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A form of classification of natural-cultural systems as biogeoclimatic units is presented. The foundation for understanding this form is initially laid by briefly reviewing classification theory. The foundation is strengthened by establishing the organismic conceptual framework and the theory of natural-cultural systems from which this form of classification is derived. After consideration of these higher level conceptual structures, the implications for the form of the classification system are made apparent.

The hierarchical form of the biogeoclimatic classification is presented by utilizing a notation that symbolizes substrate, climate, water, biota, and culture as primary subsystems of natural-cultural systems, as well as the natural-cultural system's environmental system. Natural-cultural systems are classified according to the capacity of their subsystems and the capacity of their environmental system.

After the forms of some other particular classification systems are reviewed, the conceptual ties between these systems and the integrated form of biogeoclimatic classification are established. Finally, ways of applying integrated biogeoclimatic classification to natural-cultural systems are proposed and applications for achieving the objectives of science and management are presented.

A Conceptual Unification and Application of Biogeoclimatic Classification

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INTRODUCTION

Explanation, understanding, and management of what we take to be natural-cultural systems, which entail man, his resources, and other conditions of life, must involve classification of such systems and their elements. There are, of course, numerous classification systems of value in the science and management of natural resources, including soils, waters, atmosphere, biotas, and man. Whereas some classification systems are devoted, say, just to soils or to vegetation, others are more nearly "ecosystem" classifications intended to deal with entire biogeoclimatic systems.

I here present a theory and form for integrated biogeoclimatic classification, not simply as another more or less adequate way of classifying natural-cultural systems, but also as a way of seeing the logical relations among extant classification systems, which exist in almost intimidating diversity. This can be of value to those who, for very good reasons, continue to employ the special classifications of their field of endeavor, in that it can lead to clearer understanding of natural-cultural interrelations and for enhanced communication. For those able to make use of an integrated classification system, such logical unification illuminates where extant classifications and methodologies can be brought to bear.

The integrated classification I am here proposing takes natural-cultural systems to be hierarchically ordered and, at each level, better classified by their capacities and environments than by their states or performances. The way we classify, it seems, is determined by our objectives, our conceptual framework, and our experience of the objects being classified. My objectives and conceptual framework lead me to a theoretical view of systems and their organization that allows on the one hand for classification and on the other for general systems modeling, both of which it seems to me are necessary for resource science and management.

In what follows, I will present a theory and form for integrated classification and explain the conceptual unification of biogeoclimatic classification. A foundation for understanding the theory, its form, and application will be laid by discussing the nature of classification and considering the factors that lead to adequate classification systems. The forms of more particular classification systems will be discussed in conjunction with an examination of the conceptual and methodological unification of biogeoclimatic classification. Methods for applying integrated classification to natural-cultural systems will be proposed, and the applications of unified biogeoclimatic classification to science and management will be reviewed.

A FOUNDATION FOR INTEGRATED BIOGEOCLIMATIC CLASSIFICATION

The Nature of Classification

Classification is a basic cognitive process fundamental to all conceptual thought. It is the basis of generalization and functions in communication. Classification is the foundation of science (Gilmour 1951; Sokal 1974). Resource managers classify to enhance the organization of experience and the communication necessary for decision making and management practices.

The nature of any classification system has at least three determinants: its objectives or underlying purpose, the theoretical perspective assumed, and perceptual experience of the objects to be classified (Wright 1972; Warren 1979). Although objectives exert a major influence on the nature of a classification system (Williams 1967), they are often unstated. Clear statements of objectives provide specific criteria and can lead to stronger classification systems. The theoretical perspective or point of view assumed will in part determine objectives as well as how the objects to be classified are to be perceived. The objects to be classified affect the nature of the classification system, but only as they are experienced.

The characteristics used to group entities are referred to as differentiae (Mill 1874) or differentiating characteristics (Cline 1949).

The most useful classification systems are based upon differentiating characteristics in association with accessory characteristics. The accessory characteristics are predictive covarying properties, which increase the number of inferences that can be made about each grouping (Cline 1949). Thus classes may finally be determined by the values and ranges of the differentiating and accessory characteristics, but usually only after much of the total experience of the classifier has been taken into account.

Much of the literature concerning classification deals with various types of classification systems. Polythetic classifications rely on many differentiae to organize and group objects. Monothetic classifications utilize one differentiating characteristic. A non-hierarchical classification system groups individuals only at one level, while a hierarchical classification system groups classes of objects into one or more higher level categories. These classes of objects are ordered according to the relationships between classes (Bailey et al. 1978). Classes and higher level categories are mutually exclusive on their own levels (Grigg 1965; Bailey et al. 1978). Higher ranking categories are more heterogeneous. Hierarchical systems can be generated by either divisive or associative classification techniques.

The divisive approach divides an entire population into classes on the basis of some differentiating characteristic. These groups are then subdivided into finer groups until the level of individual is reached. This process yields a descending hierarchy

(Grigg 1965; Wright 1972). The associative method or taxonomic approach (Bailey et al. 1978) groups individuals in a population according to similar characteristics to form an ascending hierarchy. The form of the integrated classification system proposed by Warren (1979) and to be discussed here is polythetic, hierarchical, and predominantly associative.

The Objectives of Classification

According to Warren (1979), the purpose of integrated biogeoclimatic classification is to facilitate the achievement of scientific and management goals. One goal of science is to increase understanding of natural-cultural systems, the functional components of the ecosphere. Because integrated classification utilizes information from many disciplines as differentia, it can provide a way of unifying and increasing understanding of natural-cultural systems. And integrated classification provides a structure for more universal generalization.

Goals are very general and, in a sense, may be more or less unattainable. Specific scientific objectives may be attainable and can provide closer guidance and even evaluative criteria in the development and use of a classification system. Warren (1979) has suggested that the scientific objectives of a classification system can be taken to be:

> (1) "To order the domain of regional and zonal systems of natural-cultural systems.
>
> (2) To provide through the ordering of empirical experience some prediction, explanation, and understanding of the behavior of natural-cultural systems.
>
> (3) To facilitate explanation and understanding of natural-cultural systems and subsystems of these through making apparent systems, problems, general objects, relations, relative invariances, and possible approaches.
>
> (4) To provide an ordering of experience about the hierarchical system that is dimensionally, dynamically, and empirically adequate for explanation and understanding."

By extending the understanding of natural-cultural systems, science lays a foundation for achieving specific management goals.

Management goals should pertain to the development and persistence of good natural-cultural systems (Minore 1972; Cooke and Doornkamp 1974; Boyce and Cost 1978; Warren 1979). Here "good" should be taken in the most universal sense. Such a management goal can provide needed orientation, but we need management objectives, as we needed scientific objectives, that are more nearly attainable. Warren (1979) suggested that management objectives for an adequate biogeoclimatic classification can be taken to be:

(1) "To unify natural and cultural domains involved in resource and environmental management.

(2) To identify and classify major systems in the hierarchy including ecosystems and watersheds according to common capacities, environments, and responses to environmental conditions including resource utilization and environmental management.

(3) To provide an adequate basis for integrated watershed resources management including the maintenance of stream quality.

(4) To provide an ordering of experience about the hierarchical system including watersheds that is dimensionally, dynamically, and empirically adequate for resource and environment management."

A Conceptual Framework for Integrated Biogeoclimatic Classification

World views and somewhat lower level conceptual frameworks, even when not made explicit, determine our explanations and even understanding. When made explicit, they exist as a set of high level assumptions according to which we would understand the world. A conceptual framework for biology proposed by Warren, Allen, and Haefner (1979) employs the terms biological system, organismic system, environment, performance, and capacity as theoretical concepts. The components of a biological system are an organismic system and its coextensive environment. The coextensive environmental system includes factors that impinge on the organismic system indirectly as well as directly. An organismic system incorporates its subsystems along with their coextensive environments and is itself incorporated by a more encompassing system.

An organismic system has performances. A performance is defined here as a single time-specific state or behavior. Organismic system performance depends on characteristics intrinsic to the organismic system as well as performances of the coextensive environment. A performance only partially describes a system.

The capacity of an organismic system can be thought of as all possible performances in all possible environments. As such, capacity is a theoretical concept, neither directly nor fully determinable. Only performances can be observed or measured. To represent capacity at all adequately, one must observe performances through a wide range of environmental conditions. The capacities as well as the performances of organismic systems tend to be in concordance with those of their environmental systems. Organismic systems and environmental systems interpenetrate.

In this view, then, organismic systems are not discrete Newtonian objects, separable from one another and from their environments and adequately describable in terms of their states. They are better understood in terms of their coextensive environments, their developing capacities, their incorporation, their concordance, and their interpenetration. They may be described in terms of their subsystems, but they cannot be meaningfully analzyed into their subsystems. The implications of this in theory, model, and classification will become apparent.

Relevant Empirical Experience

A biogeoclimatic classification theoretically or nominally based on the capacities of natural-cultural systems and their environments must immediately raise empirical difficulties. Capacities can neither directly nor fully be determined. Yet such a theoretical perspective emphasizes what is too often ignored: that the performances of systems, because of intrinsic system and environmental properties, are quantitatively and qualitatively so variant as to make any relatively limited set of performances inadequate as invariant characterizations. Without giving up the theoretical ideal of classification according to capacity, we have then to determine those sorts of performances that most adequately characterize the capacities of natural-cultural systems and their environments.

In principle, these should be the performances, states, or structures most fundamentally and invariantly causally involved in the more dynamic state behaviors of the systems being classified. Geological manifestations may often be in this category. Historic ranges of performances--as in the case of rainfall, temperature, or evapotranspiration characterizations of climate--may be substituted for capacity expressions. Where neither fundamental structures nor historic performances are available as expressions of capacity, it may be necessary to infer capacity from what is known about the organization of the system. Much of what is known about the capacities of natural-cultural systems is not easily quantifiable--

indeed it is fallacious to suppose all properties of systems are simply quantifiable. Certainly their capacities are not. It should be possible, and it is one of the advantages of a capacity classification, to informally take into account much of our experience of systems of interest. It is here that the total experiences of those involved in classification play an important role.

Criteria for Integrated Biogeoclimatic Classification

Classification systems share with theories at least two properties. They are hypothesis-like and they are instrumental: they order our empirical experiences, and in this and other ways they serve as tools. Now in no simple way are either theories or classifications falsifiable or confirmable--neither are hypothesis, which are always contingent on other matters that might be stated as further hypothesis or assumptions. And, of course, in their tool-like capacity, the truth or falsity of theories and classifications is irrelevant.

In general, then, the overall criterion for a classification in its hypothesis-like mode is that there be concordance or harmonious and rule-like relation between the classification and empirical experience. The general criterion for the tool-like mode can only be utility: Does the classification facilitate attainment of the goals and objectives for which it was designed? It is here that careful specification of the goals and objectives of a classification system being developed can later provide criteria for its evaluation.

Classification should, of course, in some sense conform to the more particular criteria of theories and other explanations. Rather generally these can be stated as internal consistency, external adequacy, explanatory power, heuristic power, and aesthetic appeal. Perhaps as a further elaboration of these general criteria, we should specify theoretical adequacy, dimensional adequacy, relational adequacy, and empirical adequacy for management (Warren 1979). It is here that there should be continuous evaluation of any classification system, for in this there is the potential for advances in understanding.

A THEORY FOR INTEGRATED BIOGEOCLIMATIC CLASSIFICATION

Natural-Cultural Theory

A conceptual framework is a relatively high level cognitive structure from which more specific general theories can be derived. The organismic conceptual framework discussed here has lead to a theory of natural-cultural systems (Warren 1981 pers. comm.). From this theory both models of natural-cultural systems and the forms for an integrated classification of natural-cultural systems are derived. Figure 1 illustrates the relationship between the conceptual framework, the theory of natural-cultural systems, and the form of integrated biogeoclimatic classification, which will be presented in the next chapter.

The axioms of the theory of natural-cultural systems are as follows:

Axiom 1. "Any natural-cultural system tends to be in concordance with a coextensive, codetermining environmental system.

Axiom 2. Persistence and distribution of any natural-cultural system depend on development, evolution, and maintenance of present and probable future concordance of its capacities as well as its performances with those of its environmental system.

Axiom 3. Any natural-cultural system is incorporated into a system of interpenetrating natural-cultural systems tending to be in concordance.

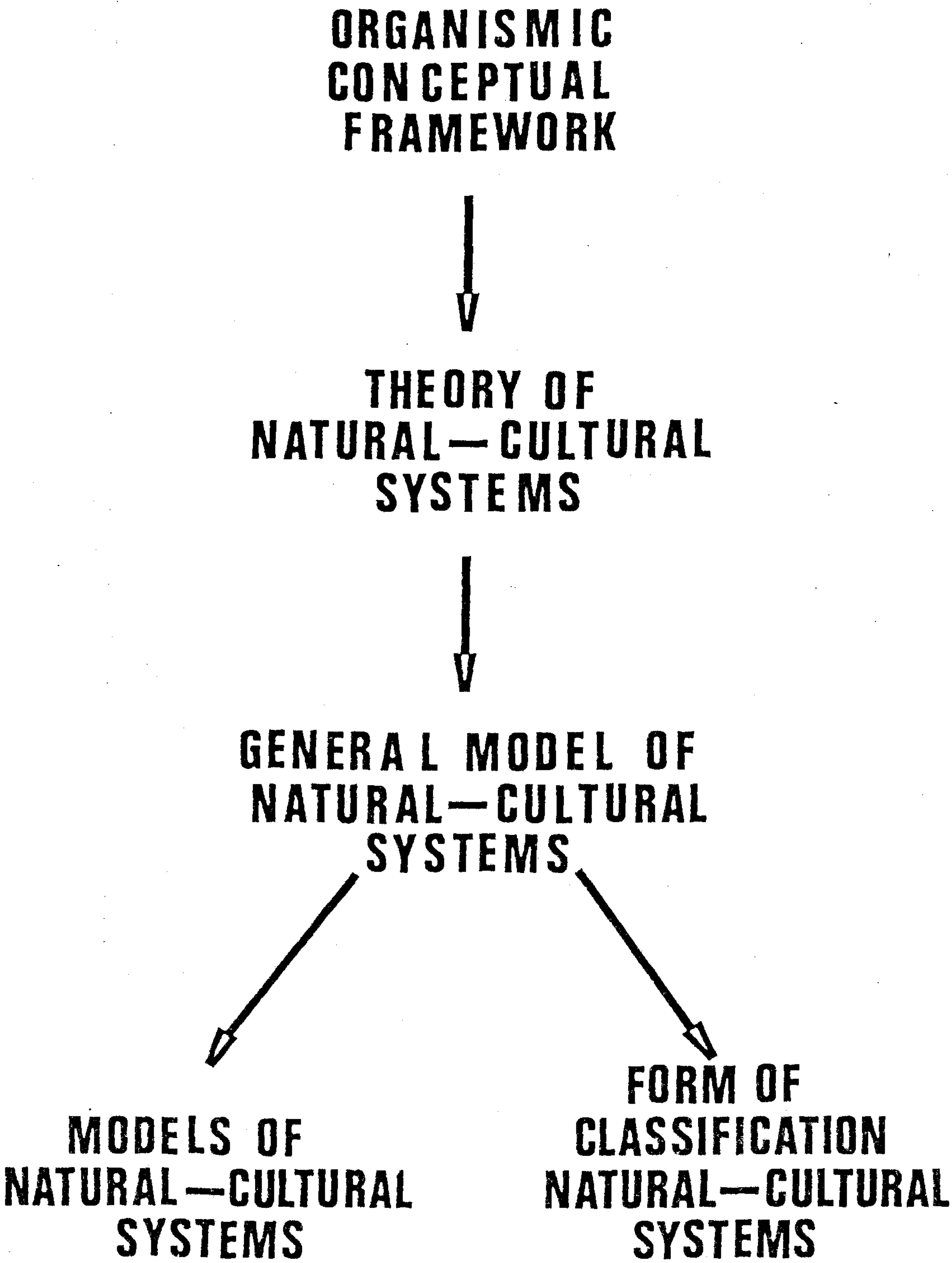

Figure 1. The relationships leading from the organismic conceptual framework to either a form of classification or models of natural-cultural systems.

Axiom 4. Potential capacities, realized capacities, and performances of any natural-cultural system are determined by the organization of the natural-cultural system, the organization of its environmental system, and the organization of the encompassing system of natural-cultural systems."

Definition 1. "The organization of any natural-cultural system or environmental system entail the incorporation, concordance, and interpenetration of the capacities and environments as well as the performances of its subsystems."

Corallary 1. "Development and evolution of any natural-cultural system, or change in its organization and thus its capacities and performances, are determined by its organization, the organization of its environment, and the organization of its encompassing system of natural-cultural systems."

Implications for a Form of Classification of Natural-Cultural Systems

The axioms of this theory provide a conception of natural-cultural systems that has certain implications for their classification. Fundamentally, the assumption that the persistence and distribution of any natural-cultural system depend on present and future concordance between the environment and the capacity of the system implies that classification of natural-cultural systems should proceed, at least in part, according to their capacities and not simply their performances. The ideal differentiae for the classification of natural-cultural systems are capacity characterizations.

According to Axiom 4 and Definition 1, the capacity of a natural-cultural system is at least in part dependent upon its organization, which entails the incorporation, concordance and interpenetration of the capacities and environments as well as the performances of its subsystems. In this view, the ecosphere is not an object that is comprised of separate immutable objects. But, for conceptional convenience, the ecosphere can be described in terms of its natural-cultural systems. In a similar manner, any natural-cultural system is recognized as an integrated unit of interpenetrating subsystems. These subsystems, their environments, and capacities are not discrete and separable but can be described to facilitate modeling and classifying natural-cultural systems. In this regard, the capacity of a natural-cultural system can be represented in terms of the capacities of its subsystems.

According to the theory, any natural-cultural system tends to be in concordance with its coextensive and codetermining environment. Furthermore, its persistence and distribution depend on probable future concordance of its capacities and performances with those of its environmental system. Even the capacity of the natural-cultural system depends, in part, on the organization of the environmental system in which it has developed. This implies that natural-cultural systems should be classified not only according to their capacities but also according to the capacities of their environmental systems. The capacities of natural-cultural systems and the capacities of their environmental systems are, the ideal differentiae for classification, at least in this theoretical perspective.

The assumption that any natural-cultural system is incorporated into a system of interpenetrating natural-cultural systems that are in concordance implies that for a form of classification system to reflect these relationships it should organize classification units in a nested hierarchy, in which similar classification units at one level are grouped to comprise the next higher category. The higher category represents a higher level natural-cultural system. Also, the nested hierarchy provides a means of symbolizing the coextensive and codetermining environmental system.

In conclusion, the theory of natural-cultural systems implies that both the capacity of the system, which can be recognized in terms of the capacities of its subsystems, and the capacity of the coextensive environment should be used to determine the classes of natural-cultural systems. These classes should be placed in a hierarchy of subsuming natural-cultural systems.

A FORM FOR INTEGRATED BIOGEOCLIMATIC CLASSIFICATION

To facilitate articulation of a form for integrated biogeoclimatic classification consistent with the organismic conceptual framework as well as the theory of natural-cultural systems advanced, a conceptual model of natural-cultural systems and their environments as understood in this theoretical perspective will be helpful. This conceptual framework and this theory are, fundamentally, general systems theories on two different levels of abstraction. Before proceeding to a classification system, we need a general systems model that is less abstract than the theory of natural-cultural systems. This conceptual model should be an "ecosystem" model in the broadest sense.

Major (1951) employed essentially the same determinants and functional notation for vegetation that Jenny (1941) had earlier employed for soil. In a somewhat more inclusive and generalized form, we can similarly define a natural-cultural system as a function of five subsystems and its environment: Substrate (S), Climate (Cl), Water (W), Culture (C), and Biota (B), and Environment (ENV), so that:

$$\text{Natural-cultural System} = f\ (\ S,\ Cl,\ W,\ B,\ C,\ ENV\ )$$

These primary subsystems have performances, capacities, and secondary and tertiary sets of subsystems. Each of the five primary subsystems is affected by the other primary subsystems and by the human (h), organismic (o), hydrologic (y), geologic/geomorphologic (g) and atmospheric (a) performances of the environment of the natural-cultural system. The natural-cultural system is embedded in a system of natural-cultural systems, each of which is defined just as is the natural-cultural system of interest in the above equation. This system of natural-cultural systems is the coextensive environment (ENV) of the natural-cultural system, upon which our attention is focused. These relationships are illustrated in Figures 2 and 3.

According to the theory of natural-cultural systems, such systems should be classified on the basis of their capacities and those of their environments:

$$\text{Natural-cultural classification unit} = f\left(\text{Natural-cultural system capacity},\quad \text{Environmental system capacity}\right)$$

The capacity of a system can be expressed as some function of the capacities of its subsystems:

$$\text{Natural-cultural system capacity} = f\ (S_{cap},\ Cl_{cap},\ W_{cap},\ B_{cap},\ C_{cap})$$

A natural-cultural classification unit may be symbolized:

$$\text{Natural-cultural classification unit} = f\ [(S_{cap},\ Cl_{cap},\ W_{cap},\ B_{cap},\ C_{cap}),(ENV_{cap})]$$

Natural-cultural systems can theoretically be associated in classification according to the capacities of their subsystems. No two natural-cultural systems or any other systems are exactly alike.

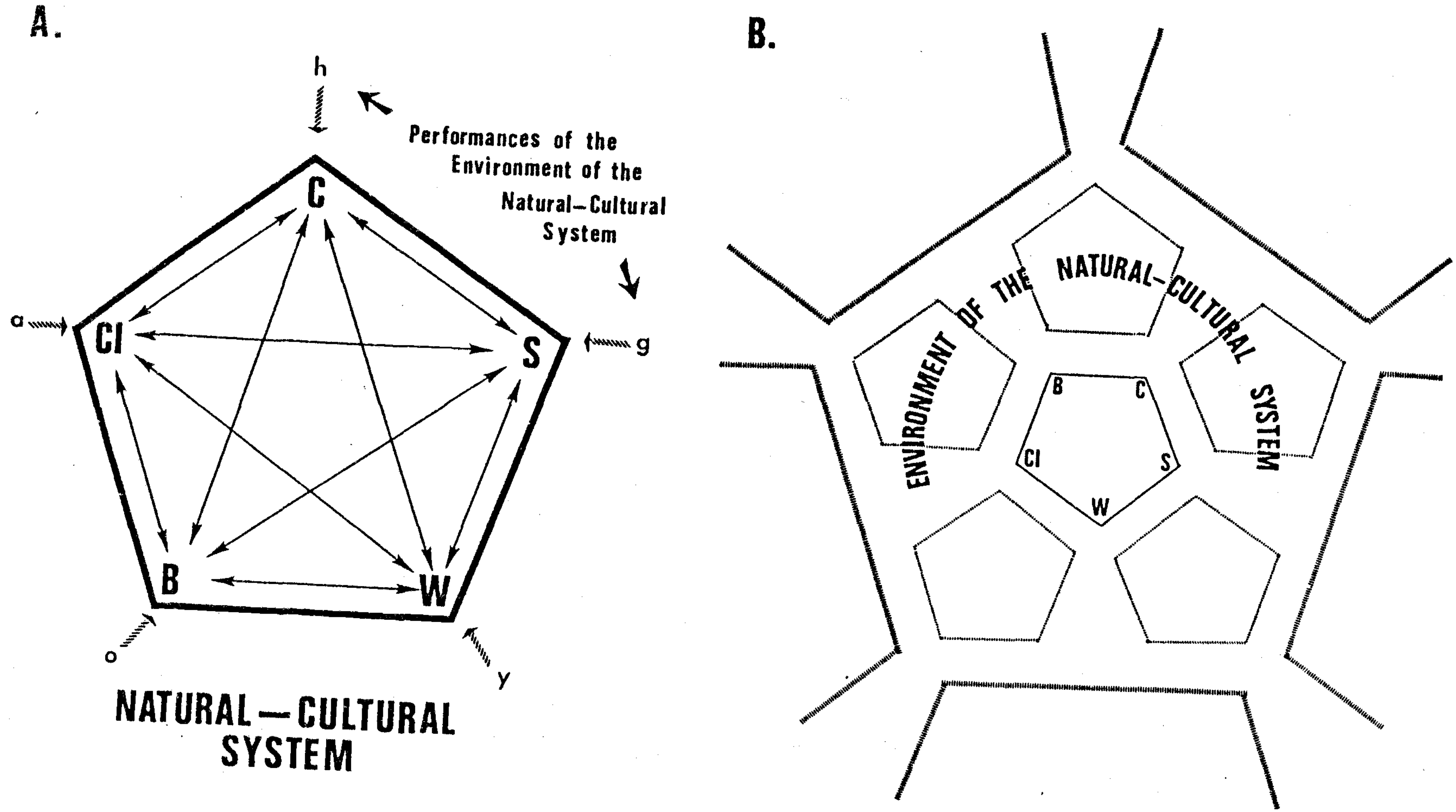

Figure 2. Kinetic diagram of a natural-cultural system and its environment.

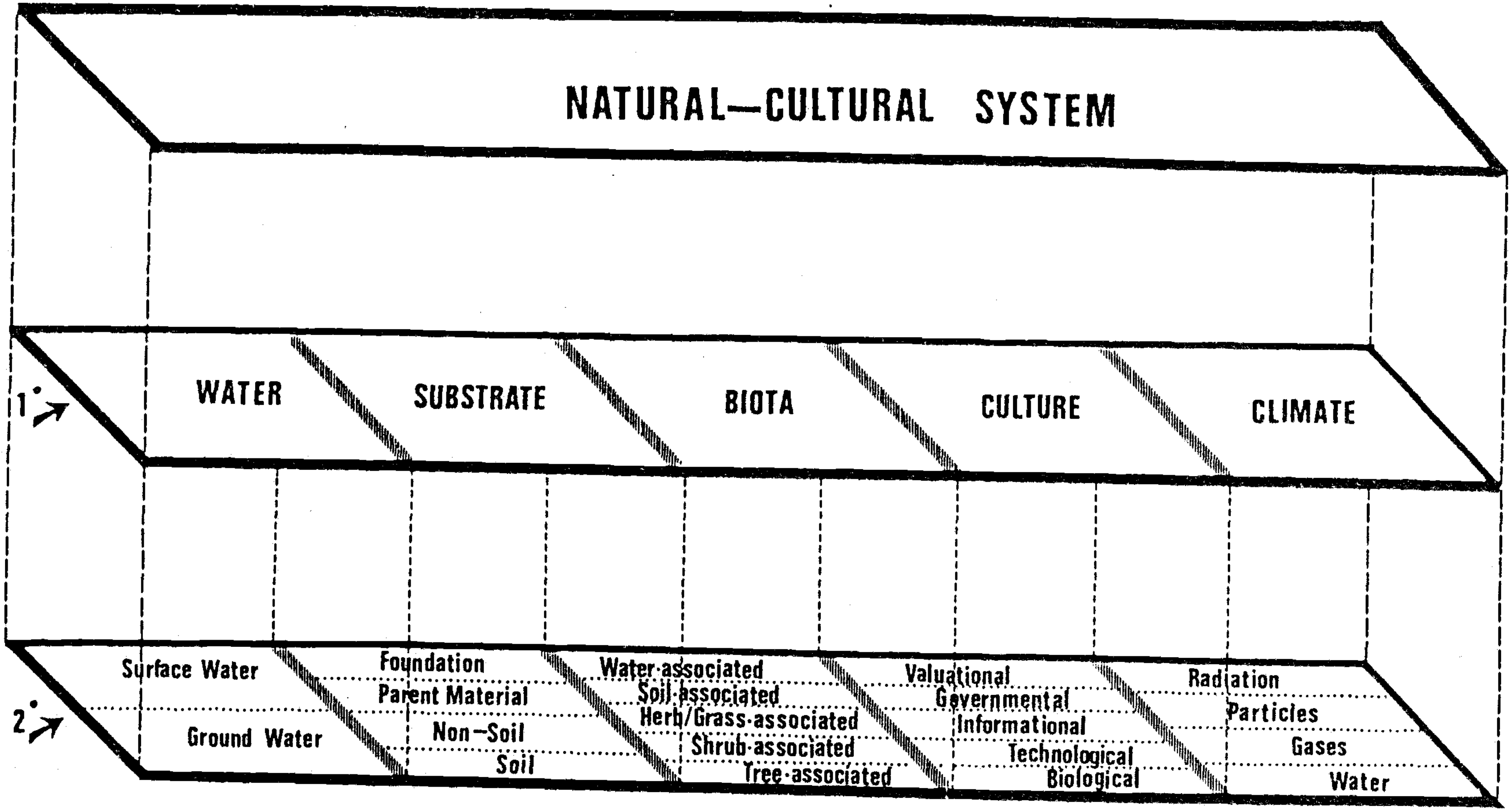

Figure 3. A natural-cultural system symbolized in terms of its primary (1°) and secondary (2°) subsystems.

But similar natural-cultural systems can be placed in the same class. In this respect, this integrated biogeoclimatic classification system is associative.

Each natural-cultural system is embedded in a more or less unique environment consisting of the system of surrounding natural-cultural system. (Fig. 2B). There is a regional framework that provides a structure in which the natural-cultural systems are placed by association (Wright 1972). This forms the system of systems to which a particular natural-cultural system belongs and which forms the next higher level in the classification hierarchy. Two natural-cultural systems having similar subsystems but different environmental systems would be placed in different classes. In this respect the form of this integrated classification system is divisive.

A natural-cultural system at the ecosystem level--the level of the individual biotic community--is relatively homogeneous with respect to its subsystems (i.e., there is one kind of Substrate, one kind of Biota, etc.). Higher level natural-cultural systems become more heterogeneous with respect to their subsystems. For example, there may be many kinds of communities comprising the Biota subsystem of a high level natural-cultural system. Such a heterogeneous mosaic of subsystems can be represented as a function of its components. If the geographic area of a mountain range is the natural-cultural system of interest, the climatic subsystem is a function of all the different climates there:

$$Cl_{mts.} = Cl_{1-n} = Cl_{all} = f\ (Cl_1,\ Cl_2,\ Cl_3,\ \ldots Cl_n)$$

The subsystems S_{1-n}, B_{1-n}, etc. will not necessarily follow the same spatial pattern in the natural-cultural system. But when all the subsystems are considered simultaneously, a mosaic of tesseras is created so that each tessera has a particular

S_{cap_i}, Cl_{cap_j}, W_{cap_k}, B_{cap_l}, and C_{cap_m}.

An upper level natural-cultural classification unit can then be symbolized:

$$\text{Natural-cultural classification unit} = f\ [(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})]$$

Upper level natural-cultural classification units are grouped according to the mosaic of such capacity tesseras. The terminology used in naming the different hierarchical levels for integrated biogeoclimatic classification is essentially the same as that Bailey (1976) used to distinguish hierarchical levels of his Ecoregions, but the criteria and classfication procedures are different. The names for the hierarchical levels are: Domain, Division, Province, Section, District, Landtype Association, Landtype, and Site. This terminology was adopted after Warren and Bailey agreed to align the two approaches as much as possible (pers. comm. 1981).

A Site is a natural-cultural classification unit at the ecosystem, or biotic community, level; it is a unit distinguishable from other such units at the Site spacial hierarchical level.

$$\text{Site Class} = f_s\ [(S_{cap}, Cl_{cap}, W_{cap}, B_{cap}, C_{cap}), (ENV_{cap})]$$

A Landtype consists of a group of related sites, so that it may be noted functionally:

$$\text{Landtype Class} = (\text{Site}_{1-n}) = f_1[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})]$$

In the same manner a Landtype Association consists of a group of related Landtypes and can be noted functionally:

$$\text{Landtype Association Class} = f(\text{Landtype}_{1-n}) = f_{la}[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})]$$

$$\text{District Class} = f(\text{Landtype Association}_{1-n}) = f_d[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})],$$

$$\text{Section Class} = f(\text{District}_{1-n}) = f_{sec}[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})],$$

$$\text{Province Class} = f(\text{Section}_{1-n}) = f_p[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})],$$

$$\text{Division Class} = f(\text{Province}_{1-n}) = f_{div}[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})],$$

$$\text{Domain} = f(\text{Division}_{1-n}) = f_{dom}[(S_{cap_{all}}, Cl_{cap_{all}}, W_{cap_{all}}, B_{cap_{all}}, C_{cap_{all}}), (ENV_{cap})].$$

Classification of a natural-cultural system at any level of the spatial hierarchy from Site to Domain requires determining the capacity of that system (perhaps by determining and integrating the capacities of its subsystems) and the capacity of its environment. This is, of course, only theoretically so. Empirically we must deal more nearly with performances, states, structures, yields, or changes in these, to approach, as nearly as we can, the capacity of the natural-cultural system of interest. To a considerable extent, this will entail methodologies of extant classification systems.

THE FORMS OF MORE PARTICULAR CLASSIFICATION SYSTEMS

Logical unification of extant systems of classifying climates, waters, substrates, and biotas in a biogeoclimatic classification system can aid understanding even when particular classification systems continue to be used, as will generally be so. And such logical unification makes available the methodologies and knowledge of other systems in support of any one system, as well as for unified biogeoclimatic classification. Prior to informally establishing logical relations among selected classification systems, their forms will be outlined. The following systems are reviewed: Köppen's (Trewartha 1943; Strahler and Strahler 1978) climatic classification, Thornthwaite's (1931; Trewartha 1943) climatic classification, Hammond's (1964) landform classification, Wood and Snell's (1960) landform classification, Küchler's (1964) classification of vegetation, Daubenmire's (1952) landscape classes according to vegetation, various physiographic province classifications (Fenneman 1931, 1938; Loomis 1937; Atwood 1940; Hunt 1974), Land Systems Inventory (Wertz and Arnold 1972; Wendt et al. 1975), Bailey's (1976, 1978) classification of Ecoregions, National Site Classification System (Merkel et al. 1980), and classification of culture. For each classification system, objectives, form, and applications will be briefly noted, insofar as possible.

Köpen: Climatic Classification

In 1918 Köppen created a classification system in which the boundaries of geographic units are determined on the basis of annual and monthly means of temperature and precipitation so that the units coincide approximately with major vegetation formations (Trewartha 1943; Strahler and Strahler 1978). Köppen's divisive system has been widely modified and revised, but also generally accepted. His climatic nomenclature is in standard use over the world (Trewartha 1943). A modification by Trewartha (1943) is used by Bailey (1976) to delineate his Division and Domain boundaries (Ellis et al. 1977). Köppen's system with the Trewartha (1943) modifications is as follows:

Climatic Groups (5)	Groups are designed to correspond to five principle vegetation formation types.
Climatic Subgroups	Climatic Subgroups are determined by temperature and precipitation differences.
Climatic Types	Climatic types are determined by seasonal distributions of temperature and precipitation (Trewartha 1943; Strahler and Strahler 1978).

Thornthwaite: Climatic Classification

Thornthwaite (1931) also developed a quantitative climatic classification system that is based on temperature and precipitation (Trewartha 1943). Since these factors are effectively tied to the soil-water balance, Thornthwaite's system is useful in assessing conditions favorable to the growth of plants. Strahler and Strahler (1978) modified Thornthwaite's system, and Bailey (1976) used Thornthwaite's 1931 (Trewartha 1943) map (scale 1:20,000,000) to identify Domain boundaries for Ecoregions of the United States (Ellis et al. 1977).

In Thornthwaite's classification, each region is identified by its values for three climatic factors:

Precipitation effectiveness (5 classes)	Precipitation effectiveness equals the sum of the monthly precipitation/evaporation values.
Temperature efficiency (6 classes)	Temperature efficiency is calculated as the sum of the monthly ratios of temperature/evaporation.
Seasonal distribution of precipitation (4 classes)	

Theoretically there are 120 permutations of possible climatic types, but Thornthwaite listed only 32 types in his classification (Trewartha 1943). Among the eight main climatic groups, five emphasize precipitation and three emphasize temperature (Trewartha and Horn 1980).

Hammond: Landform Classification

Hammond conceived of landform as a geometry (Zakrzewska 1967). His (1964) nonhierarchical classification of the conterminous United States (scale 1:5,000,000) relies on classes of the factors listed below, coded to characterize landform units. Theoretically there are 96 classes of landform possible with Hammond's technique, but his 6 mile diameter units fall into 21 classes of landforms (Zakrzewska 1967). Bailey (1976) has adopted Hammond's map (1964) as the primary determinant of the District level boundaries for his Ecoregions.

Index of slope inclination (4 classes)	There are four classes of ranges of the percentages of land area having a slope of less than eight degrees. Slope is used to make the first divisive grouping.
Vertical dimension (6 classes)	This measures local relief as the maximum difference in elevation (Hammond 1964). It is used to make the second divisive grouping.

General profile characteristic (4 classes)	Profile characteristic is an expression of vertical arrangement, described as the relative proportions of gently inclined land in the upper and lower halves of the elevation range (Hammond 1964). It is used to make the third divisive grouping (Zakrzewska 1967; Hammond 1964).

Wood and Snell: Landform Classification

Wood and Snell (1960) developed a quantitative method for classifying landforms. Four hundred and thirteen individual areas in a 100,000 square mile section of Central Europe (map scale 1:100,000) were associated into 25 regions, by means of identical scores based on the six following characteristics. The intergrade areas were associated according to priorities established by the listed significance values.

Grain	Grain is a measure of the texture of the topography. It depends on the spacing of the major ridges and valleys. Grain is determined graphically from the relationship between relief and horizontal distance, and it establishes the sample size over which the other factors are measured.

Relief (R)	Relief is the elevation difference between the highest and lowest points within the sample area. The significance is 5.
Average Elevation (E)	The average elevation is calculated by using nine points within the sample area. The significance is 3.
Elevation-relief ratio (ER)	Elevation-relief is a quantitative measure of generalized profiles. It measures the proportion of upland and lowland within an area, where L = the lowest point. Significance is 6. $ER = \frac{E - L}{R}$, $0 < ER < 1$.
Average Slope	Average slope is the mean angle of surface slope away from the horizontal. It is the feature most likely to differentiate areas. The significance is 1.
Slope direction changes	This describes the number of ridges and valleys encountered on the length of a traverse. The significance is 2.

Küchler: Classification of Vegetation

In 1964 Küchler presented a manual and a nonhierarchical map (scale 1:3,168,000) of Potential Natural Vegetation of the Conterminous United States. Potential Natural Vegetation is the vegetation that would exist today if man and his works were removed and the succession to climax were telescoped into a single moment; it is an indicator of the landscape's character. Vegetation is a mosaic of phytocoenoses or plant communities. According to Küchler, a plant community, which is a concrete, clearly identifiable unit as well as an abstract conceptual unit, is that part of the vegetation that is relatively uniform in structure and floristic composition (Küchler 1967; Ellis et al. 1977). Classifying vegetation requires identifying individual vegetation units (Küchler 1973).

For each Potential Natural Vegetation Type shown on the map and listed in the manual, the following information is given: 1. title of vegetation type (genera of 1-3 dominate plants), 2. type physiognomy, 3. common dominant species, 4. other community components, 5. occurrence of type, and 6. representative photograph of type.

Küchler's map has been used by Bailey (1976) for his Ecoregions, by the USDA Forest Service as the standard for the 1967 nation-wide Forest Survey, and by Garrison et al. (1977). According to Bailey et al. (1978), Kuchler's map is the only one suitable for evaluating vegetation on the national scale. His manual has been adopted as the guide for making Subformation descriptions in the Vegetation Component of the National Site Classification System.

Daubenmire: Landscape Classes according to Vegetation

In Daubenmire's (1952) hierarchical, associative classification system, landscapes are classified primarily according to their potentials to support different climax vegetations. Potential vascular vegetation at climax is the differentia, although certain environmental factors, such as slope, aspect, altitude, and soil characteristics (Pfister and Arno 1980) are used as accessory characteristics (Daubenmire 1952). Daubenmire (1968) assumes that climax vegetation reflects the total environment as a joint expression of climate, topography, and soils.

According to Daubenmire (1952, 1966), vegetation forms identifiable community units, not a continuum. The smallest structural unit in a community is the union, which includes a population of one species or populations of several species that have very similar ecological requirements. An Association, which is the basic vegetation classification unit, is a combination of two or more unions of vascular plants inhabiting the same area simultaneously. The term Association is applied only to climax communities, growing on uniform sites (Daubenmire 1952).

The hierarchical levels of Daubenmire's (1952) landscape classification are as follows:

Habitat Type	A Habitat Type includes all parts of the landscape that one climax Association could or does occupy. Habitat Types are discontinuous units.
Zone	A Zone is the area occupied or potentially occupied by a group of closely related Associations. It is an area of a uniform macroclimate.
Province	A Province describes an area of similar zones, having a common and distinctive geologic history, forming a distinctive geographic unit, and exhibiting strong lines of taxonomic homogeneity.
Region	A Region includes areas, in different parts of the world, in which the climatic climax Associations have a common characteristic physiognmony. A Region is associated with a common climatic regime. Essentially, it is a formation class.

Physiographic Provinces

Physiographic Provinces have been described by a number of geographers. In general, the term Physiographic Province has been applied to units of land that are joint expressions of a number of identified environmental factors.

Fenneman (1931, 1938) divides the United States into Provinces, which are physical units, and Sections, which are of particular topographic types. Then he describes the general geomorphology and the resources of the Provinces and the characteristics, boundaries, and geologic histories of the sections.

Loomis (1937) describes the physiography of the United States by delineating: 1. Divisions, which are major centers of uplift with a unified geologic history, 2. Provinces, which are areas with similar surface characteristics, and 3. Sections which are defined on the basis of finer, local differences in topography. According to Loomis, an understanding of the landforms depends on an understanding of climate. Most of his work emphasizes Provinces, for which he presents general geologic histories as well as descriptions and geologic histories of their specific landforms.

In order to provide a context for regional studies on the influence of the environment on economic and cultural development, Atwood (1940) regionalized the United States into uniform areas or Provinces according to topography. He described each Province as a whole, and then he described the major relief features, the geologic structure and materials, the geomorphic history, and features of its economic and cultural development.

Hunt (1974) divided the United States and Canada into 11 major Divisions and 40 physiographic Provinces. According to Hunt, the basic differences between various parts of the land surface are geological, structural differences. These may be accentuated by differences in climate, which governs geomorphic processes. Hunt's Province has a distinctive structural framework, determined by bedrock which gives rise to distinctive landforms with particular climatic, vegetation, soils, water, and other resource and cultural patterns. He describes the environmental factors and resources of the Provinces, their structure, boundaries, subdivisions, soils, water, and mineral resources as well as management considerations.

The Land Systems Inventory

The Land Systems Inventory was developed by the soils staff of the Intermountain Region of the USDA Forest Service (Wertz and Arnold 1972), revised (Wendt et al. 1975), and adapted and implemented by many of the National Forests. The theoretical basis of the Land Systems Inventory is that landforms, soils, and vegetation, the Manifest Components, are products of the interactions through time of climate with geologic structure and lithology, the Basic Components.

The Land Systems Inventory has seven hierarchical levels. The upper three levels are defined by the Basic Components and the lower four levels are defined by reoccurring patterns of the Manifest Components (Wertz and Arnold 1972; Ellis et al. 1977).

According to Wendt et al. (1975), classification units, which are keyed to visually recognizable land features, are delineated by combining field sampling with aerial photo interpretation and other data sensing techniques. Each classification unit is interpreted for management opportunities, constraints, and hazards for timber, water, forage, wildlife, road building, recreation, and fire management.

A summary of the hiearchical units follows:

Province	A Province is an area of similar structure and climate and has a common geomorphic history. Provinces are delineated according to landform patterns and climate as expressed by broad vegetation patterns. Provinces are 1,000 square miles or more and they are appropriately mapped at scales of 1:1,000,000 or larger. Information about Provinces is appropriate for national data summaries (Wertz and Arnold 1972).
Section	A Section is a component of a Province. It delineates differences between land units primarily by topographic patterns but also by vegetation and soil development patterns and climate. Sections are typically 100-1,000 square miles and are mapped at 1:500,000-

1:1,000,000. This level is appropriate for national and regional planning and data summary (Wertz and Arnold 1972).

Subsection	Subsections delineate the major parts of sections. A Subsection is the smallest unit that can be described using the criteria of geologic factors and climate. The appropriate mapping scale is 1:250,000-1:500,000. A Subsection typically has an area of 25-100 square miles (Wertz and Arnold 1972).
Landtype Association	This is the broadest level defined by land form, soils, and vegetation. Landtype Associations are typically 1-25 square miles and are mapped at a scale of 1:60,000-1:125,000. This level is most commonly used for land use planning within National Forests. Landtype Associations are often grouped into land capability groups having similar timber, forage, and water capabilities and responses (Wertz and Arnold 1972; Wendt et al. 1975).
Landtypes	Landtypes are visually identifiable units resulting from homogeneous geomorphic and climatic processes. They are units of land

estimated to have common capabilities, hazards and opportunities in respect to anticipated demands imposed on the land. Landtypes are units 0.1-2 square miles and are mapped at a scale of 1:30,000-1:60,000. They are appropriate for comprehensive planning (Wertz and Arnold 1972; Burkhart and Wigger 1978).

Landtype phase	These units are components of Landtypes. They are typically 0.01-0.1 square miles and are mapped at 1:15,000-1:30,000. Landtype phases are appropriate as a basis for project development and detailed planning (Wertz and Arnold 1972).
Site	This level represents the final integration of environmental factors. Sites are defined and characterized by soil polypedons and a discrete plant community. They are not delineated on a map (Wertz and Arnold 1972).

Bailey: Classification of Ecoregions

Bailey (1976) presented a map (map scale 1:7,500,000) and descriptions of Ecoregions of the United States as an experiment in classifying the major ecological divisions of the country. His manual (Bailey 1978) describes the dominant physical and biological characteristics of the classification units on the map. An Ecoregion is a biogeographical unit that occupies a continuous area of any size. It is characterized by the presence of one or more ecological associations, distinct flora, fauna, climate, landform, and soil. Ecoregions have specific potentials for biological production. Bailey uses bioclimatic criteria to determine the higher levels of a geographic hierarchy and geologic and geomorphic criteria for the lower levels.

This divisive system has been adapted from Crowley (1967) and Wertz and Arnold (1972). The following is the form of Bailey's (1976, 1978) Ecoregion Classification System:

Domain	A Domain is a subcontinental area of broad climatic similarity identified by zonal heat and water balance criteria.
Division	Divisions are parts of a Domain distinguished by differences in macroclimate, generally according to the basic climatic types of Köppen. Bailey modified two maps to delineate Domains and Divisions: Köppen's climatic map of the world

	(Trewartha 1943) and Thornthwaite's (1931) climatic map of North America.
Province	Provinces are parts of a Division identified by bioclimatic and soils criteria at the level of vegetation formations and soil orders (Soil Survey Staff 1975). Mountainous Ecoregions are distinguised from lowlands at this level. Küchler's potential vegetation map (1964) was modified to delineate provinces.
Section	Sections are parts of a Province with a single climatic vegetation climax at the level of Küchler's (1964) potential vegetation type and with related soils at the suborder level.
District	Districts are parts of a Section identified by landform types according to Hammond (1964).

Landtype Association	Landtype Associations are areas identified by a pattern of Landtypes developed through particular geomorphic processes.
Landtype	Landtypes are parts of a Landtype Association with a uniform combination of soils at the level of soil series and potential vegetation at the Association Level (Daubenmire 1968).
Landtype Phase	Landtype Phase is a spacio-temporal unit of Landtype with a uniform combination of soil Series and uniform stage of plant succession.
Site	A site is a part of a Landtype having a community homogenous in appearance, potential to produce biomass, limitations to use, and responses to management techniques.

Only the four highest hierarchical levels are delineated on Bailey's (1976) map, although District boundaries have been established by others (Earth Satellite Corporation 1975). Bailey's regionalization facilitates national resource planning as well as retrieval, organization, and interpretation of resource inventory data (Bailey 1978). This system of Ecoregions is being considered as a preliminary means of ordering the components of the National Site Classification System.

The National Site Classification System

The National Site Classification System has been developed through a five agency (Forest Service, Soil Conservation Service, Fish and Wildlife Service, Bureau of Land Managements, and Geological Survey) cooperative effort to meet various legislative requirements concerning the inventory and classification of natural resources over the United States (Merkel et al. 1980). The purpose of the system is to provide a framework for describing land that maximizes information exchange between management agencies. This is to be done by means of a hierarchical classification system with categories based on quantifiable traits of natural features of the landscape (Merkel et al. 1980).

The National Site Classification System consists of a Vegetation Component, a Soil Component, a Landform Component, and an Aquatic Component. In this classification, each of the physical and biotic components of an ecosystem are classified separately, and only those components that directly apply to a particular problem are used to solve that problem (Terrell et al. 1980).

At present, the Soil Component and the Vegetation Component have been adopted by the Interagency Team. The Aquatic Component is in draft form, and the Landform Component is being developed. Each component is treated separately in this thesis.

Because each component is classified separately and has its own hierarchy, there is no necessary correspondence between the hierarchical levels of the different components. A method must be established to integrate the applicable components for problem solving and management. Bailey's (1976) System of Ecoregions has been provisionally considered as a template for the hierarchical ordering of the various components (Merkel et al. 1980). In this approach, Bailey's system is used to name levels of Ecological Response Units.

An Ecological Response Unit is a distinct unit of land that includes a taxon from each applicable component, at roughly the same hierarchical level, in the classification system. The exact procedure for integrating these units is still being developed. As conceived, an Ecological Response Unit can be mapped and will respond in a predictable manner to management manipulations. The draft document (Merkel et al. 1980) discusses the utility of Ecological Response Units and some of the mapping and naming considerations.

National Site Classification System: Vegetation Component

The 1980 draft of the Vegetation Component of the National Site Classification System is a seven level, hierarchical system based on potential natural vegetation. The upper four levels are based on the 1973 UNESCO classification system, which is very similar to the system developed for the International Biological Program. The lower three levels have been defined for this system. The hierarchical levels according to Merkel et al. (1980) are:

Formation Class (5 world wide)	Formation class is based on physiognomy and general structure of arrangement of plant biomass in space.
Formation Subclass (19 world wide)	Different criteria are used for different Formations.
Formation Group (53 world wide)	Formations are grouped according to generalized climatic modifications such as tropical, subtropical and drought and heat tolerance.
Formation (166 world wide)	Formations are grouped according to vegetation form, such as tree shape or growth form of grasses.

Subformation (123 in U.S.)	Subformations are defined by life forms and taxa; they are recognized by the major genera in their plant communities.
Series	These are groups of plant associations with common dominant climax species. Dominant Climax species are determined by height, percent foliar cover, and regional distribution.
Association	An association is a plant community of definite composition, presenting uniform appearance and growing under uniform habitat conditions. The criteria are floristics and foliar cover. It is named by the dominant species in each of the life form layers.

Küchler's (1964) manual is indicated as the guide for developing Subformation descriptions. The subformation level is potentially important for reporting national statistics on natural resource assessments (Merkel et al. 1980).

National Site Classification System: Soil Component

In 1975, the Soil Survey Staff published "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys," which is commonly known as the "Seventh Approximation." It has been adopted as a Component of the National Site Classification System and by other nations and is used as an international reference.

According to the Soil Taxonomy, soil is a dynamic system with soil morphology reflecting the influences of generative environmental factors. Thus relationships are to be seen between classes of soils and the natural and cultural environment. The strong interdependence between soil systems and plant systems is stressed to the extent that, for purposes of classification, soil is defined as a collection of bodies on the earth's surface that contains living matter and supports or is capable of supporting plants out-of-doors (Soil Survey Staff 1975).

The Soil Classification is hierarchical and divisive. The differentiae are primarily soil properties that are observable in the field, influence plant growth, and seem to derive directly from soil genesis. Properties are choosen so that an undisturbed soil and its cultivated equivalent remain in the same category, unless the capability of the soil has been changed.

Although soil properties are continuous, soil is conceived of as a mosaic of individual units having distinctive features (Soil

Survey Staff 1975; Gersmehl 1977). A pedon, a three dimensional body of soil one to ten meters square, has been established as the basic sampling unit and the operational research unit for soil science (Soil Survey Staff 1975; Pavlik and Hole 1977). A polypedon is the individual classification unit. It is a unit of contiguous pedons having similar responses to management for growing plants, to engineering, and to other uses requiring monetary investment (Soil Survey Staff 1975).

The Soil Taxonomy has six hierarchical levels and an elaborate system of nomenclature, which reflects the properties of the soil and its position in the hierarchy. Every polypedon is assigned to categories according to the following:

Orders (10)	Orders are based on evidence of sets of processes believed to be the dominant forces in shaping the character of the soil. Each order has unique properties, chosen to exclude all soils belonging to other Orders. The criteria are: 1. gross composition 2. degree of horizon development 3. degrees of weathering as cation exchange capacity or as percent base saturation 4. presence or absence of certain diagnostic horizons.

Suborders (47)	The differentiae differ with each Suborder.
Great Groups (185)	Within Suborders soils are grouped according to: 1. kind, degree, and arrangement of horizon expression 2. close similarities in soil moisture and temperature regimes 3. similarities in base status
Subgroups (970)	There are three kinds of Subgroups within each Great Group. These are: 1. those which follow the concept of the Great Group, 2. the intergrades, 3. the extragrades.
Families (4500)	Families within a Subgroup have similar physical and chemical properties that affect their responses to management or other manipulation.

Series (10,500 in U.S.)	The differentiae used to define Series are the same as for the higher categories but the range of variation is narrower. Every polypedon can be classified into a particular soil Series, but each Series typically includes more than one polypedon. Polypedons are taken to be identifiable units, but Series are abstract units.

National Site Classification System: Aquatic Component

The Aquatic Strategy Group has presented a draft of the Aquatic Component (Terrel et al. 1980) of the National Site Classification System, but at this writing the document is still in review. As drafted, the Aquatic Component is a hierarchical classification of surface freshwater and salt water systems. The Aquatic Component is intended to classify aquatic systems and subsystems on the basis of hydrological and chemical characteristics as these affect habitats (Terrell et al. 1980). According to the authors, no existing wetland or aquatic classification system met the requirements for the National Site Classification System, although two systems (Anderson et al. 1976; Cowardin et al. 1979) were used extensively in developing the Aquatic Component. The resultant five level system uses ranges of various quantifiable characteristics to classify aquatic systems as follows:

Level I	Marine Estuarine Riverine Lacustrine Palustrine	These categories have been adopted from Cowardin et al. (1979). The Marine system is not extended below Level I.
	Perennial Ice or Snow	This category has been adopted from Anderson et al. (1976).
	Terrestrial	This category has been adopted to include all nonwetland nonaquatic habitats except ephemeral riverine or lacustrine systems.
Level II	This Level establishes divisions according to water permanence. The Estuarine and Terrestrial Systems do not have Level II divisions.	
Level III	Level III lists matrices of physical and chemical characteristics of aquatic systems for each Level II division.	
Level IV	Level IV categorizes according to Site Water Regimes, by designating the frequency, timing, and duration of surface inundation as either nontidal water regimes or tidal water regimes.	

Level V — Level V presents further site characteristic matrices based on physical and chemical characteristics.

The draft document for the Aquatic Component includes all the definitions and the detailed matrices for Levels III and V. The document states that Level IV or Level V may be implemented after considering Level III, according to the needs of the users. All the matrices were designed so that after the appropriate computer programs are available, data can be retrieved from the existing data storage systems of the resource agencies for use in the Aquatic Component of the National Land Classification System (Terrell et al. 1980).

National Site Classification System: Landform Component

At this writing, the Landform Component of the National Site Classification System is being developed. A Landform Component, which classified landform primarily according to its origin and stage of development, was rejected earlier by the Classification Work Group. A Landform Strategy Group was formed in March 1979 to formulate a classification based on actual configuration of the surface as well as on the genesis of the landforms (Merkel et al. 1980).

Culture

Most of the preceding classifications were developed within the context of a particular discipline. Anthropologists and sociologists have also devised various classifications of social systems or cultural phenomena, such as the Outline for Cultural Materials (Murdock 1961). But, by in large, these systems are appropriate only for describing the culture of small units such as villages. There are, to my knowledge, no hierarchical classification systems for culture analogous to the systems for the other natural-cultural subsystems. McHarg (1969) integrated social, physical, and biological information into plans dealing with local problems in urban development and land-use planning. Brady et al. (1979) suggested a means of classifying urban areas that accounts for changes in capacity owing to urbanization and yet ties the terrain of the urban area to the rest of the region.

But Culture or a social system, as a natural-cultural subsystem, entails more than the limited factors used in either of these approaches. I have suggested that the cultural subsystem of the natural-cultural system outlined earlier might be understood to have secondary subsystems: 1. biological subsystem, 2. technological subsystem, 3. informational subsystem, 4. governmental subsystem, and 5. valuational subsystem.

A CONCEPTUAL UNIFICATION OF BIOGEOCLIMATIC CLASSIFICATION

There are conceptual or informal logical relations between more particular classification systems and integrated biogeoclimatic classification, in that more particular systems can be deduced from an integrated classification system and integrated classification can be synthesized from other systems. Integrated classification is theoretically based on similarities in the capacities and environments of the natural-cultural systems, where:

$$\text{Natural-cultural classification unit} = f\left(\text{Natural-cultural system capacity},\ \text{Environmental system capacity}\right)$$

and

$$\text{Natural-cultural system capacity} = f\,(S_{cap}, Cl_{cap}, W_{cap}, B_{cap}, C_{cap}),\text{ and}$$

S_{cap} = capacity of substrate subsystem

Cl_{cap} = capacity of climatic subsystem

W_{cap} = capacity of water subsystem

B_{cap} = capacity of biotic subsystem

C_{cap} = capacity of cultural subsystem

In integrated classification, all the subsystems of natural-cultural systems theoretically are considered simultaneously. Most of the more particular classification systems that have been reviewed deal mainly with one of the subsystems of natural-cultural systems, though other subsystems are involved indirectly. The Land Systems Inventory, Bailey's Ecoregion classification, and the

National Site Classification system directly or indirectly involve more of the major subsystems.

These classifications rely, even theoretically, primarily on information about states or some potential state of one or more of the primary, secondary, or tertiary natural-cultural subsystems. For example, Küchler's classification system depends on potential natural-vegetation, which is a potential state of the Biotic subsystem.

$$\text{Küchler's classification unit} = f(B)$$

More specifically, it is a potential state description of the tree-associated, shrub-associated, and herb/grass-associated subsystems of the Biotic System. The form of integrated biogeoclimatic classification is such that any more particular classification system can be described in terms of the performances of primary, secondary, tertiary, or lower level subsystems of natural-cultural systems.

Theoretically, integrated classification is based on the capacity of any system and the capacity of its environmental system. Capacity includes all performances that are possible under all possible environmental states. Capacity is a theoretical concept in that it can never be directly or fully evaluated. More particular classifications are, even theoretically, based on measures or estimates of a limited number of states or potential states. A single state is a performance; potential states are potential performances. Potential vegetation, for example, is a potential state or a potential performance; it does not include all the developmental states leading to that particular vegetation climax. The concept of capacity includes all states and potential states.

More particular classification systems can, then, be seen as special cases of integrated classification. Understanding the relationship between a particular classification and integrated classification involves noting the primary, secondary, or tertiary natural-cultural subsystems that are used as differentiae in the particular classification. Then, the information used in classifying is characterized as being, most nearly, descriptive of a state, states, or capacity. The appropriate level in the hierarchical structure of the integrated classification at which to subsume the particular classification is determined by examining the level of resolution of the empirical data. For example, Köppen's system of classification provides some information on the Climate subsystem at the Domain and Division levels but not at levels much lower than these.

Informal relations between particular classification systems and the integrated biogeoclimatic classification, in terms of hierarchical position and the primary, secondary, and tertiary subsystems involved, are identified in the following paragraphs and tables. Table 1 proposes rough equivalences between the classification units of various classification systems and the hierarchical levels of the integrated form of classification. More precise equivalences of these systems cannot be stated until the integrated system of classification is actually applied to natural-cultural systems and particular comparisons with other classification units are made. Table 2 proposes the relationship between the differentiae of the reviewed classifications and the natural-cultural system's primary and secondary subsystems.

Köppen

Köppen's classification is subsumed by the integrated classification at the Domain and Division levels, primarily as a part of the Climatic subsystem, but also as a part of the Biotic subsystem. This is because climatic units calculated from long-term means of temperature and precipitation are defined to roughly coincide with the tree-, shrub-, and herb/grass-associated secondary subsystems.

Köppen
classification = f (Cl, B)
unit

Thornthwaite

Thornthwaite's climatic classification is subsumed at the Domain and Division levels in the integrated classification hierarchy. It is based on calculations on the long-term performances of precipitation, temperature, and potential evaporation.

Thornthwaite
classification = f (Cl)

Hammond

Hammond's categories are subsumed at the mid-levels of the hierarchy of the integrated classification, say Section, District,

INTEGRATED CLASSIFICATION UNITS	OTHER CLASSIFICATION SYSTEMS
DOMAIN	Köppen: Thornthwaite: Daubenmire's Region: Bailey's Domain: Vegetation Component's Formation Group
DIVISION	Köppen: Thornthwaite: Bailey's Division: Vegetation Component Formation Group
PROVINCE	Daubenmire's Province: Physiographic Provinces: Küchler: Land Systems Inventory's Province: Soil Taxonomy's Order: Vegetation Component' Fomation, Subformation
SECTION	Küchler: Hammond: Daubenmire's Zone: Physiographic Provinces: L.S.I.'s Section: Vegetation Component's Subformation, Series: Soil Taxonomy's Suborder: Bailey's Section
DISTRICT	Wood & Snell: Hammond: Küchler: Daubenmire's Habitate Type: Physiographic Provinces: Bailey's District: Vegetation Component's Series: Land Systems Inventory's Subsection
LANDTYPE ASSOCIATION	Hammond: Wood & Snell: Daubenmire's Habitat Type: Bailey's Landtype Association: Vegetation Component's Series: McHarg: L.S.I.'s Landtype Association
LANDTYPE	Hammond: Wood & Snell: Land Systems Inventory's Landtype: Bailey's Landtype Vegatation Component' Series: Soil Taxonomy's Series: McHarg
SITE	Daubenmire's Community: Land Systems Inventory's Site: Bailey's Site: Soil Taxonomy's Series: Vegetation Componet's Association: McHarg

Table 1. A rough equivalence in resolution between classification units of various other classification systems and the hierarchical levels of the integrated form of classification.

PRIMARY SUBSYSTEM	Performaces and Secondary and Teriary Subsystems / Other Classification Systems	KÖPPEN	THORNWAITE	HAMMOND	WOOD AND SNELL	KÜCHLER	DAUBENMIRE Region	Province	Zone	Habitat Type	PHYSIOGRAPHIC PROVINCES FENNEMAN	LOOMIS	ATWOOD	HUNT	NATIONAL SITE CLASSIFICATION	SOIL TAXONOMY	VEGATATION COMPONENT	AQUATIC COMPONENT	BAILEY Domain	Division	Province	Section	Distrist	Landtype Association	Landtype	Landtype Phase	Site	LAND SYSTEMS INVENTORY Province	Section	Subsection	Landtype Association	Landtype	Landtype Phase	Site
SUBSTRATE	SOIL 2°									*						*					*	*			*	*	*		*		*	*	*	*
	NON-SOIL 2°																																	
	PARENT MATERIAL 2°										*	*		*										*					*	*		*	*	
	FOUNDATION 2°							*			*	*		*										*				*						
	Topographic Performance			*	*					*	*	*	*	*							*		*				*	*	*	*	*	*	*	
WATER	GROUND WATER 2°																	*																
	LAKE 3°																	*																
	STREAM 3°																	*																
	MAN-MADE SYSTEM 3°																	*																
BIOTA	TREE-ASSOCIATED 2°	*				*	*	*	*	*							*				*	*			*	*	*	*	*	*	*			*
	SHRUB-ASSOCIATED 2°	*				*	*	*	*	*							*				*	*			*	*	*	*	*	*	*			*
	HERB/ GRASS ASSOC. 2°	*				*	*	*	*	*							*				*	*			*	*	*	*	*	*	*			*
	SOIL-ASSOCIATED 2°																																	
	WATER-ASSOCIATED 2																																	
CLIMATE	RADIATION 2°																																	
	GASES 2°																																	
	PARTICLES 2°																																	
	WATER 2°	*	*				*												*	*								*	*	*		*	*	
	Wind Performance																															*	*	
	Temperature Performance	*	*				*												*	*								*	*	*		*	*	
CULTURE	BIOLOGICAL 2°																																	
	GOVERNMENTAL 2°																																	
	INFORMATIONAL 2°																																	
	TECHNOLOGICAL 2°																																	
	VALUATIONAL 2°																																	

Table 2. The relationship between the differentia of some classifications and the natural-cultural systems's primary and secondary subsystems.

or Landtype Association. His classification is based on present topography, which is a performance of the Substrate system.

$$\begin{array}{l}\text{Hammond}\\ \text{classification}\\ \text{unit}\end{array} = f\,(S)$$

Wood and Snell

Wood and Snell's categories are subsumed at one or more of the lower levels in the hierarchy, such as District, Landtype Association, or the Landtype. They classify landform according to the state of 6 topographic performance variables.

$$\begin{array}{l}\text{Wood and Snell}\\ \text{classification}\\ \text{unit}\end{array} = f\,(S)$$

Küchler

Küchler's classes are subsumed at the Province, Section, or District levels of the integrated hierarchy. His work is based on the potential climax states of the Biotic subsystems, specifically the tree-associated, shrub-associated, and herb/grass-associated subsystems.

$$\begin{array}{l}\text{Küchler}\\ \text{classification}\\ \text{unit}\end{array} = f\,(B)$$

Daubenmire

Daubenmire's system has hierarchical levels corresponding roughly with the Province, Section, Landtype Association, and Site levels of the integrated classification. Daubenmire's levels are determined primarily on the basis of the potential climax states of the tree-associated, shrub-associated, and herb/grass-associated secondary subsystems of Biotic system. Information on present states of Substrate subsystem's topography and soil characteristics are also taken into account. Daubenmire's Zone is in part determined by the long-term performances of the Climatic subsystem. And the Province is defined by the foundation subsystem of Substrate.

$$\text{Daubenmire classification unit} = f\ (\ B,\ S,\ Cl\ )$$

Physiographic Provinces

Fenneman's (1931; 1938), Loomis' (1937), Atwood's (1940) and Hunt's (1974) Physiographic Provinces are all subsumed at mid-levels such as Province, Section or District levels of the integrated classification. These classifications are based on the Substrate subsystem, especially the topographic performance and the present and potential states of the foundation and parent material subsystems.

$$\text{Physiographic Provinces classification unit} = f\ (\ S\ )$$

The Land Systems Inventory

The hierarchical levels of the Land Systems Inventory roughly correspond to the levels of the integrated system. The differentiae of each level of the Land Systems Inventory are different. The topographic performance of the Substrate subsystem as well as the present and potential states of the soil, foundation, and parent material secondary subsystems are utilized. Long-term performances of the Climatic subsystem and secondary subsystems and the potential climax states of the tree-associated, shrub-associated, and herb/grass-associated secondary subsystems of the Biotic subsystem are also taken into account.

$$\text{Land Systems Inventory classification unit} = f\ (Cl, S, B)$$

Soil Taxonomy

The Series level of the Soil Taxonomy is subsumed at the lowest or Site level of the integrated classification hierarchy. The Soil Taxonomy classifies soils in a way that almost fully accounts for the dynamic nature of soils, and it thus approximates a capacity classification. Soils are secondary subsystem of the Substrate subsystem.

$$\text{Soils classification unit} = f\ (S)$$

National Site Classification:

Aquatic Component

The Aquatic component is subsumed at low hierarchical levels. It is based on states or performances of the secondary and tertiary Water subsystems.

$$\text{Aquatic Component classification unit} = f\ (W)$$

National Site Classification: Vegetation Component

The various levels of the vegetation component are subsumed at different levels in the integrated classification hierarchy. The differentiae for this component are the potential climax states of the tree-associated, shrub-associated, and herb/grass-associated subsystems of the Biotic subsystem.

$$\text{Vegetation Component classification unit} = f(B)$$

APPLICATION OF INTEGRATED CLASSIFICATION TO NATURAL-CULTURAL SYSTEMS

Integrated classification can be applied to natural-cultural systems through a synthesis of information based on existing particular classification systems in which additional empirical data could be incorporated. Integrated classification can also be applied in the development of other, more particular classification systems.

Since this integrated classification relies on the subsuming concept of capacity and an inclusive model of natural-cultural systems, it can be used to deduce an existing or new, more particular classification system. In general, a new system can be abstracted by first determining the objectives of the system and the information necessary for its implementation. That information is identified as a performance or potential performance of the appropriate primary, secondary, or tertiary subsystem. The information can then be abstracted from the integrated system and new classes of objects named.

For example, the Soil Taxonomy's Series is very close to what may be described as the capacity of the natural-cultural secondary subsystem, Soil (Substrate is the primary subsystem).

Natural-Cultural System

Primary Subsystems		Secondary Subsystems
WATER		Soil
CLIMATE		Nonsoil
SUBSTRATE	———	Parent Material
BIOTA		Foundation
CULTURE		

At the Site level this is represented as:

$$\text{Natural-cultural classification unit} = \text{Site} = f_{site}\,[(S_{soils\ cap} + S_{other\ cap},\ Cl_{cap},\ W_{cap},\ B_{cap},\ C_{cap}),\ (ENV_{site})]$$

And so, at the District level it is represented as:

$$\text{District} = f_{district}\,[(S_{soils\ cap_{all}} + S_{other\ cap_{all}},\ Cl_{cap_{all}},\ W_{cap_{all}},\ B_{cap_{all}},\ C_{cap_{all}}),\ (ENV_{district})]$$

In the integrated system the District is the fourth hierarchical level classification unit; it names a particular class of geographic place. A Great Group is a fourth level category for kinds of soils. Great Groups are classes of soils that indicate something about soil properties and genesis but not necessarily anything about a spatial geographic relationship. A particular soil classification unit that describes those soils Series that are geographically and ecologically related as secondary subsystems of the same District (for example, District A), can be then represented as:

$$\text{Soils District A} = f\,[(\text{Soil Series}_{\text{District A}})\quad(\text{ENV}_{\text{District A}})]$$

Applying integrated classification to natural-cultural systems through synthesis of other more particular classification systems involves determining the informal relationships between the particular systems and the integrated system. In this, special attention must be given to the geographic hierarchical levels of the particular classification systems and to definition of the natural-cultural systems or subsystems they emphasize as well as to the extent to which defining variables reflect system capacities. Particular classifications systems are then choosen to characterize, as nearly as possible, all the natural-cultural subsystems for the hierarchical levels of interest. The major emphasis in the synthesis process is determining how adequately the subsystem performances characterize the dynamic nature of the system. Those performances that account for the dynamic nature of a natural-cultural system should be utilized so that the capacity of the system is represented as well as possible.

For example, to classify natural-cultural systems at the Province level, one could use readily available information and overlay maps (McHarg 1969) of the appropriate Section level of Bailey's Ecoregion map (1976), Daubenmire's Zone, Küchler's Natural Potential Vegetation Type, and the Land Systems Inventory's Section to create a mosaic of tesseras. These are then grouped according to their similarities so as to form Provinces. Applying integrated classification is, however, not simply a matter of utilizing existing classification systems.

According to the form for integrated classification, information on all the subsystems must be integrated simultaneously. In the example above, information on climate and culture is not included. There is not an established classification system that describes climate at this scale, nor is there an appropriate classification system for culture. There are not enough particular systems available to fully apply integrated classification by subsuming existing systems.

Full application of integrated classification to natural-cultural systems would require additional empirical information about at least some of the subsystems. An actual application of integrated classification would be preceded by the development of certain rules and procedures, perhaps somewhat as follows: 1. Rules that state the map scale and area ranges that are appropriate for each of the hierarchical levels. 2. Rules that state the specific level of resolution that is appropriate to characterize each subsystem at each of the hierarchical levels. 3. Rules for modification, so that substitutions can be made without violating the integrity of the form and theory of integrated classification.

Assuming that these rules are established, application of integrated classification to natural-cultural systems might proceed somewhat as follows, whether existing classification systems or additional empirical information is used:

1. On the basis of scientific and/or management objectives, determine the appropriate levels of geographic hierarchy and degrees of subsystems to be considered.

2. Determine the appropriate mapping scale.

3. Compile the information for the appropriate subsystems from an existing classification system or other sources of information. For example, annual values for a number of climatic variables could be organized to describe the Climatic subsystem.

4. Represent each set of subsystem information on a separate map, all subsystem maps having the same scale. Maps of potential natural vegetation or landform may be mosaics of classes with clear boundaries. Other subsystem performances may be adequately represented by maps showing various ranges of performances. According to Gersmehl (1977), dot maps are the best way to represent soils that are classified by the Soil Taxonomy.

5. Overlay the subsystem maps (McHarg 1969). When the maps are overlaid, the various intersecting lines form tesseras. Each tessera is internally consistent for each subsystem performance considered.

6. Determine the minimum size for tesseras. Those tesseras smaller than the minimum size are integrated into neighboring tesseras by adjusting the lines according to predetermined rules. Because objectives and information change with each classification project, priority rules probably should be established for each individual project.

7. Classes of classification units are established by grouping similar tesseras. Computer techniques may be helpful in associating tesseras into classification units. Dubes and Jain (1980) review the theory, methods, and potential problems of using some different clustering methods. Moral and Long (1977) used agglomerative clustering followed by stepwise multiple discriminate analysis to classify forest community types. It is assumed that no two classification units in a class will have precisely the same tesseras present in exactly the same portions.

8. Evaluate the classification system on the basis of success of use as well as original objectives and criteria. Multivariate discriminate analysis can be used to display and compare the differences between classes of natural-cultural system classification units. But it should be used to classify or reclassify (Pavlik and Hole 1977) only with great care. Radloff and Betters (1978) applied hierarchical agglomerative clustering to 147 sites. The discriminate functional analysis was used to determine class membership and canonical ordination was used to further understand the class distance in coordinate space. Ayoade (1977) and Willmott (1977) used multivariate techniques to classify according to climatic variables. Winter (1977) used Principle Component Analysis to classify hydrologic settings of lakes.

APPLICATION OF INTEGRATED BIOGEOCLIMATIC CLASSIFICATION TO SCIENCE AND MANAGEMENT

If we take the goal of science to be the continuous advance of understanding and the goal of resource management to be insuring the persistence of good natural-cultural systems, we have then to examine how application of integrated classification is to facilitate our approaching these goals. To do so we have first to examine just what is to be meant by those goals. Then we have to examine the fundamental nature and potential of the envisioned classification system.

It seems that we understand something when we grasp it as being essentially simple, ordered, unified, harmonious in role, and, perhaps for those very reasons, even beautiful and good. We cannot suppose that the world is "really" this way, but rather that understanding in this form tends to bring man into concordance with his experience. Science, the humanities, and just living are about this.

We do not suppose that the goal of resource management should be to produce as much of a particular resource, even on a steady state basis, as might be possibe. Rather, we are concerned with human social systems, cultural systems, and the natural systems upon which they depend. We are concerned with the persistence of natural-cultural systems, good in the richest and most incorporating and spacio-temporarily inclusive sense.

Now the integrated system of classification of natural-cultural systems we have been considering has been advanced with the broadest possible goals and objectives, an organismic conceptual framework in a Whiteheadian world view, and the taking into account with the theoretical concepts of capacity and environment of much of our total experience. Because of the conceptual framework and the theory and form of the classification, it is a systems classification in the most fundmental sense. This is so even to the extent that one can move, through functional notation, from the classification and its variables to systems theory, models, and their variables. This formal relationship and the many informal ones it makes apparent are immeasurably important to both science and resource management, which must utilize classification and models to achieve their goals.

In a most basic sense, the integrated biogeoclimatic classification is a conceptual structure through which we can approach the scientific goal of understanding and explanation of natural-cultural systems. Simultaneous consideration of all subsystems of a system and the system of natural-cultural systems in which it is embedded facilitates this. The explanation and understanding generated through study of a natural-cultural system of a class can be extended to other systems, not as individual isolated units of study, but as systems sharing similar subsystem capacities and sharing a common environmental system. In the same manner, a hierarchy of models can be generated that illustrate the relationships between natural-cultural systems in phase space. Because the integrated classification system deals with a hierarchy of systems, it also provides a means of conceptually dealing with the range of variation in resolution of empirical experience.

The hierarchical system of geographic units, which are the natural-cultural systems, also can provide a spacial, temporal template upon which to consider other scientific empirical information. In this way the classification system becomes a heuristic device for ordering empirical experience.

The integrated biogeoclimatic classification system is also useful in facilitating management's goal of ensuring the utilization and persistence of natural-cultural systems. According to the theory of natural-cultural systems (Warren 1981, pers. comm.), the persistence and distribution of a natural-cultural system depends most on the future concordance of its capacity with the capacity of its environmental system. An objective of management must be to protect the capacities of natural-cultural systems and the capacities of their environments. It is not necessary or even possible to maintain all systems in undistrubed states, but it is necessary to manage and maintain capacities. Because natural-cultural systems and their environments grouped into classes, management plans can be devised that protect the capacities of classes of systems. Furthermore, because capacities of all subsystems are considered simultaneously, such an approach can provide a multiple resource perspective in the fullest sense.

The template of geographic units, hierarchically organized according to capacity, also provides management with a tool appropriate for making different kinds of management decisions from the local level to the highest regional level, the Domain. Management unit boundaries that coincide with natural-cultural system units of various hierarchical levels would increase the potential or rational and uniform decisions based on the capacities of the natural-cultural systems and their environments.

For example, integrated classification can be extended to the classification of streams and watersheds as a special case. Warren (1979) presented a theory in which watersheds are natural-cultural systems, that can be arranged in a hierarchy from first order tributaries to systems like the Mississippi or Amazon Rivers. To apply integrated classification to watershed and stream classification, watershed boundaries are superimposed on the mosaic of classification units. The resultant mosaic characterizes the capacities of the watersheds. Site may be an appropriate level at which to classify first order streams, and Province level classification units may be appropriate for a sixth order river. Since the primary, secondary, and tertiary subsystems of a natural-cultural system all interact and interpenetrate, it is assumed that the water systems that are in watersheds of a class will have similar capacities and performances (i.e., hydrology, physical attributes, and aquatic communities). By extending integrated classification to a particular resource, such as streams, one has a means to manage the resource.

In conclusion, integrated classification partially symbolizes the classfier's total experience by emphasizing the capacities of all the subsystems of a natural-cultural system. This form of integrated classification provides a means of partially articulating total experience by means of functional notation that can serve as the basis of general systems models. And this system provides a perspective on total experience through its conception of geographic areas as classifiable natural-cultural systems in which physical, biological, and other human resources become primary, secondary, or tertiary subsystems of natural-cultural systems, embedded in a hierarchies of natural-cultural systems.

BIBLIOGRAPHY

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Prof. Paper 964.

Atwood, W.W. 1940. The Physiographic provinces of North America. Ginn and Company. New York.

Ayode, J.O. 1977. On the use of multivariate techniques in climatic classification and regionalization. Arch. Met. Geoph. Biokl., Ser. B. 24:257-267.

Bailey, R.G. 1976. Ecoregions of the United States. USDA For. Ser. Ogden, Utah.

1978. Description of the ecoregions of the United States. USDA For. Ser. Ogden, Utah.

Bailey, R.G., R.D. Pfister, and J.A. Henderson.1978. Nature of land and resource classification--a review. J. of. For. 76:650-655.

Boyce, S.G. and N.D. Cost. 1978. Forest diversity--new concepts and applications. USDA, For. Ser. Res. Pap. SE194, SE For. Exp. Stn., Asheville, N.C.

Brady, R.F., T. Tobias, P.F.J. Eagles, R. Ohrner, J. Micak, B. Veale, and R.S. Dorney. 1979. A typology for the urban ecosystem and its relationship to larger biogeographical landscape units. Urban Ecology 4:11-28.

Burkhart, L.J. and G.J. Wigger. 1978. Landforms and soils: an inventory and analysis, Hiwatha National Forest. USDA For. Ser. Eastern Region.

Cline, M.G. 1949. Basic principles of soil classification. Soil Sci. 67:81-91.

Cooke, R.U. and J.C. Doornkamp. 1974. Geomorphology in environmental management--an introduction. Clarendon Press, Oxford.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deep-water habitats of the United States. USDI Fish and Wildlife Ser., FWS/085-97/31.

Crowley, J.M. 1967. Biogeography. Can. Geog. 11:312-326.

Daubenmire, R. 1952. Forest vegetation of Northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecol. Mono. 22:301-330.

Daubenmire, R. 1966. Vegetation: identification of typal communities. Science 151:291-298.

Daubenmire, R. 1968. Plant Communities: a textbook of plant synecology. Harper & Row, New York.

Dubes, R. and A.K. Jain. 1980. Clustering methodologies in exploratory data-analysis. Adv. in Computers 19:113-228.

Earth Satelite Corporation. 1975. Ecoregions and land-surface form maps. Scale 1:250,000. USDI. Fish and Wildlife Service.

Ellis, S.L., C. Fallat, N. Reece, and C. Riordan. 1977. Guide to land cover and use classification systems employed by Western governmental agencies. Fed. Interagency Energy/Environmental Research and Dev. Pro. US.EPA. FWS/OBS-77/05.

Fenneman, N.M. 1931. Physiography of Western United States McGraw-Hill Inc. New York.

Fenneman, N.M. 1938. Physiography of Eastern United States McGraw-Hill, Inc. New York.

Garrison, G.A., A.J. Bjugstad, D.A. Duncan, M.E. Lewis and D.R. Smith. 1977. Vegetation and environmental features of forest and range ecosystems. USDA For. Ser. Ag. Handbook No. 475.

Gersmehl, P.J. 1977. Soil taxonomy and mapping. Ann. Assoc. Am. Geogr. 67:419-428.

Gilmour, J.S.L. 1951. The development of taxonomic theory since 1851. Nature 168:400-402.

Grigg, D. 1965. The logic of regional systems. Ann. Assoc. Am. Geogr. 55:465-491.

Hammond, E.H. 1964. Analysis of properties in land form geography: an application to broad-scale land form mapping. Ann. Assoc. Am. Geogr. 54:11-23.

Hunt, C. B. 1974. Natural regions of the United States and Canada. W.H. Freeman and Company, San Francisco.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States (map and manual). Amer. Geog. Soc. Spec. Pub. 36. map scale 1:3,168,000.

Küchler, A.W. 1967. Vegetation mapping. The Ronald Press Co., New York.

Küchler, A.W. 1973. Problems in classifying and mapping vegetation for ecological regionalization. Ecology 54:512-523.

Loomis, F.B. 1937. Physiography of the United States. Doubleday, Doran and Company, Inc., Garden City, New York.

Major, J.A. 1951. A functional, factorial approach to plant ecology. Ecology 32:392-412.

McHarg, I.L. 1969. Design with nature. Doubleday & Company, Inc., Garden City, New York.

Merkel, D.L., R.S. Driscoll, D.L. Gallup, J.S. Hagihara, D.O. Meeker, D.E. Snyder and T.T. Terrell. 1980. National site (land) classification system--status and plans. Review Draft. Fort Collins, Colorado.

Mill, J.S. 1874. A System of logic: books I and IV. J.M. Robson, ed. University of Toronto Press, Toronto.

Minore, D. 1972. A classification of forest environments in the South Umpqua basin. USDA Forest Serv. Res. Pap. PNW-129, Pac. NW Forest and Range Exp. Station, Portland, Or.

Moral, R.D. and J.N. Long. 1977. Classification of montane forest community types in the Cedar River drainage of western Washington, U.S.A. Can. J. For. Res. 7:217-225.

Murdock, G.P. 1961. Outline of cultural materials. 4th rev. ed., Human relations area files, Inc., New Haven, Conn.

Pavlik, H.F. and F.D. Hole. 1977. Soilscape analysis of slightly contrasting terrains in southeastern Wisconsin. Soil Sci. Soc. Am. J. 41:407-413.

Pfister, R.D. and S.F. Arno. 1980. Classifying forest habitat types based on potential climax vegetation. For. Sci. 26:52-70.

Radloff, D.L. and D.R. Betters. 1978. Multivariate analysis of physical site data for wildland classification. For. Sci. 24:2-10.

Soil Survey Staff. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Agricultrual Handbook No. 436. USDA Soil Conservation Service, Washington, D.C.

Sokal, R.R. 1974. Classification: purposes, principles, progress, prospects. Science 185:1115-1123.

Strahler, A.N. and A.H. Strahler. 1978. Modern physical geography. John Wiley & Sons, New York.

Terrell, T.T., V. Carter, W.S. Platts, E.P. Janes, F.D. Theurer and P. Cuplin. 1980. An aquatic classification proposed for use with the National Site Classification System. Draft.

Thornthwaite, C.W. 1931. The climates of North America according to a new classification. Geog. Rev. 21:633-655.

Trewartha, G.T. 1943. An Introduction to weather and climate. Ed. 2. McGraw-Hill, New York.

Trewartha, G.T. and L.H. Horn. 1980. An introduction to climate. McGraw-Hill, New York.

Warren, C.E. 1979. Toward classification and rationale for watershed management and stream protection. Ecological Research Series. EPA-600/3-79-059.

Warren, C.E., M. Allen, and J.W. Haefner. 1979. Conceptual frameworks and the philosophical foundations of general living systems theory. Behav. Sci. 24:296-310.

Wendt, G.E., R.A. Thompson and K.N. Larson. 1975. Land systems inventory, Boise National Forest, Idaho: A basic inventory for planning and management. USDA. For. Ser. Intermountain Region. Ogden, Utah.

Wertz, W.A. and J.F. Arnold. 1972. Land systems inventory. USDA For. Ser. Intermountain Region, Ogden, Utah.

Williams, W.T. 1967. Numbers taxonomy and judgement. Bot. Rev. 33:379-386.

Willmott, C.J. 1977. A component analytic approach to precipitation regionalization in California. Arch. Met. Geoph. Biokl. Ser. B. 24:269-281.

Winter, T.C. 1977. Classification of hydrologic settings of lakes in the north central United States. Water Resour. Res. 13:753-767.

Wood, W.F. and J.B. Snell. 1960. A quantitave system for classifying landforms. H.Q. Quartermaster Res. & Eng. Com., Environmental Protection Res. Div. Technical Report EP-124., Natick, Mass.

Wright, S.R.L. 1972. Principles in a geomorphological approach to land classification. Z. Geomorph. N.F. 16:351-373.

Zakrzewska, B. 1967. Trends and methods in landform descrption. Ann. Assoc. Am. Geog. 57:128-165.