

An Interdisciplinary Definition of North America's Chihuahuan Desert: Is It Desirable and Obtainable?

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ABSTRACT

Contemporary maps of the Chihuahuan Desert vary over a twenty-fold range of sizes, from 30,000 km² to 600,000 km², and average about 350,000 km². Discrepancies between maps are conspicuous when northwestern, northeastern, and especially southern borders are compared. Several researchers have attempted unsuccessfully to establish consensus maps.

Deserts are alternatively viewed as climatic systems, physiographic landforms, and biotic provinces. In addition to these three philosophical perspectives, alternative protocols for map constructions, and the varied databases utilized, also lead to different delineating maps. Database biases, have further generated disagreement, especially in regard to the southern border of the Chihuahuan Desert.

A climatic-physiographical model is proposed as an initial step in constructing a definition of the Chihuahuan Desert acceptable to the disciplines involved. It combines an annual deficit water budget with terrestrial landform characteristics of arid climates. Such a model would be tested against putatively responsive taxa to evaluate its ability to predict the boundaries of a quantitatively-defined biotic province. By testing a physical geographical model as the predictor of a biogeographical province, the criteria of several different disciplines may be satisfied. This protocol would convert the static descriptive operations of desert categorization into a dynamic process of hypothesis testing.

INTRODUCTION

More than a decade has passed since both Morafka (1977) and Schmidt (1979) "resolved" the dilemma of defining/delimiting the "real" Chihuahuan Desert. Both authors recognized the incongruence among the constructs of their predecessors. Each presented definitive maps which were meant to have broad interdisciplinary appeal. Ultimately, each failed to achieve consensus and acceptance. So too, did Medellín-Leal (1982) in his review and synthesis of Chihuahuan Desert geography. The Schmidt (1979) survey revealed that some maps of the Chihuahuan Desert differ in area from others by several fold. Among North American deserts, the degree of disagreement between maps of the Chihuahuan Desert is unique (Schmidt 1979). The only uniformly accepted desert core is a minimum consensus area extending across the low valleys from the Río Nazas drainage of Coahuila to the upper Río Grande of Texas and southern New Mexico. Failure to obtain generally accepted borders is also implicitly acknowledged in two of the most important recent documents defining the Chihuahuan Desert, Henrickson and Straw's (1976) gazetteer and Henrickson and Johnston's (1986) article on Chihuahuan Desert vegetation. These authors adopted an approach opposite to that of Schmidt's core. They designated the "Chihuahuan Desert Region" in order to establish a maximal area which would include within it virtually all the borders used by previous workers.

Underlying this continuing state of confusion and compromise are a set of conceptual, procedural, and data-based problems which are symptomatic of our generally eclectic efforts to define biotic provinces. This paper will review and quantify the degree of conflict between competing definitions of the Chihuahuan Desert, identify the sources of these conflicts, and suggest an interdisciplinary approach to their resolution.

QUALIFICATION AND QUANTIFICATION OF THE PROBLEM

The controversies about the borders of the Chihuahuan Desert center largely upon the three areas previously identified by Schmidt (1979). These are identified in Figure 1. Schmidt's core area and the eastern and western borders were subject to considerably less revision than are other aspects of the desert. However, even here some authors expanded the desert's width by inclusion of all ecotonal mesquite (*Prosopis grandulosa*) grasslands within the desert, the "Sacaton Grassland" of Henrickson [end p. 23] and Johnston (1986). One author, Conant (1978), virtually doubled the width of the traditional longitudinal limits of the desert by including most of the drainages east of the Continental Divide and west of the high crest of the Sierra Madre Oriental within his Chihuahuan Desert region. All definitions framed their desert borders within the coordinates of 99°-110° W and 20°-35° N. Virtually every other aspect of desert shape, size, and internal continuity has been subject to differing interpretations. Prominent among these differences (Figure 1) are disagreements about (1) northwestern extensions along the Cochise Filter Barrier (A in Figure 1), also known as Son-Chih Desert by Schmidt (1979) and upper Río Grande Valley between Las Cruces and Albuquerque, New Mexico, (2) the northeastern limits following the Pecos River of Texas and New Mexico (G in Figure 1), and (3) the south, the Saladan Sub-province of Morafka (1977) in Zacatecas and San Luis Potosí. This last region, as incorporated into the Hidalgo Desert of Axelrod (1979), is the most

controversial aspect of the Chihuahuan Desert, comprising approximately, 30,000 km², about 20 percent of the median estimate of total desert area, as presented in Table 1. It includes not only the Saladan region proper but also the canyon wall desert relict areas of Río Pánuco drainage. See D and E of Figure 1 respectively, and Wells (1978) for the relict areas. The Anticlinorium of Arteaga (F of Fig. 1) partially separates the Saladan Desert from the rest of the Chihuahuan Desert.

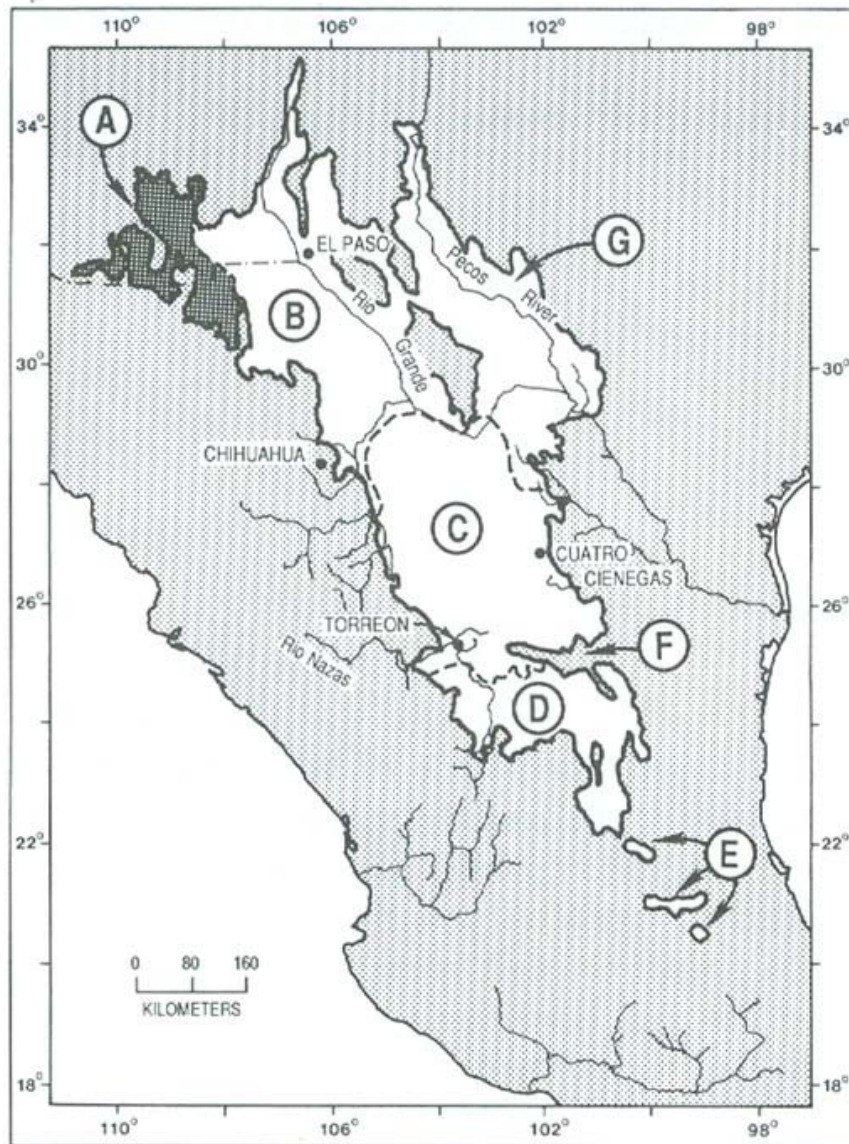


Fig. 1. Map of the Chihuahuan Desert indentifying major features, subprovinces, and borders in contention. Key: A = Son-Chih/Cochise Filter Barrier (dark stippling); B = Transpecos Subprovince; C = Mapimian Subprovince; D= Saladan Subprovince; E = Río Pánuco relict desert; F = Anticlinorium of Arteaga; G = Pecos River border. Solid borders = Morafka's (1978) Chihuahuan Desert limits; light stippling = nondesert; dash/dot line = international boundary; and broken line = division between subprovinces within the Chihuahuan Desert.

The effects of these controversies in determining areas inscribed by differing maps of the Chihuahuan Desert are displayed in Table 1. While these area estimates reveal fourfold differences in total area between the extremes among the seventeen definitions tested, real area discrepancies may be much greater when topographic relief is factored into the area calculations. This is especially so because the maps are rarely so finely drawn as to mark off small disjunct non-desert ranges. Some authors do not exclude high elevation surfaces. In contrast, Morafka (1977) would exclude all topographical features above 1,500 meters north of 25°N latitude and all relief above 1,700 meters south of it. Schmidt (1986) excluded montane islands above 1,800 meters, and at least one writer, Gehlbach (1967), rather vaguely confined the Chihuahuan Desert to limestone sequestered endemic sclerophyll formations (again occurring below 1,700 m) contiguous with Big Bend National Park, Texas. If the latter interpretation were taken literally, it would confine the Desert to about 30,000 km², only 1/20th the size of the largest estimate, the 600,000 km² approximation of Conant (1977). Figure 2 contrasts these two extremes.

Sources of Discrepancy

Conflicting definitions of the Chihuahuan Desert owe their differences to three major domains of disagreement: conceptual, procedural, and empirical. A fundamental lack of consensus exists regarding the nature of deserts, ecosystems, and one of their identifiable manifestations, biotic provinces. Similarly, the second category, procedure, reveals a history of eclectic approaches, most of which fail to offer a rigorous, biologically sound, and repeatable protocol. While the first two issues apply generally to the generation of biogeographical provinces, the empirically derived problems of defining the Chihuahuan Desert geographically are largely peculiar to it. [end p. 24]

Concepts of Deserts

Deserts are treated as climatic, physiographic, or biotic entities, or as synthetic combinations of these three. Climatic definitions are traditionally preeminent. Ten-inch annual precipitation, various coefficients depicting precipitation/temperature ratios, and formulas which calculate annual net water budgets have all been developed to characterize and classify arid climates. Reitan and Green (1968) have provided an excellent summary of these coefficients and their efficacy. Generally, deserts are recognized as arid zones with annual net deficits in the water budgets (Trewartha 1954, McGinnies 1968). Climatic purists would ascribe "deserts" even to climatic systems overlaying oceans. Webster's New Universal Unabridged Dictionary defines desert as (p. 492): "(1) an uninhabited tract of land; ... (2) a dry barren region, mostly treeless and sandy." While simple dictionary definitions hardly resolve the issue, it must be noted that ocean "deserts" are oxymorons, antithetical to most basic implications of the word desert. Most biogeographers would confine them to climatic systems interfacing with terrestrial surfaces.

A few definitions may place particular weight on physiographic evidence, such as Conant's (1978) hydrogeographical definition of the Chihuahuan Desert Region (Figure 2b), but these are rare. Many others have incorporated classical features of desert physiography (sand dunes, aridosols, playas, bolsons and their closed basin drainages) into their more broadly based definitions (Morafka 1977; Medellín-Leal 1982). Surprisingly, even analysts of polar deserts include classic physiographic criteria (dunes, pavements, saline lakes) in their descriptions (Pewe 1974, 45-48). Vegetational definitions of the Chihuahuan Desert are also commonplace (Shreve 1939; Rzedowski 1957; Gehlbach 1967; Brown 1982; Brown et al. 1979; Henrickson and Johnston 1986).

As noted by Hastings and Turner (1965, 7), the perspective itself varies with discipline. Climatologists contend with macroscopic systems in which local predictive powers are low, while ecologists and microclimatologists strive for more complex and localized definitions with more predictive information about interface between climate and earth.

Definitions of Ecosystems and Provinces

The nature of the ecosystems' conceptual arguments tend to polarize around two opposing views about interspecific population distributions; namely, that ecosystems assembled from these populations are individuals, and its antithesis, that ecosystems are classes. In each set of arguments, the ecosystem is viewed as a unique unit/process in both temporal and physical contexts. The individual has, at least by implication, its own co-evolved history and intrinsic and interdependent properties, and is self-defining by virtue of those properties. Clements (1916), founder of the "individual" perspective, viewed plant communities and, by extension, entire ecosystems as having coordinated and predictable or successional responses to temporal and spatial environmental gradients.

In contrast, Gleason (1917 and 1926) treated communities more as existential clusters of populations of different species, which at that instant of time, had similar environmental tolerances and similar access to the geographical area of observation. In his view the assemblage was much more a physically constrained correlation of taxonomic distributions than evidence of biological interdependence. [end p. 25]

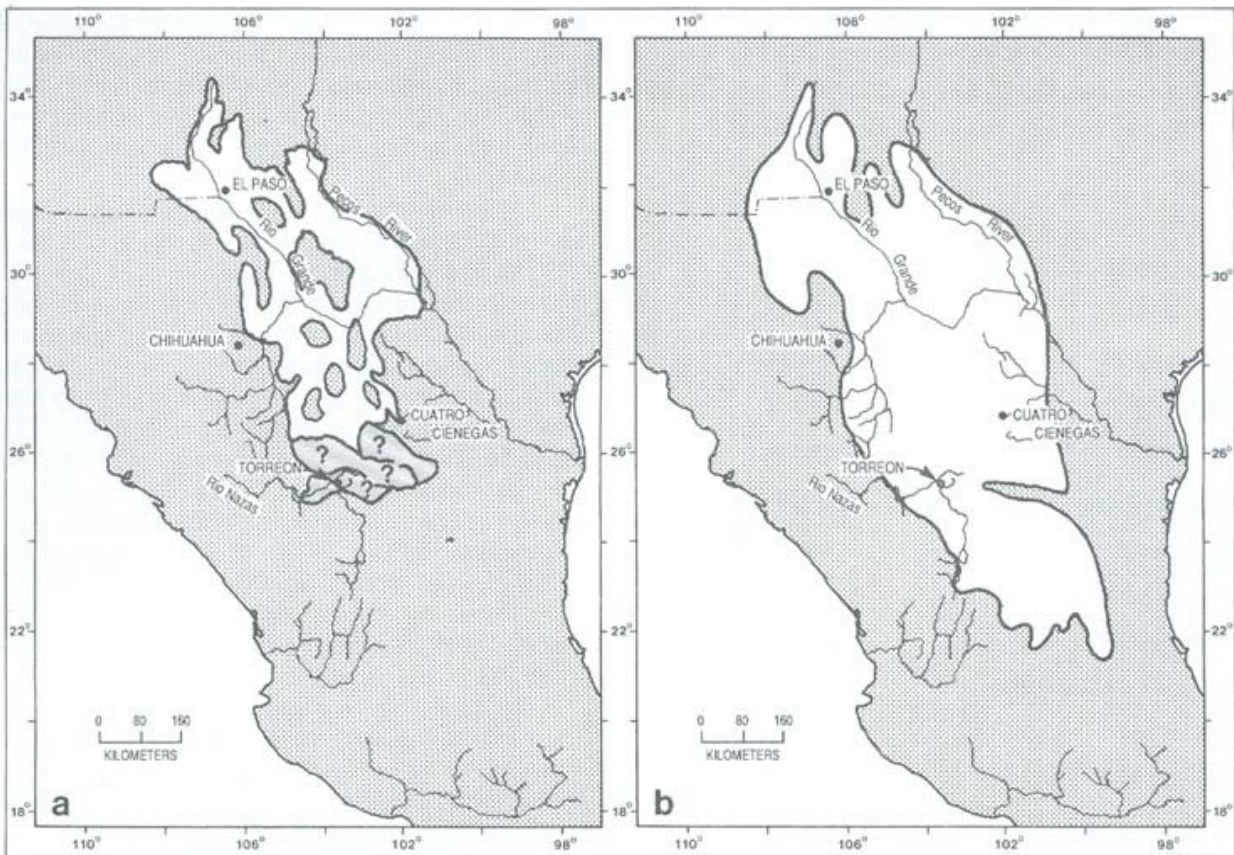


Fig. 2. Minimal and maximal configurations of the Chihuahuan Desert. (a) This is a minimal Chihuahuan Desert reconstructed from Gehlbach's (1967) written characterization of the Chihuahuan Desert as a limestone scrub formation including endemics. By this definition, the true Chihuahuan Desert formation is confined to the rocky slopes wedged between pinyon woodlands above and alluvial creosote scrub below and surrounding the outcrops. The clear area on the map illustrates this zone; however only a small fraction of the area indicated would actually be occupied by the edaphic limestone association designated by Gehlbach. (b) Maximal desert region redrawn from Conant (1978). Unmarked areas designate the desert region; stippling indicates nondesert.

This class is externally defined by a subset of characteristics which are not necessarily predicated upon a common evolutionary history or a functional interdependence. Whittaker (1953; O'Neil et al. 1986) integrated Clements' concepts of succession into his climax-pattern hypothesis; however, his spatial perspective on the interacting taxa of the system is essentially that of Gleason.

Biotic provinces are the mapped manifestations of ecosystems (Dice 1943). The opposing philosophical perspectives of ecosystems as individuals versus classes has led their adherents to produce very different constructs. Three representative definitions of the Chihuahuan Desert illustrate the practical influence of these differing views, not only in terms of conceptualization, but in the selection of data and methods of analysis as well.

Alternative Definitions of the Chihuahuan Desert

The three examples consist of an individualistic model, based on a single plant formation (Gehlbach 1967), an integrative synthetical approach (Morafka 1977), and a physical-climatic definition utilizing a class categorization (Schmidt 1979). Only Morafka's analysis is aimed directly toward the construction of formal biotic provinces. Gehlbach's Chihuahuan Desert is defined by a limestone-based edaphic vegetational formation, confined to the Rio Grande lowlands adjacent to Big Bend, Texas. If the formation is construed as an ecosystem in the Clementian context, this type of desert depicts an individual. However, such a formation might equally be treated as a class in the sense that Gleason viewed such systems as classes. It was not formally mapped, but a version based [end p. 26] upon his written depiction is illustrated by Figure 2a. The resulting construct is sharply defined. This binary delineation tends to follow the 1,500 m to 1,700 m contour of topographic relief. Complex transitional zones, involving analog degrees of change, are largely precluded by the limited nature of the data. The

resulting potential area consists of only 30,000 km². The area actually occupied by Gehlbach's limestone-endemic vegetation formation could be reduced by another order of magnitude, making this the smallest surface area designated for the Chihuahuan desert by far. In response to the complex basin-range topography of the Big Bend Rift Valley and Coahuila Folded Belt, Gehlbach's Desert assumed the form of a labyrinth of continuous and intersected hillsides and outcrops. Much more sophisticated and less assumptive maps of the Chihuahuan Desert vegetation also produce a similar labyrinth or lattice outline of great complexity (Brown 1982).

Morafka's (1977, 59-65) Chihuahuan Desert is a hybrid between "individual" and "class" approaches. Climatic criteria are recognized as primary. These measurements define the desert as a subset of weather stations, thereby generating a class. Soil types (sierozem, aridisols) are integrated into the model. The definition is further resolved by plotting the distribution of characteristic xerophytic woody plants. This synthesis, with its averaged borders serves as model by which other characteristic desert taxonomic distributions could be predicted. Herpetofauna is used as a test set of taxa. The success of the model was evaluated statistically by its ability to predict the existence and borders of a herpetofaunal biotic province. The existence of such a province is confirmed. Northern Transpecos, central Mapimian, and southern Saladan subprovinces are also recognized. An area of about 440,000 km² is inscribed within these boundaries, including small ranges above 1,500 m elevation.

Schmidt (1979; 1983; 1986) defines the Chihuahuan Desert in terms of a class of weather stations. Of nearly 800 surveyed stations, a set 115 stations are identified as desert localities. Schmidt uses the value of 10 or less in the de Martonne (1926) P/T formula, dividing the annual average precipitation (mm) by average annual centigrade temperature, plus 10. Recognizing the paucity of weather stations in critical but poorly populated areas, Schmidt extrapolates between reporting points, using elevational limits adjusted for latitude. Secondly, he identifies the "Son-Chih" transition area, more traditionally known to biologists as the Cochise Filter Barrier. This area is dominated by New Mexico's Deming Plain and more mesquite grasslands, stretching westward across the Continental Divide through Cochise County of southeastern Arizona and adjacent Sonora and Chihuahua. The resulting area is almost twelve-fold larger than Gehlbach's. It is more restricted than Morafka's definition and eliminates the latter's southern subprovince entirely. The Schmidt map inscribes an area of 350,000 km². The resulting definition is clearly a class.

Protocol Differences

Of the many approaches to the definition of the Chihuahuan Desert reviewed by Morafka (1977), Schmidt (1979), and Medellin-Leal (1982), virtually no two constructions utilized identical protocols. The differences are best explained by the variation in four procedural decisions: (1) framing the initial area; (2) data collection, including the issues of intrinsic bias in empirical data sets, standard comparative units of area, and the uniformity and randomness of data collection; (3) the choice of coefficients for climate, especially aridity indices; and (4) criteria for discriminating one primary area from another ecologically, particularly coefficients and algorithms for clustering samples and defining groups.

Each of these aspects are reviewed below with recommendations as to which alternative approach renders the most accurate assessment where such judgements are clearly discernable.

Framing The Initial Area

Framing an initial area for investigation is the first step in virtually all biogeographical endeavors. The appropriateness of the frame will pre-determine the capacity of the study to be complete, unbiased, and accurate. Most important, and most frequently violated, is the axiom that the initial area should encompass the largest physiographic feature under investigation, such as continents, tectonic plates, climatic belts, major water masses, and hydrological systems. Only by including the largest relevant and potentially limiting feature may the unit under study be framed in its entirety. Most importantly, units should not be framed by political boundaries. Such boundaries fragment some natural units, while recombining others into artificial synthesis. Unfortunately, such politically framed analyses are traditionally the rule, rather than the exception.

The use of political units as initial areas for analysis generates the same kinds of problems when they are used as primary units of sampling. U.S. counties have been particularly popular as units of biogeographical comparison (Lambert and Reid 1981; Dixon 1987). Counties are arbitrary and conducive not only to the lumping of several [end p. 27] different ecosystem fragments, but also to serious inequities in sample areas. Morafka (1988) noted that west Texas counties are often a full order of magnitude larger than those in the southeastern part of the state.

Hagmeier and Stults (1964; Hagmeier 1966) argue for the use of standardized grid analyses of initial areas. The procedures overcome many of the problems posed by political units and open the opportunity for standardization between studies.

Database Gaps and Biases

Weather stations are subject to tremendous bias as a result of human population distribution, and their use as a database has had very real consequences for interpretations of Chihuahuan Desert limits, especially in the south. Schmidt (1979) used

available weather stations as his sampling source. Reporting stations north of 25N latitude were highly skewed toward river valleys (Ríos Grande, Conchos, Florido, Nazas, Aguanaval, and the drainage of the Parras Bolson), since most human habitation is directed toward agriculture. As a result recorded temperatures tend to be very high. Many well-drained Chihuahua and Coahuila desert uplands are virtually uninhabited and lack weather stations. In the controversial southern Saladan Sub-province south of 25N latitude, especially involving Zacatecas, San Luis Potosí, and Nuevo León, the situation tends to be reversed. Of the few long-term reporting stations, approximately 11, for this critical area, only four stations were below 1,800 m elevation. The remaining stations averaged 300 m higher in elevation (1,982 m vs. 1,675 m) and reflected the human bias toward high montane mining towns in a region devoid of rivers and significant irrigated agriculture. This intrinsic demographic bias in the sampling sources exaggerates temperatures to the north and depresses them in the south. This skewing, coupled with an absolute dearth of valley stations, in turn, probably led Schmidt to his decision to exclude the Saladan region from his "real" Chihuahuan Desert.

Even the de Martonne index places the three lowest elevation stations in the Saladan Subprovince. Matahuala, San Luis Potosí, in San Luis Potosí and Dr. Arroyo in Nuevo León, when recalculated (from Morafka 1977 and sources cited in that text) run from 9 to 13, right on the division (10) Schmidt used to separate desert from non-desert. If the region had reports from more weather stations in the 1,500-1,750 elevational range, the outcome would have unambiguously identified desert climates across the lower Saladan valleys. This situation is very much analogous to that found in the upper Rio Grande Valley of New Mexico. Here abundant reporting stations made it possible for Schmidt (1979) to recognize lowland desert climates continuing north along the Rio Grande Valley, and to discriminate between lowland weather stations and those in the adjacent mountains reporting very different conditions.

Climatic Coefficients

The choice of climatic coefficients also exerts a great influence on the extent and accuracy of Chihuahuan Desert definitions. Virtually all researchers have attempted to quantify and/or classify aridity in terms of a net deficit water budget, one in which evapotranspiration annually exceeds incident precipitation. However individual indices approach this objective with radically different formulations. Some, like Koppen (1931), simply inferred climate from vegetation, while others correlated total precipitation (mm) to temperature ratios with expected climatic outcomes (de Martonne 1926). A few, including Thornthwaite and Mather (1962) attempted to reconstruct a water budget more directly. Reitan and Green (1968,50-51) provided an excellent and evaluative review of aridity coefficients available at that time and their summary of index systems is particularly insightful:

Maps using the various indexes of aridity have proven useful in vegetation studies and agro-meteorological work. There is, however, something unsettling about a procedure that uses relationships without a clear understanding of the physical processes involved in those relationships. Thornthwaite's scheme of the interaction of rainfall, potential evapotranspiration, and soil moisture seems sound, although he computes potential evapotranspiration as a function of existing temperature records and day length only. Other expressions such as de Martonne's $P/(t + 10)$, Emberger's $100 P/(M+m)$ ($M-m$), or Prescott's $P/s.d.$ seemingly do not have the same sound fundamental basis on which to base a system of climatic classification. On the other hand, Budyko's R/LP appears well-founded and has proven useful in widely varying locations (Reitan and Green 1968, 50-51).¹

Bailey (1981) provided a more current and equally informative review of climatic variables measuring aridity and characterizing deserts. He observed that highly erratic rainfall patterns, as revealed by comparisons between years, might exacerbate conditions of aridity. Precipitation variation could be quantified by the coefficient of variation, the ratio of the standard deviation to the mean. Biologists have also recognized the role of precipitation variability in explaining [end p. 28] animal distributions (Pianka 1966). Medellin-Leal (1982) reviewed a wide range of aridity coefficients, specifically as they applied to Chihuahuan Desert delineation and classification.

Most reporting Chihuahuan Desert stations simply lack the ancillary information necessary to calculate indices reflecting true precipitation/evapotranspiration ratios. However, seasonality of rainfall information is almost universally available and the failure of both authors to utilize formulas which incorporate this factor (Meigs 1957) is regrettable. Certainly, incident rainfall in December is exposed to a relatively minimal evapotranspirative loss compared to that operative in July. Crude annual P/T ratios make no recognition of this difference, particularly relevant to the Chihuahuan Desert where 70 percent of annual precipitation falls in the six warmest months. The greater percentage is confined to three of the hottest months, from July through September (Comet 1984). Therefore, simple P/T ratios lend to a severe underestimation of the aridity of Chihuahuan Desert stations. Like the montane bias of reporting weather stations in the south, this underestimation tends to eliminate inclusion of the southern Saladan Subprovince from the Chihuahuan Desert. Both Morafka and Schmidt recognized the defining significance of seasonal rainfall (Morafka as percentage of winter rain, Schmidt as percentage of May-October rain). Yet neither incorporated seasonality into his chosen Pff formula. However, Schmidt (1979) did utilize seasonality of precipitation in assigning the weather stations of the Son-Chih Transition area to Sonoran Desert if they reported less than 55-60 percent of their precipitation in the six warmer months. Those with more than 60 percent in summer

were designated as part of the Chihuahuan Desert.

Coefficients for Ecological Discrimination Just as the choice of an aridity measure effects categorical size, shape, and categorical designation of the defined climatic system, so too does the choice of coefficients for comparing biotic assemblages. Ecologists and biogeographers use three major types of indices for defining and/or comparing biotas. These three are (1) indicators of biotic change, (2) coefficients of biotic resemblance, and (3) coefficients of evaluating biotic diversity. In addition to these indices, more recent works have defined and compared biotic assemblages in relation to environmental gradients using multivariate statistics. Among the simplest and most widely used formula of the first category is the Index of Faunal Change, or IFC (Hagmeier and Stults 1964). This is essentially a percentage value calculated by dividing the number of taxa with ranges terminating within a designated area by the total number of taxa occurring in that unit. This approach was used by Morafka (1978) to evaluate his Chihuahuan Desert model as predictor of amphibian and reptile distributions.

The second category, that of biotic similarity coefficients, also employs simple fractional or percentage values. Simpson (1960) and Cheetham and Hazel (1969) reviewed the most commonly used of these formulas, concluding that they constitute two major types. The first are those emphasizing overall similarity, such the Jaccard (1902) Coefficient of Community; this is actually the Braun-Blanquet Similarity Formula according to Murphy (1983). And second are those which emphasize the derivation of the smaller of two compared samples, illustrated by Simpson's (1960) Similarity Coefficient. Whenever any of these coefficients are applied to geographical issues, it is critical that they be drawn from samples from the same habitats, for example, lizards from flatland desert habitats (Pianka 1966). Inconsistent combinations of sampled habitats will grossly exaggerate differences.

Analysis of the herpetofaunal assemblage occurring in the southern third of the Chihuahuan Desert, the Saladan Subprovince (Morafka 1977, 116-121; 1978) illustrates several of these points. IFC value along the Saladan border with its northern neighbor (the central Mapimian subprovince) is an impressive 54 percent. Even when only flatland desert taxa are compared, the coefficient Of Community between them is only 23 percent. However, when the Simpson's Similarity Coefficient is employed, the value rises to 57 percent. The shift is due entirely to the depauperate nature of the smaller Mapimian sample. The most desert-adapted species are, in fact, derived almost entirely from Mapimian conspecifics. A sophisticated multivariate evaluation by Harper (1983) came to the opposite conclusion, actually excluding this total derived fauna from the Chihuahuan Desert entirely. This contradicting conclusion is due, in part, to the fact that the latter study did not confine itself to single habitat comparisons, or recognize differences due only to the reduction in total diversity, nor did it use an unambiguous "outside" sample to distinguish between Chihuahuan and non-Chihuahuan faunas.

The third category, that of true diversity coefficients, is largely derived from formulas utilized in information theory and requiring information about relative abundance of individual taxa rather than simple species density values which are based upon presence alone (Panka 1974). Just as was the case with the more sophisticated climatic coefficients, these highly informative values require more [end p. 29] information than is available to most biogeographers dealing with large and/or incompletely investigated regions. As a result, they have rarely been used to define biotic provinces in the past.

Because of the aforementioned considerations, multivariate tools have only recently been employed both to define primary areas and to identify influencing environmental parameters. These approaches are probably more appropriate for the latter task than for the former. However, the recent studies of Gehlbach (1984; 1988) incorporate the Shannon-Weiner Diversity values (Shannon 1948) into his principal component analysis of bird faunas inhabiting Texas counties bordering Mexico. The Lambert and Reid (1981) study of Colorado herpetofauna has already been noted. Owen and Dixon (1989) have applied the use of multivariate, especially principal component, analyses to correlate environmental factors with the collective distributions of Texas herpetofauna.

PROTOCOL FOR CONSTRUCTION OF AN INTERDISCIPLINARY CHIHUAHUAN DESERT

Given the problems reviewed in the forgoing discussion, the outline of a new protocol is presented here which might provide the following:

- A. Definition of a climatic physiographic province
- B. Definition of a biotic province
 1. Framing an initial area
 2. IFC-grid to determine primary areas
 3. Resemblance clustering of primary areas into biotic provinces

C. Testing the correlation between the physical and biological boundaries

Step A. Defining a Climatic Physiographic Province

Since the task at hand involves a desert, the specific physical definition must delineate a physical system characterized by progressive and sustained net loss of water over repeated annual cycles. Ideally, climatic definitions should rely on water budget-based formulas such as those of Thornthwaite or on a classification system like that of Meigs. Equally desirable would be the inclusion of Bailey's coefficient of variation in precipitation in a defining formula. If the incompleteness of the data from reporting weather stations continues to force the employment of less direct coefficients like the de Martonne, then a control study should be undertaken. Well-documented stations, existing in the U.S. and to be established in Mexico, should be used to calculate simultaneously both Thornthwaite and de Martonne coefficients. To remove the aforementioned cultural biases, standardization of compared sites must also be imposed. If both formulas assign the same degree of aridity and delimit shifts in climate at the same points, one might be able to rely on the de Martonne formula with more confidence. If not, one might need to use a smaller number of stations with greater extrapolation between sites, or establish new, more fully recording installations (especially in the Salladan region). Recent maps commissioned by U.S. and Mexican federal agencies² should make it possible to refine limits based upon the distribution of aridosols (and other characteristic halomorphic soils), closed-basin drainage, and other features indicative of an arid landscape. While these features are not all unique to dehydrating climates, they are at least characteristic, especially when alternative causes are easily eliminated. Remote sensing also provides new databases for both surveying the physical desert and for characterizing its vegetation. A grid analysis for physical isobars might be able to identify interfaces of maximal change thereby outlining the physical desert in a fashion similar to that by which IFC values delimit biotic units. This physical definition must be framed in terms of the largest physiographical systems involved, not in terms of political entities. The initial area should encompass all competing definitions currently available. Maximal range of latitude and longitude are noted in the introduction. The entire Mexican Plateau (Altiplano) and its subordinate drainages (Rio Grande and tributaries) serve well as a preliminary framework for the Chihuahuan Desert.

Step B. Definition of a Biotic Province

1. Framing an initial area Procedures suggested for framing the physical province would apply equally here.
2. IFC-Grid: determining primary areas The procedure has been explained in detail by Hagmeier and Stults (1964) and by Morafka (1977). The first operation involves superimposing a grid of squares (80 km to a side) across the entire initial area. The second operation is the calculation of the maximal IFC values for a particular set of taxa. Vascular plants would probably be the ideal, and the opportunity to do this is enhanced by the extensive survey of dominants reported by Marroquín et al. (1964) and even more so by the forthcoming monograph on Chihuahuan Desert flora by Johnston and Henrickson. Diversity, responsiveness to both climate and soil, and our increasing knowledge of their taxonomy would recommend vascular-plant distributions as the primary database for defining the biotic province. Other taxonomic groups which would provide adequately diverse [end p. 30] and complete distributional databases would be rodents, amphibians and reptiles, and select insect groups (see Cohn 1965 for katydids). Of more marginal value would be scorpions and terrestrial gastropods. All of these groups, except rodents, are heterotherms. These cold blooded "conformers" with limited dispersal abilities are highly responsive to barriers imposed by differences between local climates, both past and present.
3. Resemblance clustering of primary areas utilizing Jaccard's 1902 Coefficient of Community (or C.C.), the primary areas inscribed by Step 2 may be clustered into a dendrogram (tree) based on biotic resemblance. The originally framed initial area is sufficiently large to include non-desert provinces, so that clustering will be able to discriminate between desert and non-desert as well as subordinate degrees of similarity. Following Hagmeier and Stults (1964), primary areas sharing more than 55-60 percent of their species would be assigned to the same biotic province, but in some cases would retain identity as subprovinces. Primary areas which share a lower C.C. solely because one unit is considerably smaller than the other, could be reevaluated by Simpson's Similarity Coefficient, or Sc. If such pair-wise similarities exceeded 75 percent, the two could then also be combined into the same province. The product of this set of operations would then serve as the basis for testing the predictions of the physical model of the desert.

Step C. Testing the Correlation Between the Physical and Biological Provincial Boundaries

The statistical procedure employing the original IFC grid to assess the significance of the physical model in predicting shifts in biotic assemblages has been previously described by Morafka (1977). Since biotic information is specifically excluded from the climatic-physical model, any circular testing would be eliminated. Coincidence between predicted and actual IFC ranking for grid squares inscribing putative borders could be evaluated by a Mann Whitney Rank Sum Test (Mansfield 1980, 313) for significance. The results of this test would either affirm and quantify the effectiveness of the physical definition and map of the desert; or require specific modifications at local or regional sections of the grid; or nullify the particular map boundaries proposed. If the model were upheld, testing could be extended to other groups. Assuming the

distributions of individual taxa were accurate, rejection might indicate that the physical definition was itself defective in its ability to predict major biotic disruptions or transitions, or that no such abrupt borders did, in fact, exist. Unlike some multivariate techniques which will ordinate predetermined data sets to maximize their discrimination, the simple IFC grid is quite capable of presenting a grid of continuous change without sharp boundaries or cores of stability. Such systems, especially in the tropics, most certainly exist.

CONCLUSIONS

The complex basin and range topography of the Chihuahuan Desert and the associated mosaics of edaphic vegetation (Morafka 1977, Henrickson and Johnston 1986) present a formidable test for the series of models, tests, and analyses proposed here. Its complexity is compounded by its geographical position along the temperate-tropical climatic and biotic interface. In short, a protocol which is capable of resolving a system of this complexity should be appropriate for any ecosystem which could be mapped.

The Chihuahuan Desert stands as the largest, least understood, and most poorly defined natural component of the increasingly exploited U.S.-Mexican borderland (Horsburgh 1986). Climatic displacement of current ecosystems may be accelerating as "greenhouse" conditions become increasingly operative. As a result, the time remaining in which meaningful baseline studies may be constructed is limited. Yet, we live in an age in which major taxonomic inventories, international cooperation, and remote sensing are yielding more robust databases than have heretofore been available. Surely, an improved resolution is within our grasp---if only we could decide precisely for what it is we are grasping.

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NOTES

1. P = average annual precipitation (mm); t = average annual temperature; M = average maximum for hottest month (centigrade); m = average minimum for coolest month; s.d. = saturation deficit (with all values in inches and fahrenheit); R = radiation balance of Earth's surface; L = latent heat of vaporization.

2. Especially DETENAL, Dirección de Estudios del Territorio Nacional.

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RESUMEN

Los mapas contemporáneos del desierto Chihuahuense varían considerablemente en tamaño, desde 30,000 km² hasta 60,000 km², con un promedio de alrededor de 350,000 km². Discrepancias entre distintos mapas fueron observadas al comparar los límites nordeste, noroeste y especialmente los del sur. Varios investigadores han intentado unificar dichos mapas sin lograrlo. Los desiertos en general han sido considerados como sistemas climáticos, provincias fisiográficas y bióticas. Además de estos argumentos filosóficos, existen varios protocolos para la construcción de mapas y el uso de datos diversos, resultando en la delineación de distintos mapas. Preferencias personales en los datos recopilados han causado más desacuerdos en la ubicación del borde sur del desierto Chihuahuense.

Como paso inicial para la creación de un mapa del desierto Chihuahuense que sea aceptable para todas las disciplinas involucradas, se ha propuesto un modelo climático-fisiográfico para el desierto. El cual combina el déficit anual de agua con las distintas formas topográficas características de climas áridos. Dicho modelo sería probado contra diversos grupos taxonómicos, para así evaluar la posibilidad de predecir las delineaciones, limitaciones, o demarcaciones a través provincias bióticas cuantificadas. Probando un modelo fisicogeográfico para predecir una provincia biogeográfica, se puede satisfacer las varias disciplinas involucradas. Este propuesto "protocolo" puede servir para convertir las operaciones descriptivas estáticas actuales utilizadas para categorizar los desiertos, en un proceso dinámico para probar un sinnúmero de hipótesis. [end p. 34]