounted for 11% of all ecoregion publications between 1976 and 1998. This category was created to include the maps, books, and publications that have been developed which define or delineate ecoregions. Ecoregion delineation has increased and expanded (see chapter 3). In all, 37 different citations focused on ecoregion delineation, twenty-five centering on the EPA classification. The EPA published maps delineating ecoregions for individual states and regions of the United States (see figure 3.9) accounted for the majority of the citations. Delineation of ecosystem regions will likely continue to increase as user familiarity with ecoregions increases.

4.9 Aquatic Fauna

The use of ecoregions to characterize the distribution of aquatic macroinvertebrate and ichthyofauna has yielded mixed results. While some studies have found ecoregions useful, others have determined that ecoregions are not a worthwhile measure of fish assemblages. In all, aquatic faunal studies accounted for 7% of all ecoregion citations. Thirteen studies used the EPA ecoregions, eight used Bailey's classifications, and three citations used both frameworks.

Whittier et al. (1988) tested the correspondence between ecoregions and stream fauna in Oregon. The researchers evaluated Omernik's ecoregion classification by determining how well spatial patterns in several characteristics of small stream ecosystems corresponded with the eight ecoregions of Oregon. The researchers collected data concerning fish patterns, periphyton, macroinvertebrate assemblages, physical habitat, and water quality in 49 small streams in Oregon the surrounding areas.

The researchers concluded that ecoregions were an effective framework for broad-scale stream classification and management and provided a useful alternative to river basins. The results of data analysis showed a hierarchy of differences among the eight ecoregions. Clear regional differences existed between montane and nonmontane regions. Moreover, the nonmontane region was further subdivided according to regional patterns. Streams within an ecoregion were similar but unlike those of other regions (Whittier et al., 1988).

The researchers also attempted to evaluate the correspondence of other geographic models and spatial patterns in small stream ecosystems. Their evaluation was primarily qualitative due to the variety of scales among frameworks. They analyzed Brussock et al.'s (1985) geographic stream classification and found that the regions were too coarse for Oregon and much of the mountain and intermountain West.

Bailey's (1976, 1981) maps of ecoregions were also evaluated. Bailey mapped nine ecoregions in Oregon, five corresponding with Omernik's ecoregions. The other four regions could not be evaluated precisely, but the researchers determined that if the regions were reclassified then Bailey's section level ecoregions could also be a useful framework for streams in Oregon (Whittier et al., 1988).

Hawkes et al. (1986) obtained quite different results. The state of Kansas was partitioned into a small number of homogeneous areas, or fish ecoregions, using multivariate statistics based on fish assemblage patterns. The fish ecoregions were compared to patterns of climate, landform, geology, soil, potential natural vegetation, land use, and land cover (Hawkes et al., 1986).

Statistical tests were conducted on fish presence/absence data for thirty-nine fish species in 410 Kansas stream sites. The analysis identified ten ecologically different fish assemblages. These assemblages were clustered into six geographic areas, or fish ecoregions. Mean annual runoff, mean annual growing season, and discharge were the most important distinguishing environmental variables for separating the fish ecoregions. The researchers found a correspondence between the fish ecoregions and the patterns of physiographic regions, river basins, geology, soil, and potential natural vegetation in Kansas. The scientists believed the approach could be used successfully in other states as well (Hawkes et al., 1986).

The fish ecoregions in Kansas did not concur with the aquatic ecoregions developed by Hughes and Omernik. The differences were likely a result of the use of different variables as the basis for classification since Hawkes et al. (1986) used fish association patterns to stratify the regions. The study also found no correlation between Omernik's ecoregions and the study's fish ecoregions.

These early applications of ecoregions to describe fish assemblage patterns heavily influenced later studies. A detailed analysis of all the studies utilizing ecoregions to analyze aquatic fauna was not conducted; however, interested researchers should consult Hawkes et al., (1986); Hughes et al., (1987); Brooks and Hughes, (1988); Lyons, (1989); Kinsolving and Bain, (1993); Rabeni and Sowa, (1996); Whittier et al. (1997); Maret et al., (1997); Belliard et al. (1997). These studies led Harding et al. (1997) to develop a similar system of ecoregions for steam water quality management in New Zealand.

Support for the use of ecoregions in stream fauna classification is divided. Research in this area could represent a possible misuse of the ecoregion classification. Users should consider ecoregions as multi-purpose regions for the assessment of broad, holistic environmental concerns. Omernik and Bailey (1997) pointed out that the bulk of misuse and misunderstanding of ecoregions centered on the failure of researchers to recognize the purpose of ecoregions and the appropriate methods to evaluate them. They stressed that ecoregions were *generally* useful for structuring research and for assessing and managing the multitude of environmental resources. Ecoregions were not the most appropriate framework for evaluating individual resources (Omernik and Bailey, 1997). Thus, studies that attempt to classify individual species of fish might find that ecoregions are not a useful classification.

4.10 Forestry

Forestry applications of ecoregion frameworks have largely focussed on the classification developed by Bailey and the United States Forest Service. Applications range from prediction of canopy cover and forest inventories to pesticide and fertilizer applications. Eighteen of the twenty-three forestry citations used Bailey's ecoregion framework in their studies.

A common application of ecoregions in forestry involves characterization of forest communities. Ecoregion names sometimes coincide with forest types, and, therefore, represent a useful means for describing large landscape areas and the vegetative types contained therein. The province level of Bailey's ecoregion classification parallels forest species distributions. Ecoregion names such as, mixed forest, broad-leaved forests, and Mediterranean hard-leaved evergreen forests are based on the biotic classification of the regions (Bailey, 1998b).

Forest site classification systems could provide a method for organization and communication of ecologically based information. Future forest resource management actions could be anticipated, predicated, or extrapolated by using ecosystem regions (Sims et al., 1995).

Dixon et al. (1994) used ecoregions as a means for estimating the amount of land available to implement agroforestry management and alternative land use practices. The researchers were testing a plan that would improve the removal and storage of carbon from the atmosphere (Dixon et al., 1994). This study used ecoregions to integrate atmospheric science, land use management, and forestry.

O'Brien (1996) found significant differences in the extent and conditions of forest resources among northern Utah ecoregions. This study reinforced the validity of using ecoregions for ecosystem management. Forest inventory data stratified by ecoregion could help facilitate landscape level planning and monitoring (O'Brien, 1996).

Another study used ecoregions to identify optimal stand and treatment factors to defoliate trees with the herbicide tebuthiruon. Van Pelt and West (1993) used the EPA's ecoregion framework because of similarities among precipitation, soils, and environments of the testing sites. The researchers tested several methods of herbicide application to find out what type of influences caused tree mortality. The amount of herbicide and method of application could be standardized for entire ecoregions. The researchers identified the most efficient method of herbicidal application and proved that differences were a result of landscape characteristics, such as precipitation and soil type. When applying herbicide on a large-scale basis, the amount needed could be adjusted according to the landscape characteristics of the ecoregion (Van Pelt and West, 1993).

The CEC (1997) suggested ecoregions would be useful for forestry management of the North American Temperate Rainforests. Ecoregions could be used to assess old growth preservation, conservation and maintenance. This application includes analyses of the region and determination of areas that are currently protected. Conservation, protection, and maintenance programs could, then, be focused on other old growth stands within the ecoregion (CEC, 1997).

Characterization of forest communities, forest site classification systems, implementation of agroforestry practices, application of herbicides, and preservation and conservation of old growth forests are among the diverse applications for which ecoregion level studies might improve forestry management practices.

4.11 Remote Sensing

Remote sensing technology has rapidly expanded within the last decade and such studies have utilized ecoregions on twenty-three different occasions. While many applications merely mention ecoregions, some studies have actually used ecoregions to stratify land cover information and to test the accuracy of remotely sensed information. Bailey's framework was used on 13 occasions, the EPA classification was used 8 times, and two studies cited both frameworks. Nearly all of the remote sensing studies occurred in the 1990s.

The use of ecoregions in remote sensing applications originated as a means to deal with file size and classification of AVHRR data into land cover classes. Loveland et al. (1991) attempted to define and evaluate the potential for using AVHRR 1-km digital imagery and multi-source data (climate, terrain, and ecoregions) in concert to characterize global land cover.

In developing a nationwide landcover database, the large datasets have the potential to create analysis problems. The researchers proposed the use of the EPA's ecoregions to partition remote sensing information into smaller data sets. The researchers rejected the initial idea due to the possibility of post-classification mosaicking and interregional class correlation problems. Loveland et al. (1991) serendipitously discovered a valuable use of ecoregions.

Ecoregion maps were digitized and the attributes of the region such as land surface from, major soils, land use, and potential natural vegetation were summarized for use in characterization. The researchers created the land cover map from the various sources, and encountered problems with the classification scheme that had to be dealt with qualitatively. The ecoregion framework was found to be a useful tool for correcting the majority of the misclassifications and resolving class confusion.

Brown et al. (1993) found ecoregions useful for reclassification as well. Multi-source data, course-resolution satellite data and ancillary data were used to produce a land-cover characteristics database for the conterminous United States. Elevation and ecological region datasets were critical to the development, refinement, and information content of each class in the database.

Ecoregion data were used to rectify classes more than any other type of ancillary data. The ecoregion data provided separation rules for clusters 86 times by itself, and 59 times when used in conjunction with frost-free periods or elevation criteria. The ecoregion data were most useful in situations where a single spectral-temporal cluster represented several different land-cover types that were spatially separate. Ecoregions were used to stratify 127 of 189 occurrences (67%) of cluster confusion (Brown et al., 1993).

Ecoregions were most helpful for resolving confusion involving anthropogenic factors. Because the EPA's ecoregions include land use information, the framework was the most logical ancillary variable for post-classification stratification when the confusion was spatially separated.

The researchers indicated that the minimum set of ancillary variables needed for a similar post-classification refinement must contain digital elevation data and ecoregions (Brown et al., 1993). By using ecoregions to resolve misclassifications in remotely sensed data, the researchers took advantage of the multifaceted nature of an ecoregion classification. With the expansion of remote sensing technology, and the increased use of the data for mapping, a framework is needed to correct classification problems. According to this study, ecoregions could be the best choice for post-classification refinement of data.

Lachowski et al. (1995) discussed the usefulness of ecoregions for assessing broad scale planning. The following diagram (Figure 4.2) shows the correlation between advanced very high resolution radiometer (AVHRR) data and the boundaries of Bailey's ecoregions of the Intermountain West. The image is centered primarily on Wyoming and includes portions of surrounding states. The ecoregion boundaries tend to coincide with the land cover types from the AVHRR data. AVHRR data have been used to refine the boundaries that failed to correspond (Lachowski et al., 1995).

Other remote sensing applications have focused on the spatial relationship between the normalized difference vegetation index (NDVI) and ecoregion frameworks (Ramsey et al., 1995). Homer et al. (1997) found that multi-scene digital classification holds promise as a viable landscape-level mapping methodology, especially in diverse biogeographical regions. They indicated that the ecoregion-based classification provided a reasonable framework to work with during the creation of a spatially large data set. It also aided optimization of ground training site extrapolation and ancillary model application. An important point made by the researchers was that edge matching between ecoregions was not required because the ecoregion boundaries stratified spectrally homogeneous areas (Homer et al., 1997).

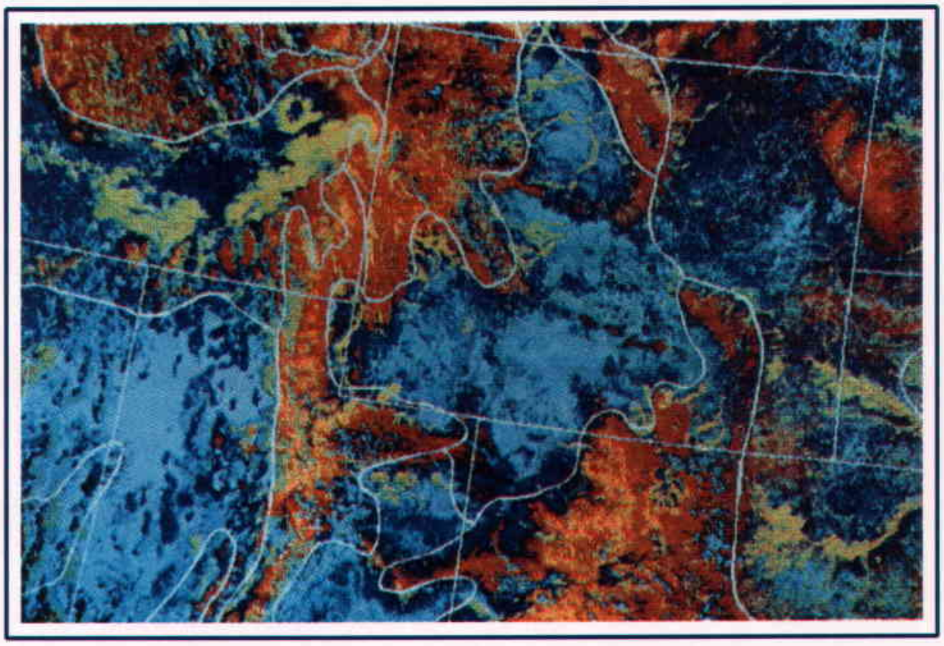

Figure 4.2 AVHRR and Ecoregion Correspondence
(Lachowski et al., 1995; 39)

Technological advances have allowed the construction of broad-scale vegetation maps based on remotely sensed data. New advances have created a rapid expansion in the creation of such large-scale maps. Accuracy assessment for these maps has not been able to keep up with the rapidly expanding technology. Edwards et al. (1998) attempted to outline estimation formulas for simple map accuracy measurements and reported the results for the cover types and ecoregions mapped as part of the Utah Gap Analysis project.

The sheer size of the areas modeled in Gap Analysis pose immense field and fiscal difficulties that complicate sampling designs for accuracy (Edwards et al., 1998). The researchers created a seamless mosaic of 14 LANDSAT Thematic mapper scenes and subset the mosaic into three Utah ecoregions (Omernik, 1987). Each ecoregion was independently classified, modeled and subsequently edge-matched into the statewide coverage. The drawback the researchers encountered for assessing ecoregion-scale vegetation cover maps were the lengthy time of movement between each sample site. The cost of collecting information from randomly distributed locations across an ecoregion would also be substantially higher than collecting information at clustered locations easily accessible by highways.

Thus, ecoregions were not always found to be a useful framework for remote sensing studies. Several remote-sensing researchers, however, found that ecoregions could yield significant advantages to researchers willing to include them within land classification studies.

4.12 Avifauna

Six percent of all ecoregion applications focused on avian fauna. Ecoregions have been applied to the study of bird habitats and avifaunal distributions. Twenty studies were conducted, and all of them used Bailey's framework. Commonly, ornithological researchers use ecoregions as a means for defining and describing their study areas (Chester et al., 1990; Apfelbaum and Haney, 1981; Ringelman and Longcore, 1982) . Other ornithologists and zoologists have undertaken more intensive studies.

Aldrich and James (1991) studied the geographic patterns in size, shape and color of the plumage of the American Robin for all of North America. Knowing that the smallest robins resided in the eastern US, and that the largest were located in the Western and northern states, the researchers wanted to identify linkages between species dynamics and geographical location. They stratified information on wing length, leg size, bill shape, and plumage variation by ecoregion. Figure 4.3 depicts median values of wing tip and wing length for male robins in 36 ecoregions.

Recent studies indicate that Neotropical migrant birds breeding in North America and wintering in Central and South America are generally declining (James et al., 1996). Using the World Wildlife fund's ecoregions of Latin America and the Caribbean, researchers focused on the conservation assessment and population trends of transmigratory Neotropical migrant birds (James et al., 1996; Roca et al., 1996). Both studies were aimed at developing new international conservation strategies to deal with intercontinental bird migrants.

Research on avifaunal conservation is expanding. The CEC is currently developing a system of bird conservation regions for North America. A draft of the United States portion of this framework

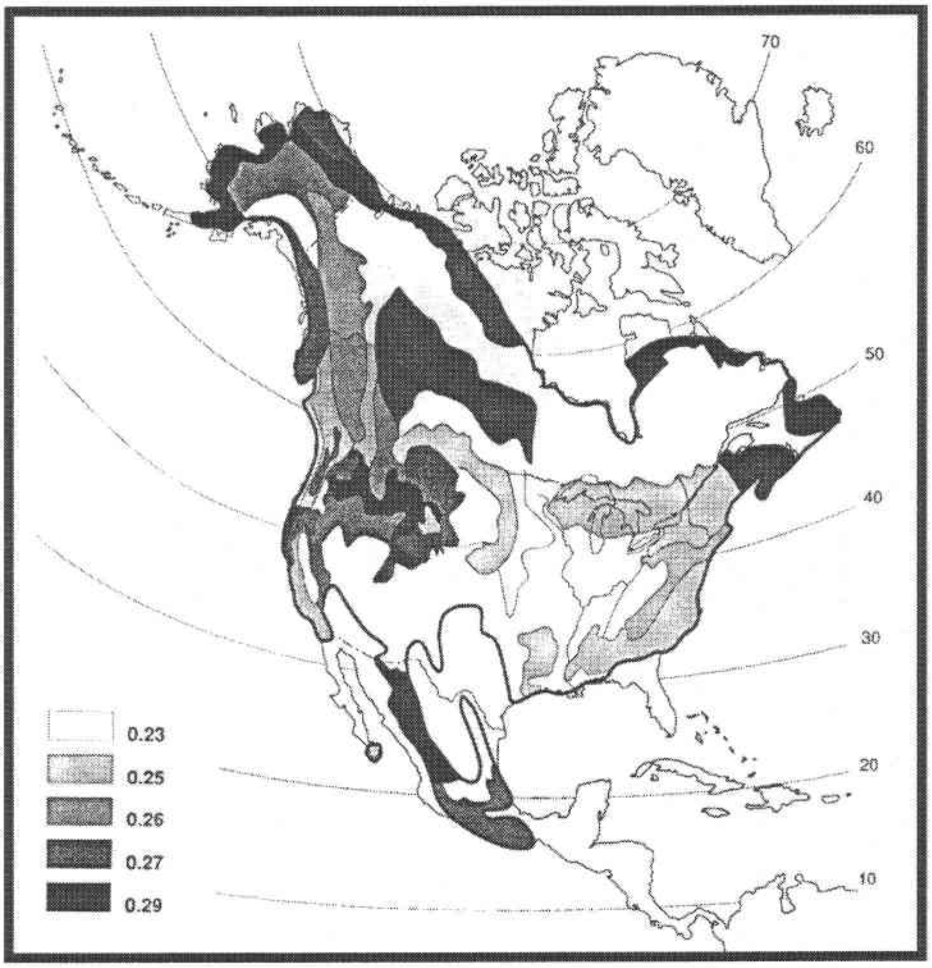

Figure 4.3 Wing length of the American Robin stratified by ecoregions (Aldrich and James, 1991)

appears on the following page (Figure 4.4). The proposed bird conservation regions were delineated with the cooperative help of the CEC, the Fish and Wildlife Service, Ducks Unlimited, and other bird conservation organizations. This study not yet been published and was not included in the data set, but will likely prompt future uses of ecoregions for avifaunal conservation and management.

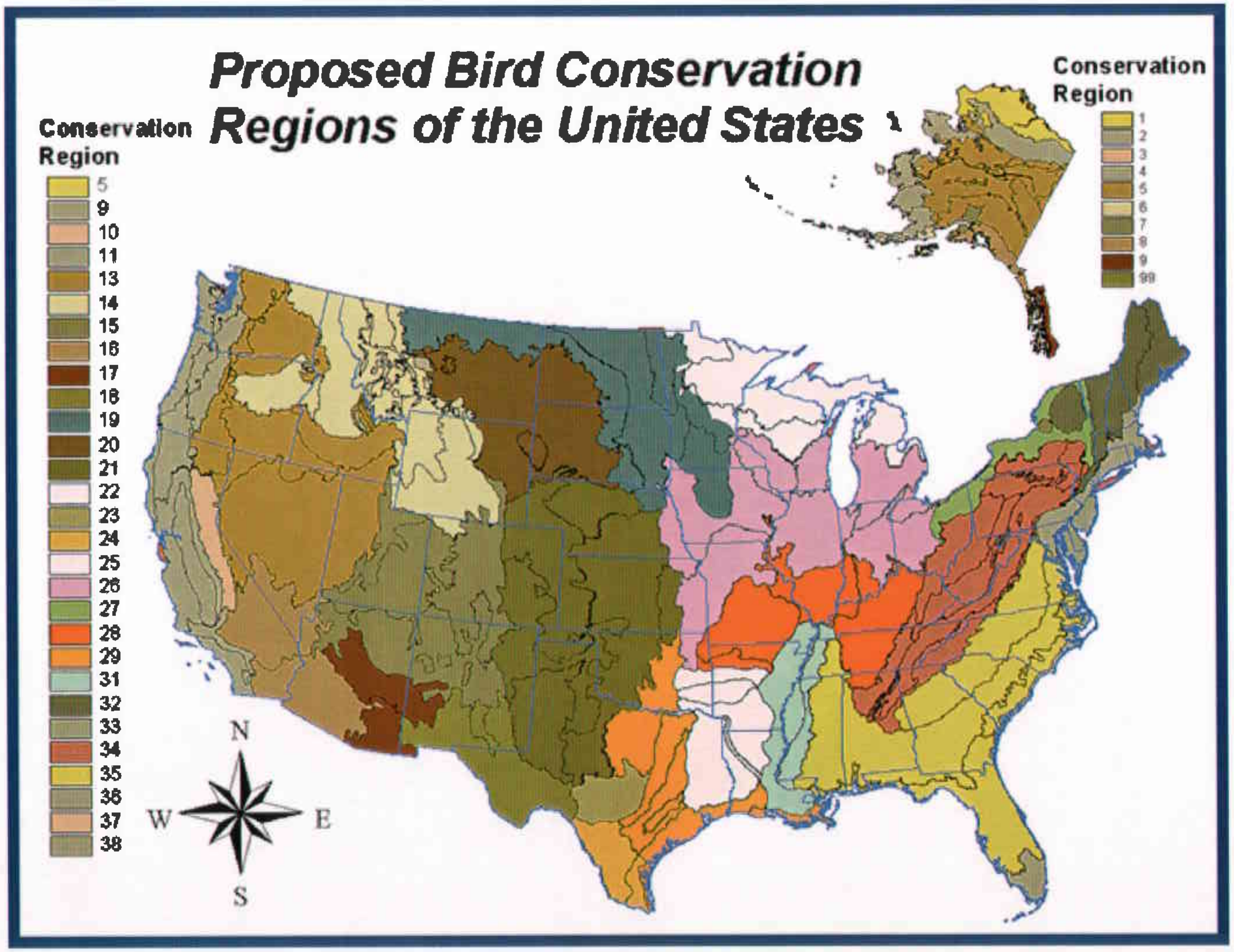

Figure 4.4 Proposed Avifaunal Regions of North America

4.13 Climate and Atmospheric Studies

More climatic studies used Bailey's ecoregion classification than used the framework developed by the EPA. Seventeen of the eighteen climatic studies, conducted between 1991 and 1998, used Bailey's ecoregion classification.

Hogg (1993) studied the linkage between climate zones and forest provinces to determine how global climate change would affect forest distribution in the future. The study used the major vegetation zones (ecoregions) developed for Canada by the Ecoregions Working Group (1989) based on the approach of Bailey et al. (1985). Close correspondence was found between the climatic and ecoregion boundaries.

Similarly, Neilson (1993) studied global biomass change and employed ecoregions to calibrate vegetation maps used to analyze global vegetation redistribution. He investigated the regions of the planet that would produce carbon dioxide emissions as well as those regions that would sequester carbon dioxide global warming of 1.5 to 4.5 degrees Celsius were investigated (Neilson, 1993).

Other climatically oriented studies focused on methodological concerns for delineation of climatic zones as a factor in ecosystem classifications (Paruelo, 1995; DeGaetano, 1996). Bohm et al. (1991) attempted to characterize the diurnal curves of tropospheric ozone near coniferous forests in the western United States. Ecoregions were crucial for identifying representative study sites (Bohm et al., 1991).

4.14 Rangeland Management

Twelve studies used Bailey's ecoregion map to study environmental issues in North American grasslands and shrub-lands. Ecoregions were used for location, description, identification of regional patterns, and model development in grassland regions (Paruelo and Lauenroth, 1995; Peinado et al., 1995). Location was not the only way ecoregions were used in rangeland management.

Temperature, precipitation, and other environmental factors play significant roles in grassland distribution. Parton et al. (1994) used ecoregions in a study that developed a model to predict environmental change in grassland areas. Such broad-based studies of North American grasslands may find a classification such as ecoregions useful.

4.15 Terrestrial Fauna, Entomology, and Agricultural Science

Terrestrial fauna, entomology, and agricultural science represented 3%, 2%, and 1% of ecoregion applications, respectively. The categories were combined because of their usage similarities. Location and description of the study sites dominated ecoregion citations of terrestrial fauna, entomological fauna, and agricultural science. Species distributions were the focus of the first two categories while the eradication of noxious weeds and landscape scale pesticide applications dominated the agricultural science category.

Ten ecoregional studies were linked to the management or analysis of terrestrial vertebrate fauna. Location of species ranges and habitat types were the most common use within this category.

Ecoregions were also included in an index for GAP analysis of vertebrate fauna because the regions represented a habitat variable useful for identifying species ranges and distributions (Edwards et al., 1995).

Dobson and Wigginton (1996) analyzed sexual dimorphism among bobcats in the western United States. The researchers stratified their data sets by ecoregion. The researchers found that sexual dimorphism decreased as longitudinal movement continued inland from the West Coast ecoregions (Dobson and Wigginton, 1996) and similarities between the sexes increased with continentally.

Entomological studies, similar to the terrestrial vertebrate studies, used ecoregions to describe location or habitat types (Oosterbroek and Tangelder, 1987). Rykken et al. (1997) used ground beetles as indicators of landscape diversity and concluded that invertebrates could be used as a measure of biodiversity for similar ecological landscape assessments (Rykken et al., 1997).

4.16 Biodiversity Conservation and Preservation

Biodiversity conservation represented only one percent of the total use of ecoregions; however, this figure should soon increase. The primary goal of the World Wildlife Fund, The Nature Conservancy, the Sierra Club, and other similar organizations is the preservation and conservation of the earth's ecoregions. The organizations have each initiated strategies for preserving the world's diverse ecoregions. The methods employed for preservation have been widely distributed on the World Wide Web.

The CEC ecoregions could also be used to assess biodiversity conservation in the North American Arctic. The distribution of protected areas varies across ecoregions. The framework could be used to determine what proportion of the arctic is protected by certain nations, how well the regions are protected and managed, and whether or not all ecosystems within each ecoregion were protected (CEC, 1997).

The World Wildlife Fund developed its ecoregion framework primarily to aid in the development of similar conservation strategies. This framework was intended to identify the biological distinctiveness of ecoregions, and set aside portions of the regions of biodiversity for preservation. Continental assessments of species richness and rarity were conducted for the regions of the world. The following diagram (Figure 4.5) depicts the biological distinctiveness of North America.

Globally Outstanding ecoregions (depicted in red) were evaluated according to conservation status and conservation priorities were developed for the ecoregions with the highest levels of globally distinct biodiversity and the least amount of protected areas. This system has aided the decisions of land donors throughout the world (Ricketts et al., 1997).

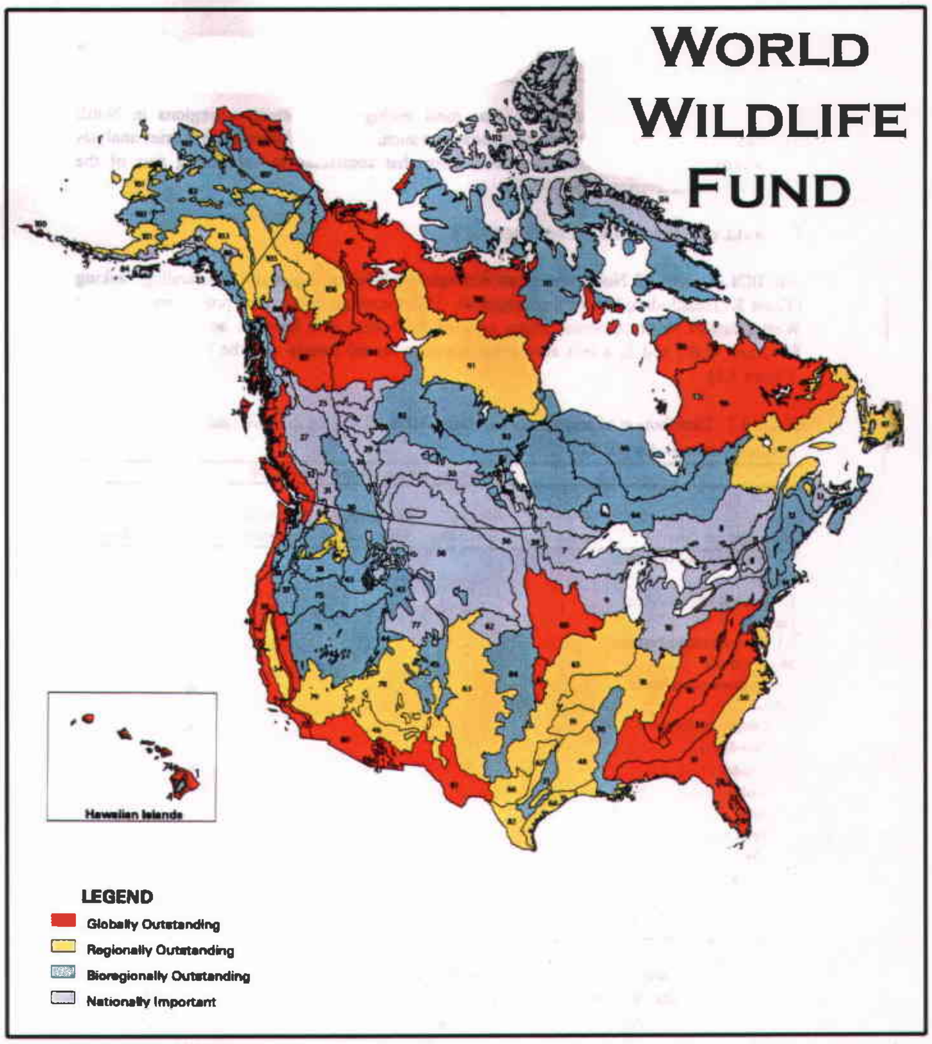

Figure 4.5 WWF Species Distinctiveness (Ricketts et al., 1997)

4.17 Geology

Ecoregions were used in two geological studies (Breyer and McCabe, 1986; Hughes, 1995). Hughes (1995) developed a two-step approach for integrating geological components into ecological studies. Classification required the development of geological terrain units. These units were areas with similar geologic evolution, chemistry, physical characteristics, and landscape determinants. Ecoregions represented an example of an integrated geologic terrain.

4.18 Medical Geography

Rubio-Palis and Zimmerman (1997) sought to develop an integrated control program to combat the resurgence of malaria in the Americas. The plan represented a shift from individual house spraying to large-scale vector control approach. The researchers reported that malaria transmission patterns could be characterized based on knowledge of the distribution of the vectors, biology, and environmental factors such as climate, soil, geomorphology, vegetation, and landuse.

The plan was considered an asset to resource managers because it linked malaria transmission to ecological boundaries rather than political stratification. The system could be used for risk assessment programs. In resource inhibited areas, management could be focused on locations where the vector occurred, instead of only where individual malaria cases appear (Rubio-Palis and Zimmerman, 1997).

The researchers concluded that the ecoregional classification provided an approach that was essential to the development of integrated management strategies. They also stated that the ecosystem classifications developed by the EPA and Bailey held promise for vector mapping.

4.19 Recreation Management

One of the first applications of ecoregions involved recreation management. Steven Stadler (1988) presented a paper at a meeting of the Association of American Geographers that used ecoregions as a measure of golf course maintenance fees. The cost of golf course maintenance per acre varies with location. Soil type, vegetation, landforms, and rainfall all influence the costs of golf course maintenance. Because ecoregions were based on such landscape factors, they were tested as a measure of expenditure. Ecoregions were useful in explaining cost per acre; however, climate type was found to be a better identifier (Stadler, 1988).

Bhat et al. (1998) developed a new use of ecoregions in recreation management. The researchers attempted to provide a methodology for estimating recreation values in the United States using the ecoregion approach. The ecoregion classification of Bailey (1983), was used to group over 300 recreational site data across the United States. The researchers found that outdoor recreation values vary across ecoregions. The results could help identify priorities for recreational planning and policy for ecoregions within the United States (Bhat et al., 1998).

4.20 Statistical Theory

Developing accurate tests and procedures for testing the validity of ecoregion frameworks has been an obstacle for statistical researchers because relatively few tools are available for evaluating the strength and utility of proposed qualitative and quantitative classifications based on multivariate measurements of objects within individual classes. Van Sickle (1997) presented the mean similarity dendrogram for evaluating low-order classifications. He used ecoregions in order to show the validity of his new multivariate graphical procedure. Van Sickle (1997) suggested that mean similarity dendrograms could be an attractive, nontechnical tool for evaluating environmentally oriented land classifications.

4.21 Nature Writing

Writers have employed ecoregions to describe the natural environment. The book, *Far From Tam: Reflections from the Heart of a Continent* (Allmann, 1996) was organized into eight sections that corresponded to the eight ecoregion divisions of southwest Michigan and northwest Minnesota. The ecoregions were based on an adaptation of Bailey's ecoregion classification. Though not an important scientific advancement, this use represents an increase in the public's awareness of ecoregions.

4.22 Alternatives and Opposition to Ecoregions

Ecoregions are not always a useful classification for environmental management. In fact, some studies have rejected ecoregion frameworks in favor of alternative classifications. For instance, Hondzo and Stefan (1993) and Stefan et al (1996) found that ecoregions were not useful for classifying water temperature in Minnesota lakes or for the subdivision of fish habitats because the scale of the classification was too detailed for their study.

Similarly, Hunsaker and Levine (1995) considered and rejected ecoregions for a study of stream water quality because they lacked sufficient detail. Despite the fact that ecoregions have limitations, these three studies do indicate the importance of scale in regional classifications. Broad-scale ecoregions are too detailed for continental-scale studies, while not detailed enough for landscape or watershed level studies. Therefore, selection of the scheme with the 'best fit' is extremely important for users to appropriately apply this environmental management tool.

Because of these limitations, some researchers support quantitative approaches to regional ecosystem classification. This support has made the development of quantitative techniques for defining ecoregions a major contemporary research endeavor. For information on quantitative development see Noronha and Goodchild (1992).

One researcher has argued that the ecoregion management concept is fatally flawed (Fitzsimmons, 1993; 1995; 1996a; 1996b; 1998). Fitzsimmons (1993) contends that the ecosystem concept was not designed as an aid to federal policy or for regulatory purposes. The locations of ecoregion boundaries are arbitrary, imprecise, and change over time and are, therefore, inappropriate guidelines for policy management decisions (Fitzsimmons, 1993).

Fitzsimmons also emphasizes that ecosystems are geographic fabrications devised to facilitate an analysis or to address some problem of human concern and are not entities in their own right (Fitzsimmons, 1996b). He presents three major flaws of ecosystem management. First, there is a lack of an agreed-upon definition of ecosystems and the ecoregions that define them. Second, Fitzsimmons argues that there are significant differences in agency ecosystem classification systems (i.e. Bailey, 1976 versus Omernik, 1987). The increasing number of ecoregion classifications and methodologies used for delineation are significant problems that need to be addressed. "As a means of partitioning the landscape, ecosystems represent a classical Frank Sinatra approach-ecosystems are determined 'my way,'" (Fitzsimmons, 1995; 79). Without a consensus, ecoregions do not represent a coherent system for guiding federal ecosystem management policy (Fitzsimmons, 1995; 1996a; 1996b; 1998). Finally, Fitzsimmons (1995) argues that ecosystems are not real. He returns to arguments that appeared early in geographical literature. These works argue that regions are nothing more than fictional and mental constructs and, therefore, cannot be defined.

J.F. Hart (1982) provides an ample response to the arguments put forth by Fitzsimmons, "Regions are subjective artistic devices and they must be shaped to fit the hand of the individual user. There can be no standard definition of a region, and there are no universal rules for recognizing, delimiting, and describing regions," (Hart, 1982; 21-2). Regional classifications are, by nature, tailored for user and use. Each agency has a different goal, and a need for a different classification system.

However, Fitzsimmons does introduce an interesting point. If ecoregions were used to guide policy decisions, would the subjectively defined classifications withstand the scrutiny of the law? On this point, it is important to recall that ecoregions represent broad generalities, and the lines distinguishing the regions are transition zones. As long as users acknowledge these inherent facts, policy problems should not arise.

4.23 Ecoregion Research Trends

The use of individual ecoregion classifications has changed in the last twenty years. In the 1980's, researchers most often cited Bailey's framework. The use of the EPA's interagency classification has since displaced the use of Bailey's ecoregion classification in the 1990's. The frequency of publications that developed or used ecoregions appears in the following graph (Figure 4.5).

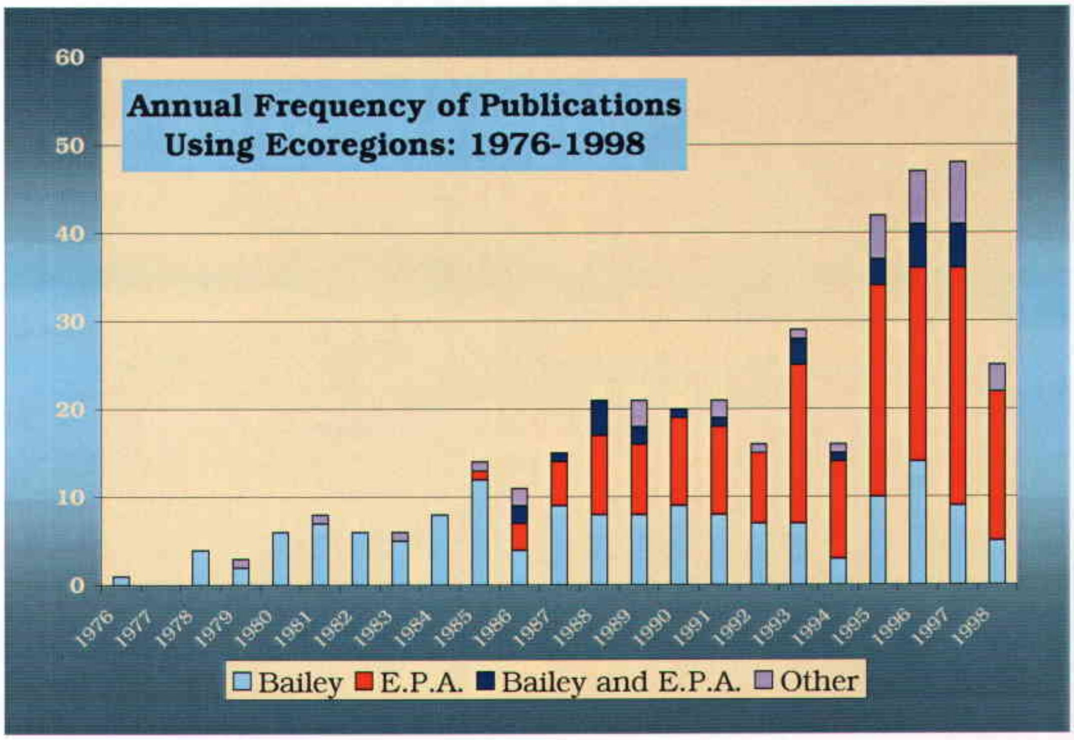

Figure 4.6 Annual Frequency of Ecoregion Publications: 1976-1998

Figure 4.5 also depicts the overall expansion of the ecoregion classification. Ecoregions are being used with increasing frequency, and the overall trend appears to be a steady increase (the low value for 1998 is likely the result of an incomplete data set). The recent development of several new ecoregion classifications and the dissemination of the information on the World Wide Web will continue the expansion of ecoregion use. The Internet is already influencing the development of ecoregions; a search for the term ecoregion yields numerous websites utilizing ecoregions in some form.

There are notable differences between Bailey's classification system and that of the EPA. Water quality management issues are the dominant, distinguishing factors in the EPA's classification. However, climate, habitat, and remote sensing applications form the crux of Bailey's classification. The following diagrams (Figures 4.7 and 4.8) show the differences in uses between the two classifications.

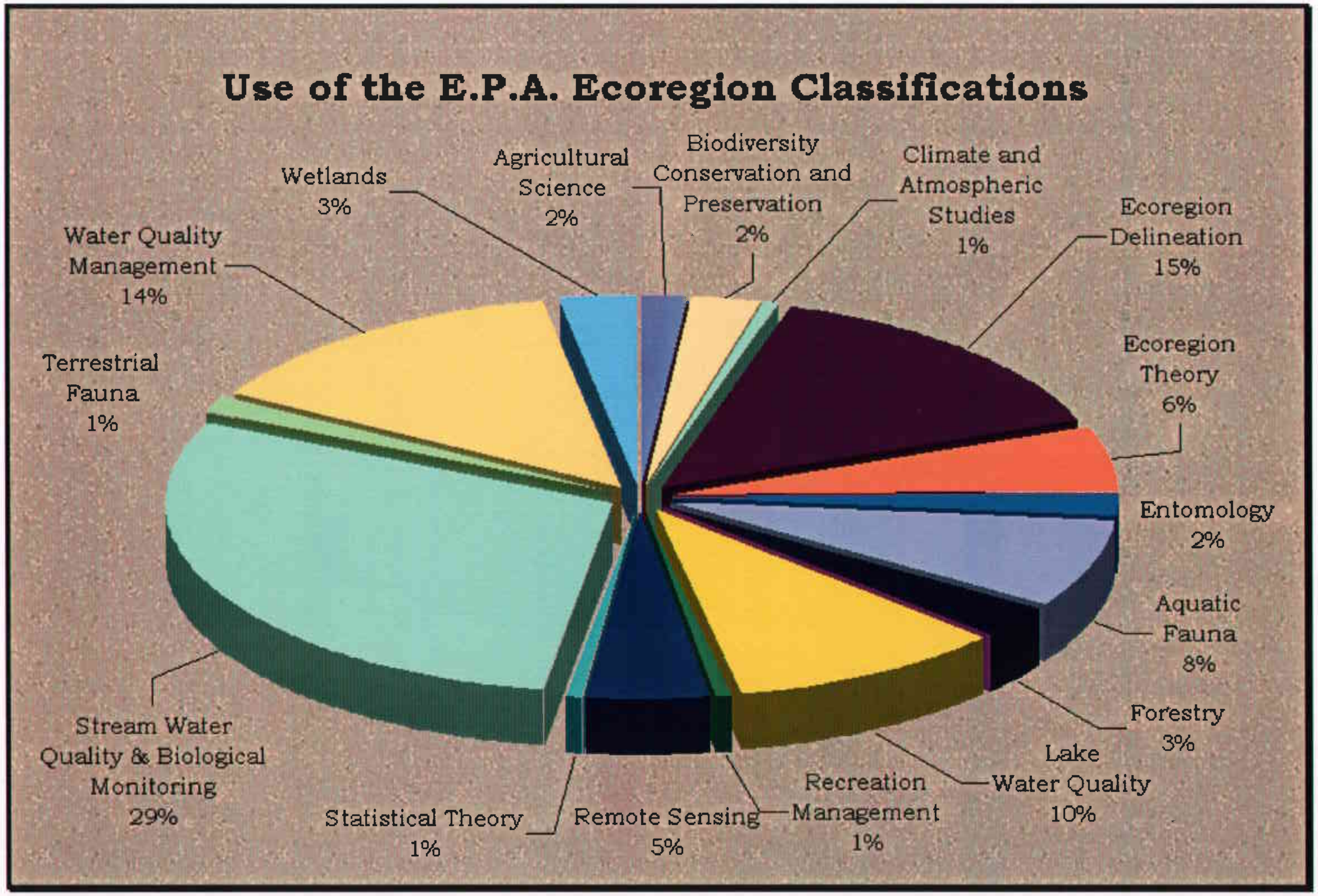

Figure 4.7 Use of the EPA ecoregions: 1976-1998

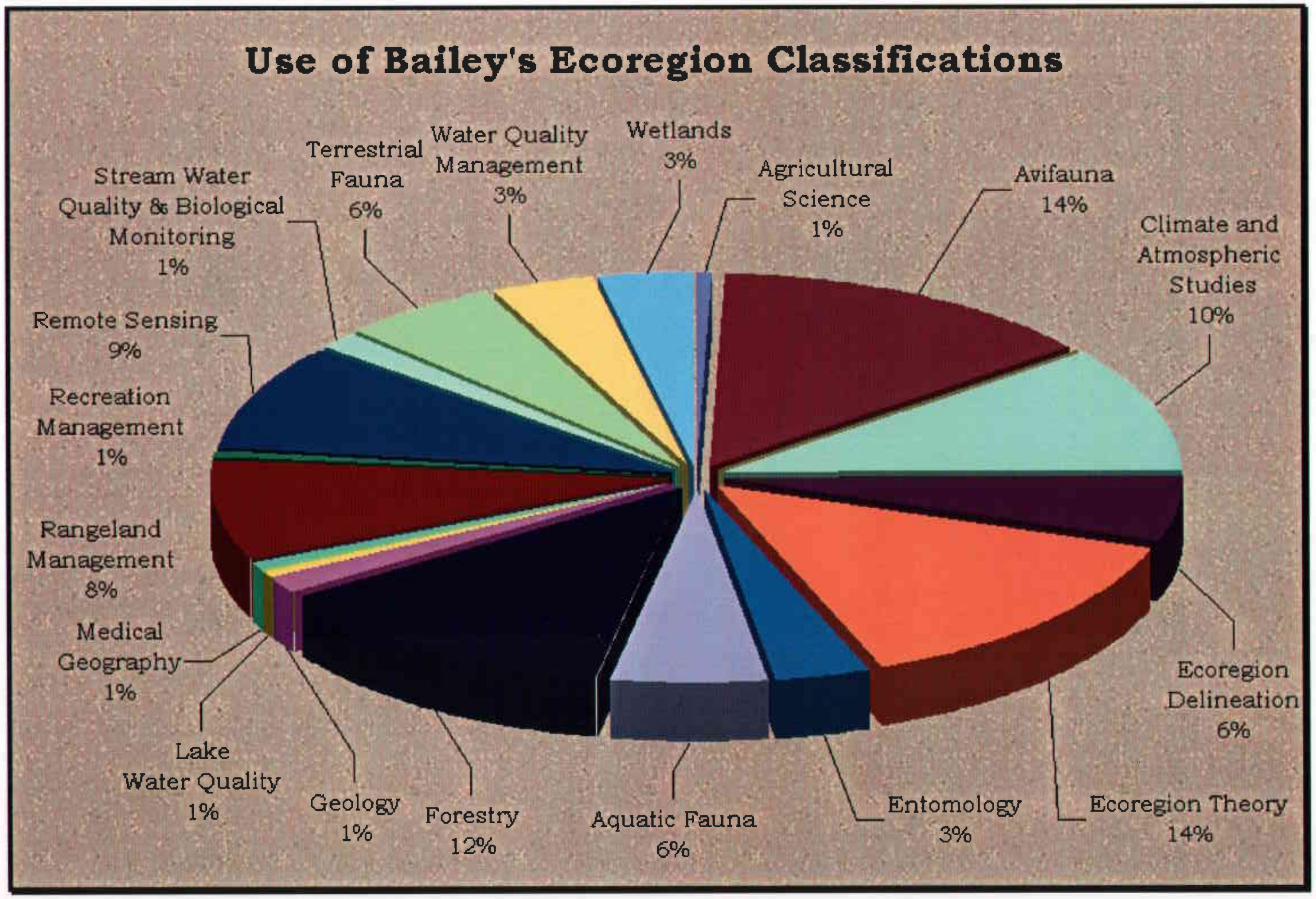

Figure 4.8 Use of Bailey's ecoregions: 1976-1998

4.24 Summary

Ecoregions have proven a useful framework for a wide variety of applications. The examples presented in this chapter are a sampling of the multitude of ways researchers could employ ecoregion frameworks for environmental and geographical studies. The numerous ways that ecoregions can be used are testament to the broad-based holistic nature of ecoregion classifications. While Bailey's ecoregions, originally developed for the Forest Service, and Omernik's first map, developed for the EPA, were first used for management primarily by the agencies for which they were developed, the use of the frameworks has steadily expanded. In recent years, other organizations and research agencies have used ecoregions for biotic conservation strategies, remote sensing applications, and climate change studies.

That such a diverse range of fields and disciplines has found ecoregions useful suggests the sustainability of ecoregion studies, yet dissention remains. The arguments made by Fitzsimmons (1995; 1996a; 1996b; 1998) should not be disregarded without ample consideration; however, with over 350 uses of ecoregions within a 32 year period, it would seem that his argument, which states that ecoregions are not useful for federal environmental management, is untenable.

Chapter V

Conclusions

"The highest form of the geographer's art is producing good regional geography,"
(J.F. Hart, 1982; 2).

5.1 Areas of Expanded Use and Concern

Certain applications will likely see expanded use of the ecoregion classification. For example, water quality management, remote sensing, and biodiversity conservation are among the applications that will be utilized more extensively than they are today.

Water quality management applications will also likely increase because the creation of level IV EPA ecoregions for individual states will promote their use. State agencies currently use the level IV ecoregions to select regional reference sites and to implement water quality management strategies. The EPA framework will likely continue to be used for water quality purposes.

Ecoregions could be used to extrapolate data from Long Term Ecological Research sites (LTER's). The system of LTER's was created to promote baseline studies of ecological conditions, but difficulties have arisen with data uniqueness. One of the difficulties studies based on data obtained from LTER's have encountered is data are only useful for the specific area in which the research was conducted. Ecoregions could be used as extrapolation units for the information discovered in LTER's. The information could then be used for resource management applications, rather than solely for baseline research.

Education and public awareness are also areas in which ecoregions could be used. Ecoregions could aid educators who teach regional and physical geography. Course work could be stratified by ecoregions. This stratification would allow teachers to incorporate information about soils, climate, vegetation, landforms, and land use activities in the course curriculum. These additions would help promote integrative thinking and holistic environmental management.

The tropical dry ecosystem in Mexico is an example of a North American ecosystem in peril. The ecoregion concept could explain the factors involved in developing programs that promote public awareness of diversity, or stimulate scientists to conduct research on the conservation and use of the tropical dry ecosystem (CEC, 1997). Conservation organizations utilize ecoregions this way. Environmental information could be disseminated to the public through ecoregion classifications.

Bird conservation programs using an ecoregion approach will likely increase as well. The delineation of a new system of avifaunal ecoregions will provide the impetus for future studies that promote the use of ecoregions for bird conservation, preservation, and management.

Ecoregions could be also be useful for historical reconstruction of environmental landscapes. Emily Russell, an historical ecologist, points out that historical landscape studies should first compile the natural abiotic features of the research area at an appropriate scale. Consideration of climate, microclimate, bedrock, surficial geology, and soils was deemed important because the factors determine the possible ecosystems, species composition and structure. Abiotic features and location strongly influence the potential natural vegetation and human activities (Russell, 1997). The military is responsible for restoration and preservation of environmental landscapes on military bases, and might find ecoregions useful for identifying the original landscape patterns and restoring the ecosystem to its natural state.

Anthropogenic and climatic change could yield ecoregions less useful after many years, therefore, temporal variability is an important research issue. A useful approach might be the addition of an expiration date to ecoregion classifications. With the increased ease of computer mapping and online distribution, ecoregion developers could update versions of the maps in a short period of time, thus keeping the framework current. Developers of ecoregion theory should investigate this issue further.

The rapid expansion of urban areas is also an area of concern. Large cities such as Las Vegas and Phoenix are significantly changing the environmental surroundings of the region. Increased moisture from lawns and golf courses has caused microclimatic changes, and the smog from automobile emissions affects precipitation patterns. Soils are also altered with chemical and organic inputs, further altering the natural status of the region. Roads and parking lots prevent native plant species from establishing themselves, allowing non-native flower and garden varieties to spread throughout the region. These alterations might create the need for the delineation of a new class of urban ecoregions.

5.2 Final Thoughts

This thesis has provided information that can help researchers better use the ecoregion concept effectively. Effective use of ecoregions for environmental management requires the consideration of a several important issues. First, the user must adopt a holistic perspective, in which the focus is on broad-scale as opposed to point source management. The development of the ecoregion concept evolved from a combination of historical geographical theory for classifying natural regions, in addition to governmental mandates and legislation of the 1960s and 1970s (NEPA). The development of the currently accepted ecoregion classifications represents the integration of geographic theory and legislative mandates. These classifications would provide a rationale for regional classification and would also serve to link theory to practice.

Potential users of ecoregions should be cognizant of the similarities and differences among the ecoregion classifications in use today. Specific delineation techniques, methodologies, and criteria used for boundary demarcation vary widely among classifications, and common sense dictates care should be taken in the selection of an ecoregion scheme designed to meet the user's needs.

The final criterion for effective use of ecoregions requires a formal understanding of the purpose of ecoregion classifications. Ecoregions were not created to aid in classification of individual species or resource factors. This is not to say that ecoregions could or should not be used for single species faunal analyses; ecoregion classifications might ultimately prove useful for such endeavors. On the contrary, users would most likely achieve better results, and reduce or eliminate the possibility of wasting finite, research resources if they used ecoregions for studies that spanned a broad range of environmental variables and resources. Therefore, the use of ecoregions for broad-based, environmental management concerns represents the best application of this diverse classification scheme.

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Appendix

ECOREGION QUESTIONNAIRE

Name: ______________________________

Job Title: __________________________

What is your collegiate training?

Undergraduate Major / Location:

Master's focus / Location:

Thesis or Project Title:

Ph.D. focus / Location:

Title of Dissertation:

What do you consider to be your geographic specialty? (e.g. climate, geomorphology, biogeography, etc)

Additional Training:

Number of years spent working on ecoregions: _____

What are the states in which you have worked on ecoregion delineation?

What is your motivation for working on ecoregions?

Please circle the *BEST* definition of the term ecoregion on the following list. If none of these examples are suitable, feel free to compose your own.

I. Area depicting ecosystems of regional extent at the macroscale in which there is a distinctive association of causally interconnected features in which a change in one feature would cause a change within another and the geographic distribution.

II. Any large portion of the Earth's surface over which ecosystems have characteristics in common

III. A classification of ecologically distinctive areas, at a variety of scales, of the Earth's surface. Each area can be viewed as a discrete system which has resulted form the mesh and interplay of the geologic, landform, soil, vegetative, climatic, wildlife, water and human factors which may be present.

IV. Areas with relative homogeneity in ecosystems within which the mosaic of ecosystem components, biotic (including humans), abiotic, terrestrial, and aquatic, is different than that of adjacent regions.

V. Relatively large areas of land or water that share a large majority of their species, dynamics, and environmental conditions.

VI. Ecoregions follow living boundaries, laid down by climate and natural ground cover and within each lives a cohesive collection of living things, a characteristic cover of plants and animals adapted to the terrain and seasons, the natural trials of wildfire, drought and floods.

VII. ____

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____

Rank of Importance of Geographical Factors at Level III

Assume you are confronted with the task of delineating Level III ecoregions for a hypothetical continent that contains all of the following factors. Please rank the importance of the various factors, and point out those factors that are not applicable for Level III delineation. Circle any factors that stand out from the rest in level of importance.

Extremely Important 5
Important 4
Moderately Important 3
Somewhat Important 2
Not Important 1
Not Applicable N/A

_____ Presence of Glaciated Terrain
_____ Fish Faunal Distributions
_____ Urban Features
_____ Mammal Fauna
_____ Avifaunal Distributions
_____ Bedrock
_____ Soils
_____ Vegetation
_____ Agricultural Development
_____ Mining (including tailings)
_____ Microclimates
_____ Mesoclimates
_____ Macroclimates
_____ Physiography
_____ Stream Water Quality
_____ Logging Activity
_____ Chemical soil components
_____ Lake Water Chemistry
_____ Hydrology
_____ Political Boundaries
_____ Land Use
_____ Surficial Geology
_____ Nuclear Test Sites
_____ Engineered Waterways (Canals, Aqueducts)
_____ User's objectives
_____ Human Population Density
_____ Federal Agency Jurisdictions (e.g. BLM vs. NPS vs. FS operated lands)
_____ Regional Anomalies (former swamps, lakebeds)
_____ Weather Anomalies

Rank of Importance of Geographical Factors at Level IV

Assume you are confronted with the task of delineating Level IV ecoregions for a hypothetical place that contains all of the following factors. Please rank the importance of the various factors, and point out those factors that are not applicable for Level IV delineation. Circle any factors that stand out from the rest in level of importance.

Extremely Important 5
Important 4
Moderately Important 3
Somewhat Important 2
Not Important 1
Not Applicable N/A

_____ Presence of Glaciated Terrain
_____ Fish Faunal Distributions
_____ Urban Features
_____ Mammal Fauna
_____ Avifaunal Distributions
_____ Bedrock
_____ Soils
_____ Vegetation
_____ Agricultural Development
_____ Mining (including tailings)
_____ Microclimates
_____ Mesoclimates
_____ Macroclimates
_____ Physiography
_____ Stream Water Quality
_____ Logging Activity
_____ Chemical soil components
_____ Lake Water Chemistry
_____ Hydrology
_____ Political Boundaries
_____ Land Use
_____ Surficial Geology
_____ Nuclear Test Sites
_____ Engineered Waterways (Canals, Aqueducts)
_____ User's objectives
_____ Human Population Density
_____ Federal Agency Jurisdictions (e.g. BLM vs. NPS vs. FS operated lands)
_____ Regional Anomalies (former swamps, lakebeds)
_____ Weather Anomalies

To better understand the inclusion and significance of reference sources, please rank the categories of references that are most important when delineating ecoregions. You may assign equal ranks to material.

Departmental literature (not peer reviewed)	_____
Professional Papers (peer reviewed journals, etc)	_____
Text and Reference books (excluding atlases)	_____
Maps	_____
Atlases	_____
Internet Websites	_____
Other ______________________	_____

Rank the following features of ecoregion classifications based on importance. Write N/A any features that do not apply:

_____ Transcend agency jurisdictions

_____ Transcend political boundaries

_____ Use for fishery management

_____ Use for forestry management

_____ Aid conservation of biodiversity

_____ Aid wildlife management

_____ Improve water quality management

_____ Use as an Extrapolation Unit

_____ Broad-Based Holistic Environmental Management

_____ Other _________________________________

Briefly state the greatest advantage ecoregions have over other environmental classifications?

Rank the following concerns associated with ecoregions. The greatest area of concern should be assigned the number one:

_____ Lack of a formal procedure for delineating and subdividing ecoregions

_____ Lack of formal methods for selecting reference sites

_____ Difficulty defining and locating boundaries

_____ Difficulty in repeatability of delineation

_____ Use of different landscape variables among frameworks

_____ Extreme differences in relative ecoregions size at the same level

_____ Varying levels of within region homogeneity

_____ Other: ________________________________

In your opinion, what will be the foremost "future use" of ecoregions in the next century?