Macroclimate and plant forms:
An introduction to predictive modeling
in phytogeography

Tasks for vegetation science 1

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Preface by the T:VS Series editor

The first volume of any scientific book series is always something special. Long deliberations and negotiations have finally borne fruit. A new scientific series, Tasks for Vegetation Science, presents itself with the first 3 volumes almost simultaneously, setting in content and format standards for the books to come. Volumes 1 and 3 deal with modelling attempts of the structure and function of vegetation. Volume 1, this volume, contains the attempt to predict vegetation structure from various climatic parameters. This book will probably serve as a milestone in the long list of previous attempts to correlate vegetation structures with climatic parameters. Aridity indices, EP-values, bioclimatic thresholds of various sorts have been tried in the past with increasing success to predict vegetation types.

All these attempts were of limited value, however, since considerable margins of uncertainties or exceptions for greater portions of the world remained. Previous workers in this field together with the many critics always demanded better solutions after they had presented their models. They demanded better data for meteorological observations, closer networks for vegetation data, the inclusion of more environmental parameters, better systems for vegetation classification to name only a few.

It was therefore a noteworthy attempt of Dr. Box to select such a difficult task for his thesis. Dr. Box, a mathematician by early training, possessed the mathematical tools seldom available to a vegetation scientist to undertake a new attempt towards the prediction of vegetation structure from environmental, climatic parameters.

Since our time has generally better information than our colleagues in the past, it is only natural that we try to model relations between vegetation parameters and environmental parameters more precisely, if such relations, indeed, exist.

To show the vegetation types, geographical areas, and parameters where such relations exist and where they do not or only weakly exist was the purpose of Dr. Box' study. His approach has entered a new field of numeric vegetation modelling, the use of information systems. Since the approach is the first of its kind in vegetation science, one cannot expect perfection in the predictive power of his model set. However, the new method once presented is open for discussion, for refinement and for intensive testing.

For the series editor it is especially gratifying to present the volume as the first one in a row of volumes with similar tasks. The author of this book worked for a long time together with the series editor while he developed the basic structure of his information system called 'ECOSIEVE'.

Once perfect, the predictive power of this model has considerable theoretical and practical value for management purposes and is therefore very timely in its appearance. As an intensive study, combining skills in vegetation science and mathematics and computer science, it will certainly set an example for the next student generation of vegetation science. The use of information systems as well as multifactorial regression analysis has just begun to yield results in vegetation analyses of various kinds. Our plan is to present in future volumes of this series more new techniques and concepts of this kind useful for our science to the vegetation scientists.

Volume 3, by Dr. Ross, dealing with biophysical modelling on ecosystems, is already in print. Several more books, presenting new methods and special treatments of important ecosystems, are in various stages of completion.

With the first volume appearing, the new series T:VS is on its way. It is our hope that the series will serve our profession in the future and that the first volume will have a good start.

Osnabrück, March 1981

H. Lieth

Foreword

This study arose out of the old question of what actually determines vegetation structure and distributions. Is climate the overriding control, as one would suppose from reading the more geographically oriented literature? Or is climate only incidental, as suggested by more site and/or taxon-oriented writers? The question might be phrased more realistically: How much does climate control vegetation processes, structures, and distributions?

It seemed to me, as an ambitious doctoral student, that one way to attempt an answer might be to try to predict world vegetation from climate alone and then compare the predicted results with actual vegetation patterns. If climatic data were sufficient to reproduce the world's actual vegetation patterns, then one could conclude that climate is the main control. This book represents an expanded, second-generation version of that original thesis. It presents world-scale vegetation and ecoclimatic models and a methodology for applying such models to predict vegetation and for evaluating model results. This approach also provides a means of geographical simulation of vegetation patterns and changes, which represent necessary data inputs in other fields such as atmospheric chemistry and biogeochemical cycling.

It has been fairly well accepted that climatic and other environmental conditions are associated with the evolution of particular aspects of plant form (convergent evolution). The particular configurations of plant size, photosynthetic surface area and structure (e.g. sclerophylly, stomatal 'resistance'), and their seasonal variations represent what one can recognize fairly readily as distinct growth forms. These aspects of form, however, also determine the potential rates and annual totals of photosynthesis, respiration and water loss of plants and thereby set the climatic limits on their water and energy budgets and thus their distributional limits in the real world. This logic is perhaps best called 'ecophysiognomic' and can be stated as an initial hypothesis:

> Plant form and structure are evolutionary results of climate (among other factors) but also largely determine the current distributions and viability of plants through their effects on plant water and energy budgets.

If true, this implies both an ecology and a biogeography at the level of plant life forms – a fundamentally ecological life-form approach to vegetation, which not only should provide new insights and conceptual tools but perhaps also make vegetation study and appreciation somewhat more accessible to those without special training in botanical Latin and taxonomy.

The study presented herein represents an attempt to discern world patterns in the relationship between plant form and vegetation structure (physiognomy and morphology) on the one hand and environmental, mainly climatic conditions on the other. The focus is on plant water and energy budgets and how they and related physiological processes are related to and limited by climatic conditions (in different types of climates) working through the particular combinations of form characters represented by different plant life forms. The project attempts to organize much detail and many smaller explanations into a world-scale framework and initial empirical model, as the basis for subsequent, more analytical work on relations between plant form and physiological limits. The proposed world set of plant life forms is related to climate by means of climatic envelopes, which are used with a world climatic data-base to predict world life-form distributions. These are interpreted as vegetation types and compared with actual vegetation patterns and site data, with generally good results. (The validation suffers some from insufficient descriptions of local vegetation which also provide climatic data. Readers are invited to send local vegetation and climatic data for comparison with predicted vegetation profiles.)

As the title states, the book is intended as an introduction. In developing the vegetation classification the first criterion was to cover the main types of terrestrial plants in the world (but not necessarily all taxa). In describing climate the main emphasis was on covering the most important ecological aspects. For sake of manageability, both vegetation and climate had to be described with as few units as possible. Since the purpose is to discern basic, general relationships, if they exist, sweeping generalizations and simplifications are sometimes made. These are then pushed as far as possible in the modeling in order to see where they break down when exposed to the full range of variation in earth's climatic conditions. Criticism is expected. Only by this sort of generalization, however, can one put together a world-scale model which can be expected to answer general questions. The model represents perhaps the first serious attempt to predict fairly detailed vegetation profiles, including seasonal aspects, and distributions for all parts of the world's land area. It is also probably one of the first vegetation studies, at any geographic scale, to compare predicted and actual vegetation profiles rigorously as a means of assessing model accuracy and thus the validity (and adequacy) of the underlying assumptions.

The study draws on several sources and methods which are not commonplace in traditional American botany and plant ecology (as judged at least by recent journal articles). Among these are a comparative, geographic outlook over large areas (involving literature in other languages); a fairly rigorous quantitative approach (involving necessarily large amounts of climatic data); a focus on life forms as the fundamental plant unit (providing better ecological and physiognomic resolution); geographical and mathematically simple ecological modeling; and rigorous scrutiny of predicted results. The result of this synthesis is a quantitative geographical methodology which can be used both for simulation/prediction and as a geographic alternative and complement to traditional statistical hypothesis-testing. It nevertheless represents an approach which must be superficial, at least initially, and which requires further development and improvements.

This book is dedicated to Heinrich Walter for his many and enormous conceptual and geographic contributions to the ecological study of world vegetation; and to Helmut Lieth, who made the author's admission to doctoral study in ecology at an American university possible, provided early guidance, and encouraged the development of latent world-scale interests. Special thanks is also due the Kernforschungs-anlage (Nuclear Research Center) in Jülich, Germany, where much of the computerized basis for this and other research was initially developed. Work in Jülich and Hohenheim (with Walter) also permitted the author to observe many vegetation types of Europe, North Africa and Atlantic islands which could not have been visited otherwise. (More extensive ecological study during 1981–82 in the Old and New World tropics is anticipated.) Grateful acknowledgement is due the computer center of the University of North Carolina, and also those of Duke University and the University of Georgia, for computing time and other assistance; and to the UNC Photographic Laboratory for photography of the largest computer maps.

The manuscript was typed by the superb office staff at the University of Georgia geography department: Pat Wall, Mildred Bell, Anne Berryman, Kathy Smith, Sharon Mullins, Dawn Tolbert, and Sue Werner, under the direction of Yvonne Pommerville, office manager. No department ever had a more helpful office staff.

Most importantly, this project would not have been even remotely possible without the perseverance of the author's wife, who worked rotating shifts to provide daily transportation, all living expenses, and some school expenses while the author was a doctoral student.

Athens (Georgia), 31 May 1981 Elgene Owen Box

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CHAPTER 1

Introduction

Man has probably always recognized vegetation as a most conspicuous and characteristic aspect of landscape. Not only does vegetation provide food and other resources, but it is also responsible for the general appearance of landscapes, providing both individual landmarks and perhaps the most basic means of distinguishing and characterizing different regions. Certain rough correlations between climate and vegetation types were appreciated certainly by the peoples of classical times and probably long before that. Modern botanists and ecologists certainly recognize the correlation between climate and vegetation types but view climate, as the main determinant of vegetation types and distributions, with varying degrees of skepticism, preferring to look instead for individualistic properties of species, particular community or association affinities, complex biotic interactions, or edaphic or other overriding site factors. These non-climatic factors certainly may be present and play interesting roles at the species level. It is the basic premise of this study, however, that their effects are super-imposed on a general climatic situation and are of secondary importance in determining the general structural, functional and geographical patterns of land vegetation.

Plant and vegetation geography have been studied most commonly at two levels:

1. The taxonomic level, involving distributions of individual species, genera and families.
2. The formation level, involving distributions of particular vegetation formations and formation types.

The vegetation units in the first case are entirely taxonomic, while those of the second are mainly physiognomic and ecological.

Between these two levels is that of a more general concept of plant types, at which the vegetation unit is particular types of plants composing the vegetation but at which the plant types are ecological and/or physiognomic rather than taxonomic units. The level of physiognomic plant types, i.e. growth forms, is at least as important as the taxonomic and formation levels for the following reasons:

1. Plant growth forms provide the basic structural components of vegetation stands, thus also the most obvious level of subdivision both for describing and explaining vegetation structure.
2. The primary physiological processes of plants are largely controlled by such aspects of plant form as the amount of respiring phytomass (plant size), amount and configuration of photosynthetic and transpiring surface (leaf form and size), and seasonal variations in form (e.g. leaf habit).
3. Since plant species tend to cluster into characteristic general forms, plant form provides a useful means of getting at general principles of plant-environment relations without becoming mired in taxonomic detail.

The idea of ecological plant types (groups of taxa with similar ecological requirements) leads directly to that of ecophysiognomic life forms, i.e. growth forms which show a more or less obvious adaptation to environmental conditions due to similar form-based water and energy budgets.[1] Since the mechanisms of environmental limitation operate primarily at this level, life forms would appear to be the most appropriate unit for studying the ecological aspects of vegetation geography.

In mapping vegetation and other larger ecological distributions (e.g. ecosystems and biomes) geobotanists and biogeographers have generally focused on more or less physiognomically defined vegetation formation types. These are usually characterized by one or more dominant or co-dominant life forms, such as the evergreen and summergreen needle-leaved trees of the boreal forest or the larger trees, shrubs and stem-succulents of warm semi-deserts and open woodlands. Formations, however, generally also include other important and lesser life forms which cannot always be recognized in more general formation approaches. For the boreal forest such additional forms regularly include the summergreen birches plus summergreen and smaller evergreen shrubs and herbs, and various ferns, mosses and lichens. These different synusiae are constituent parts of most boreal forests and as such make their own particular contributions to vegetation and ecosystem structure and functional integration. The individual roles of the constituent life forms are important to any system. The actual mix of forms within different formations of the same general type (e.g. forests, woodlands, semi-deserts) may be less consistent, however, because of reduced dominance by a single form (e.g. semi-deserts) or because of various historical (e.g. Australia) or other ecological factors. Although tropical rainforests, mediterranean oak forests, and warm-temperate 'laurel forests' are all dominated by broad-leaved evergreen trees, for example, their physiognomy, structure, and functional patterns all differ widely because of both the general size of the plants and the mix of constituent subdominant and understorey forms. Perhaps more importantly, however, the life-form approach provides a means of interpreting vegetation change along gradients at some ecological level higher than that of individual species and genera, thus hopefully providing more insight into mechanisms of environmental limitation.

It has been known for a long time that important relations exist between climate and terrestrial vegetation patterns. General levels and seasonal patterns of solar radiation, air and soil temperature, water availability (precipitation) and runoff and potential water loss (potential evaporation) determine the basic conditions of existance for land plants. Plants in turn must adapt to environmental conditions through modification of form and surface structure, physiological processes, and seasonal habits. In many respects the most important of these is the general growth form, since it is through its amount of surface area and its area-volume ratios that the other processes are constrained to operate. The rates of basic physiological processes and thus the seasonal and annual water and energy budgets of plants are directly governed by such aspects of plant form as general plant size (respiring biomass), growth form (potential leaf area and canopy height), leaf size and 'hardness' (potential water loss), and leaf duration. Climatic limits to the adequacy of particular combinations of leaf and plant size, shape, surface resistance and duration, as measured by positive water and energy balances, can thus be seen as the most important mechanism of environmental limitation. The logic of environmental (primarily climatic) limitation and its applicability to distributions of such features as soils, vegetation, animals and even human land-use patterns have been recognized since the early 19th Century, if not before. The main obstacles to quantitative application of environmental limitation principles have generally involved problems of scale: micro-environments, spatial heterogeneity, and above all the availability of sufficient quantitative data for all important environmental factors.

The usefulness of world and regional-scale vegetation models has also been well recognized in plant geography since the early 19th Century. Such models have generally been based on environmental limitation, correlating distributional limits of vegetation types with various values for important

[1]The term 'growth form' is used throughout this book as a purely physiognomic concept, the combination of a particular 'structural type' (e.g. tree, shrub), leaf type (form but not size or texture), and seasonal habit. The term 'life form' involves the assumption of certain environmental relationships as well as a bit more physiognomic detail (namely leaf size and texture). The actual life form of a plant or species is not always known, particularly as regards functional characteristics such as seasonal habit. As a result, the term 'life form', as used herein, does not refer to any particular classification system unless explicitly stated or implied by context. The structural types recognized in this study are shown in Table 1, p. 14.

macroclimatic factors. Predictive modeling, i.e the rigorous application (extrapolation) of quantitative models to environmental data (at sites other than those used to construct the model) in order to predict actually occurring patterns, can be particularly useful in plant geography and plant-environment relations, since it provides a ready means of testing the validity of the model and the understanding behind it. This was not done until recently because of the lack of sufficient world climatic data and of a sufficiently convenient means of generating and analyzing the results. The existence of large computers, computerized climatic data-bases, and computer mapping systems, however, now means that ecological hypotheses can be turned into quantitative models and then into maps within a few days. If world maps can be generated, representing the full range of climatic variation found on earth (and presumably much of that from past climates), they can often be interpreted quickly by someone familiar with world patterns in order to evaluate the hypotheses behind the maps.

It is hoped that the life-form approach will provide a more versatile and accurate basis for analyzing and synthesizing plant-environment relations and vegetation geography. In order to assess the degree to which meaningful vegetation units can be predicted from climate, an empirical model was developed which relates the world's geographically most important plant life forms to macroclimatic conditions. This model differs from earlier models in at least three important ways:

1. It treats plant life forms rather than formation types, as the units of vegetation. These life forms can be combined to provide characterizations of particular formations and formation types.
2. It includes more vegetation units (77 life forms plus sub-types) than most models. This provides much greater potential for resolution of vegetation types.
3. It includes more predictive climatic variables (eight) than most other models. This permits greater resolution of seasonal patterns which are reflected in vegetation phenology and seasonal physiognomy.

The model is used to predict and characterize the natural vegetation at 1225 terrestrial test-sites worldwide. These predictions are then compared with known vegetation distributions and detailed descriptions of the actual vegetation composition at a set of validation sites not used for developing the model.

The model described herein is a more analytical, enlarged version of an earlier 'synthetic' model (Box 1978a, 1981c), which focused only on dominant life forms and which attempted to include some aspects of vegetation structure (e.g. forest vs. open woodland) within the vegetation units. The present 'analytical' version separates plant form and stand structure entirely and includes the many understorey forms omitted from the first model. Both models relate plant life forms entirely to macroclimatic variables by means of climatic envelopes composed of limiting values determined from correlations between distributional limits and local climatic conditions. This was felt to be a necessary first step because such empirical environmental correlates sometimes represent the only readily available type of appropriate ecological data but will permit generation of readily interpretable results which can be used to develop models based on more integrative environmental factors. The model was specifically designed for world-level applicability and evaluation, i.e. for generation of world-scale vegetation predictions and rigorous comparison with actual vegetation. Vegetation predictions at particular sites are generated from the model using the general screening program ECOSIEVE (Box 1979a, 1981b). World results were computer-mapped using SYMAP (Harvard University) plus base-map, climatic data, and auxiliary software described elsewhere (Box 1975, 1978a, 1979a).

CHAPTER 2

Modeling ecological structure and function

One of the central problems in ecological modeling involves the coupling of continuous and discrete submodels. Most functional processes, such as production and transpiration, and many related environmental and state phenomena, such as air and leaf temperature, are mathematically continuous in the sense that their values vary continuously as the values of environmental determinants vary, at least on the time-scales usually employed in ecology. These processes are continuous because they represent well buffered feedback systems which are not overpowered by even rapid environmental changes. Mathematically this means that most functional processes and many state phenomena can be related to environmental determinants by continuous, often exponentially-based (i.e. feedback-based) mathematical functions. Annual net primary productivity, for example, has been successfully related to annual actual evapotranspiration and to annual precipitation by simple saturation curves and to mean annual temperature by a simple sigmoid curve, providing two bases for predictive world maps (Lieth & Box 1972).

Structural phenomena, on the other hand, generally represent balances among several basic functional processes and thus are often more complex. Some structural aspects, such as amount of leaf area or standing biomass, may require much more complex mathematical forms but still vary continuously, if less smoothly, with variations in environmental determinants. Other structural phenomena, however, such as species occurrence (distribution) and community composition, plus many behavioral phenomena, may involve processes which are discrete, combinatorial, hierarchical, probabilistic or iterative (state-dependent) in nature and which require quite different mathematics. Plant and vegetation distributions, at a given time, are best described as discrete (e.g. maps with discrete boundaries) or as probabilistic. Vegetation composition, whether described determinately or probabilistically, is a combinatorial phenomenon, involving interacting combinations of plant types or taxa. The processes which determine competitive success and vegetation succession (including productivity and leaf area) are continuous over the range of environmental conditions involved, but the structural dynamics of vegetation succession, in terms of life-form composition, is hierarchical in nature. Coupling the different types of models required to simulate these various aspects of vegetation structure, dynamics and distribution is certainly one of the main problems encountered in vegetation modeling and one which probably has no single best solution.

A. World vegetation models in general

Most quantitatively expressed vegetation-environment models can be thought of as consisting of three components:

1. a vegetation classification system characterizing plant and vegetation diversity (vegetation submodel);
2. a set of environmental variables important in describing the effective environment and in limiting vegetation distributions (environmental submodel); and

3. some sort of quantitative values (e.g. environmental limiting values) which relate the vegetation types to the environmental variables and represent an expression of plant-environment ecological relationships (ecological model).

The first quantitatively expressed world vegetation classification system and environmental model was probably that of Schimper (1898). Quantitative world and regional models have been presented also by Rübel (1930), Holdridge (1947), Troll & Paffen (1964), Mather & Yoshioka (1966), Hueck & Seibert (1972), and others. The classification of vegetation-related world climate-diagram types by Walter & Lieth (1960–67) represents a useful and elegant semi-quantitative system. Each model recognizes certain environmentally delimited vegetation types and provides appropriate, empirically determined limiting or critical values relative to important climatic variables.

The primary data-bases for modeling plant-environment relations are the various accumulated climate and other physical data and the available vegetation descriptions (including maps) and ecological interpretations for all parts of the world. Over the last century climatologists have been able to collect an enormous volume of climatic data for most parts of the world (though some important climatic factors have been poorly represented in data-collecting programs). It has been possible to construct detailed maps of macroclimatic conditions for most of the world. Plant data, on the other hand, have not been so complete, especially in tropical and other less accessible areas. Classification of plants has generally been approached on the three levels of:

1. plant species (taxonomy), based primarily on the relatively invariable reproductive parts of plants;
2. plant life forms, based on plant ecophysiognomy;
3. vegetation formations and formation types, based on the physiognomy of plant stands, which depends also on that of the dominant species.

Because of the need to be able to identify all plants relative to some classification system, primary emphasis was necessarily placed on the taxonomic effort. Coordinated data on other aspects of plant form, on process rates, on phenology, and on their environmental situations have generally been neglected until quite recently and are still inadequate. Fortunately, a few geobotanists have provided enough detailed, coordinated physiognomic and climatic data for various parts of the world that one can begin to piece together world ecophysiognomic patterns and attempt to model them predictively.

B. The current model

The model presented herein, being an initial attempt, necessarily reflects a very simplistic modeling structure. The purpose of the project was to produce a model which, without attempting to simulate major ecophysiological mechanisms in detail, can:

1. Determine, at global scale, to what extent plant form and vegetation structure are determined by climatic factors and which factors are most important.
2. Provide a world-scale modeling framework for geoecologic hypothesis-testing, further model development, and study of vegetation response to changes in climate.

This is attempted by examining the available world climatic and vegetation data and relating the distributional limits of plant life forms to what appear to be their most important climatic determinants. The model developed is essentially descriptive (empirical) and geographic in nature. Its output is a spectrum of plant life forms which can be used to characterize the vegetation at the climate site. The model is applied to a world climatic data-base in order to predict world distributions of plant forms and vegetation formation types. The predicted global results are used to check the model and can be expected to provide information on questions such as the following:

1. To what extent are the world's large-scale vegetation patterns really determined by climatic conditions? (Is climate the overriding factor, as has always been supposed?)
2. Which vegetation occurrences appear to be climatically anomalous?
3. To what extent do similar plant types and vegetation structures in different regions and possibly dissimilar climates represent the same ecophysiognomic response?
4. To what extent are certain vegetation types actually limited to known regions by climatic factors rather than by other proposed factors,

such as historical development, floristic relations, biological interactions, soil conditions, or man's influences?

Information on questions such as these, along with an initial world catalog of ecophysiognomic plant types, can be expected to provide a more unified, albeit initial theoretical framework for plant-environment studies than has previously been available. World patterns of both the predictive ecoclimatic variables and predicted vegetation are presented as computer-printed world maps. Validation of the model is attempted by comparing actual and predicted vegetation at particular sites. The sensitivity of the plant types to changes in particular climatic variables is also studied.

The logic of the life-form approach places certain constraints on the methodology, the most important of which can be summarized briefly as follows:

1. The definition of plant types must be based on plant features, i.e. there can be no vague environmental or taxonomic groupings such as 'semi-desert', which may consist of many life forms while retaining some uniformity as a formation type.
2. The model must be based on environmental limitation of major physiological processes, such as water uptake and transpiration, stomatal behavior, cold-hardiness, phenological phases, production and respiration, growing season length, etc., all operating through the particular characters of form.
3. The set of plant types must cover the full range of variation in plant form found on earth.
4. The plant types must also be global in concept, i.e. must cover ecological relations in all major occurrences of the types.
5. The model must be applied equally to all climatic situations.

The first two requirements are fairly obvious and state essentially that the model must be ecophysiognomic, which is to say that it must relate plant forms to the environmental factors most important in determining plant form. The third requirement states the necessary criterion for any general model. The last two requirements are equally important, however, since only by examining each disjunct occurrence of a particular plant form in different parts of the world can one hope to ascertain to what extent these occurrences represent the same biological answer to similar but disjunct environmental situations. A world-scale study does not guarantee that all possible ecophysiognomic manifestations will be covered, since some may have been precluded by historical or other reasons. World-scale simulation is, however, the best one can do without going to a quite different, less geographic approach.

Both available environmental data and the logic of 'first things first' strongly suggest that an initial model be based on macroclimatic factors and seek to characterize macro-level ecoclimates corresponding to the occurrence of particular plant forms. Macroclimatic data are also the only environmental data provided with almost all ecological vegetation descriptions and so represent the best basis for an initial world model. Although soil, historical, anthropogenic, biological, and other factors also influence plant distributions and vegetation structure, climate is the most important factor on most sites, and some of the other factors, such as soil conditions, may also be under macroclimatic control to a significant degree.

The global nature of the study requires that the model be able to predict life-form spectra which can be used to characterize both world vegetation distributions and the vegetation at particular sites. Since macroclimatic data are readily available for thousands of sites, these can be used with the model to generate implied world vegetation distributions which can be used to check the model.

Finally, the available ecological data strongly suggest that the model focus on environmental limitation patterns as the most feasible approach. The global scale requires a generalized but quantitative approach. Despite the several models of world vegetation which have been presented, a systematic, quantitative, global correlation of physiognomic forms (including seasonal aspects) with major ecoclimatic factors has never been attempted. The existing models are either too restricted geographically (e.g. Mather & Yoshioka) or involve vegetation units which are much too general or vague (e.g. Holdridge) to describe ecosystem structure or plant-environment relations.

C. Model structure and technical considerations

The basic structure of the model is that of descriptive vegetation and climate submodels related to each other through a deterministic ecological model. The vegetation model consists of a set of ecophysiognomic plant forms identified in Table 2, each well defined physiognomically. The climatic model consists of a minimal set of macroclimatic variables which are particularly important in determining plant form and vegetation structure and which represent a model of the main ecological aspects of climate. These variables can be thought of as defining an environmental hyperspace in which the occurrences of the plant types can be represented by environmental envelopes relative to the hyperspace variables. The ecological model consists of the estimated climatic limiting values for the plant types, which define their climatic envelopes, plus a growth-form dominance hierarchy expressing the ability of the forms to outcompete each other.

The main problems associated with this approach include the following:

1. The large number of hyperspace dimensions (ecoclimatic variables) which may be required to describe the effects of environmental limitation adequately.
2. Factor interaction between the variables, and the need for mathematical simplicity in the model.
3. The rigidity of envelope boundaries, with no mechanism for environmental variation resulting from factors not included in the model.

All three problems must be viewed, however, with reference to the so-called 'law of diminishing returns'. The first problem is basically one of model design. It was found that, for world-scale vegetation patterns, the main climatic effects could be represented adequately with eight variables. The problems of factor interaction and envelope boundaries require more discussion.

One manifestation of factor interaction and general complexity in both biological and environmental systems is that limiting values for environmental factors can be mathematically complex. Environmental limits can also vary with recent environmental conditions, as in the case of cold-hardening. Factor interaction between environmental variables can be expressed mathematically either through environmental limits which are variable-valued functions of other factors, resulting in curved or state-dependent envelope boundaries, or through the use of compound variables which combine highly interactive factors into critical variables, for which limiting values are usually much more uniform. The latter is much simpler mathematically. A central example in plant-environment relations can be seen on scattergrams of vegetation occurrence plotted against mean annual temperature and average annual precipitation (e.g. Lieth 1956; Whittaker 1975). Temperature limits are typically very nearly linear, but precipitation limits increase rapidly with increasing temperature, because of the increased evaporative demands. By contrast, the models of Holdridge (1947) and Mather & Yoshioka (1966) use a moisture index expressing the relationship between precipitation and potential water loss (evapotranspiration). The result is that the shape of the envelopes is greatly simplified, approaching an orthogonal form. Many authors have recognized both the simplified mathematical properties and greater scientific insight associated with such incisive compound variables as actual evapotranspiration and moisture indices (e.g. Major 1963; Lieth & Box 1972; Carter & Mather 1966; Holdridge 1947; Budyko 1975; Meentemeyer & Elton 1977). The choice of environmental variables can also result in artificial interaction, as in the case of temporally related monthly and annual values. This can be useful in representing different aspects of limitation by the same factor (e.g. total annual and seasonal moisture), but one must then understand that individual limiting values may not remain accurate if removed from the total configuration of variables.

The problem of rigid envelope boundaries can be overcome somewhat by generosity in estimation of limiting values, coupled with some degree of redundancy in interrelated variables. Limiting values must be chosen so as to include the effects of normal microclimatic variations. A probabilistic approach to environmental limits could also be employed but may require additional, less available data. The environmental-envelope approach has been used in many types of ecological studies, including studies of plant and animal habitats and environmental niches at the species level (e.g. Twomey 1936; Bodenheimer 1938; Fry 1947; Hart 1952; Went 1957; Gates 1969) and other quantitative models of world and regional vegetation (e.g. Lieth 1956; Holdridge 1947; and Mather & Yoshioka 1966). Each of these vegetation models involves only two environmental dimensions (the third in Holdridge's model being redundant). This number of variables is quite insufficient to represent seasonality. An apparent growing interest in environmental-envelope models is well illustrated by a recent formalized nomenclature and ecological theory of environmental envelopes by Dobson (in press) and by a recent cataloguing by Duke & Terrell (1975) of the climatic limits of some 1000 economic plants. To some extent, rigid limits can be softened by coupling with spatial environmental indices such as potential cover by the particular plant type.

A major consideration in designing an initial model was that the model be as simple as possible both structurally and mathematically. In order to make the model applicable without requiring a computer, all climatic limits are constrained to be constant-valued. Factor interactions are expressed through compound variables within an orthogonal system of environmental factors. The climatic envelopes include their limiting values. The prediction of plant types at a given site is then performed by a screening operation which involves comparing site climatic values, for each variable, with the climatic limits of each life-form candidate. Although this can be done without a computer (see Appendix F), a general computer program ECOSIEVE was developed to facilitate application of the model to larger data-bases (Box 1978a, 1979a, 1981b). ECOSIEVE sets up the user-specified screening structure, generates and prints the results for the sites provided, can provide optional cross-tabulation (i.e. distributions) by plant type and optional, user-designable output files for use with other programs, and can be coupled with user-designed successional or other models for further analysis of results. Each site is treated separately by ECOSIEVE, but some site interaction can be provided by coupling with computer mapping programs which interpolate values between sites. The spectrum of life forms predicted to occur at a site can be interpreted as a vegetation formation type by means of a life-form dominance model to be described later. This model can be coupled with ECOSIEVE and with the mapping programs.

As a result of earlier research (e.g. Lieth & Box 1972; Box 1975, 1978b), the author had helped develop a sufficient world computer-cartographic capability and climatic data-base (1225 terrestrial sites) to permit world-scale extrapolation, mapping and testing of quantitative vegetation models. As background for development of the present model, the vegetation types predicted by the earlier models of Rübel, Holdridge, Troll, and Mather & Yoshioka were generated for the 1225 climatic sites by ECOSIEVE and mapped for comparison with actual vegetation patterns (Box, unpublished). Due to omission of important environmental factors and/or insufficient discrimination of vegetation types, only Troll's model comes close to reproducing actual vegetation patterns over most of the world.

CHAPTER 3

Ecological classification of world vegetation

The area of plant ecology which deals with the relation of plant structure (including its seasonal variation) to environmental conditions has been called ecophysiognomy (Mooney 1974). One of the most conspicuous (and gratifying) features of plant structure is that it tends to converge to certain successful structural-functional forms, which can be called ecophysiognomic forms or life forms. These life forms provide adequate form-based water and energy budgets, life cycles, and other aspects of strategy for survival in their respective environments and can generally be described structurally by particular combinations of characters such as general growth form, size, leaf type, and seasonal habit. These characters are not independent, however, and compensation of one character by another implies that it is the combination, i.e. the life form, which is the basic unit and which must be related to environmental conditions. Because of the central importance of plant form, understanding the relation of form to environmental conditions suggests a means of interpreting plant-environment relations in general. A logical foundation for this approach would appear to be an initial, putative list of environmentally correlated plant forms. In order to ensure that we understand as much as possible about the relations between form and function, such a list must be based on the full range of plant-form variation found on earth. Although world classifications of growth forms, life forms and vegetation types have existed for some time, most suffer from some combination of insufficient scope, weakness in certain regions, vagueness, or lack of ecological conceptualization or applicability. Even the life-form classification of Raunkiaer (1934) is not very useful in arid areas (Zohary 1952; Orshan 1953; Walter 1973). Its elaboration by Ellenberg & Mueller-Dombois (1967b) is the best available classification, employing both growth-form and seasonality criteria. This geographic classification still requires some adaptation for use with a climate-based geographic world model.

A. Vegetation description and vegetation data

Development of a world classification of ecophysiognomic plant forms requires not only general familiarity with the vegetation of all parts of the earth but also more information on the physiognomic characters of at least the most important plants of these regions than is necessary for other types of world vegetation classification. The most important physiognomic characters of plants include the basic growth form, plant size, leaf form and size, leaf duration (or other index of seasonal activity), and some indicator of the more detailed nature of gas-exchanging surfaces. This last item, which represents the plant's control over water loss and related CO_2 intake ('stomatal resistance'), can be described crudely by leaf-texture terms such as sclerophyllous, malacophyllous, or coriaceous. Descriptions of individual species can best be obtained from local manuals (floras) where these exist but must be interpreted with reference to the species' importance in the structure of the local vegetation. Since the model is to predict vegetation type as well as plant distributions, information on cover and structure is needed also. The same plants, depending on available water, may grow so closely together that both canopies and root systems overlap or may grow in much more open stands (with little difference in the form characters of the individual plants). As a result, in order to obtain information on the effective mix of ecophysiognomic characters of the entire vegetation stand, one must seek data from a variety of more general, integrative and geographical sources, including vegetation manuals, vegetation descriptions, photographs, vegetation classifications, and maps.

Complete physiognomic description of local or regional vegetation requires information on species composition, species structural characters, formation structure (synusiae and dominance), and degree of ground cover and amount of leaf area by each synusia. Successional information often provides additional insight. Formation structure and ground cover are often suggested adequately by formation-type descriptors such as savanna, forest, open woodland, or steppe and by photographs. The formation approach has also acted, however, to limit description by identifying only the current or potential dominant synusia. The vegetation of the Carolina piedmont (USA), for example, has been characterized by various authors as Southern Pine Forest, Summergreen Broad-Leaved Forest, Oak-Pine Forest, or Southern Mixed Forest, without adequate reference to the other synusiae or to the fact that the pines are successional and remain indefinitely only on poorer sites, in open stands, and along forest edges. Descriptions of vertical structure and the lower synusiae are not always readily available for all parts of the world and must often be pieced together from individual data.

Horizontal variation in vegetation structure, due to such factors as topography, soil and microclimatic heterogeneity, is generally beyond the scope of the current project but cannot be ignored completely. Problems of gradual transitions in flat country, sharper boundaries in mountains, and various types of mosaics are well known in phytogeography. It is also well known that environmental heterogeneity becomes much more important in less favorable climates, as opposed to mesic climates where forest trees can attain complete dominance and produce more uniform microclimates. Situations of co-dominance by several life forms do not always represent ecotones, since there are often certain degrees of regularity in the mixtures of life forms and of randomness to some spatial patterns, as in the warm semi-deserts. Walter (1975), with reference to the semi-desert vegetation of Soviet Middle Asia, has provided a useful and graphic description of gradual transitions, macromosaics and more complicated interdigitations along environmental gradients.[1] Only the first of these can be predicted without reference to the environmental heterogeneity of the particular site. True physiognomic ecotones generally involve environmental limitation of at least one dominant life form.

In trying to develop any world vegetation classification system it is useful to examine existing classifications. Vegetation has been classified and mapped, with increasing refinement and detail, using three main bases: physiognomy, environmental conditions, and floristics. Physiognomic classifications (e.g. von Humboldt 1807; Schimper 1898; Rübel 1930; Küchler 1967) employ the most obvious features of vegetation and best convey an impression of vegetation structure and appearance. 'Ecological' classifications, employing primarily climatic conditions (e.g. Merriam 1898; Holdridge 1947), point out general vegetation-environment relationships but provide less information about the vegetation and can be used to cover areas where the vegetation is insufficiently known. Floristic criteria are often employed as convenient surrogates for physiognomy (e.g. *Coniferae, Graminiae*). The relative merits of the remarkably few basic approaches to vegetation classification and mapping are well summarized by Küchler (1951, 1967), Whittaker (1962, 1975), Shimwell (1971), Mueller-Dombois & Ellenberg (1974), and de Laubenfels (1975). A useful bibliography of vegetation maps was compiled by Küchler (1965–1968) and is being updated.

In reality, most vegetation classification and mapping systems employ aspects of more than one approach. Two recent classification systems proved to be especially useful for ecophysiognomic studies. The life-form and associated 'physiognomic-ecological' vegetation classifications of Ellenberg & Mueller-Dombois (1967a, 1967b, reprinted as appendices in Mueller-Dombois & Ellenberg 1974)

[1]These patterns are described more fully, with examples of actual vegetation, by Walter & Box (in press).

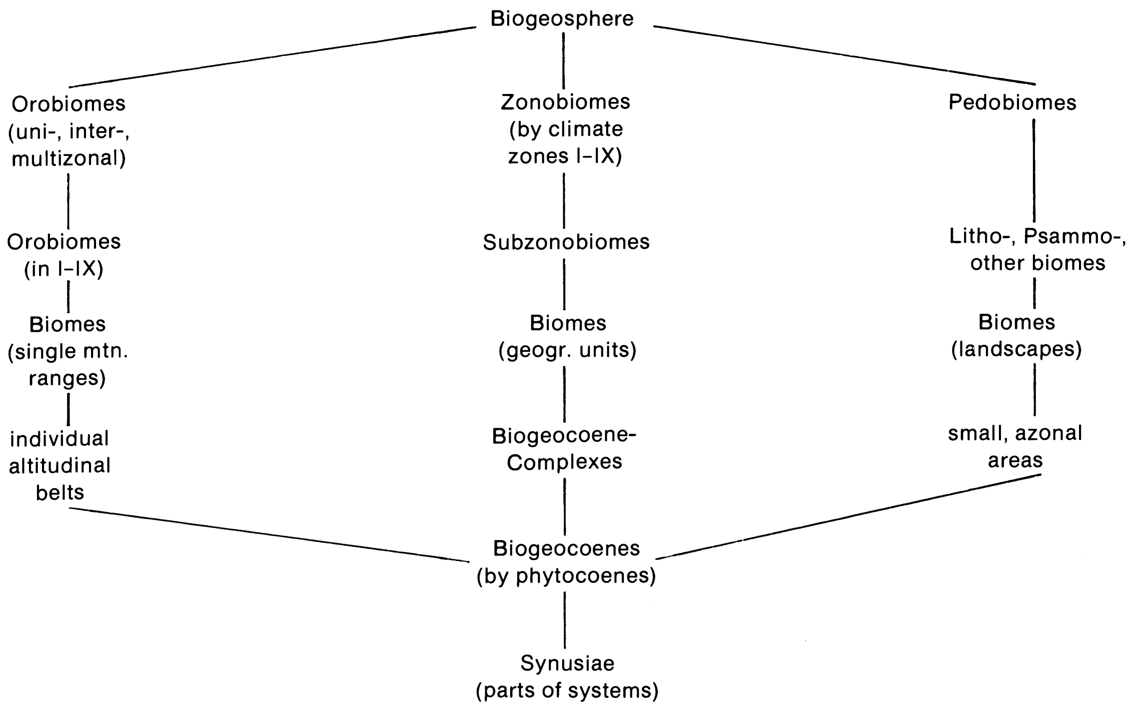


Fig. 1. Schematic representation of the global vegetation classification system of H. Walter (1975).
The biogeosphere (land areas of the world) is divided into climatically determined zonobiomes, within which there may also be edaphically determined pedobiomes and mountain ranges constituting orobiomes. Each can be subdivided on down to the level of individual phytocoenes. The Walter system provides a framework and nomenclature for classification of terrestrial vegetation units of all levels, including a systematic basis for distinguishing edaphic and other variants from the basic, climatically determined types. Classification can be based on Walter's own ten ecoclimatic zones or on other climatic classifications. Walter's ecoclimatic types, denoted by Roman numerals (see also Walter & Lieth 1960–67), are:

I – equatorial, with diurnal seasonality
II – tropical, with summer rain
III – subtropical arid
IV – mediterranean, with moist winters and dry summers
V – warm-temperate (maritime; this zone should be divided into east-coast and west-coast sub-types)
VI – typical temperate, with short frost period (nemoral)
VII – arid temperate, with cold winters (continental)
VIII – cold temperate, with cool summers (boreal)
IX – arctic/antarctic
X – highlands (divided into altitudinal belts but with reference also to the corresponding lowland climate zone).

The system is described in detail by Walter (1975). An English-language summary (Walter & Box 1976) is also available. A description of world zonobiomes and the more important pedobiomes and orobiomes has been presented by Walter (1977).

Table 1. Structural types of terrestrial plants and obvious ecophysiognomic bases for ecological subdivision.

The main structural types among terrestrial plants are listed in the left column along with what appear to be the most important ecophysiognomic bases for differentiation into ecological types (life forms). The central importance of leaf type (including size) in regulating energy and water budgets makes it the starting-point for subdivision of many basic forms. Seasonal habit (e.g. evergreen vs. deciduous) is also of central importance to all forms except those which show no variation (e.g. rosette-trees, which are always evergreen). The term structure can refer to branching structure, means of leaf deployment, and/or general plant (including leaf) shape. Morphs are different growth forms which can be assumed by a given taxon (usually species) under different environmental conditions, such as flagged and matt krummholz forms. The greatest variety in ecological types and forms (as well as species) may be shown by the forbs, which can be classified immediately into hemi-cryptophytic, geophytic, therophytic, and perhaps other (including larger) subtypes, each with a different ecological significance.

Structural type	Ecophysiognomic bases for subdivision
Trees	leaf type, seasonal habit, size
Dwarf-trees	leaf type, seasonal habit
Rosette-trees	size, leaf type
Rosette-treelets	general structure (palmiform, fern, xeric)
Arborescents	leaf type, seasonal habit, water source
Krummholz	leaf type, morphs, seasonal habit
Shrubs	leaf type, seasonal habit, size
Dwarf-shrubs	seasonal habit, leaf type, morphs
Rosette-shrubs	general structure
Stem-succulents	size, structure
Graminoids	structure, size, morphs, seasonal habit
Forbs	Raunkiaer life form, structure, leaf type, seasonal habit
Vines	structure, seasonal habit
Ferns	seasonal habit
Epiphytes (incl. hemi-epiphytes)	structure, leaf type, root type
Thallophytes	stand structure, substrate, plant type, seasonality

provided the life-form basis for the classification presented below. The life-form classification is a further development of that of Raunkiaer (1934), with the inclusion of such forms as tuft-trees, bottle-trees, and vines, and the useful distinction between woody, suffrutescent, herbaceous and succulent forms. The other especially useful system is the comprehensive framework for vegetation classification developed by Walter (1975, see also Walter & Box 1976). This system provides for classification of climatically determined, azonal (edaphic) and mountain vegetation units from biome scale on down to individual local synusiae (see Fig. 1). In combination with Walter's own (1968, 1973, 1976, 1977, or Walter & Lieth 1960–67) or any other adequate classification of world eco-climates, the system provides a means of partitioning the world into regions which can be expected to have different mixes of plant life forms. This was especially useful in mountainous areas, as seen in the example of the alpine belt, which takes quite different forms in the different (Walter) climate zones:

I – páramo (rosette-treelets, grasses, cushion-shrubs)
II – wet puna (grassland)
III – dry puna (grass and cushion-plant semi-desert)
IV – sclerophyllous cushion-shrubs and grasses
VI – alpine mats
VII – montane-alpine steppes
VIII – montane tundra (herbs and dwarf-shrubs) with permafrost.

It is rare to find the necessary physiognomic data reported in world, regional or even local vegetation descriptions. It is even more uncommon to find those data coördinated with sufficient local climatic data, even in some recent volumes of the International Biological Program. Collecting and synthesizing these data from various sources is a major task in itself. By far the most useful vegetation descriptions in the literature are those which have followed the example of Heinrich Walter to include both site climate-diagrams or comparable monthly climatic data and vegetation description by life form, stratum, synusia, or other structural basis. Such descriptions include the following: Walter (1968, 1973, 1974, 1977), Knapp (1965, 1973), Hueck (1966), Cabrera (1968), Cuatrecasas (1968), many from the journal *Vegetatio,* and others.[2] It appears that the volumes of the new 'Ecosystems of the World' series will be quite useful, but monthly rather than quarterly data (as in Specht 1979) would be more useful.

B. Ecophysiognomic characters of terrestrial vegetation

It has been hypothesized already that the main links between plant form and plant function are the plant water and energy balances, both of which are directly linked to external environmental conditions through such features of plant form as surface area, surface (stomatal) resistance to gas exchange, and plant size. As a result, the most important ecophysiognomic characters of terrestrial plants are those which describe the various aspects of plant size, effective leaf area and structure, their effects on adjacent external microclimates, and their temporal variations. Six plant characters appear to be adequate to describe the main aspects of form which determine plant water and energy budgets:

1. structural type (without reference to the other characters, e.g. tree)
2. relative plant size (relative to others of the same structural type)
3. leaf type (form, e.g. broad, narrow)
4. relative leaf size (relative to others of the same leaf type)
5. leaf surface structure (e.g. sclerophyllous)
6. seasonal photosynthetic habit (e.g. evergreen)

The term 'leaf' is understood here to include phyllodes, cladodes, and other primary photosynthetic surfaces. The six characters are described in more detail in the following sections.

1. Structural type

Structural type is the most important and comprehensive aspect of general plant form. It is used here to refer to the most basic structural features, primarily size, branching pattern, and the distinc-

[2]Most of these volumes are in German. It is interesting to note that the most comprehensive geoecologic volume on the vegetation of all of North America, until the appearance of Daubenmire's (1978) work, was written by a German (Knapp 1965) and is not even available in a North American language! This same is true for South America (Hueck 1966).

tion between woody, herbaceous, and succulent forms (without reference to seasonal foliage patterns or the other characters). Structural types are thus such things as trees, shrubs, and graminoids. The structural types recognized in this study are shown in Table 1, along with ecophysiognomic bases for further classification.

Trees are generally the tallest and longest-lived forms. They have the largest leaf area, require the most water, may have the deepest roots, and are perhaps the ultimate K-strategists in that, despite requiring longer to reach maturity, they then form a stable structure and are relatively insensitive to most normal environmental variations. In the new plant-strategy system of Grime (1979) trees are seen as often the most successful competitors, since they can effectively shade all shorter forms except when occurring as isolated individuals. Small trees (also called treelets) can occur as obligate understorey forms or as facultatively smaller open-woodland or savanna forms.

Rosette-trees are not true dendritic trees but rather form their 'trunks' by superposition of branches which grow from a terminal bud to form a terminal rosette (tuft) and eventually die, leaving a contribution to a permanent stem. The terminal branches are actually leaf-fronds, and there is no secondary branching. Included are palms and tree ferns as well as representatives of a variety of other taxonomic groups with large rosette forms, such as yuccas (*Liliaceae*), papyas (*Caricaceae*), and the tropical alpine species of *Espeletia* and *Senecio* (*Compositae*).

Intermediate between tree and shrub forms are two somewhat more variable types: arborescents (de Laubenfels 1975) and krummholz. Arborescents may grow to tree size but are essentially overgrown shrubs, becoming arborescent if sufficient water is available. Examples include the mallee eucalypts of Australia and the mesquites (*Prosopis*) of the Americas. Both of these are phreatophytes. Krummholz can be distinctly creeping (e.g. junipers near tree-line), erect but wind-formed (flagged), or some intermediate combination. In any case the effective environmental factor is nearly constant wind which causes the low-growing and often intricately branched structures. Cushion-shrubs in particular are common to almost all windy environments. The height of krummholz in cold-winter climates is determined primarily by the winter snow cover, which protects against high winds and ice-blasting.

Shrubs may have much the same strategy and structure as trees but have much lower crowns (branching from very near ground level), less leaf area, less standing (respiring) biomass to support, but do not necessarily occur in drier environments and can occur under tree canopies where light and excess moisture permit. Rosette-shrubs are trunkless analogs of rosette-trees, to which they generally bear the same ecological relationship as just described for shrubs and trees.

Stem-succulents are generally leafless forms with fleshy, photosynthetic, expandable stems capable of storing water. These forms often have a woody internal infrastructure. Stem-succulents include the arborescent cacti and euphorbs, plus a wide variety of shorter barrel, cushion, or flat-stemmed forms.

Graminoids are efficient, narrow-leaved herbs with small flowers, well-developed root systems, and an ability to respond quickly to favorable growing conditions. They can form swards by sending out lateral shoots, grow in bunches or larger clumps, or grow in large tussocks. Dense lateral growth is favored both by killing winter temperatures and by grazing. The tussock form, best developed in maritime climates of the Southern Hemisphere, appears to be an adaptation for protection against wind and near-freezing temperatures.

The remaining types rarely attain dominance. Forbs are herbs which are neither graminoids nor ferns. Many subdivisions of form are possible, but most have relatively large, broad, malacophyllous leaves. Undifferentiated small herbs are often ephemeral and are found in extreme climates. They are generally so small that the particular plant and leaf form is less important than the plant size. Vines are woody or annual herbaceous plants which have weak stems, elongate rapidly, and support themselves by climbing or sprawling over other vegetation. Ferns (excluding tree ferns) are small, herbaceous, generally poikilohydrous plants which can often form dense ground synusiae. Epiphytes are plants which grow on other plants and include, for present purposes, hemi-epiphytes (pseudo-lianas) and semi-parasitic but photosynthetic forms. Thallophytes are non-vascular cryptogams (*sensu* Ellenberg & Mueller-Dombois) and include mosses, liverworts, lichens and algae.

The principal advantage gained by the assumption of a particular structural form is an appropriate size and shape (ratio of photosynthetic surface to respiring volume) for environmental conditions. The amount of water required by plants, without reference to particular water-conserving mechanisms, generally increases with the size of the plant. On the other hand, larger plants may be better adapted, through deeper root systems, to obtain more water and may also gain competitive advantages through greater size.

The total amount of water available can often be used to predict the structural types which will be present, although this pattern can be complicated considerably by such factors as length and dependability of rainy seasons and by various morphologic adaptations collectively referred to as xeromorphy. Also, a short but reliable wet season, providing enough water for tree growth, often produces a grassland instead, since the water may be intercepted very quickly and effectively near the surface and may not penetrate in sufficient quantities beyond the reach of grass roots. On the other hand, in the Middle Asian sand deserts, a leafless tree (*Haloxylon ammodendron*) forms the dominant vegetation because its deeper roots and adequate regulation of water loss permit it to reach sufficient water at depths which are too great for grasses and shrubs but at which the water is protected from direct evaporation.

Temperature can also control the size and type of plants present, primarily at the cold end of the spectrum, through the amount of summer warmth available at plant height. The air is generally warmest in the first few decimeters above the surface. Thus, as summers become shorter toward the poles or cooler in polar maritime climates, sufficient warmth for wood production at tree height disappears, then sufficient warmth for shrubs and krummholz. Finally only reptant dwarf-shrubs (chamaephytes) and herbs with short life-cycles find enough warmth near the surface for their annual development. Perennial evergreen species may grow significantly only in favorable years. This successive environmental limitation of structural types results to a considerable extent from the size of the plants involved, without major variation in temperature requirements.

2. Relative plant size

Relative plant size refers to the size (height) of the particular form in relation to other forms of the same structural type. The combination of structural type and relative plant size provides measures of actual plant size and (to some extent) total leaf area. Inclusion of this character also permits distinction, for example, between:

1. tall (including emergent), normal, and small (e.g. understorey) trees and rosette-trees;
2. large, normal and dwarf shrubs;
3. tall and short grasses; and
4. arborescent and non-arborescent stem-succulents.

Four sizes are recognized: tall (large), normal, short, and dwarf. Relative plant size is also generally limited by water and temperature. Increased height usually means greater leaf-surface or other photosynthetic area but also greater transpiring area, increasing potential water loss. This must be balanced against metabolic and competitive requirements, such as respiration and the need for more incident solar radiation. The factors which determine the height of vegetation in general are quite complex and are not yet well understood.

3. Leaf type

Leaf type refers to the general form of the leaf or other photosynthetic organ, such as phyllodes, cladodes or photosynthetic stems. Four types are recognized: broad, narrow, graminoid, and absent. Narrow leaves include true needles (as in pines), flattened linear leaves (as in *Podocarpus*), and cupressoid scales. Most narrow-leaved species are conifers, though other species with similar structure are also included (e.g. *Casuarina*).

In general, broad leaves offer both greater photosynthetic and greater transpiring areas and, thus, are found in more favorable environments. Narrow leaves (often harder than broad leaves) are smaller, offer better resistance against desiccation from both heat and cold, and are generally found in environments with at least some period of more extreme conditions. These generalizations can be modified, however, by leaf size and hardness.

4. Relative leaf size

Relative leaf size refers to sizes of the leaf or other photosynthetic organ in relation to those of other plants of the same leaf type. Thus, a broad megaphyll and the long needles of *Pinus palustris* can both be considered to be large leaves, suggesting certain favorable aspects of the climates where they are found. It seems useful to distinguish four leaf sizes: large (macrophyll and larger), normal (mesophyll), small (microphyll), and very small (nanophyll and smaller). Small leaves would include those of boreal birches, boreal short-needled conifers, and the microphylls of drier tropical climates (e.g. *Acacia,* including most phyllode types). Very small leaves would include the reduced, scale-like leaves of most *Cupressaceae* and the very small leaves or other organs (e.g. *Zygophyllaceae*) of many cold-climate and warm semi-desert shrubs and herbs. Leaf-size classes were suggested by those of Raunkiaer (1934).

There have been many theories concerning the factors which determine leaf size. Earlier interpretations are well summarized by Shimwell (1971). Gates (1968) assumed that leaf sizes evolved to regulate leaf temperature and developed a mathematical energy-balance equation relating the size and temperature of broad leaves to ambient conditions. Taylor (1975) used this approach in attempting to define optimal leaf forms and sizes for broad-leaved plants. A similar explanation for narrower leaves and needles does not exist. Parkhurst & Loucks (1972) maintained that Gates' approach ignores the adaptability of thermal aspects of photosynthesis and developed a leaf-size model based on water-use efficiency. Most recently, Givnish & Vermeij (1976) have improved on the Parkhurst-Loucks approach by considering the additive difference between photosynthetic gains and transpirational losses, rather than their ratio. Because of data requirements, none of these models can be used quantitatively in the current approach.

In general, larger leaves both assimilate and transpire more. Leaf size, however, is connected through energy and water relations to several other morphologic characters. Total leaf area can be affected by number of leaves as well as by leaf size. Thoday (1931) pointed out that small leaf size can facilitate both water diffusion within the leaf and more uniform illumination of a greater depth of plant foliage. Gates' results showed that smaller leaves often transpire less because they overheat less. Microphylly may be coupled with sclerophylly or less extreme cuticular hardening ('leathery' leaves) in order to reduce water loss further. Total leaf area, however, may remain high, as in the case of dense mediterranean woodlands. The large leathery leaves of tropical humid and even perhumid areas seem to represent an intermediate situation in which high leaf area is desirable but water loss must be controlled, as least for a few hours around midday.

5. Leaf structure

Leaf structure refers to the general 'hardness' of leaves or other photosynthetic surface and serves as an index of the plant's ability to control its rates of water loss and gas exchange. Leaf-structure adaptations are primarily anatomical and involve such aspects as amount of sclerenchymous tissue, stomate morphology, and degree of succulence. Six basic surface types (with considerable variation) can be readily distinguished.

1. Most broad deciduous leaves are malacophyllous (herbaceous), like the leaves of birches or maples. These are typically thin and soft but can become more reinforced with age, as in the case of beeches and summergreen oaks.
2. Coriaceous (leathery) leaves have thickened cuticles and are somewhat tougher but are still quite pliable. These are designed to retard water loss but not to withstand winter or nighttime cold. Tropical evergreen leaves, even in rainforests, are typically coriaceous, as are the narrow leaves or needles of summergreen larches and some temperate-maritime conifers.
3. Sclerophyllous leaves are mechanically reinforced with sclerenchyma and are both hard and stiff. These are designed to restrict water loss over longer periods, including colder winters, and are typical of temperate-zone evergreens, especially in mediterranean climates and in such taxa as *Eucalyptus,* evergreen *Quercus, Ericaceae, Ilex* (holly), and boreal conifers.
4. Succulent leaves or other parts have leathery or harder surfaces to retard water loss combined with internal cell structures designed to store water. These generally do not withstand prolonged freezing temperatures (some excep-

tions) and can be vulnerable to rotting in wetter areas.

5. Woody photosynthetic parts (e.g. stems) can be referred to as ligneous and can be found on evergreen, deciduous and leafless plants. Ligneous surfaces show the lowest photosynthesis rates but reduce water loss to almost zero during dry periods and can withstand cold winters.
6. Pubescent leaves or other parts are typically rather soft but somewhat fleshy and are covered with more or less dense, often white pubescence, which reduces water loss by mitigating the drying effects of wind and direct insolation. Such surfaces are typical of less extreme dry climates.

In general, deciduous leaves are malacophyllous and rarely truly harder. Evergreen leaves, on the other hand, are typically coriaceous in the tropics (lowlands), sclerophyllous where frost occurs, and rarely ever malacophyllous. 'Softer' leaves generally both transpire and photosynthesize more rapidly. They may, however, have little or no ability to regulate water loss by closing their stomates, since they would quickly overheat without the cooling effects of transpiration. 'Harder' succulent and ligneous surfaces can reduce transpiration almost completely during dry periods but permit only very low annual photosynthetic rates. There are, of course, many transitional and perhaps other basic forms. In some situations, such as tropical-rainforest canopy and understorey leaves, one can find wide variations in leaf morphology and structure on individual plants.

6. Photosynthetic habit

Photosynthetic habit refers to the seasonal photosynthetic activity of a plant (or population), as measured by obvious features such as leaf tenure or the dying back of aerial shoots. Seven basic types can be readily identified:

1. Evergreen plants (or populations) effectively retain their photosynthetic organs in active condition throughout the year. True evergreens retain their leaves or other green parts for more than one year, but plants which lose their old leaves in 'spring' when new ones are produced are also considered to be effectively evergreen.
2. Semi-evergreen ('tardily deciduous') plants are evergreen where conditions permit but may lose most or all of their leaves as the unfavorable season progresses.
3. Raingreen plants lose their leaves or annual shoots in response to a dry season and produce new ones at the beginning of a wetter season, as in tropical summer-rain climates. The old leaves are generally not killed directly by the dryness but rather close their stomates and cease production, turning yellow rather than brown.
4. Summergreen plants lose their leaves or annual shoots in response to a cold winter and produce new ones in the spring, as in temperate-zone and polar climates. Summergreen leaves and annual shoots generally are 'killed' by autumn nighttime frost, but leaves in particular may continue to produce and accumulate sugars for several days or even weeks after ceasing translocation, turning brilliant yellow or red before withering and being dropped.
5. Suffrutescent plants have perennial woody bases but produce annual herbaceous or slightly lignified shoots (with or without leaves) which are discarded at some time after the end of the growing season. The perennial base may or may not have some secondary foliage.
6. Marcescent plants (generally graminoids or other erect herbs) produce annual herbaceous or slightly lignified shoots (e.g. tropical grasses) which die at the end of the growing season but may remain standing throughout the unfavorable season and perhaps longer. The photosynthetic habit of these plants can often best be described as seasonal (no distinction between summergreen and raingreen) or opportunistic, and the term marcescent refers only to the persistence of the dead shoots.
7. Ephemeral plants can be annuals or perennials (e.g. geophytes) but produce annual herbaceous shoots which generally appear quickly in response to favorable conditions but which may endure for only a few weeks or even days.

In general, plants are evergreen if they have adaptations (sclerophylly, microphylly, etc.) which permit them to survive unfavorable periods and are deciduous or otherwise seasonal if they do not. Thus the vegetation of equatorial, mediterranean, and warm-temperate maritime climates is mostly evergreen, while that of tropical summer-rain, subtropical arid, typical temperate and polar climates is mostly seasonal. The exception to the above generalization is the boreal conifers, which are evergreen despite severe winters in order to make full use of the short, cool summer growing season. Boreal conifers survive the cold winter by a combination of sclerophylly, microphylly, and physiological changes (cold-hardening and winter dormancy) which almost eliminate respiration in winter. The situation can also be quite complicated in mediterranean and sub-mediterranean arid climates, where rainy and warm seasons overlap the least. Suffrutescent, summer-deciduous, semi-evergreen and spring-ephemeral forms can be especially important in such climates and can become dominant where total moisture is not sufficient for evergreen plants.

In some cases, especially those of summergreen and ephemeral plants, seasonal habits may be closely tied to other, mandatory life-cycle functions. Summergreen trees have been grown, for example, in nonseasonal, continuously favorable environments, but after a few years the life-cycle functions become confused (continuous blooming; simultaneous blooming foliation, and defoliation on different parts of the same plant) and the plants die. In other cases, notably that of raingreen plants, seasonal deciduousness is often facultative (at least over periods of a few years), with leaf-fall not occurring if water remains sufficient. This can be observed in many botanical gardens in tropical climates with seasonal drought.

Obligatorily evergreen, raingreen, and summergreen habits, plus facultative deciduousness, represent four different life-form physiologies. In many cases the actual character, and thus the true life form, is very difficult to determine and may remain unknown. Distinction between summergreen and raingreen life forms, for example, can be especially difficult in areas such as subtropical mountains, where the two regions often merge. Distinction between obligate and facultative evergreens can be equally difficult in rainforests.

C. Life forms of world terrestrial vegetation

The main criteria for the classification of plant life forms were discussed earlier and include provisions for covering the variation existing on earth, for definition in terms of ecologically significant physiognomic characters, and for identification of convergent forms which are typical of particular environmental situations. Fortunately for the ecologist, plant form does tend to cluster into successful, definable types. The life forms presented here and in most other classifications are intended to characterize these ecophysiognomic nodes, while at the same time realizing that there are many transitional forms which may be very hard to classify.[3]

The ecophysiognomic life forms presented here are postulated to represent structural-functional forms which have evolved as the result of adaptation to particular climatic conditions. Among other advantages, such as necessary simplification, this sort of ecophysiognomic generalization of plant detail serves to focus on the most ecologically important relationships and to overcome partly the lack of data on particular species, morphs and ecotypes. The life-form classification was patterned after those of Rübel (1930), Whittaker (1975), and Ellenberg & Mueller-Dombois (1967a, 1967b). The types were identified by studying many types of plant and vegetation data at various scales and grouping species which are physiognomically and physiologically similar and occur in similar climatic situations. Life forms generally involve groups of particular species, but some species can occur in more than one form (morph), such as various *Juniperus* species in tree, shrub and krummholz forms. Furthermore, the life form is not known for all species, especially when it depends on functional characteristics such as deciduousness.

The life-form classification is presented in Table 2, along with examples of the individual types and a textual summary of the system. More detailed descriptions of the individual forms, including general environmental relations, geographical distribution, prototypic taxa, and relevant literature, are provided in Appendix A. Identification of characteristic species or genera is especially useful but also problematic. Some very important species span two entire ecoclimates and must be considered to belong to both life forms simultaneously, for example *Pinus sylvestris* (boreal

[3]The extent of species clustering into life forms and the relative numerical importance of transitional forms will be studied in a forthcoming paper (Box, in preparation) in which the entire flora of the Carolinas, as compiled by Radford et al. (1968), is classified by life form.

Table 2. Life forms of world terrestrial vegetation.

The life forms (numbered) are listed in the left column, grouped by general growth form or structural type (e.g. broad-leaved trees) and with sub-types in some cases (e.g. warm-temperate, mediterranean, and rainforest broad-evergreen trees). Some forms are divided further into ecoclimatic sub-types with less physiognomic difference (e.g. lowland and montane tropical rainforest trees). Examples of each life form (or sub-form) are provided in the right column. The 77 life forms (90 counting all sub-types) cover the full range of variation in terrestrial plant form, including both potential formation dominants and understorey forms, which are usually more generalized. The life forms were conceived primarily as ecologically significant combinations of certain physiognomic characters, including general structural type, size, leaf form and size, and seasonal habit. Some life forms thus include very few species while others involve many hundreds (even thousands) of species and still considerable variation in less obvious aspects of both form and function. Each life form is related to various annual and seasonal aspects of temperature and water balance regimes by means of estimated tolerance limits (Table 7). Predicted world distributions and importance of the life forms, based on their tolerance limits and hypothesized form-based dominance relationships, are shown in Table 12 and in Maps 10–22. Estimates of potential changes in distribution with changes in climate are presented in Tables 17–19.

Plant form	Examples
Trees (Broad-leaved)	
Evergreen	
1. Tropical Rainforest Trees (lowland, montane)	*Lauraceae, Rubiaceae*
2. Tropical Evergreen Microphyll Trees	*Leguminosae, Meliaceae, Simaroubaceae*
3. Tropical Evergreen Sclerophyll Trees	*Eucalyptus*
4. Temperate Broad-Evergreen Trees	
a. Warm-Temperate	*Quercus virginiana*
b. Mediterranean	*Quercus ilex, Arbutus, Olea europaea*
c. Temperate Rainforest	*Magnoliaceae, Lauraceae*
Deciduous	
5. Raingreen Broad-Leaved Trees	
a. Monsoon mesomorphic (lowland, montane)	*Tectona, Dipterocarpaceae*
b. Woodland xeromorphic	*Acacia, Adansonia, Caesalpinaceae*
6. Summergreen Broad-Leaved Trees	
a. typical-temperate mesophyllous	*Quercus, Acer, Fagus*
b. cool-summer microphyllous	*Betula, Populus, Nothofagus*
Trees (Narrow and needle-leaved)	
Evergreen	
7. Tropical Linear-Leaved Trees	*Podocarpus, Agathis*
8. Tropical Xeric Needle-Trees	*Juniperus procera, Widdringtonia*
9. Temperate Rainforest Needle-Trees	*Tsuga, Thuja, Sequoia*
10. Temperate Needle-Leaved Trees	
a. Heliophilic Large-Needled	*Pinus taeda, P. caribbea*
b. Mediterranean	*Cedrus, Cupressus, Pinus pinea*
c. Typical Temperate	*Pinus strobus, P. ponderosa*
11. Boreal/Montane Needle-Trees	*Picea, Abies*
Summergreen	
12. Hydrophilic Summergreen Needle-Trees	*Taxodium, Metasequoia*
13. Boreal Summergreen Needle-Trees	*Larix, Pseudolarix*

Table 2 (continued).

Plant form	Examples
Small and dwarf trees	
14. Tropical Broad-Evergreen Small Trees	rainforest understorey, *Leguminosae*
15. Tropical Broad-Evergreen Dwarf-Trees	'campo cerrado' treelets
16. Cloud-Forest Small Trees	*Podocarpus, Ericaceae*
17. Temperate Broad-Evergreen Small Trees (typical, cool-maritime)	*Ilex, Nothofagus, Berberis*
18. Broad-Raingreen Small Trees	*Leguminosae*
19. Broad-Summergreen Small Trees	*Prunus, Nothofagus, Betula tortuosa*
20. Needle-Leaved Small Trees	*Juniperus, Actinostrobus*
Rosette-trees	
21. Palmiform Tuft-Trees	palms, *Caricaceae*
Rosette-treelets	
22. Palmiform Tuft-Treelets	understorey palms, cycads
23. Tree Ferns	*Cyatheaceae, Dicksoniaceae*
24. Tropical Alpine Tuft-Treelets	*Senecio, Espeletia*
25. Xeric Tuft-Treelets	*Yucca, Dracaena, Xanthorrhoea*
Arborescents	
26. Evergreen Arborescents	mallee eucalypts
27. Raingreen Thorn-Scrub	*Acacia, Commiphora*
28. Summergreen Arborescents	*Prosopis, Salix*
29. Leafless Arborescents	*Haloxylon, Calligonum*
Krummholz	
30. Needle-Leaved Treeline Krummholz	*Picea, Abies, Juniperus*
Shrubs	
31. Tropical Broad-Evergreen Shrubs	*Coffea, Rubiaceae, Ericaceae*
32. Temperate Broad-Evergreen Shrubs	
a. Mediterranean	*Proteaceae, Quercus dumosa, Rhamnus*
b. Typical Temperate	*Ilex, Ligustrum*
c. Broad-Ericoid (perhumid)	*Rhododendron*
33. Hot-Desert Evergreen Shrubs	*Zygophyllaceae, Acacia aneura* (mulga)
34. Leaf-Succulent Evergreen Shrubs/Treelets	*Crassula argentea*
35. Cold-Winter Xeromorphic Shrubs	*Artemisia*
36. Summergreen Broad-Leaved Shrubs	
a. mesomorphic	*Rosa, Vaccinium*
b. xeromorphic	'deciduous chaparral', šibljak
37. Needle-Leaved Evergreen Shrubs	*Juniperus communis*
Dwarf-shrubs	
38. Mediterranean Dwarf-Shrubs	*Thymus, Salvia, Eriogonum*
39. Temperate Evergreen Dwarf-Shrubs (typical, maritime heath)	heath and arctic/alpine *Ericaceae*
40. Summergreen Tundra Dwarf-Shrubs	*Betula nana, Salix reptans*
41. Xeric Dwarf-Shrubs	*Ephedra, Anabasis, Retama*
Cushion-shrubs	
42. Perhumid Evergreen Cushion-Shrubs	*Azorella selago*
43. Xeric Cushion-Shrubs	puna/Patagonian hard cushions

Table 2 (continued).

Plant form	Examples
Rosette-shrubs	
44. Mesic Rosette-Shrubs	understorey and ground palms
45. Xeric Rosette-Shrubs	*Agave, Yucca, Aloë*
Stem-succulents	
46. Arborescent Stem-Succulents	*Carnegiea gigantea, Euphorbia candelabrum*
47. Typical Stem-Succulents	unbranched barrel cacti, *Mammillaria*
48. Bush Stem-Succulents	branched *Opuntia* spp.
Graminoids	
49. Arborescent Grasses	bamboos
50. Tall Cane-Grasses	*Imperata, Arundinaria*
51. Typical Tall Grasses	*Andropogon, Festuca,* prairie grasses
52. Short Sward-Grasses	*Cynodon dactylon, Bouteloua gracilis*
53. Short Bunch-Grasses	*Festuca, Stipa, Agropyron*
54. Tall Tussock-Grasses	pampas and Patagonian grasses (e.g. *Stipa*)
55. Short Tussock-Grasses	puna grasses, *Festuca novae-selandiae*
56. Sclerophyllous Grasses	'spinifex' (*Triodia*), *Scleropoa*
57. Desert Grasses	*Aristida* (wire grass), *Stipa*
Forbs	
58. Tropical Evergreen Forbs	*Cannaceae, Begonia, Zingiberaceae*
59. Temperate Evergreen Forbs	*Gaultheria, Chimaphila, Hexastylis*
60. Raingreen Forbs	*Leguminosae, Compositae*
61. Summergreen Forbs	forest dicots, geophytes, *Compositae*
62. Succulent Forbs	*Portulacca, Sedum, Sempervivum*
Undifferentiated small herbs	
63. Xeric Cushion-Herbs	*Saxifraga, Dryas, Draba*
64. Ephemeral Dry-Desert Herbs	annuals, dwarf-geophytes, graminoids
65. Summergreen Cold-Desert Herbs	dwarf-geophytes, graminoids
66. Raingreen Cold-Desert Herbs	geophytes, graminoids
Vines and lianas	
67. Tropical Broad-Evergreen Lianas	*Ficus, Calamus,* stranglers
68. Broad-Evergreen Vines	*Philodendron, Lonicera, Smilax*
69. Broad-Raingreen Vines	*Leguminosae, Ipomoea*
70. Broad-Summergreen Vines	*Vitis, Parthenocissus, Rhus radicans*
Ferns	
71. Evergreen Ferns	rainforest ferns (e.g. *Polypodium*)
72. Summergreen Ferns	temperate ferns (e.g. *Aspidiaceae*)
Epiphytes	
73. Tropical Broad-Evergreen Epiphytes	bromeliads, orchids, aroids, cacti
74. Narrow-Leaved Epiphytes	ferns, mosses, *Tillandsia*
75. Broad-Wintergreen Epiphytes	'mistletoes' (*Loranthaceae*)
Thallophytes	
76. Mat-Forming Thallophytes	forest and tundra mosses, folious lichens
77. Xeric Thallophytes	crustose lichens

and temperate needle-trees) and *Pseudotsuga menziesii* (temperate and sub-mediterranean needle-trees). Also, should linear-leaved *Adenostoma fasciculatum* and *Rosmarinus officinalis* be called needle-leaved or mediterranean evergreen shrubs? What should one do with *Casuarina, Tamarix* and de Laubenfels' 'overgrown bushes'? Most problematic of all, as one might expect, is probably the genus *Eucalyptus,* which shows such minimal physiognomic variation in different climates and which clearly can thrive in many areas of the world into which it has been introduced only recently.

The current 'analytical' classification differs from an earlier, shorter 'synthetic' classification (Box 1978a) by having completely separated plant form and stand physiognomy (forest vs. open-woodland trees) and by including some important larger forms (e.g. palms and tropical conifers) and the understorey forms (forbs, vines, epiphytes, thallophytes) which were omitted from the earlier classification. Some earlier forms were also divided, merged and/or renamed.

Life forms are grouped in Table 2 by general growth form, but this does not always imply similar ecology, as in the case of phreatophytic and non-phreatophytic arborescents. Although the forms are given names intended to suggest regional, seasonal

Table 3. Plant ecophysiognomic diversity within structural classes.

Structural class (1)	Total number of life forms (2)	Number of growth forms (3)	Structural class (1)	Total number of life forms (2)	Number of growth forms (3)
Trees	19	5	Stem-succulents	3	3
Small trees	7	4	Graminoids	9	7
Rosette-trees and treelets	5	3	Forbs	5	4
Arborescents	4	4	Undifferentiated herbs	4	4
Krummholz (incl. Cushion-shrubs)	3	3	Vines and lianas	4	4
Shrubs	10	6	Ferns	2	2
Dwarf-shrubs	4	4	Epiphytes	3	3
Rosette-shrubs	2	2	Thallophytes	2	2

The basic structural classes of plants are shown in column 1, along with the number of corresponding life forms identified in the model, column 2. The number of growth forms (combinations of structural type and size, leaf type, and seasonal habit) represented among the life forms of each structural class is shown in column 3. Ecophysiognomic diversity within structural classes, as expected, appears to be best represented among the larger forms.

Table 4. Life-form diversity of ecoclimatic regions.

Region (1)	No. of life forms (2)	Main growth forms (3)
Tropics (excluding alpine)	18	trees, rosette-trees, etc.
Tropical alpine	2	tuft-treelet, small herb
Subtropical (including arid and mediterranean)	20	shrubs, succulents, rosettes, etc.
Tropical and temperate (mild winters, mainly S. Hem.)	10	trees, rosette-trees, ferns, cushions, etc.
Temperate zone	25	trees, shrubs, grasses, forbs, etc.
Boreal/temperate montane	3	needle-trees, krummholz
Temperate and polar/alpine	3	dwarf-shrub, herbs
Polar/temperate alpine	2	dwarf-shrub, small herb
Global	3	thallophytes, bunch-grass

The regions were determined by the ranges of the life forms involved. Each life form in Table 2 (including sub-types) was assigned to a single region of which it is most characteristic. The number of life forms assigned to each region is shown in column 2, and the most common growth forms in column 3. The greater diversity in the temperate zone probably reflects the greater diversity of temperate ecoclimates combined with the greater dominance by tree forms in the tropics.

or other obvious environmental situations, each form is well-defined physiognomically by means of the six physiognomic characters described earlier. These physiognomic characters are listed in Appendix A along with a more detailed description of each form, including geographical distribution, prototypic taxa, and relevant literature.

The distribution of life forms and growth forms among the basic structural classes is shown in Table 3. The numbers of growth forms represent different configurations of leaf type and seasonal habit among the life forms of the respective structural classes. Relatively low numbers of basic growth forms suggest a wider variety of leaf sizes and structures, as among the trees in particular. The apparent lack of such diversity among smaller forms reflects greater environmental constraints. As niches become smaller, however, smaller forms can be very diverse in specific detail, as can be seen from the number of graminoid and forb species in most florae.

The regional affinities of the various life forms are summarized in Table 4. Each life form was assigned to a single region throughout which it occurs most typically. The high number of temperate forms reflects the fact that the temperate zone is in the middle of the spectrum and reflects the greater ecoclimatic diversity and complexity of the temperate zone. Table 4 shows that the life-form classification is balanced geographically and that no region is grossly over- or under-represented.

The Box life-form classification was developed largely from the Raunkiaer-based classification of Ellenberg & Mueller-Dombois (1967b, 1974). The correspondence of these three systems is summarized in Table 5. The Box classification is not intended to be as strictly systematic (i.e. as precise) as the others but rather more generalized and readily applicable to geographic and ecologic description of vegetation and ecosystem structure. This implies omission of ecologic detail in some cases, especially the smaller forms, while seeking to cover the earth's main forms within a system of manageable size.

Table 5. Correspondence of the Raunkiaer, Ellenberg & Mueller-Dombois, and Box systems of terrestrial plant life forms.

The basic life forms of Raunkiaer (1934) plus some later additions within the Raunkiaer framework (e.g. Braun-Blanquet 1928) are listed in the first column. The main subdivisions of the system of Ellenberg & Mueller-Dombois (1967b, 1974), which represents an elaboration of the Raunkiaer system, are shown in the column 2. These subdivisions are always subdivisions of the corresponding Raunkiaer form shown in column 1. Column 3 shows the life-form groups of the Box system as presented in this monograph (see Table 2). The basic life forms or life-form groups of the Raunkiaer and Ellenberg/ Mueller-Dombois systems are retained in the Box system (generally with common names, e.g. trees and shrubs) except for the hemi-cryptophytes, geophytes and therophytes, which are divided into graminoids, forbs, small herbs, and ferns. Further division of these commonly recognized general forms as hemi-cryptophyte, geophyte and therophyte forms and sub-forms is being pursued locally using initially the flora of Carolina (Box, in preparation).

Raunkiaer system (1)	Ellenberg & Mueller-Dombois (2)	Box system (3)
1. Phanerophytes	1. Trees, Shrubs, Krummholz (mega-, meso-, micro-, and nano-phanerophytes)	Trees (broad and narrow-leaved) Small and Dwarf Trees Arborescents Krummholz Shrubs
	2. Tuft-trees	Rosette (tuft)-trees and treelets
	3. Bottle-trees (normal, palmiform, leaf-succulent, aphyllous forms)	(not recognized separately)

Table 5.

Raunkiaer system (1)	Ellenberg & Mueller-Dombois (2)	Box system (3)
	4. Tall Succulents (single-stemmed and caespitose forms)	Stem-Succulents: Arborescent plus some typical and bush forms
	5. Herbaceous Phanerophytes graminoid forb	Graminoids: Arborescent Forbs: various (height not differentiated)
	(not explicitly recognized)	Rosette-Shrubs
2. Chamaephytes	1. Woody Dwarf-Shrubs (frutescent)	Dwarf-Shrubs Cushion-Shrubs
	2. Semi-Woody Dwarf-Shrubs (suffrutescent)	Dwarf-Shrubs (semi-shrubs) Cushion-Shrubs
	3. Herbaceous Chamaephytes (caespitose, reptant, pulvinate, scapose)	Graminoids: various Forbs: various
	4. Low Succulents (stem-, leaf-, and root-succulents)	Stem-Succulents: some typical and bush forms Rosette-Shrubs: smaller forms
	5. Poikilohydrous Chamaephytes (generally xeric ferns)	Forbs: larger Succulent Forbs Ferns: some xeric forms
3. Hemi-Cryptophytes (generally herbaceous throughout, with some partial lignification in old stems)	1. Caespitose 2. Reptant 3. Scapose 4. Aquatic	Graminoids (differentiated by size and form) Forbs, Small Herbs, and Ferns (differentiated by seasonality)
4. Geophytes (herbaceous)	1. Root-budding 2. Bulbous 3. Rhizome-Geophytes 4. Aquatic	(not recognized separately)
5. Therophytes (annuals and other herbs completing their life cycles within one favorable growing period)	1. Caespitose 2. Reptant 3. Scapose 4. Aquatic 5. Succulent	(not recognized separately except for some Ephemeral Desert Herbs)
Not recognized originally: 6. Lianas (including vines)	1. phanerophytic and chamaephytic 2. hemi-cryptophytic 3. geophytic 4. therophytic	Vines and Lianas (differentiated by form and seasonality)
7. Hemi-Epiphytes (epiphytic lianas)	roots dying, strangling, or descending	Vines and Lianas (differentiated by form and seasonality)
8. Epiphytes (vascular)	1. facultative epiphytes 2. obligative epiphytes	Epiphytes (differentiated by leaf form)
9. Thallophytes (non-vascular cryptogams)	thallo-chamaephytes thallo-hemi-cryptophytes thallo-therophytes thallo-epiphytes	Thallophytes (mat-forming vs. xeric)

CHAPTER 4

Modeling the effective environment

Modeling the effective environment, perhaps more than any other aspect of ecological modeling (*sensu lato*), represents the point at which modeling becomes as much an art as a science. Unlike the modeling of well-defined processes, amounts, forms and other phenomena, modeling the effective environment involves choosing, out of the entire set (continuum) of environmental factors, those which are most important and then choosing or constructing variables which best and most economically represent the most important spatial, temporal or other particular aspects of those factors. The primary hypothesis behind the current project is that plant form and vegetation structure are determined mainly by general climatic conditions. This means that the effective environment to be modeled is those aspects of climate which most influence plant and vegetation water and energy budgets, life-cycle processes, ecological interactions, and which are most important in limiting species and life-form distributions. The model must at the same time be simple and understandable.

A. Climate data

Data on climate phenomena are generally more readily available than are many important types of vegetation data. Of the many climatic variables monitored, the best records are for various aspects of annual regimes of temperature and precipitation. Various studies relating vegetation distributions to climatic factors (e.g. Rübel 1930; Schimper & von Faber 1935; Lieth 1956; Troll & Paffen 1964) have shown that, to a remarkable extent, it is the general levels and patterns of these macroclimatic phenomena which are best correlated with the distributions of particular plant and vegetation types. This greatly simplifies the problem of data-collection. The other important factor (e.g. Thornthwaite 1948; Major 1963; Mather & Yoshioka 1966) is evaporation, which must be estimated since few and often only questionable measurements are available. Many other climatic factors can be important in particular situations. Climatic phenomena are closely interrelated, however, and to a large extent these other factors, such as cloudiness, wind, solar radiation, and frost occurrence, plus diurnal patterns of the primary factors, can be expressed through various aspects of annual temperature, precipitation, and evaporation regimes.

Temperature is usually the easiest to treat, since the important aspect, ambient air temperature near the ground, is relatively uniform over large areas. Means of daily and monthly temperatures averaged over available periods of measurement usually converge within a few years to relatively smooth, characteristic annual patterns. Although intra-annual patterns may vary from year to year, more general trends are persistent, and it is these general trends which are most important to plants.

Precipitation can be a much more local and erratic phenomenon. It is actually soil moisture rather than precipitation, however, which is of greater importance to plant water budgets. Depending on soil depth, texture, porosity, and general rainfall levels and temporal patterns, soil moisture supplies may be much less variable than is actual precipitation.

The aspect of evaporation which is perhaps of greatest importance to plants is the climatic potential rate of water loss, generally called potential evapotranspiration (PET), which is a function of the energy supplied and the saturation deficit of the air near the vegetation. The latter can be effectively increased by wind, which removes transpired water vapor from the plants' vicinity and prevents a reduction of drying power. PET can be estimated with reasonable accuracy for periods of not less than a month by various methods based on air temperature alone, provided that the climate is not unusually windy. Although evaporative demands can change drastically within very short periods, most plants are well enough adapted to their local PET regimes that they can regulate their stomatal behavior adequately to withstand large variations.

When the author first became interested in ecological modeling (1972), records of monthly mean temperature and average precipitation were available for most parts of the world covering periods of measurement ranging from 10 to nearly 100 years. By 1977 records covering 3–20 years of measurement were appearing in print for most of the areas not represented earlier. The most comprehensive source of world climate data available at the time was the *Climate-Diagram World Atlas* (Walter & Lieth 1960–67), which includes data for about 8000 stations. Various compendia of digital monthly data were or became available, but these covered too few stations and could be used only for individual sites not available in the climate-diagram atlas. Computerized files of world climate data (e.g. Spangler & Jenne 1979) were not yet available or known. Some error is involved both in printing and in reading the non-digital monthly values on climate diagrams. Comparison of corresponding monthly climate-diagram and digital data from various sources showed, however, that the error involved with climate diagrams is no greater than the normal variation in digital values based on different 30-year periods of measurement. Monthly climate-diagram values can generally be read with an error of ±1 °C or ±2 mm at most.

As data-collection began it had not yet been determined which variables would be used in the final model. This could not be determined until results were generated using several combinations of variables. The data to be collected were thus chosen so that monthly values of annual temperature, precipitation and PET could be estimated from them if necessary. Because of the large number of values needed (potentially about 40 for each site), it was necessary to reduce the number of values actually read. This was done by recording only all local (monthly) maxima and minima of the annual temperature and precipitation curves and interpolating the other monthly values by means of cosine curve segments (see Box 1978a, Appendix F). The data collected initially included:

1. Highest monthly mean temperature (TMAX)
2. Lowest monthly mean temperature (TMIN)
3. Other local extrema in the annual mean-temperature curve
4. Highest average monthly precipitation (PMAX)
5. Lowest average monthly precipitation (PMIN)
6. Other local extrema in the annual precipitation curve.

Each datum was paired with the time of its occurrence, expressed on a continuous scale from 0 to 12 representing the twelve months. Extrema do not always occur, however, at monthly mid-points. As a result, many extrema may be better represented by the continuous climate-diagram curves than by the digital monthly data available from other sources.

Data for annual mean temperature and average precipitation, plus approximate geographic coordinates, were already available in coded form for about 1000 sites from production of the 'Miami Model' world map of estimated annual net primary productivity (Box, Lieth & Wolaver 1971). These sites were supplemented in 1976 by an additional 237 sites located in poorly represented areas and in areas of high topographic complexity. Geographic coordinates were refined from those of the Miami Model data, and annual temperature and precipitation values were scrutinized for errors. Errors in data transcription were located quite effectively by the interpolation routine used to generate the monthly values not read directly, since the iterative algorithm does not converge if data are not consistent (Box 1978a). Both the hard data and the amplified file including the interpolated monthly data were computerized for future use. The amplified file, called CLIMDAT1, contains annual and monthly data for 1225 sites covering the world's land areas and is described in more detail in Appendix E.[1] Only one interpolated monthly value (precipitation of the warmest month) was included directly in the final model. Estimated annual PET (divided by annual precipitation to provide an annual moisture index) was also included in the final model and was estimated from the interpolated monthly temperature curve using the method of Thornthwaite & Mather (1957).

B. Selection of ecoclimatic variables

In general, ambient temperature, incident solar radiation, and water availability appear to be the most important climatic factors affecting plants. Temperature levels determine potential metabolic and water loss and uptake rates. Infrequent temperature extremes may also constitute insurmountable limits to plant adaptation and distribution. Solar radiation provides the necessary energy for plant growth but can often be represented through surrogate temperature variables. Light-compensation points are generally low, and many plants assimilate more on cloudy days than under direct sunshine. (See, for example, Pisek & Tranquillini 1954; Lieth 1960; Daubenmire 1974; Larcher 1976.) Water availability determines the degree to which plants can meet the evaporative and physiologic demands posed by their particular structures, thereby influencing plant structure as well as plant productivity.

Earlier climatic models of both vegetation types (e.g. Rübel 1930; Holdridge 1947; Troll & Paffen 1964; Mather & Yoshioka 1966) and plant productivity (e.g. Rosenzweig 1968; Lieth & Box 1972) have generally been based on some measure of temperature and water availability. The most readily available and generally useful data on temperature and water availability are provided by measurements of air temperature and precipitation. Six variables are needed to represent even the most basic aspects of annual temperature and precipitation regimes. These represent, for each factor, the annual mean or total and the average maximum and minimum (monthly) values during the year. This representation of general annual levels and extreme period provided the initial basis for the model.

[1]The computerized file of world climatic data compiled by Spangler & Jenne (1979) is being modified by the author to produce a larger ecoclimatic data-base of somewhere over 2000 sites. This file should be available by late 1981.

The first configuration of predictive variables for which world vegetation results were generated (using ECOSIEVE, see section 6.B and Appendix F) involved the above-mentioned six temperature and precipitation variables and the months in which the precipitation extremes occur. The model was used with 13 biome-level vegetation units (Lieth 1975) and predicted general biome distributions reasonably well over about half of the world's land area. Overestimation of forested area and poor distinction between mediterranean and other vegetation types, however, immediately confirmed expectations that both quantitative and temporal relationships between precipitation and water demand (evapotranspiration) would have to be expressed in order to improve prediction.

The relation between water supply and demand was approached through estimation of potential evapotranspiration (PET), since it (unlike actual evapotranspiration, AET) is a function of climate alone and would not require any prior assumptions concerning the nature of the vegetation cover. PET was introduced into the model in the form of an annual moisture index given by annual precipitation divided by annual PET. Annual PET was estimated by the method of Thornthwaite and Mather (1957), since this method requires only air temperature data and has been widely used over many parts of the world (e.g. Thornthwaite 1952; van Hylckama 1956; Pelton et al. 1960; Carter & Mather 1966; Mather 1974). It is well recognized that the Thornthwaite estimate generally underestimates PET in tropical and windy areas. It is necessary, however, to have a recognized standard for purposes of comparison, and the Thornthwaite estimate is as accurate and as widely used as any, especially in the northern temperate zone. A geographical comparison of world PET estimates by the Holdridge (1959) and Thornthwaite methods has been performed (Box 1979c), and further worldwide evaluation of estimation methods is in progress (Box, in preparation).

World vegetation patterns predicted by Rübel's (1930) model using ECOSIEVE and the world data-base (Box, unpublished) had shown that particular extreme months are not very effective predictors of even seasonal vegetation types. A number of other expressions for precipitation seasonality were tried, including precipitation of the warmest month, of the warmest three-month period, and of the warmer half-year as a fraction of the annual total. Precipitation amounts of fixed periods or months were found not to be as useful as hoped, since the length and timing of dry seasons vary significantly even in similar climates. The most useful single predictor was found to be the precipitation of the warmest month, which combines both precipitation and maximum water demand in one variable.

In an attempt to increase predictive accuracy, as well as to simplify the model, a number of other approaches were also tried. These were primarily of three types:

1. A more integrative, growing season-based approach which focused on positive plant requirements (e.g. sufficient growing-season length and warmth) instead of the negative aspect represented by environmental limitation.
2. Attempts to describe ecoclimates more completely through measures of the plant microenvironment (e.g. leaf temperature, soil water, AET) and/or inclusion of more climate factors (e.g. temperature extremes, wind speed).
3. Attempts to describe more accurately environmental limitation by the basic ecoclimatic factors already recognized, primarily by inclusion of more aspects (variables) of these factors.

Attempts of the third type involved additional limiting variables such as the annual range of mean temperature, the precipitation fraction during the summer half-year, and summer and winter moisture indices. The annual range of mean temperature was found to be useful in the initial 'synthetic' model for separating tropical and extra-tropical forms and replaced mean annual temperature, which appeared to be superfluous.

Studies of the first two types (often combined) involved development of:

1. A soil-moisture simulation model SOLWAT applicable to the full range of naturally occurring soil conditions (Box 1981a). SOLWAT has since been used for a variety of other studies.
2. A model PHOSYN for simulating plant metabolic rates and production balances from environmental conditions for periods ranging from hours to years (unpublished).
3. A simple routine PERIOD for delimiting intervals during which a particular criterion is met (e.g. precipitation exceeding PET) and then intersecting the intervals for different elements to estimate more complex periods, such as (climatic) growing seasons (see SOLWAT documentation).

Other environmental variables tried in predictive configurations involving these models include length of the (longest) dry season, length of the climatic growing season, depth of aerated soil, leaf temperature and related actual transpiration, climatically estimated actual evapotranspiration, minimum soil water levels, and the length of the period with a positive climatically-estimated production balance.

These approaches provided useful quantitative estimates of plant-environment relations in different climates. One related but simpler approach involving temperature, precipitation, and PET variables and biome-level vegetation units provided the basis for world maps of estimated annual energy fixation by the vegetation cover (Box 1976) and estimated annual photosynthetic efficiency (Box 1977). It was not possible, however, to refine these integrative and microenvironmental approaches sufficiently to predict plant-form distributions accurately at the world scale. The main reason is the much greater data requirements of these methods. In addition, more simulative, integrative approaches are complicated by the fact that plant activity may not track environmental conditions in a uniform way throughout the year but responds also to genetic programming in quite complex ways, such as winter dormancy (e.g. Levitt 1972; Walter 1968; Tranquillini 1959, 1979). In general, the 'negative' environmental-limitation approach was found to be more accurate and more readily applicable than 'positive' growing-season or other more analytical or simulative approaches, which usually require estimation of the basic microenvironmental data such as soil water or leaf temperature. Average wind speed, absolute temperature extremes, and average diurnal temperature variation were identified as important additional factors but could not be investigated in detail at world scale because of the much greater data requirements. The results of the model constructed without these factors suggest that they are of secondary importance in most situations.

C. The ecoclimatic variables and their significance

The climate model finally employed consists of a set of eight macroclimatic variables which together are intended to express what appear to be the most important aspects of annual temperature, precipitation and evaporation regimes as they affect plant energy and water budgets. Special attention was payed to factors such as warm-season water availability and degree of winter cold which appear to delimit distributions of particular plant types. The ecoclimatic variables were selected by trying various combinations and comparing both predicted plant types at particular sites and predicted world distributions with known vegetation distributions. Particular reference was made to relations between climate and vegetation at a set of 113 sites chosen to represent the different occurrences of Köppen (1931) climate types throughout the world. A particular effort was made to include variables which express concurrent seasonal variations in both climate and physiognomy, factors which are generally poorly represented in earlier models (e.g. Holdridge 1947). The variables employed (with their computing abbreviations) are:

1. Mean temperature of the warmest month (°C) (TMAX)
2. Mean temperature of the coldest month (°C) (TMIN)
3. Annual range of monthly mean temperatures (°C) (DTY)
4. Average annual precipitation (mm) (PRCP)
5. Annual moisture index (annual precipitation divided by the Thornthwaite estimate of annual potential evapotranspiration) (MI)
6. Highest average monthly precipitation (mm) (PMAX)
7. Lowest average monthly precipitation (mm) (PMIN)
8. Average precipitation of the warmest month (mm) (PMTMAX)

Temperature is used as a surrogate for solar radiation since the two factors are closely related quantitatively except for a time-lag of about a month. Factor interactions involving the effects of temperature on precipitation requirements are expressed through the annual moisture index and the precipitation of the warmest month. Mather & Yoshioka (1966), Lieth & Box (1972), and others have shown that more integrative environmental variables, such as actual evapotranspiration, might provide similar results with fewer predictive variables. Such more integrative variables must be computed, however, and were rejected from this initial model, since they render non-computerized use of the model impossible and introduce additional error into the environmental data. Six of the eight variables involve directly measured data. PMTMAX is measured directly when it coincides with PMAX or PMIN and is interpolated otherwise. The moisture index MI involves PRCP and annual PET estimated from the interpolated monthly temperature values. World distributions of the eight variables, plus Thornthwaite's estimate of annual potential evapotranspiration, were obtained by computer-mapping the values at the 1225 test-sites (see section 6.B and Table 11). The resulting world distributions are shown on Maps 1–9.

Results of models involving these eight variables plus other above-mentioned variables (requiring no additional data) consistently showed little if any increase in prediction accuracy. Each of the eight variables chosen, however, appeared to be necessary and to have a particular ecological significance in most environmental situations.

The lower limit for TMAX represents the minimum temperature requirement during the growing season, which is important in probably all situations. It also serves as a rough measure of available solar energy. The upper limit for TMAX serves to estimate the point at which respiration begins to outweigh production or at which some form of metabolic collapse may occur. This is especially important for plants adapted to cooler environments.

Lower limits for TMIN specify minimum mean temperatures which can be tolerated and provide some estimate of the lowest tolerable absolute temperatures. Upper limits represent low temperatures which may be required to induce dormancy and vernalization in seasonal plant types. TMIN is the most important variable for separating evergreen and summergreen plants.

DTY is used primarily to distinguish only slightly seasonal tropical types from seasonal extra-tropical types which may occur in otherwise similar thermal situations. It is a somewhat artificial method of distinction, since it is generally not well known to what extent tropical vegetation types could exist under more seasonal temperature regimes and vice versa. It seems probable, for example, that most warm-season temperate-zone grasses came from the raingreen tropical zone, adapting their already possessed drought-dormancy to the physiological drought of the temperate-zone cold season. Moreover, for example, there is a widespread affinity between the vegetation of moist tropical mountains and the maritime temperate climates of the Southern Hemisphere (Troll & Lauer 1978). The results of the current improved model cast some doubt on the need for this variable.

The total average annual precipitation PRCP, apart from its relation to potential water loss (PET), is a measure of the total amount of water available for storage by the soil and subsequent use by vegetation. Since PRCP represents measured data, it can serve in warmer climates as a backup of MI limits when PET is underestimated. In cooler climates, limits on PRCP express the minimum annual water requirement more accurately than does PET or MI, since these variables do not include the effects of runoff.

The annual moisture index MI expresses the important relation between potential water loss and total water available (PRCP), i.e. the general wetness or dryness of a climate (without expressing seasonality). This is the most useful single variable for predicting the dominant plant structural types. The utility of annual MI as a predictive variable relies on the ability of the soil to store rain or snowmelt from wetter seasons for use during climatically drier seasons. This can be appreciated when one observes, for example, that the annual MI values of raingreen and mediterranean evergreen forests and woodlands, with their extreme dry seasons, can be only slightly lower than the MI values for summergreen and boreal (evergreen) forests and woodlands, with much less extreme, if any, dry seasons.

The lower limit for PMAX represents the minimum amount of water needed at one time for beginning or sustaining growth. This is most important in climates with low, seasonal or irregular precipitation. In dry climates the upper limit for PMAX may represent maximum amounts of stored soil water, beyond which both succulent structures and drought-conditioned life-cycle functions are either impaired or quickly out-competed by other forms.

The lower limit for PMIN represents the greatest degree of drought which can be tolerated, especially by evergreen vegetation. The upper limit represents the degree of drought which may be required by raingreen plants to induce dormancy or other life-cycle functions. This is the most important variable for separating evergreen and raingreen vegetation.

PMTMAX attempts to express the degree of summer drought in a single, easily valuated variable. The accuracy of PMTMAX as a measure of drought assumes a quasi-sinusoidal course in both temperature and precipitation patterns, a requirement which is usually met. In most climates, precipitation reaches either a maximum (polar, boreal, typical-temperate, temperate-continental, and tropical climates) or a minimum (mediterranean climates) at the time of highest temperatures. Climates transitional between temperate and mediterranean can be problematic. PMTMAX is the main variable for separating mediterranean from summergreen forms.

CHAPTER 5

The ecological model: life-form limitation, cover and dominance

In perhaps most modeling situations, including correlation models and many simpler systems models, one simply relates the target phenomena to environmental factors and does not bother with formalities about modeling the important aspects of environment or target phenomena. The distinction between models of structure and of environment, however, the two then linked by a process or 'ecological' model, can be very useful when the target phenomenon is more complex than a single quantity, since this permits one to develop structural and environmental complexity separately and then to focus on their interactions. World vegetation models (as stated in Chapter 2) have always done this, but without saying so, the ecological model being simply the set of particular environmental (climatic) values used to represent distributional limits. The ecological model presented herein has two components:

1. A traditional but much larger set of climatic correlates for the plant types, which define their macroclimatic envelopes in the environmental space employed.
2. A life-form dominance hierarchy, which permits one to interpret predicted sets of life forms as resulting in particular successional patterns and ultimately in a particular climatic-climax formation type.

The effective environment in the second component is no longer macroclimatic conditions but is instead the most important ecological aspects of the environment within the plant stand, namely the vertical shading structure and the soil water status. The ecological sub-model relating the now reduced set of potential life forms to environmental conditions within the stand is a simple hierarchy but represents a type of model which may be of more use in ecology than has generally been appreciated.

The ecological-model components together are intended to represent, in a simple way, an empirical quantification of the great body of existing literature and accepted theories concerning the environmental relations, distributions, and successional relations of the world's terrestrial plant types. Since open and closed stands are fundamentally different in their successional and dominance relationships, a simple estimator of potential vegetative cover is included, as is also a measure of potential life-form importance based on proximity to environmental limits. Synthesis of these various estimates and submodels in order to interpret potential (climatic-climax) vegetation structure is treated in the final part of this chapter.

A. Ecological data

Ecological data, in our case, involve observations of relationships between vegetational and environmental phenomena. Such data may include:

1. Qualitative and quantitative observations on mechanisms of environmental limitation of plant growth.
2. Large-scale descriptions of vegetation distributions in relation to climatic factors.
3. Coordinated, detailed climatic and vegetation data at particular sites.
4. Analyses of vegetation changes along environmental gradients.

5. Quantitative models and correlations relating vegetation distributions to climatic factors.
6. Observations of plant successional relationships and patterns.

Possible effects of non-climatic factors must always be considered in attempting to interpret plant-climate relationships.

The first step in the collection of ecological data involved cataloguing known mechanisms of environmental limitation of species and life-form distributions (Table 6). Plant-environment relations can be approached both through the negative aspect of environmental limitation and through the complementary, positive aspect of the particular environmental requirements of plants. To some extent Table 6 reflects both aspects. The list was intended to be as complete as possible but also manageable. Instrumental in its construction were, in particular, works by Levitt (1972), Larcher (1976), Odum (1971), Whittaker (1975), Daubenmire (1974), Lieth (1974), Lieth & Whittaker (1975), Gates & Schmerl (1975), Krebs (1972), Walter (1968, 1973), Strain & Billings (1974), Precht et al. (1973), and Kozlowski (1971). Table 6 was used as a basis for identifying the most important ecoclimatic factors and for collecting and interpreting quantitative ecological data, such as correlations between distribution boundaries and climatic values.

Quantitative data had to be collected, of course, before the most important limiting mechanisms could be postulated. Quantitative estimates of physiological tolerance limits to various temperature and water-related situations are given, in particular, by Levitt (1972), Larcher (1976), Daubenmire (1974), and in various collections of symposium proceedings in the areas of physiological ecology and photosynthesis research. Most useful, however, were the ecophysiological descriptions of world and regional vegetation primarily by Walter and colleagues. These provided the main ecological and geographic basis for estimation of quantitative limits. These geoecological volumes include Rübel (1930), Walter (1968, 1973, 1974, 1977), Knapp (1965, 1973), Hueck (1966), Horvát et al. (1974), Zohary (1973), and Walter & Box (in press). The ecological works on regional vegetation were supplemented by many individual papers and by simultaneous observation of vegetation from maps and of the corresponding climatic data. Coordinated climatic and vegetation data, both at particular sites and occasionally in the form of gradient analyses, were obtained from numerous individual sources. These are listed in Appendix A, both by plant type and by geographic region.

Finally, an initial conceptual framework and initial estimates for many climatic limits were provided by various quantitative vegetation models which had appeared earlier. The first quantitative descriptions were presented by Warming (1895, see also 1909), Schimper (1898, see also 1935), and Rübel (1930). When Rübel's climatic characterizations of 18 vegetation types were projected (using ECOSIEVE and the 1225 test sites) onto a world base-map, however, less than half of the world's land area was covered (Box, unpublished). The next and perhaps most familiar model was that of Holdridge (1947), who related 19 largely environmental and only moderately physiognomic vegetation types to average annual precipitation, a moisture index (PET/precipitation), and what he called biotemperature (an annual average based only on above-freezing monthly mean temperatures). Holdridge's climatic envelopes appeared to be fairly accurate in the tropics when projected onto a world base-map (Box, unpublished) but can distinguish only general ecological types, not plant size, seasonal habit or leaf type. Lauer (1952) related vegetation zones in East Africa to length of the dry season, with generally good results, and then compared the relations with those in tropical South America. Troll has presented a quantitative climatic characterization of 37 vegetation types along with a world map (Troll & Paffen 1964). The most sophisticated models are those of Mather & Yoshioka (1966), who relate 20 physiognomic vegetation types (some representing individual dominant genera or species) to annual evapotranspiration (potential or actual) and the Thornthwaite (1952) annual moisture index composed of largely seasonal aridity and humidity components.

B. The environmental-limitation model

The model relating potential life-form occurrence to environmental conditions involves a macroclimatic envelope for each life form, within which the form occurs and outside of which it does not. The envelopes are composed of an upper and a

Table 6. Selected important climatic and non-climatic mechanisms of environmental limitation of terrestrial plant distributions.

Temperature
- winter cold
  - direct damage by degree of cold
  - required dormancy and vernalization
  - unseasonal temperatures (without cold-hardening, etc.)
  - production-respiration balance (evergreens)
- summer heat
  - lethal temperatures
  - length of warm season
  - sufficient warmth
  - production-respiration balance
- diurnal variations
  - sudden cold (without cold-hardening)
  - required thermoperiodism
- simultaneous extremes of different plant parts
- annual regime and life-cycle phases

Moisture
- drought
  - atmospheric (high saturation deficit, rapid dehydration)
  - soil (water-holding capacity relative to PET)
  - physiological (reduced uptake at low temperatures, etc.)
  - length of seasonal dry period(s)
  - required dormancy and aestivation
- surfeit
  - rotting
  - flooding and reduced aeration
- alternation of drought and surfeit
- sufficient degree and length of wet period(s)
- diurnal aspects involving saturation deficit, leaf morphology, transport, and water supply
- soil-moisture regime and life-cycle phases
- vulnerability to disease due to drought or surfeit

Other climatic factors
- wind
  - increased moisture loss and desiccation
  - mechanical damage
  - effects on surface temperatures
- insolation
  - effects on soil and plant temperatures
  - sufficient insolation
  - solar declination
  - photoperiodism

Non-climatic factors
- soil (depth, texture, nutrients, water-holding capacity, available water capacity, depth to water table, parent material, mobility, pH, etc.)
- topography (soil and surface heterogeneity, slope, aspect, effect on soil catenas, effect on water table, snow accumulation, microrelief)
- fire (frequency, type)
- geologic history (frequency of disruptions, recolonization time since last disruption, equilibration time since last disruption)
- biological interactions (root competition, light competition, allelopathy, life-history strategy, positive interactions, etc.)

The above list is intended to serve as a guide to the identification of critical environmental factors and the estimation of envelope dimensions, especially for the more important, macroclimatically based factors. Many aspects of environmental limitation have been grouped under more general headings, and many more could be added.

lower limiting value with respect to each of the eight ecoclimatic variables. (This can be thought of as defining 'rectangular' hypervolumes within the eight-dimensional ecoclimatic hyperspace.) This amounts to 16 limiting values for each of 90 life forms or sub-forms, a total of 1440 values. Many upper limits, especially for precipitation variables, may be outside the actual range of climatic conditions known on earth and are thus left unspecified and effectively infinite.

The limiting values generally represent correlations between observed plant or vegetation distributional limits and corresponding climatic values. Such correlates, however, can represent a variety of ecological as well as physiological limiting mechanisms. The ranges defined by the limiting values employed should be wide enough to represent not only truly physiological limits (assuming the ecological be narrower) but also to include a certain amount of compensation in more favorable microclimates and on more favorable (azonal) sites. When limiting values appeared to differ in different parts of the world, the wider limits were always employed except when the form concerned was known to be occuring in a special situation (e.g. near a river in a dry climate).

Initial estimates for most finite limits were made using ecological data described above or were estimated from general relationships when more specific data were not available. The more general data were supplemented, when possible, by data at particular representative sites. Gradient analyses, where available, were particularly useful but require careful interpretation. Data were sought from each regional occurrence of each plant type.

Once a complete set of limits was constructed or the set totally revised, ECOSIEVE was employed to generate the corresponding predictions for the 1225 test sites, both for each site and cross-tabulated to provide a list of potential sites for each plant type. These results were used to identify problem situations and were compared with known vegetation and plant distributions in order to improve the climatic limits as far as possible. Development of the final set of limits required about 10 iterations. Only the results predicted by the final set of limiting values were mapped.

The estimated macroclimatic envelopes of the 90 plant types, plus three types of extreme desert, can be represented by a large table of the limiting values, as shown in Table 7. The plant types are ordered in Table 7 by structural type (growth form) and, within classes, by general latitudinal order of occurrence from equator to poles, as also in Table 2.

Although the climatic limits were essentially empirically determined, certain observations concerning general patterns can be made which are not unexpected and which represent the basis for a quantitative theory.

1. Mean temperature during the warmest month (lower limit for TMAX) must be at least 10° (15° to over 20° for tropical types) for all tree, shrub and vine forms with the exception of the subantarctic small evergreen trees (*Nothofagus*) at 7°. Most xeromorphic forms (e.g. stem-succulents, xeric shrubs and scrub) require 15°, and the tall grasses (except tall tussocks) require 10°. The smaller growth forms, as groups, generally do not require such high minimal temperatures: dwarf-shrubs 6° (12° for most forms), cushion-shrubs only 3°–5°, ferns 10°, epiphytes 8°–16°, shorter grasses and most forbs 0°–10°, and thallophytes −2° to 0 °C.
2. Most forms do not tolerate mean temperatures (upper limit of TMAX) higher than 30°–35° and the limit may be much lower, especially for forms adapted to colder climates with lower threshold temperatures (minimum warmth requirements).
3. Deciduous forms, especially summergreens, tolerate lower temperatures (lower limit for TMIN) than do similar evergreen forms. Summergreen forms in particular generally require lower temperatures (upper limit for TMIN). Smaller, lower-growing evergreen plants (e.g. dwarf-shrubs) extend further into cold-winter climates than do larger evergreens (e.g. trees), due primarily to reduced wind, greater protection by snow or litter, and proximity to the warmer ground surface.
4. Some general structural types, such as rosette-trees (except perhaps tropical alpine dicots) and stem-succulents (except certain *Opuntia* spp.) appear to be generally frost-sensitive. Others, such as epiphytes and broad-evergreen trees, are frost-sensitive only in certain forms (e.g. tropical rainforest and eucalyptoid trees) and frost-tolerant in others (e.g. wintergreen epiphytes, subpolar *Nothofagus*).

5. Other characters being equal, larger plants (and some with only larger leaves) require more water at all times while foliated than smaller plants. This can be altered, however, by sclerophylly, by dissimilar total leaf area, and by microphylly alone. Water requirments can be reduced most by deciduousness or aphylly.
6. The annual (Thornthwaite PET-based) moisture index MI must be at least 0.9 for rainforest trees, 0.8 for broad-deciduous trees (except Xeric Raingreen Trees with long dry seasons), 0.75 for broad-evergreen trees (except eucalyptoids), and 0.6 for narrow or needle-leaved evergreens. The limits may be slightly lower for the corresponding small-tree forms. Limits may be significantly higher, however, generally around 1.0, for occurrence in closed stands. Threshold MI values are generally high for vines (0.9–1.0, except raingreen), epiphytes (1.0–1.1, except wintergreen), ferns (1.1), and evergreen forbs (0.9) but are lower for tall grasses (0.7–0.8), short sward and tussock-grasses (0.5), most shrubs (0.05–0.75), and seasonal, desert and other ephemeral herbs (0.01–0.2). Upper MI limits seem to be appropriate only for sclerophyllous, microphyllous, succulent or other generally xeromorphic forms.
7. Deciduous plant types require either a cold period (summergreens) or a period of moisture stress (raingreens). Evergreen plant types, on the other hand, are limited by such periods unless their effects can be overcome by sclerophylly, microphylly, dormancy or such. Short (1–2 month) dry periods can be tolerated by most evergreen types, even in tropical rainforests. Values (lower limits) of PMIN higher than 20 mm seem required only by tall tussock-grasses (25 mm but usually windy environments), evergreen and tree ferns (30 mm), temperate broad-leaved rainforest trees (50 mm), and subpolar broad-evergreen trees (80 mm, but probably only to ensure an even temperature).

Table 7. Estimated limiting macroclimatic values for terrestrial plant life forms.

The estimated macroclimatic envelopes for the 90 plant forms and subforms of Table 2 and for three types of extreme desert are defined by ranges for the eight ecoclimatic variables, as shown in the computer-printed table. The ecoclimatic variables are indicated by the following abbreviations:

TMAX	=	highest monthly mean temperature (°C)
TMIN	=	lowest monthly mean temperature (°C)
DTY	=	annual range of mean monthly temperatures (°C)
PRCP	=	average annual precipitation (mm)
MI	=	annual moisture index (PRCP/annual potential evapotranspiration estimated by the Thornthwaite method)
PMAX	=	highest average monthly precipitation (mm)
PMIN	=	lowest average monthly precipitation (mm)
PMTMAX	=	average precipitation of the warmest month (mm).

Asterisks denote open-ended variable ranges, i.e. unspecified and presumably unimportant (e.g. unattained) limiting values. The values are to some extent context-dependent and may not be accurate if applied individually. Some values also represent compromises between actual outer limits in unusual climates (e.g. monsoonal) and more commonly occurring limiting values (especially for PMTMAX). The estimates of limiting values were derived by iteration using the ECOSIEVE-generated world distributions implied by particular sets of limiting values. The accuracy of the limiting values can best be assessed by referring to the predicted world life-form distributions (Maps 10–22), the predicted results for 74 independent validation sites (Tables 14 and 15, plus Appendices C and D), and the predicted results for 100 potentially well known sites from the world data-base (Appendix B).

Table 7. Environmental limits (continued).

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
TROPICAL RAINFOREST TREES								
MAXIMUM	30.0	28.0	12.0	******	******	******	******	******
MINIMUM	20.0	18.0	0.0	1100.	0.90	150.	5.	10.
TROPICAL MONTANE RAINFOREST TREES								
MAXIMUM	24.0	23.0	12.0	******	******	******	******	******
MINIMUM	15.0	8.0	0.0	700.	0.90	100.	5.	10.
TROPICAL EVERGREEN SCLEROPHYLL TREES								
MAXIMUM	35.0	30.0	28.0	3000.	2.50	2000.	100.	2000.
MINIMUM	15.0	8.0	0.0	400.	0.50	50.	0.	10.
TROPICAL EVERGREEN MICROPHYLL-TREES								
MAXIMUM	32.0	30.0	25.0	******	******	******	******	******
MINIMUM	15.0	7.0	0.0	400.	0.75	75.	0.	10.
WARM-TEMPERATE BROAD-EVERGREEN TREES								
MAXIMUM	30.0	20.0	22.0	******	******	******	150.	******
MINIMUM	20.0	7.0	7.0	500.	0.75	80.	15.	50.
MEDITERRANEAN BROAD-EVERGREEN TREES								
MAXIMUM	32.0	15.0	30.0	******	2.50	******	75.	75.
MINIMUM	20.0	5.0	5.0	500.	0.80	60.	0.	0.
TEMPERATE BROAD-RAINFOREST TREES								
MAXIMUM	28.0	18.0	22.0	******	******	******	******	******
MINIMUM	13.0	5.0	4.0	600.	1.10	75.	50.	60.
MONSOON BROAD-RAINGREEN TREES								
MAXIMUM	35.0	28.0	15.0	******	3.00	******	30.	******
MINIMUM	23.0	14.0	0.0	800.	0.90	100.	0.	20.
MONTANE BROAD-RAINGREEN TREES								
MAXIMUM	25.0	22.0	20.0	******	******	******	30.	******
MINIMUM	15.0	8.0	0.0	400.	0.80	90.	0.	20.
XERIC RAINGREEN TREES								
MAXIMUM	40.0	30.0	25.0	******	1.00	******	25.	******
MINIMUM	24.0	10.0	0.0	400.	0.35	75.	0.	10.
SUMMERGREEN BROAD-LEAVED TREES								
MAXIMUM	30.0	17.0	50.0	******	******	******	******	******
MINIMUM	15.0	-20.0	8.0	500.	0.90	60.	3.	30.
BOREAL BROAD-SUMMERGREEN TREES								
MAXIMUM	25.0	5.0	60.0	******	******	******	******	******
MINIMUM	13.0	-30.0	8.0	100.	0.80	40.	10.	30.

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
TROPICAL LINEAR-LEAVED TREES								
MAXIMUM	28.0	25.0	12.0	******	******	******	******	******
MINIMUM	15.0	5.0	0.0	500.	1.00	50.	5.	10.
TROPICAL XERIC NEEDLE-TREES								
MAXIMUM	30.0	28.0	20.0	2000.	1.10	300.	75.	300.
MINIMUM	15.0	8.0	0.0	300.	0.70	75.	0.	10.
HELIOPHILIC LONG-NEEDLED TREES								
MAXIMUM	33.0	25.0	35.0	******	2.50	******	100.	******
MINIMUM	20.0	2.0	2.0	400.	1.00	40.	20.	75.
SUB-MEDITERRANEAN NEEDLE-TREES								
MAXIMUM	28.0	15.0	25.0	******	3.00	******	100.	100.
MINIMUM	14.0	-1.0	4.0	400.	0.85	75.	0.	0.
TEMPERATE RAINFOREST NEEDLE-TREES								
MAXIMUM	25.0	15.0	15.0	******	******	******	******	******
MINIMUM	12.0	-2.0	4.0	400.	1.40	80.	20.	25.
TEMPERATE NEEDLE-TREES								
MAXIMUM	24.0	15.0	30.0	2000.	3.00	300.	100.	300.
MINIMUM	15.0	-6.0	4.0	300.	0.65	30.	3.	3.
BOREAL/MONTANE SHORT-NEEDLED TREES								
MAXIMUM	22.0	3.0	60.0	******	******	******	******	******
MINIMUM	11.0	-30.0	10.0	100.	0.60	25.	5.	10.
SWAMP SUMMERGREEN NEEDLE-TREES								
MAXIMUM	28.0	20.0	30.0	******	******	******	******	******
MINIMUM	22.0	3.0	7.0	1000.	1.00	100.	20.	100.
BOREAL SUMMERGREEN NEEDLE-TREES								
MAXIMUM	22.0	3.0	90.0	******	3.00	******	50.	******
MINIMUM	12.0	-60.0	15.0	100.	0.40	30.	0.	25.
TROPICAL BROAD-EVERGREEN DWARF-TREES								
MAXIMUM	35.0	30.0	15.0	******	2.00	******	40.	******
MINIMUM	20.0	15.0	0.0	1000.	0.80	100.	1.	50.
TROPICAL BROAD-EVERGREEN SMALL TREES								
MAXIMUM	32.0	28.0	20.0	******	******	******	******	******
MINIMUM	15.0	8.0	0.0	700.	0.90	75.	5.	10.
TROPICAL CLOUD-FOREST DWARF-TREES								
MAXIMUM	20.0	18.0	6.0	******	******	******	******	******
MINIMUM	10.0	5.0	0.0	500.	1.00	50.	5.	20.

Table 7. Environmental limits (continued).

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
TEMP. BROAD-EVERGREEN SMALL TREES								
MAXIMUM	32.0	15.0	25.0	******	******	******	******	******
MINIMUM	12.0	2.0	4.0	400.	0.75	60.	5.	10.
SUBPOLAR BROAD-EVERGREEN SMALL TREES								
MAXIMUM	15.0	10.0	15.0	******	******	******	******	******
MINIMUM	7.0	2.0	2.0	500.	2.00	150.	80.	80.
BROAD-RAINGREEN SMALL TREES								
MAXIMUM	35.0	30.0	25.0	******	******	******	30.	******
MINIMUM	15.0	8.0	0.0	300.	0.25	50.	0.	10.
BROAD-SUMMERGREEN SMALL TREES								
MAXIMUM	30.0	17.0	60.0	******	******	******	******	******
MINIMUM	11.0	-30.0	8.0	150.	0.70	40.	1.	20.
DWARF-NEEDLE SMALL TREES								
MAXIMUM	30.0	13.0	40.0	******	3.00	300.	100.	200.
MINIMUM	18.0	-5.0	10.0	200.	0.45	25.	0.	5.
PALMIFORM TUFT-TREES								
MAXIMUM	40.0	30.0	30.0	******	******	******	******	******
MINIMUM	16.0	11.0	0.0	400.	0.70	50.	0.	10.
PALMIFORM TUFT-TREELETS								
MAXIMUM	35.0	30.0	30.0	******	******	******	******	******
MINIMUM	14.0	10.0	0.0	400.	0.70	50.	0.	5.
TREE FERNS								
MAXIMUM	22.0	22.0	12.0	******	******	******	******	******
MINIMUM	10.0	10.0	0.0	500.	1.20	75.	30.	50.
TROPICAL ALPINE TUFT-TREELETS								
MAXIMUM	15.0	10.0	5.0	******	2.00	******	100.	******
MINIMUM	1.0	0.0	0.0	200.	1.00	50.	0.	0.
XERIC EVERGREEN TUFT-TREELETS								
MAXIMUM	35.0	30.0	25.0	1500.	1.00	300.	50.	300.
MINIMUM	19.0	8.0	0.0	100.	0.25	50.	0.	0.
EVERGREEN GIANT-SCRUB								
MAXIMUM	32.0	28.0	25.0	******	2.00	******	100.	******
MINIMUM	20.0	8.0	0.0	100.	0.25	20.	0.	0.
RAINGREEN THORN-SCRUB								
MAXIMUM	40.0	30.0	25.0	1500.	1.00	1000.	20.	1000.
MINIMUM	15.0	8.0	0.0	100.	0.08	30.	0.	10.

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
SUMMERGREEN GIANT-SCRUB								
MAXIMUM	35.0	17.0	60.0	******	******	******	******	******
MINIMUM	12.0	-30.0	8.0	150.	0.40	40.	1.	20.
LEAFLESS XEROMORPHIC LARGE-SCRUB								
MAXIMUM	40.0	30.0	60.0	600.	0.80	100.	30.	100.
MINIMUM	15.0	-20.0	0.0	50.	0.05	5.	0.	0.
NEEDLE-LEAVED TREELINE KRUMMHOLZ								
MAXIMUM	13.0	3.0	70.0	******	******	******	100.	******
MINIMUM	10.0	-35.0	5.0	75.	0.60	25.	2.	15.
TROPICAL BROAD-EVERGREEN SHRUBS								
MAXIMUM	32.0	30.0	20.0	******	******	******	******	******
MINIMUM	10.0	6.0	0.0	400.	0.70	75.	0.	5.
MEDITERRANEAN EVERGREEN SHRUBS								
MAXIMUM	30.0	18.0	35.0	******	2.00	******	100.	125.
MINIMUM	16.0	5.0	5.0	300.	0.45	60.	0.	0.
BROAD-ERICOID EVERGREEN SHRUBS								
MAXIMUM	25.0	10.0	35.0	******	******	******	******	******
MINIMUM	13.0	-10.0	0.0	400.	1.40	35.	2.	30.
TEMPERATE BROAD-EVERGREEN SHRUBS								
MAXIMUM	30.0	20.0	50.0	******	******	******	******	******
MINIMUM	15.0	-2.0	5.0	200.	0.60	40.	1.	30.
HOT-DESERT EVERGREEN SHRUBS								
MAXIMUM	40.0	30.0	40.0	1000.	0.75	150.	20.	150.
MINIMUM	22.0	6.0	5.0	50.	0.08	10.	0.	0.
LEAF-SUCCULENT EVERGREEN SHRUBS								
MAXIMUM	32.0	25.0	20.0	1000.	0.80	300.	30.	300.
MINIMUM	15.0	12.0	0.0	100.	0.15	10.	0.	1.
COLD-WINTER XEROMORPHIC SHRUBS								
MAXIMUM	32.0	6.0	60.0	800.	0.90	200.	30.	60.
MINIMUM	15.0	-20.0	10.0	50.	0.10	15.	0.	0.
BROAD-SUMMERGREEN MESIC SHRUBS								
MAXIMUM	30.0	17.0	60.0	******	******	******	******	******
MINIMUM	14.0	-30.0	8.0	300.	0.70	30.	1.	20.
XERIC SUMMERGREEN SHRUBS								
MAXIMUM	35.0	12.0	60.0	800.	1.00	100.	30.	100.
MINIMUM	14.0	-30.0	8.0	100.	0.25	30.	1.	10.

Table 7. Environmental limits (continued).

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
NEEDLE-LEAVED EVERGREEN SHRUBS								
MAXIMUM	35.0	15.0	65.0	******	2.00	300.	100.	300.
MINIMUM	10.0	-30.0	0.0	100.	0.40	40.	0.	0.
MEDITERRANEAN DWARF-SHRUBS								
MAXIMUM	35.0	15.0	35.0	******	1.20	******	50.	50.
MINIMUM	16.0	3.0	5.0	150.	0.15	35.	0.	0.
TEMPERATE EVERGREEN DWARF-SHRUBS								
MAXIMUM	24.0	18.0	50.0	******	******	******	******	******
MINIMUM	6.0	-20.0	0.0	100.	0.70	30.	5.	25.
MARITIME HEATH DWARF-SHRUBS								
MAXIMUM	23.0	10.0	18.0	******	******	******	******	******
MINIMUM	12.0	-1.0	5.0	500.	1.00	60.	20.	20.
SUMMERGREEN TUNDRA DWARF-SHRUBS								
MAXIMUM	18.0	3.0	80.0	******	******	******	******	******
MINIMUM	6.0	-60.0	5.0	100.	0.70	20.	10.	10.
XERIC DWARF-SHRUBS								
MAXIMUM	40.0	30.0	60.0	1000.	0.80	100.	30.	100.
MINIMUM	12.0	-20.0	0.0	50.	0.05	5.	0.	0.
PALMIFORM MESIC ROSETTE-SHRUBS								
MAXIMUM	35.0	30.0	30.0	******	******	******	******	******
MINIMUM	15.0	8.0	0.0	500.	0.90	60.	5.	20.
XERIC ROSETTE-SHRUBS								
MAXIMUM	40.0	30.0	30.0	1500.	1.20	200.	50.	200.
MINIMUM	20.0	3.0	1.0	100.	0.10	20.	0.	2.
MESIC EVERGREEN CUSHION-SHRUBS								
MAXIMUM	18.0	10.0	15.0	******	******	******	******	******
MINIMUM	3.0	1.0	0.0	500.	1.30	60.	5.	40.
XERIC CUSHION-SHRUBS								
MAXIMUM	35.0	25.0	20.0	1000.	0.90	200.	30.	150.
MINIMUM	5.0	-5.0	0.0	50.	0.10	10.	0.	0.
ARBORESCENT STEM-SUCCULENTS								
MAXIMUM	40.0	30.0	35.0	1500.	0.80	250.	20.	250.
MINIMUM	22.0	8.0	0.0	90.	0.07	15.	0.	10.
TYPICAL STEM-SUCCULENTS								
MAXIMUM	40.0	30.0	40.0	1500.	0.60	250.	20.	250.
MINIMUM	20.0	7.0	0.0	50.	0.05	10.	0.	0.
BUSH STEM-SUCCULENTS								
MAXIMUM	40.0	30.0	40.0	2000.	1.50	300.	100.	300.
MINIMUM	10.0	0.0	0.0	50.	0.05	10.	0.	0.
ARBORESCENT GRASSES								
MAXIMUM	30.0	25.0	30.0	******	******	******	******	******
MINIMUM	10.0	4.0	0.0	100.	0.80	75.	5.	20.
TALL CANE-GRAMINOIDS								
MAXIMUM	35.0	30.0	35.0	******	3.00	******	300.	******
MINIMUM	10.0	1.0	0.0	500.	0.70	100.	0.	0.
TALL GRASSES								
MAXIMUM	35.0	23.0	60.0	******	******	******	300.	******
MINIMUM	10.0	-20.0	0.0	350.	0.70	60.	5.	30.
SHORT SWARD-GRASSES								
MAXIMUM	35.0	25.0	60.0	******	******	******	******	******
MINIMUM	5.0	-50.0	0.0	100.	0.50	40.	2.	25.
SHORT BUNCH-GRASSES								
MAXIMUM	40.0	30.0	100.0	******	3.00	******	300.	******
MINIMUM	2.0	-60.0	0.0	100.	0.20	30.	0.	0.
TALL TUSSOCK-GRASSES								
MAXIMUM	23.0	10.0	20.0	******	******	******	******	******
MINIMUM	5.0	-1.0	2.0	500.	0.80	50.	25.	30.
SHORT TUSSOCK-GRASSES								
MAXIMUM	25.0	10.0	20.0	1000.	1.20	300.	75.	300.
MINIMUM	2.0	-1.0	2.0	100.	0.50	40.	10.	25.
SCLEROPHYLLOUS GRASSES								
MAXIMUM	40.0	30.0	30.0	1000.	1.20	150.	30.	75.
MINIMUM	20.0	10.0	0.0	100.	0.10	25.	0.	10.
DESERT-GRASSES								
MAXIMUM	40.0	30.0	100.0	1000.	0.50	300.	20.	300.
MINIMUM	3.0	-60.0	0.0	40.	0.02	10.	0.	0.
TROPICAL EVERGREEN FORBS								
MAXIMUM	35.0	30.0	15.0	******	******	******	******	******
MINIMUM	3.0	2.0	0.0	500.	0.90	75.	5.	40.
TEMPERATE EVERGREEN FORBS								
MAXIMUM	30.0	18.0	50.0	******	******	******	******	******
MINIMUM	5.0	-5.0	5.0	400.	0.90	50.	10.	20.

Table 7. Environmental limits (continued).

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
RAINGREEN FORBS								
MAXIMUM	35.0	30.0	20.0	******	******	******	50.	******
MINIMUM	10.0	7.0	0.0	200.	0.20	30.	0.	10.
SUMMERGREEN FORBS								
MAXIMUM	35.0	15.0	100.0	******	******	******	******	******
MINIMUM	10.0	-50.0	6.0	100.	0.20	30.	0.	0.
SUCCULENT FORBS								
MAXIMUM	40.0	30.0	40.0	1500.	1.20	200.	50.	200.
MINIMUM	18.0	5.0	0.0	10.	0.05	10.	0.	0.
XERIC CUSHION-HERBS								
MAXIMUM	30.0	25.0	100.0	1000.	1.00	300.	50.	300.
MINIMUM	5.0	-60.0	0.0	40.	0.20	5.	0.	0.
EPHEMERAL DESERT HERBS								
MAXIMUM	40.0	28.0	100.0	500.	0.50	200.	15.	200.
MINIMUM	1.0	-20.0	0.0	30.	0.01	10.	0.	0.
SEASONAL COLD-DESERT HERBS								
MAXIMUM	15.0	0.0	******	******	******	******	******	******
MINIMUM	0.0	-100.0	3.0	10.	0.10	5.	0.	0.
RAINGREEN COLD-DESERT HERBS								
MAXIMUM	15.0	10.0	20.0	******	3.00	******	30.	******
MINIMUM	1.0	-3.0	0.0	100.	0.20	30.	0.	0.
TROPICAL BROAD-EVERGREEN LIANAS								
MAXIMUM	30.0	30.0	15.0	******	******	******	******	******
MINIMUM	18.0	10.0	0.0	500.	1.00	75.	2.	30.
BROAD-EVERGREEN VINES								
MAXIMUM	32.0	30.0	25.0	******	******	******	******	******
MINIMUM	10.0	4.0	0.0	400.	0.90	75.	1.	30.
BROAD-RAINGREEN VINES								
MAXIMUM	35.0	30.0	25.0	******	******	******	30.	******
MINIMUM	15.0	10.0	0.0	200.	0.25	30.	0.	10.
BROAD-SUMMERGREEN VINES								
MAXIMUM	30.0	12.0	50.0	******	******	******	******	******
MINIMUM	15.0	-5.0	8.0	400.	1.00	60.	2.	40.

	TMAX	TMIN	DTY	PRCP	MI	PMAX	PMIN	PMTMAX
TROPICAL BROAD-EVERGREEN EPIPHYTES								
MAXIMUM	30.0	30.0	12.0	******	******	******	******	******
MINIMUM	12.0	10.0	0.0	500.	1.10	75.	10.	30.
NARROW-LEAVED EPIPHYTES								
MAXIMUM	32.0	30.0	18.0	******	******	******	******	******
MINIMUM	8.0	5.0	0.0	500.	1.00	75.	10.	30.
BROAD-WINTERGREEN EPIPHYTES								
MAXIMUM	30.0	28.0	30.0	******	******	******	******	******
MINIMUM	16.0	0.0	0.0	400.	0.60	50.	0.	2.
EVERGREEN FERNS								
MAXIMUM	30.0	28.0	15.0	******	******	******	******	******
MINIMUM	10.0	5.0	0.0	500.	1.10	75.	30.	50.
SUMMERGREEN FERNS								
MAXIMUM	30.0	12.0	60.0	******	******	******	******	******
MINIMUM	10.0	-20.0	8.0	300.	1.10	50.	2.	50.
MAT-FORMING THALLOPHYTES								
MAXIMUM	30.0	30.0	130.0	******	******	******	******	******
MINIMUM	0.0	-100.0	0.0	20.	0.80	10.	1.	1.
XERIC THALLOPHYTES								
MAXIMUM	40.0	30.0	150.0	******	2.00	******	100.	******
MINIMUM	-2.0	-100.0	0.0	1.	0.01	1.	0.	0.
NON-SEASONAL COLD DESERT								
MAXIMUM	3.0	3.0	3.0	******	3.00	******	******	******
MINIMUM	0.0	-2.0	0.0	10.	0.05	2.	0.	0.
DRY DESERT								
MAXIMUM	******	******	******	200.	0.25	25.	5.	25.
MINIMUM	0.0	******	0.0	0.	0.0	0.	0.	0.
ICE DESERT								
MAXIMUM	6.0	-1.0	******	******	******	******	******	******
MINIMUM	******	******	0.0	1.	0.10	0.	0.	0.

C. The cover model

Vegetative cover (percent of ground surface covered) is essentially a function of water availability in relation to evaporative demands. This can be seen from the fact that even tundras and grasslands, growing not more than 0.5 m high, can produce seasonal cover values as high as those of forests, effectively 100%. Larcher (1976) and various IBP studies have provided scattered data which suggest the annual moisture index (MI) as an adequate and convenient initial estimate of maximum seasonal cover, up to 1.0. MI values greater than 1.0 are interpreted as 100% cover, indicating closed forests except in climates too cold for trees. MI values less than 1.0 are interpreted as indicating open stands, from open woodlands (0.75–1.0) and savannas (0.6–0.8) on down to semi-desert scrub (below 0.5). These values are also suggested by a variety of other sources, including Holdridge (1947), Budyko (1956), and Mather (1974). The correspondence of MI values with general formation classes is summarized in Table 8.

D. The dominance model

Those plant growth forms which produce the greatest total cover above that of competing forms generally make the greatest contributions to the general character of plant stands and can be thought of as dominant forms. In order to predict dominant forms in a given situation, the forms were arranged in a dominance hierarchy based on leaf area and height of the respective forms, with some consideration also of amount of lateral branching. On cleared sites free of non-climatic complications (euclimatopes) secondary succession can be

Table 8. Composition and cover requirements for vegetation formation classes.

Predicted life-form spectra can be interpreted as prediction of particular vegetation formation types by means of criteria concerning forms predicted, their expected dominance relationships (see Table 9), and expected vegetative cover. In closed stands (forests, dense shrubland, arctic/alpine grasslands) the dominant forms and thus the vegetation formation type are determined primarily by the dominance hierarchy. As stands become more open, the estimated cover, mix of forms predicted, and proximity to environmental limits become more important determinants of stand structure and formation type.

Formation class	Forms required	MI range
Rainforest (evergreen)	rainforest trees understorey trees shrubs, forbs or ferns	>1.1 (tropics) >1.3 (elsewhere)
Forest	trees or rosette-trees (not small or dwarf)	>1.0 (closed) 0.90–1.10 (open)
Woodland (open)	trees or rosette-trees (any forms)	0.75–1.00
grassy woodland or savanna forest	tall grass	0.75–0.90
forest-tundra	boreal tree and tundra forms	temperature-limited
Savanna (forest-steppe in temperate zone)	trees or rosette-trees (generally not conifers) sward and/or bunch-grass	0.60–0.80
Grassland	any grass form (except bamboo), trees unimportant	
steppe	short bunch or sward-grass	>0.30
Shrubland	any shrub form, trees unimportant	>0.30
shrub-steppe	small shrubs with grass	(open)
Scrub	various forms (usually mixed), no canopy trees	
	grass cover not continuous	<0.50
Tundra	tundra/temperate dwarf-shrubs and/or forbs	
	short grasses	>0.30
Semi-desert	various forms, no canopy trees	>0.30
Desert	no higher plants	≤0.10
cold-desert	cold-desert herbs plus thallophytes only	temperature-limited

expected to proceed up the dominance hierarchy, ending eventually with dominance by the highest ranked forms climatically possible at the site. The lower forms are not necessarily eliminated but are less prominent and generally reduced in number. The general vegetation structure and formation type are determined by the dominant forms.

The hierarchy (Table 9) consists of six levels (with sub-levels). Dominance is primarily a function of growth form and relative plant size (since taller forms usually produce greater cover) and of growth rate. Evergreen forms may or may not outcompete corresponding deciduous forms in a given environment and so are usually placed in the same dominance level. (An exception is the slow-growing boreal larches, which dominate only in areas too cold for evergreens.) Also, forms which are low-growing but form dense covers may be more successful than taller but more scattered forms, as in the case of grasslands. Tree forms are considered to dominate smaller forms only if the estimated total cover (MI value) exceeds 0.9 (see also part F of this chapter). Inclusion in the same level of forms with overlapping climatic envelopes implies that these forms will coexist and be 'co-dominant' forms if no forms from a higher level are predicted. Such forms are considered to be complementary (e.g. Gimingham 1978) in the sense that they can coexist without competing directly. Coexisting forms should always be placed in the same dominance level if they commonly occur as co-dominants in mixed stands, their competition being insufficient to exclude one form or the other regularly. Life forms which never occur together, such as tropical and boreal forms, can conveniently be placed in the same dominance level, without implying anything about relations between them.

The dominance hierarchy is not intended as an ecological theory but rather as a convenient, empirically based means of predicting which forms will be most important in a given life-form mix and environmental situation. Strictly speaking, the

Table 9. Hierarchy of potential life-form dominance in vegetation stands.

Taller, leafier plant forms are expected to dominate smaller forms in a plant stand in the sense that they may reduce or exclude other forms through more successful competition for sunlight and water and thereby determine the general structure and character of the stand. Potential life-form dominance, in this sense, is summarized by the hierarchy below, in which potential dominance increases upward. This hierarchy is employed to predict dominant and sub-dominant forms in a stand in order to identify and characterize the vegetation formation type. The hierarchy is not intended to predict relative importance of forms in quite open formations or below the top two or three dominance levels present in closed formations, since these forms may be influenced more by other aspects of environment than competition for water and light.

Level	Life forms
6	Forest trees
	a. tropical rainforest trees
	b. other climax canopy trees
	c. smaller canopy trees (stressful environments), tuft-trees, taller sub-climax trees
	d. other successional canopy trees
5	Small-trees and tall grasses
4	Mesic tuft-treelets, large shrubs and arborescents, sward and tall-tussock grasses
3	Xeric tuft-treelets, xeric shrubs and bushes, mesic small-shrubs, short bunch and tussock-grasses, arborescent stem-succulents
2	Leafless and leaf-succulent scrub, dwarf-shrubs, forbs, ferns
1	Small herbs of extreme environments, leafless dwarf-shrubs, thallophytes
0	Plant-less deserts

Never dominant: vines and epiphytes
Edaphically constrained: phreatophytes (e.g. arborescents, swamp trees and scrub)
Biologically constrained: bamboos (vegetative colonies)
Extremely slow-growing (restricted to undisturbed areas): larger stem- and leaf-succulents

dominance hierarchy is applicable only to closed and only moderately open stands (including grasslands). Since it is based largely on plant size, however, it also suggests the most conspicuous forms even in the most open formation. The dominance hierarchy is empirical but does not lack a theoretical basis. The entire hierarchy can be generated by a simple algorithm employing only the physiognomic characters (see Box 1978a) of the individual life forms.

Most trees are placed in the top level (level 6) because they produce the greatest leaf area at the greatest height. Level 6 is subdivided, however, because of observable successional and other dominance relationships between tree types. Tropical rainforest trees are placed above all other because of their clearly dominant position in closed tropical forests. Most other climax canopy trees are in level 6b, since probably all of these forms can occur in more or less evenly mixed forests, such as the sub-boreal mixed forest of broad-leaved summergreens and evergreen conifers. Some canopy trees which do not commonly become dominants, have edaphic constraints, or which for some other reason would cause problems if placed with climax canopy trees are placed in level 6c. These include the tropical evergreen sclerophyll and microphyll trees, the swamp (*Taxodium*) and boreal (*Larix*) summergreen needle-trees, and the palms. These can be important forest components but usually dominate only where other trees are much reduced. Larches, for example, are slower-growing at maturity than evergreen boreal conifers (Tranquillini 1963) and form extensive forests only where evergreens are absent, in eastern Siberia. Two climax canopy tree types of generally shorter stature, the cloud-forest and sub-antarctic broad-leaved evergreen trees, are also placed in level 6c. Other successional canopy or sub-canopy trees, such as boreal summergreens (e.g. *Betula, Populus*), are placed in level 6d.

The various understorey and open-woodland smaller trees, except the slower-growing dwarf-needle (juniperoid) trees, are placed in level 5. With them in this level are the tall grasses with which the small trees often co-exist in open woodlands and savannas.

Level 4 includes tall-tussock and short sward-forming grasses, the juniperoid small trees, and a variety of other forms including understorey tuft-treelets and larger shrub forms, including arborescents. Of the shrubs and bushes, only raingreen thorn-scrub and mediterranean evergreen shrubs cover large areas as dominants, though summergreen shrubs can dominate locally (e.g. 'deciduous chaparral' of western USA).

Level 3 includes many smaller and more xeric analogs of the forms in level 4, namely the xeric tuft-treelets, xeric shrubs, smaller mesic shrubs, and short bunch and tussock-grasses. Arborescent stem-succulents are also included in this level. These forms often co-exist in warm semi-deserts and in some steppes.

Even smaller and more xeromorphic shrubs and scrub are found in level 2, including the slow-growing leafless and leaf-succulent scrub forms. These are placed with the forbs and ferns, which occur in a wide variety of environments and may occur in semi-deserts.

The smallest and most extreme forms, such as ephemerals and thallophytes, are placed in the lowest level. Outside the dominance hierarchy are certain other forms which may be dependent on other plants for support (vines and epiphytes), biologically constrained (e.g. bamboos, which occur mainly in localized colonies), or otherwise not capable of dominating large areas, except perhaps under special conditions.

E. Proximity to environmental limits

As environments become more stressful, and vegetation more open, physical conditions become equally and then more important than potential life-form dominance relationships in determing actual stand structure and life-form importance. Proximity to environmental limits may result in physiological stresses and eventual environmental limitation by any of a great variety of factors or mechanisms, the most important of which were summarized in Table 6.

In order to examine proximity to environmental limits in particular cases, the processing program ECOSIEVE was equipped with an optional algorithm to identify the closest environmental limit of each plant type possible at a site. In order to standardize for the different environmental factors and to overcome the problem of unspecified limits in some cases, the 'distance' between the site value and the closer (upper or lower) limiting value for an environmental variable is always expressed as the raw distance divided either by the greatest corresponding raw distance for any plant type at the site (with respect to the same variable) or by the plant's own tolerance range (if both limits are specified), whichever is smaller. The standardized 'distance' or 'proximity' is thus always a value between one and zero, with values approaching one occurring usually only for lower forms with wide tolerance ranges. The environmental variable with the closest limiting value and the corresponding (fractional) distance to that value are identified by ECOSIEVE and printed next to the life-form name on the printout of site results (see Table 10 and Appendices B and C). In this way one can always see which forms are occurring very near environmental limits and thus presumably not growing as vigorously as other forms at the site.

This measure of life-form 'fitness' in a given environmental situation provides additional information for use in interpreting model predictions. Fitness values of zero or very nearly zero, in particular, suggest that the plant form in question is occurring at an environmental limit and will not be abundant or important in stand structure at the site. The fitness measure is intended to eliminate forms occurring near limits from dominance considerations. (The computerized model ignores those potential dominants which have fitness measures lower than 0.1.) It is not intended to imply relative importance or potential cover of forms which are occurring well within their environmental limits (fitness values of 0.1 or greater), since this depends more on the attributes of the particular life forms.

F. Interpreting vegetation formations

Interpreting the results at a particular site as occurrence of a particular vegetation formation type is not and perhaps should not be a computerized operation, despite our desire for rigorous prediction free of subjectivity.

Interpreting model results involves at least the following operations:

1. identification of dominant forms;
2. interpretation of total stand cover and the cover (importance) of particular components;
3. interpretation of vegetation strata; and
4. selection of appropriate adjectives and nouns to describe the vegetation formation type.

The last of these requires the other three and involves both identification of the most appropriate formation class (forest, woodland, etc.) and selection of a minimal set of appropriate descriptors for the mix of dominant forms and their seasonal habits.

Formation class is a function of dominant growth forms, vegetation strata and the degree of cover provided by each. At the level of resolution required here, each is predicted sufficiently by the annual moisture index MI, which expresses the general level of water availability for robust or less dense vegetation growth. Assuming that the appropriate life forms (growth forms) have been predicted to occur (and are not occurring as scattered individuals at environmental limits), one can recognize formation classes by the criteria indicated in Table 8.

Closed stands (including forests, dense shrublands, and dense tundras or meadows) generally require that MI be at least 1.0. In such cases, the dominant forms and the formation type can be determined primarily by the dominance hierarchy (Table 9). As stands become more open, the estimated cover, mix of predicted forms, and proximity to environmental limits become more important determinants of stand structure and formation type. Grasses immediately become more important because of their ability to spread rapidly, form more or less dense ground covers, and prevent invasion by seedlings of larger forms (especially when grazed regularly). Shrubs also become more important, since they are ecologically much like trees, can form dense covers, but have much reduced total transpiring surface areas. Trees may disappear rapidly or remain as well-spaced individuals.[1] Other forms such as stem-succulents, rosette-treelets and scrub, slow-growing forms (e.g. succulents in general), and forms with edaphic (e.g.

[1]Because of the slow seasonal thawing of boreal and polar soils, permitting conifers in particular to exist at unusually low MI values, the lower MI limits for boreal evergreen and especially summergreen needle-trees had to be set artificially low. This must be kept in mind when, as a result, boreal needle-trees are predicted in dry climates south of the boreal zone. One should also keep in mind that, except for pines, tall conifers rarely form savannas or open woodlands on the warmer sides of their ranges.

phreatophytes) or other constraints characteristically occur as more scattered individuals and must be interpreted specially.

All of these characteristics, as well as the particular environmental situation, must be considered when attempting to interpret the structure and composition of open stands. In such situations the potential dominance relationships may provide useful information but can also be subordinated by more direct controls by the physical environment. In open stands (MI $<$ 0.90) the model selects potentially dominant and other important forms (pluses on the ECOSIEVE listing, see Table 10) by consulting both the dominance hierarchy and a list of forms which are identified as capable of importance in open stands. This list is designed to eliminate frequently predicted slow-growing forms with wide environmental ranges, such as needle-leaved and extremely xeromorphic (e.g. leafless) shrubs and scrub. The list of forms identified as capable of importance in most open-stand situations includes all trees except the most mesophilic (hydrophilic), raingreen thorn-scrub, evergreen large scrub, all shrubs except the mesic broad-ericoids and slow-growing forms (needle-leaved, leaf-succulent, leafless), arborescent stem-succulents (because of their conspicuousness), and all graminoids except the bambuscoid arborescents. All forbs, small herbs, ferns, vines, epiphytes and thallophytes are excluded from identification as potentially dominant in open stands. They may, however, be reconsidered if no other forms are present, as in the near-deserts. Interpretation of open and closed stands will be illustrated by examples in the next section (Table 10).

Once the results have been obtained, the formation class is determined by the dominant forms. Physiognomic (e.g. leaf form) and seasonality descriptors are attached to the name of the formation class to provide a more complete characterization of formation type, e.g. broad-leaved evergreen forest or warm-temperate mixed forest. The usual conventions are followed (e.g. Küchler 1967), with 'mixed' referring to a mixture of broad and narrow leaf forms (among the dominant elements). 'Semi-deciduous' refers to a mixture of deciduous and evergreen forms of the same stratum, whereas 'semi-evergreen' refers to a deciduous forest overstorey with an evergreen tree understorey, as is common in tropical summer-rain transitional areas (e.g. Eyre 1968). Other combinations require more detailed descriptions.

CHAPTER 6

Model results

The combined ecophysiognomic model presented in the previous three sections marshalls a variety of data and submodels and produces a variety of outputs on several levels.

The environmental-limitation model is designed so that all forms which could occur climatically at a given site are retained in the screening process. Exclusions due to non-climatic factors such as soil, competition or succession must be accomplished by additional modeling components applied subsequently. Total vegetation cover is estimated from the annual moisture index (MI). The dominance hierarchy is applied after all other operations in order to predict which of the climatically and otherwise possible forms are most likely to dominate and characterize the vegetation formation.

The model is designed for application at particular real or hypothetical sites. Such sites can be anywhere in the world's land areas, and application of the model to a large world data-base may provide interesting new perspectives. At least this probably represents the best means of evaluating the results and the usefulness of the approach. The model was applied to the world climatic data-base of 1225 sites in order to predict world distributions of the individual life forms and of related vegetation types. The predictions were computer-mapped using the mapping basis described earlier (Chapter 2), as were also the world data for the eight ecoclimatic variables plus Thornthwaite PET. Before looking at predicted world results, it is necessary to consider model use and applicability in a bit more detail.

A. Model output and applicability

Model output, at each site, consists of a spectrum of plant forms which can be expected to occur under the climatic conditions specified, provided that:

1. the soil is drained, and edaphic or other factors do not significantly alter such microenvironmental conditions as water availability;
2. particular forms are not precluded by unusual chemical conditions, such as high salinity or low nutrient content;
3. climatic conditions not included in the model, such as wind and climatic variability, do not significantly alter the climatic conditions represented by the ecoclimatic variables;
4. the local vegetation is in reasonable equilibrium with current climatic conditions; and
5. the natural vegetation has not been greatly altered or destroyed, as by natural catastrophe or anthropogenic influences.

Sites which meet all criteria except the third (and perhaps the fourth) are called euclimatopes (Walter 1975), i.e. sites where the climate can exert its full influence on the natural vegetation. The dominance hierarchy and cover considerations can be applied to the predicted plant-form spectrum in order to predict, as an end-result, a vegetation formation type characterized by particular dominant forms but including also the other predicted forms.

As examples, the life-form spectra predicted for Raleigh (North Carolina piedmont) and Dar es-Salaam (coastal Tanzania) are shown in Table 10, along with the local climatic values. Raleigh represents the temperate zone and a site (MI = 1.43)

Table 10. Predicted vegetation at Raleigh (North Carolina) and Dar es-Salaam (Tanzania).

As examples of model output and its interpretation, the life-form spectra predicted for Raleigh (temperate zone, closed formation) and Dar es-Salaam (tropical zone, open formation) are shown as they appear on an ECOSIEVE computer printout. The site name, country, and geographic coordinates are listed on the first line for each site (with site sequence-number at far left). The second line for each site shows the climatic values at the site, as indicated in the heading. (DTY is omitted since it can be obtained easily by subtracting TMIN from TMAX). The life forms predicted to occur at the site are listed after the first two lines in order of decreasing dominance level (see Table 9). Within dominance level the forms are listed in order of increasing proximity to an environmental limit (i.e. decreasing 'fitness'). The variable involved in the closest environmental limit and the corresponding 'distance' (see section 5.E) to that limit are shown to the right of each life form. Life forms of the highest dominance level represented are indicated by a preceding asterisk (except when their fitness values are below 0.1) and are interpreted as dominant forms in closed stands. In open stands (MI < 0.90) other life forms predicted to be important and perhaps dominant (primarily grass and shrub forms, see section 5.F) are indicated by preceding pluses. Interpretation of the predictions at Raleigh and Dar es-Salaam is covered in the main text.

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT	LONG
198. RALEIGH,N.CAROLINA USA	35.78	-78.65
25.0 5.0 1145. 145. 72. 145. 1.43		
* 1. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.33
* 2. HELIOPHILIC LONG-NEEDLED TREES	TMIN	0.13
3. TEMPERATE BROAD-RAINFOREST TREES	TMIN	0.0
4. SWAMP SUMMERGREEN NEEDLE-TREES	TMIN	0.12
5. BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.0
6. TALL GRASSES	TMAX	0.40
7. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.26
8. ARBORESCENT BAMBUSOID GRASSES	TMIN	0.05
9. TEMP. BROAD-EVERGREEN SMALL TREES	TMIN	0.23
10. TALL CANE-GRAMINOIDS	TMIN	0.14
11. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.32
12. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.31
13. DWARF-NEEDLE SMALL TREES	PMTMAX	0.38
14. BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.0
15. SHORT SWARD-GRASSES	TMAX	0.37
16. SUMMERGREEN GIANT-SCRUB	TMAX	0.43
17. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.40
18. SHORT BUNCH-GRASSES	TMAX	0.56
19. SUMMERGREEN FORBS	TMAX	0.40
20. SUMMERGREEN FERNS	MI	0.23
21. TEMPERATE EVERGREEN FORBS	TMAX	0.20
22. BUSH STEM-SUCCULENTS	MI	0.05
23. BROAD-EVERGREEN VINES	TMIN	0.04
24. BROAD-WINTERGREEN EPIPHYTES	TMIN	0.18
25. BROAD-SUMMERGREEN VINES	MI	0.30
26. MAT-FORMING THALLOPHYTES	TMAX	0.19
27. XERIC THALLOPHYTES	MI	0.41
664. DAR-ES-SALAAM TANZANIA	-6.80	39.28
28.0 24.0 1110. 300. 27. 77. 0.77		
* 1. TROPICAL XERIC NEEDLE-TREES	TMAX	0.13
+ 2. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.35
3. PALMIFORM TUFT-TREES	MI	0.09
4. TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.02
5. TALL CANE-GRAMINOIDS	MI	0.09
6. TALL GRASSES	MI	0.09
+ 7. BROAD-RAINGREEN SMALL TREES	TMAX	0.35
8. SHORT SWARD-GRASSES	TMAX	0.23
9. PALMIFORM TUFT-TREELETS	MI	0.09
10. TROPICAL BROAD-EVERGREEN SHRUBS	MI	0.09
11. XERIC EVERGREEN TUFT-TREELETS	MI	0.31
+12. SHORT BUNCH-GRASSES	TMAX	0.40
13. EVERGREEN GIANT-SCRUB	TMAX	0.33
14. BUSH STEM-SUCCULENTS	TMAX	0.40
15. RAINGREEN FORBS	TMAX	0.28
16. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
17. BROAD-RAINGREEN VINES	TMAX	0.35
18. XERIC THALLOPHYTES	TMAX	0.40

at which a closed forest would be expected. The tree component at Raleigh consists of five potential canopy forms plus three small-tree forms, all of which actually occur (examples in parentheses):

1. Summergreen Broad-Leaved Trees (*Quercus, Acer,* etc.)
2. Heliophilic Needle-Trees ('southern pines')
3. Temperate Broad-Rainforest Trees (e.g. *Magnolia*)
4. Hydrophilic Summergreen Needle-Trees (*Taxodium*)
5. Boreal Broad-Summergreen Trees (e.g. *Betula*)

plus understorey forms:

1. Temperate Broad-Evergreen Small Trees (e.g. *Ilex opaca*)
2. Broad-Summergreen Small Trees (*Cornus, Prunus,* etc.)
3. Dwarf-Needle Small Trees (*Juniperus virginiana*).

Of the five candidates for formation dominance, one can see immediately that the rainforest trees are occurring at their winter temperature limit of 5° (fitness value of zero) and that the boreal and hydrophilic trees are from lower levels in the dominance hierarchy (and are also constrained climatically or edaphically). Considering the two predicted dominants (asterisked in Table 10), one sees that the heliophilic needle-trees may be approaching a winter temperature limit and thus less robust. More importantly, however, they are evergreen sclerophylls and cannot be expected to grow as rapidly at maturity as the broad-malacophyllous summergreens. These considerations suggest that the vegetation can be characterized as a summergreen broad-leaved forest with evergreen needle-trees, with the other tree forms as scattered individuals, and with a well developed understorey composed of small broad-summergreen trees, more scattered broad-evergreen and dwarf-needle small trees, and a good variety of summergreen and some evergreen shrubs, forbs, grasses and vines. The predicted formation can be called a Summergreen Broad-Leaved Forest with evergreen needle-trees. The actual vegetation in and around Raleigh is a summergreen mixed oak forest with persistent successional pines in the canopy (up to 100 years), a wide variety of other canopy and understorey broad-summergreen trees, bald cypress (*Taxodium*) in wet depressions, well developed shrub strata where light permits (especially along edges), and a wide variety of forbs, grasses, etc. Magnolias occur only rarely as natural forest components and more often as planted ornamentals. All 27 of the forms predicted actually occur naturally, even the bush stem-succulents (*Opuntia compressa*). Not predicted but actually occurring on dry sites are also xeric tuft-treelets and rosette-shrubs (*Yucca* spp.).

The situation at Dar es-Salaam is more complicated (despite having fewer forms predicted), since it is a drier site (MI = 0.77) at which open vegetation and reduced dominance by any one form are to be expected. Of the 18 forms predicted, all can be identified (Knapp 1973; Lind and Morrison 1974) as actually occurring except the xeric needle-trees (primarily *Juniperus procera*), which are generally confined more to upland and highland areas.[1] Not yet knowing this, one must interpret the predicted vegetation as an open, rather grassy semi-deciduous woodland in which evergreen sclerophyll trees and smaller raingreen trees are the main components and xeric needle-trees are scattered, along with some palms and evergreen microphyll trees but more frequent scrub forms. The MI value, the mix of predicted forms, and the proximity of many (no fewer than six) to moisture limits strongly suggest a vegetation mosaic affected by topography and other spatial variations in water availability. Since the site is in Africa rather than Australia, one must also not picture the evergreen sclerophyll trees or arborescents as tall eucalypts but rather as forms more like the raingreen trees in size. The predicted vegetation, using the criteria in Table 9, can be called a Semi-Deciduous Mixed Short-Grass Savanna-Woodland or Savanna-Woodland Mosaic, since the MI value is clearly transitional between the two formation classes. The actual vegetation along the coastal strip including Dar es-Salaam has been described by various authors (e.g. Eyre 1968; Knapp 1973; Lind & Morrison 1974; Keay 1959; Shantz & Marbut 1923) as a dry, grassy open forest-woodland-scrub mosaic, with areas of species-rich dry forest near the coast. The trees are predominantly raingreen but xeric evergreens and facultatively deciduous trees are important. The degree of

[1] Problems with this form in other regions also suggest that its upper TMAX limit (30 °C) is probably set too high and should be lowered to around 27°–28 °C.

deciduousness of many of these trees is poorly known and even less frequently reported. Important taxa include *Cynometra, Manilkara, Diospyros, Combretum, Cussonia, Erythrina, Strychnos,* and many others, plus *Adansonia digitata, Olea africana,* and a great variety of shrubs, scrub taxa, grasses, etc. The relatively high PMIN value of 27 mm at Dar es-Salaam precludes prediction of larger raingreen trees (limit 25 mm) and raingreen thorn-scrub (limit 20 mm), but these forms do occur (e.g. *Adansonia*). Thorn-scrub is the dominant vegetation behind the wetter coastal strip.

The model is designed for application to euclimatopes and, strictly speaking, is applicable only there. It can be used to provide information at other sites, however, if appropriate modifications of microenvironmental conditions can be estimated. For sites with azonally coarser or finer soils, the precipitation requirements must be increased or decreased accordingly. (This effect is buffered in dry climates by the soil itself, however, since coarser soils may reduce actual evaporation from unvegetated areas by storing the precipitation at greater depths.) In windy climates precipitation requirements are greater, since PET may be greatly increased. Waterlogged soil may preclude trees in some environments (e.g. bogs), where the local species are not adapted to anaerobic conditions, but not in others (e.g. swamps). Dry environments with mosaic-like microrelief may produce vegetation mosaics. In such cases gentle slopes may most nearly represent the actual macroclimatic conditions, while conditions on hilltops or in depressions are shifted one way or the other.

The results predicted by the model and, more importantly, the degree to which climate determines or at least provides the initial constraints on vegetation patterns and types can best be evaluated by comparing climatically predicted and known actual vegetation at particular sites. For this reason, the vegetation predictions at 100 potentially better known sites from the world data-base (as they appear on the ECOSIEVE printout and in Table 10) are reproduced in Appendix B for readers in various regions to evaluate. Vegetation predictions for an additional 74 validation sites are shown in Appendix C.

B. Generating and mapping world results

As discussed earlier, generation of world or other large-area results requires a large climatic data-base for the area and a computer. The program ECOSIEVE was developed to apply environmental-limitation models to large, computerized data-bases (Box 1978a, 1979a, 1981b) and includes provisions for coupling with user-provided adjunct routines, such as the dominance hierarchy. ECOSIEVE was used to generate all world predictions and can provide results both for the respective sites and as potential distributions, as represented by lists of sites.

Once 'final' results have been obtained it is often desirable to map them for easier interpretation and evaluation. This can be done using the program SYMAP, developed by the Laboratory for Computer Graphics and Spatial Analysis at Harvard University. SYMAP produces raster-based maps on a normal line-printer using irregularly spaced site data as input. Contour (isoline), proximal (nearest-neighbor), and conformal (choropleth) maps can be produced by the various interpolation algorithms. The use of SYMAP has been documented by Dougenik and Sheehan (1975) and locally by Reader et al. (1972), Rase (1976, in German), and various other groups. SYMAP requires computerized base-map, a data-base with site coordinates, and various user-provided instructions for map design. The mapping process can be both facilitated and expanded (e.g. map quantification by computerized planimetry) by a variety of SYMAP simplifying and adjunct routines (Box 1979a, 1979b, 1979c).

In order to display the world ecoclimatic values and predicted plant-type distributions, the values at the 1225 test-sites were computer-mapped using SYMAP, a computerized world base-map (AOWDGL, see Reader et al. 1972), and a general coordinate-conversion routine for cylindrical and pseudo-cylindrical projections (FLEXPROJ, see Box 1979a). Since a high degree of cartographic detail is not required (and would be artificial considering the nature of the data), large computer-printed maps provide an adequate and convenient medium. The maps are based on a pseudo-cylindrical projection by Robinson (1974), which is designed to reduce polar shearing. This projection represents a compromise between areal equivalence and correct shapes, and is an excellent projection for visually oriented presentations. The computerized version (AOWDGL) was traced in 1971 from a large wall map (Rand-McNally and Co., without date) by several University of North Carolina students and has been used since for a wide variety of geoecologic maps (e.g. Lieth & Box 1972, 1977; Box 1976, 1977, 1978a, 1978b, 1979a, 1979c). The area deformation of the projection increases with latitude but is such that areas in the latitude of Iceland are enlarged by a factor of only about two. The use of a non-equal area projection does not mean that planimetry cannot be performed on the map. The area-representation of AOWDGL was investigated (Box 1975) using the planimetry program MAPCOUNT (Box 1975, 1978b, 1979a) which performs the mathematics necessary to process non-equivalent projections. It was found that AOWDGL under-represents the earth's true land area by about 7%, mostly in the polar regions.

The coordinate-conversion routine FLEXPROJ permits execution-time conversion of geographic site coordinates into the required SYMAP coordinates. It has been used for most of the above-cited maps involving the Robinson projection. The coordinate conversion is based on the mathematical definition of the Robinson projection and is added to SYMAP via its subroutine FLEXIN (FLEXible INput).[2]

The use of 1225 data-sites as the basis for world maps represents a minimum requirement. This density is not sufficient to permit accurate prediction of boundaries but does permit a reasonable representation of predicted general patterns. About 200 sites were added to the original data-base of 988 sites in order to improve the spatial representation in areas of high topographic complexity. Areas of high topographic complexity and/or low site density are misrepresented most. Poorly represented areas include the southwestern part of the Arabian Peninsula, the area just east on the Caspian Sea, the Himalayan highlands and their southern face, the deep river valley region of southern China, the mountain chains of Europe, and most of Antarctica.

[2]FLEXPROJ also enables various other modifications, including coding of data-site locations and corresponding values on the same input record, which is much more convenient that the standard SYMAP input structure.

The values of the eight ecoclimatic variables plus PET were mapped as world isoline maps. The interpolation on these maps is based on a distance-squared decay function (see Shepard 1968) using from 4 to 10 sites within a variable search radius. Isoline levels are represented by shading ranging from a single dot at each print-position to a completely blackened print-field. These maps are about 131 cm (52 inches, 515 columns) wide by 65 cm (25 inches, 204 rows) high.[3] When photo-reduced, the maps present a spectrum of shades from light to black. Photography was performed by the University of North Carolina Photographic Laboratory using high-resolution 35 mm film.

Mapping the vegetation predictions is somewhat more complex, since complete physiognomic spectra cannot be shown meaningfully on a single map. One is most interested in seeing the predicted dominant forms, plus certain other features which might give a general impression of the vegetation formations to be expected. In order to make the predicted results more comprehensible, the plant forms are grouped by growth-form, with various groups presented on separate maps, as follows:

Map	*Plant types*
10	Broad-leaved evergreen trees
11	Importance of broad-leaved evergreen trees
12	Broad-leaved deciduous trees
13	Importance of broad-leaved deciduous trees
14	Narrow-leaved trees
15	Shrubs and arborescents
16	Graminoids
17	Stem- and leaf-succulents
18	Forbs and semi-desert herbs
19	Warm-evergreen (eucalyptoid) sclerophyll trees
20	Tuft-tree forms
21	Vines and lianas
22	Epiphytes

Each map contains from two to nine forms and shows the areas in which these forms are predicted to occur as important or co-important forms, plus other occurrences on some maps. Where predicted co-important forms belong to the same map (same growth form), a special symbol for multiple predic-

[3]American computers unfortunately still think in inches: 8 rows per inch vertically and 10 columns per inch horizontally.

tions is employed. Where predicted co-dominant forms belong to different maps (different growth forms), each form is shown on its own map without any special notation. Separate maps showing the occurrence of co-dominant forms (Map 24) and the number of forms predicted at each site (Map 25) are also included. Ecological sub-types which do not greatly differ in physiognomy are grouped before dominance considerations.

Graphic limitations presented by the computerized mapping procedure represent a major consideration in the production and interpretation of the maps. Multi-colored computer printouts are not yet available at most universities. Since SYMAP permits overprinting of up to four characters at each print-position, however, there is ample opportunity for the construction of graphic symbols so that the raw predicted results can be shown without any retouching. The vegetation maps employ distinctive, hopefully intuitive symbols for the various plant forms. Symbols for forests are based on tall symbols, especially capital T (broad-leaved) and a tall vertical line (narrow-leaved), with rainforests and other evergreen forests shown by darker overprint combinations. Open woodlands are represented by more open combinations, with height of vegetation suggested by the height of the symbols. Grasses, shrubs, scrub, etc. are shown by shorter and generally simpler symbols. Some symbols are necessarily used on more than one map for different vegetation types.

The maps of plant-form distributions (and the map of co-dominants) are proximal maps produced by the SYMAP nearest-neighbor algorithm. Each vegetation zone is centered on one or more data-sites, but its shape depends on distance to sites with other predicted forms. Transitions are not shown except when they result in intermediate dominant-form mixes at intermediate sites. Because of insufficient site density, the occurrence of such transitional sites often makes the mapped patterns harder to discern. This is especially true in areas where transitional zones are long and narrow, as south of the Sahara desert. Since the vegetation maps depend on recognition of individual computer-printed symbols, which would be obscured by photoreduction, the vegetation maps are presented in their computer-printed form. This also seems most appropriate, since it best represents the predictive accuracy of the results.

C. Overview of world ecoclimates

In defining climatic envelopes for different plant types one is essentially defining a set of plant ecoclimates. More general aspects of world ecoclimates, as they affect animals, human activity or other aspects of plants, can be seen by examining the ecoclimatic variables individually. This is done by means of world maps (Maps 1–9) and distributional statistics (Table 11) for the eight ecoclimatic variables plus annual PET, based on data at the 1225 test-sites.

The map of highest mean monthly temperature, TMAX (Map 1), identifies primarily the treeless polar and subpolar regions, including the plantless ice deserts of Greenland and Antarctica (TMAX $<$ 0 °C), the polar cold deserts with few plants (0° $<$ TMAX $<$ 5 °C), and the tundra areas with more complete plant covers (5° $<$ TMAX $<$ 10 °C). Because of lower site density in polar areas, these regions represent larger fractions of world land area than suggested in Table 11. Other areas can be considered to be potential tree climates, at least thermally. Higher summer temperatures indicate more energy available for plant growth, but the potential increase in plant size in warmer areas is strongly limited by water availability. Note that the world frequency distribution of maximum mean temperature is bimodal, with 43% of the stations having tropical summer temperatures ($>$25°), only 16% having subtropical, and 25% having typical temperate summer temperatures.

The map of lowest mean monthly temperature, TMIN (Map 2), separates those areas which can support year-round plant activity, provided that water is not limiting, from those areas with winter dormancy. The division outside the tropics generally falls near the 10 °C isotherm for TMIN, though extreme absolute temperatures and overall temperature regimes may cause significant differences between maritime and continental climates. The −20 °C isotherm for TMIN delimits the coldest areas of northern North America and Eurasia, within which summergreen larches become very significant vegetation components. The world frequency distribution for TMIN is also generally bimodal, reflecting distinctly different tropical and temperate core areas.

The continental climates of northern Eurasia and North America, with extremely cold winters, are suggested by those regions on Map 3 in which the annual range of mean monthly temperature, DTY, is greater than 40 °C. Otherwise the world frequency distribution is remarkably even. This map also best identifies the tropical regions (DTY < 15 °C), in which plant activity is less seasonal than diurnal and in which evergreen plants are dominant except in areas with long dry periods. The division ot the land areas into seasonal north and largely stenothermal south is most evident on this map.

The map of annual precipitation, PRCP (Map 4), best identifies the desert climates (PRCP < 10 cm) and indicates the total amount of water available. Within broad latitudinal belts it also separates wetter and drier ecoclimates. Except in the polar and boreal/austral areas, PRCP serves as a crude index of leaf size and of the general size of the largest plants. The world distribution (Table 11) may be slightly bimodal, with moderately low-precipitation areas most common (grasslands, woodlands, boreal forest), but note that the value ranges are not uniformly wide.

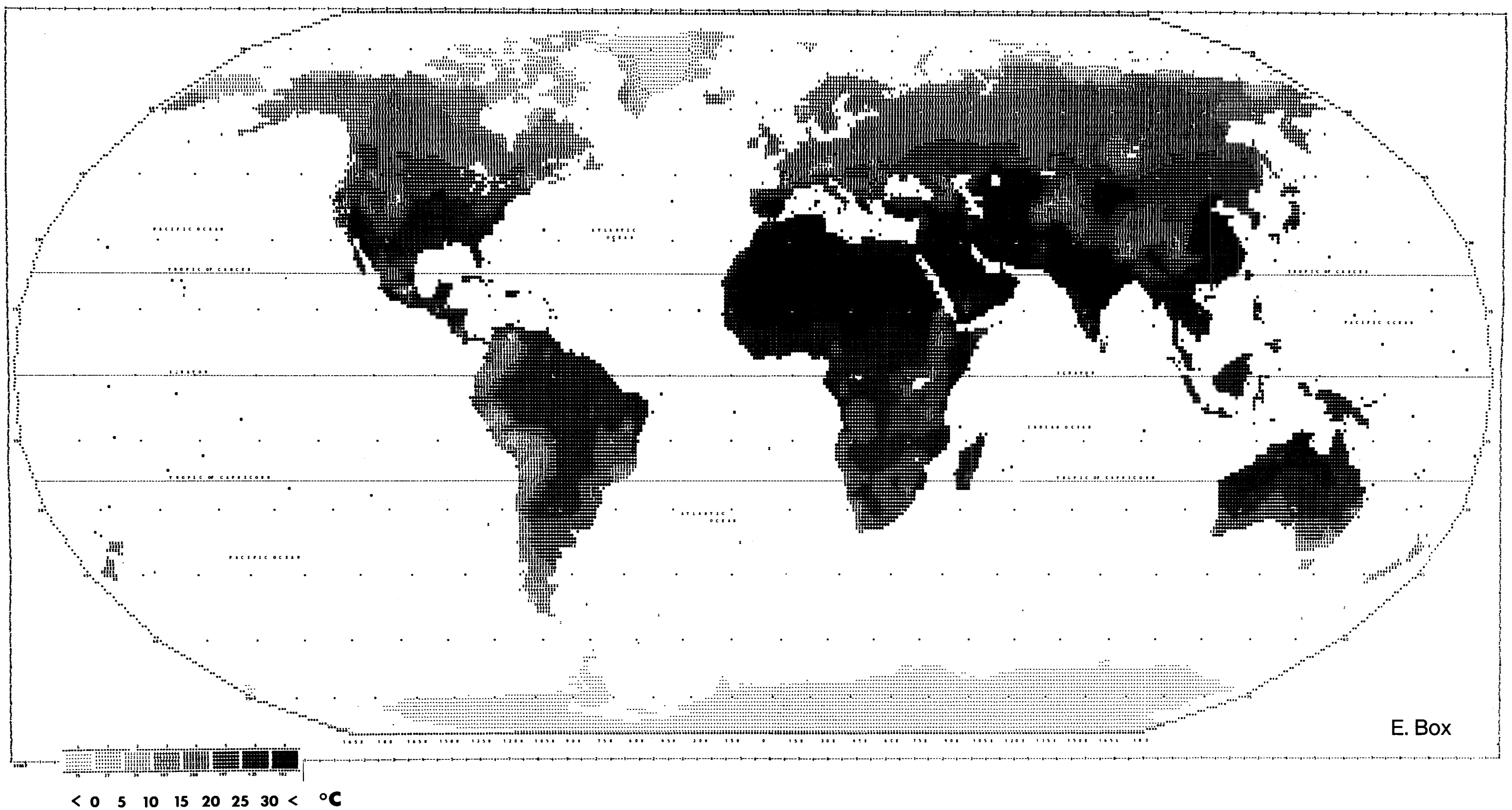
The world pattern of the Thornthwaite estimate of potential evapotranspiration (Map 5) indicates the potential rate of water loss by plants and, thus, the extent to which xeromorphic features may be prominent, even under high-rainfall regimes. The daily water stress and xeromorphic structure of canopy leaves even in tropical rainforests, for example, have been pointed out by many authors (e.g. Richards 1952, Walter 1973).

The map of the annual moisture index MI (Map 6) suggests the life-form possibilities, the leaf structure, and the general structure of vegetation formations. More mesic environments generally have larger life forms, softer leaves, and often greater dominance by particular forms. Grasses are an important exception to the first generalization, however, since they can form dense covers and dominate without greater size. In general, forests do not dominate where MI < 1.0 (52.6% of the sites), but this leaves nearly half the world as potential forest climates. Trees generally disappear completely, except where additional water is available, when MI falls below about 0.5 (22.7% of all sites). Except for the slight increase below MI = 0.1, the world frequency distribution appears to be unimodal and centered on about MI = 1.0 as the most common value. The map of MI is the most useful single map for estimating plant physiognomy and vegetation structure. Most of the above generalizations do not hold, however, in the treeless polar and subpolar climates.

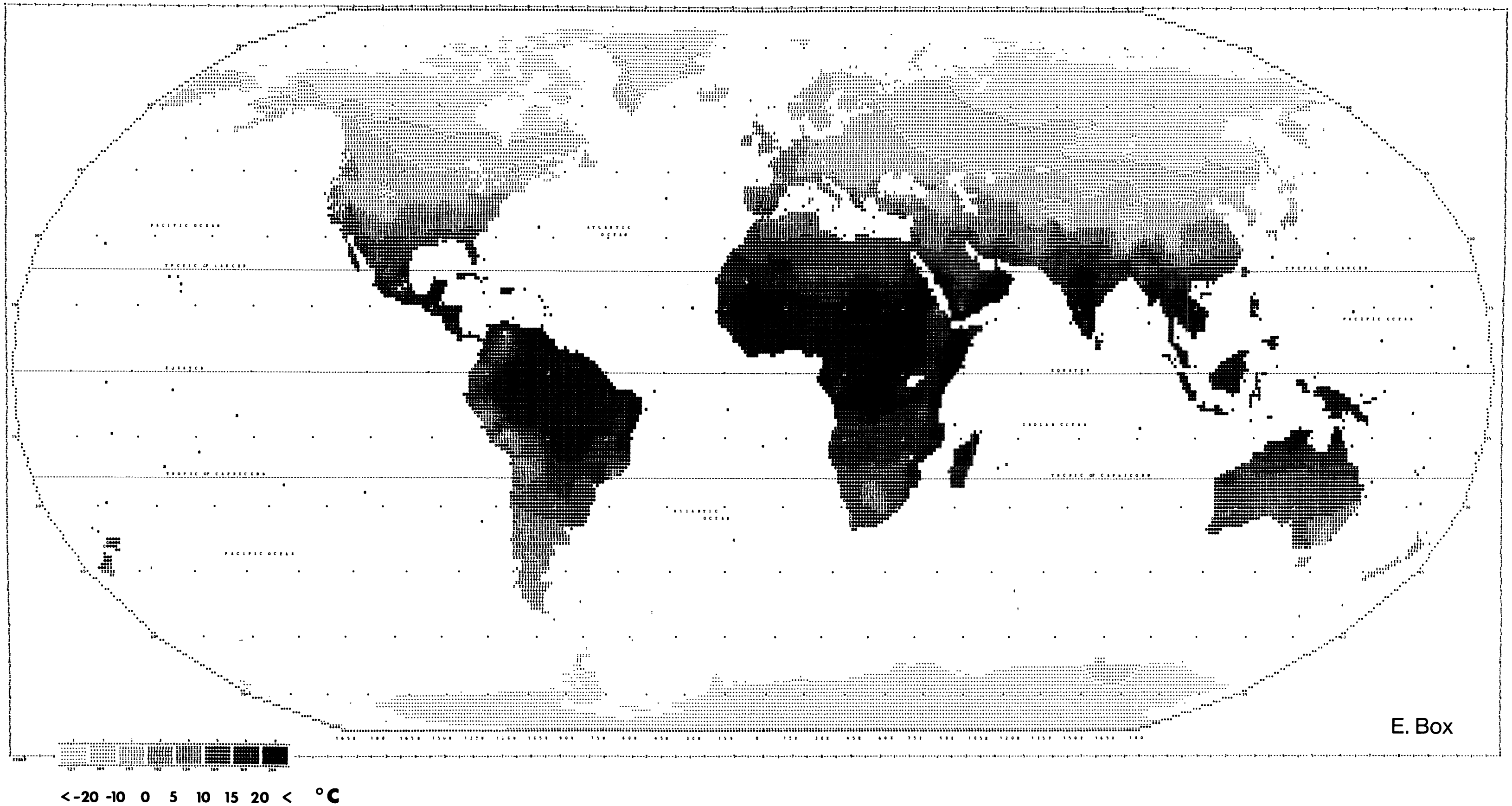
The map of highest average monthly precipitation, PMAX (Map 7), is the most important map for locating the extreme deserts and semi-deserts. Because of the reduced water content of colder air, this generalization also holds somewhat for the polar and subpolar regions. In climates with dry seasons and deciduous or ephemeral vegetation, PMAX may also be a useful indicator of leaf size and structure. On a linear scale, the world frequency distribution (Table 11) appears to be unimodal with mode around 75 mm but with many sites receiving larger amounts.

The map of lowest average monthly precipitation, PMIN (Map 8), very effectively identifies the world's evergreen rainforest regions (PMIN > 75 mm) as well as other regions with significant year-round rainfall (PMIN > 50 mm), such as the typical four-season (nemoral) temperate climates of Western Europe and eastern North America. The most important ecoclimatic difference between these climates and the winter-dry temperate climates of East Asia is evident on this map. Most plants in areas with PMIN < 10 mm are distinctly deciduous or ephemeral (48.6% of all sites, see Table 11). PMIN may also be a good index of leaf size and structure. Note, despite the appearance given by the logarithmic value ranges, that the frequency of PMIN amounts decreases steadily from driest to more favorable amounts.

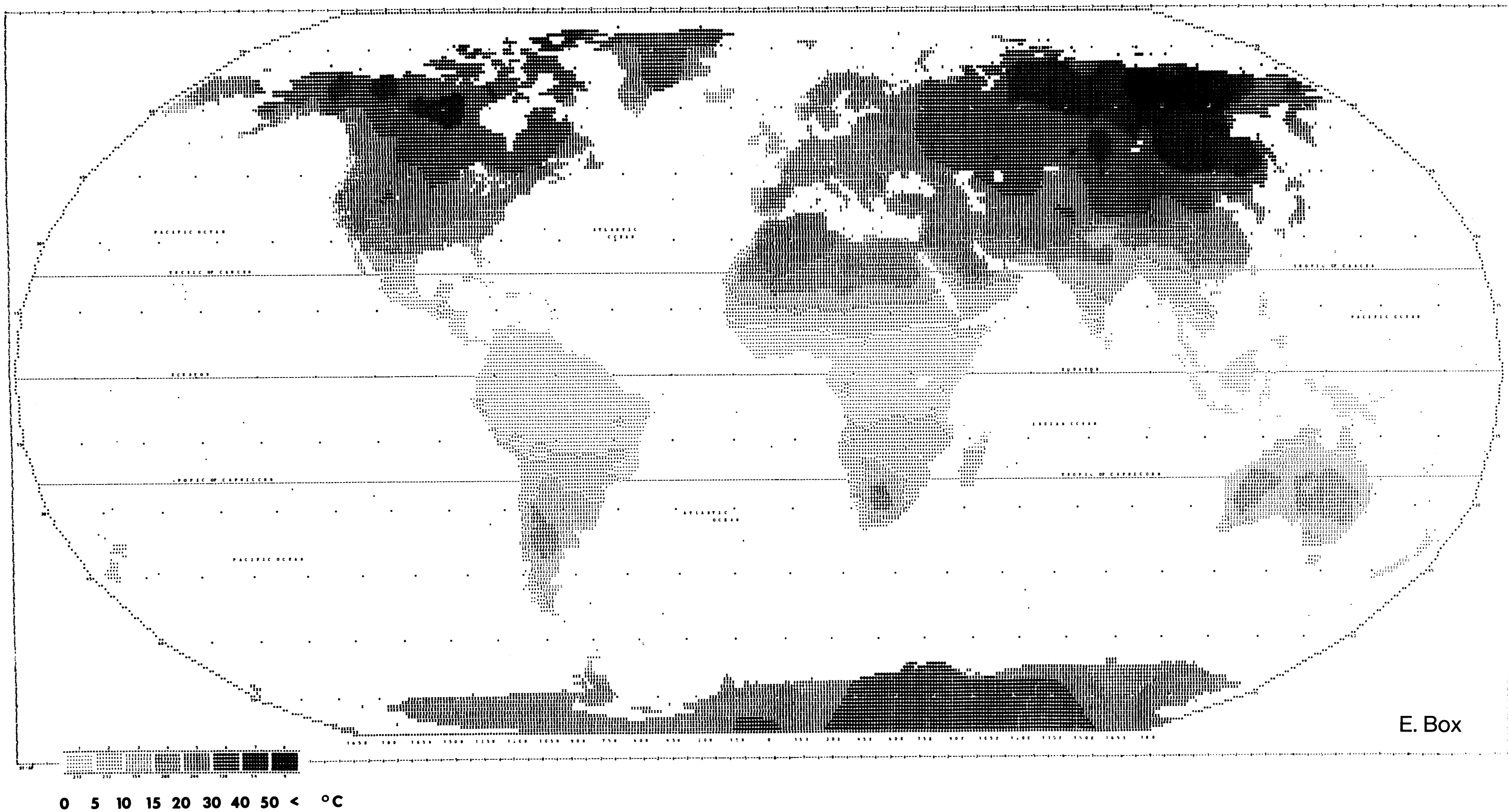
The map of average precipitation of the warmest month, PMTMAX (Map 9), is very useful for separating generally mesic and generally dry climates, since the warmest months represents critical periods. The zonal differences between PMTMAX on corresponding east and west sides of land masses are very evident. Plants in low-PMTMAX areas are usually small forms or stunted larger forms, except where summer fog moderates the effect of low rainfall (e.g. northern California to British Columbia and in southwestern Australia) and produces the world's tallest plants. The areas where PMTMAX > 75 mm (less in boreal regions) are generally dominated by forests, (38% of all sites). Note what appears, to be a bimodal distribution in Table 11.



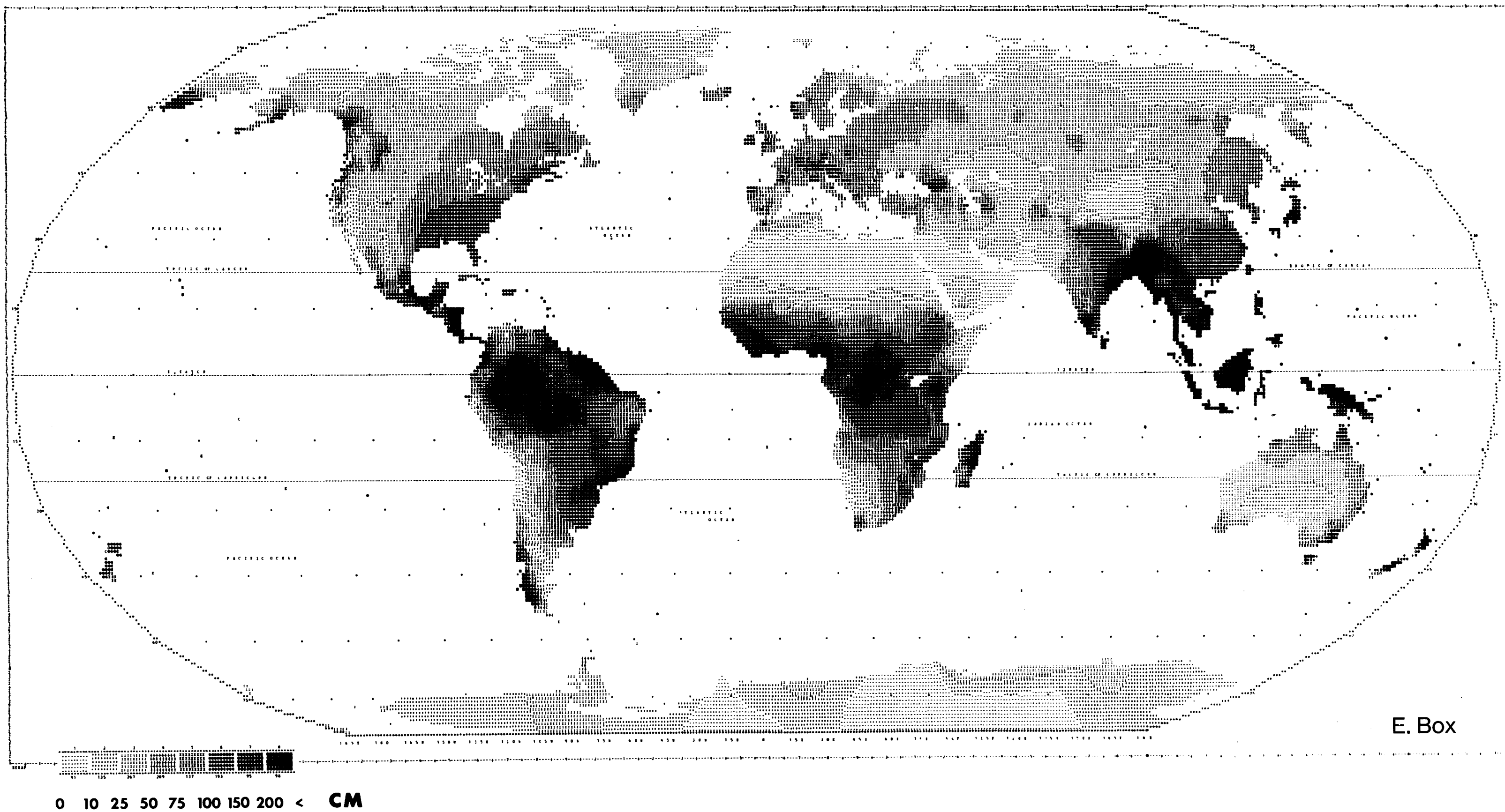
Map 1. World terrestrial pattern of highest mean monthly temperature, TMAX.
The highest mean monthly temperature serves as a measure of energy input during the year and/or growing season. Plant production, the size of the dominant plants, and the complexity of the vegetation structure generally increase with increased energy input and ambient temperatures, provided that water or other factors are not limiting.



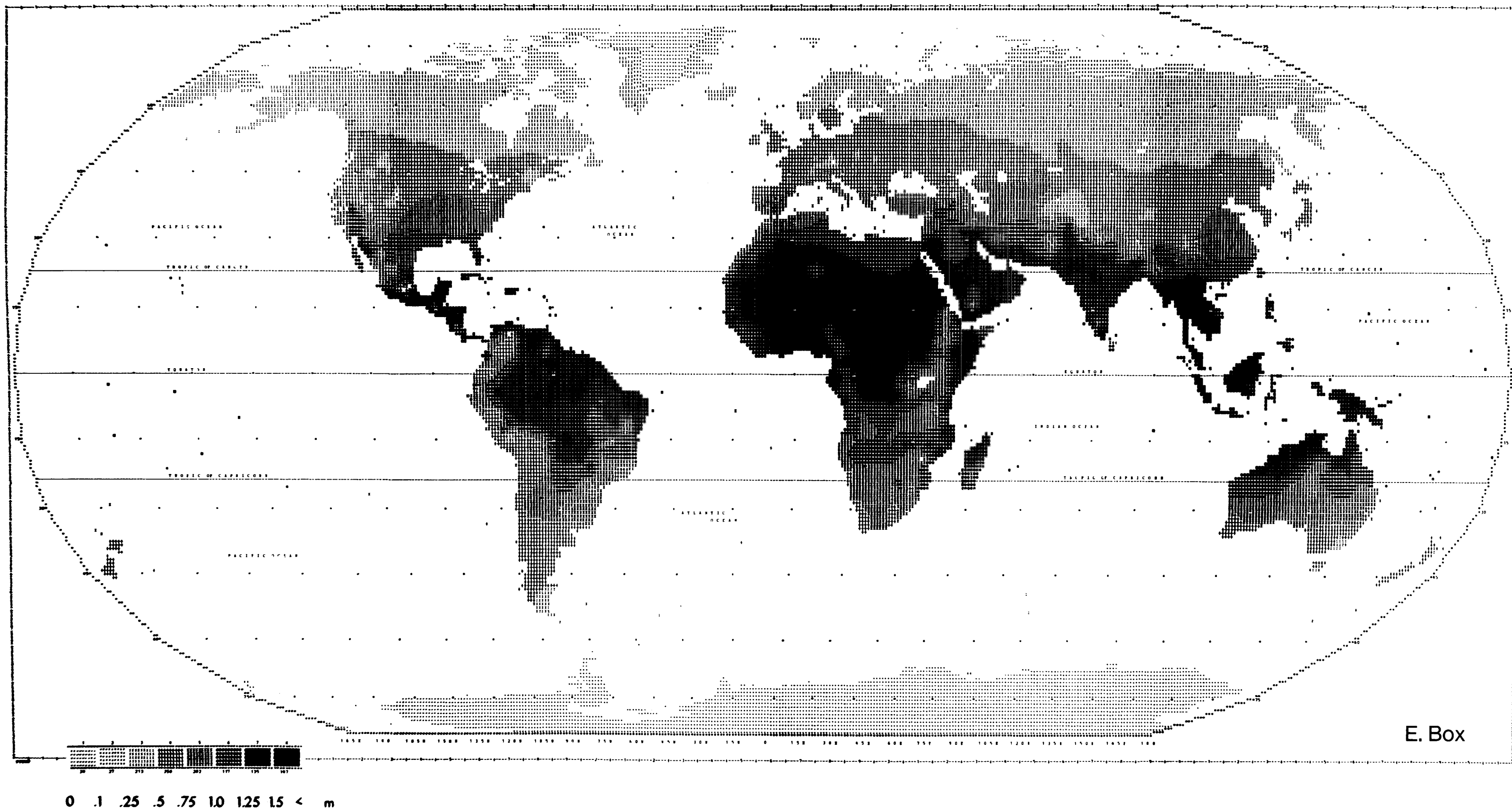
Map 2. World terrestrial pattern of lowest mean monthly temperature, TMIN.
The lowest mean monthly temperature provides an estimate of both the degree of winter cold in general and absolute minimum temperatures which must be endured. These factors represent limits to the distributions of many evergreen forms and may constitute vernalization requirements for summergreen forms.



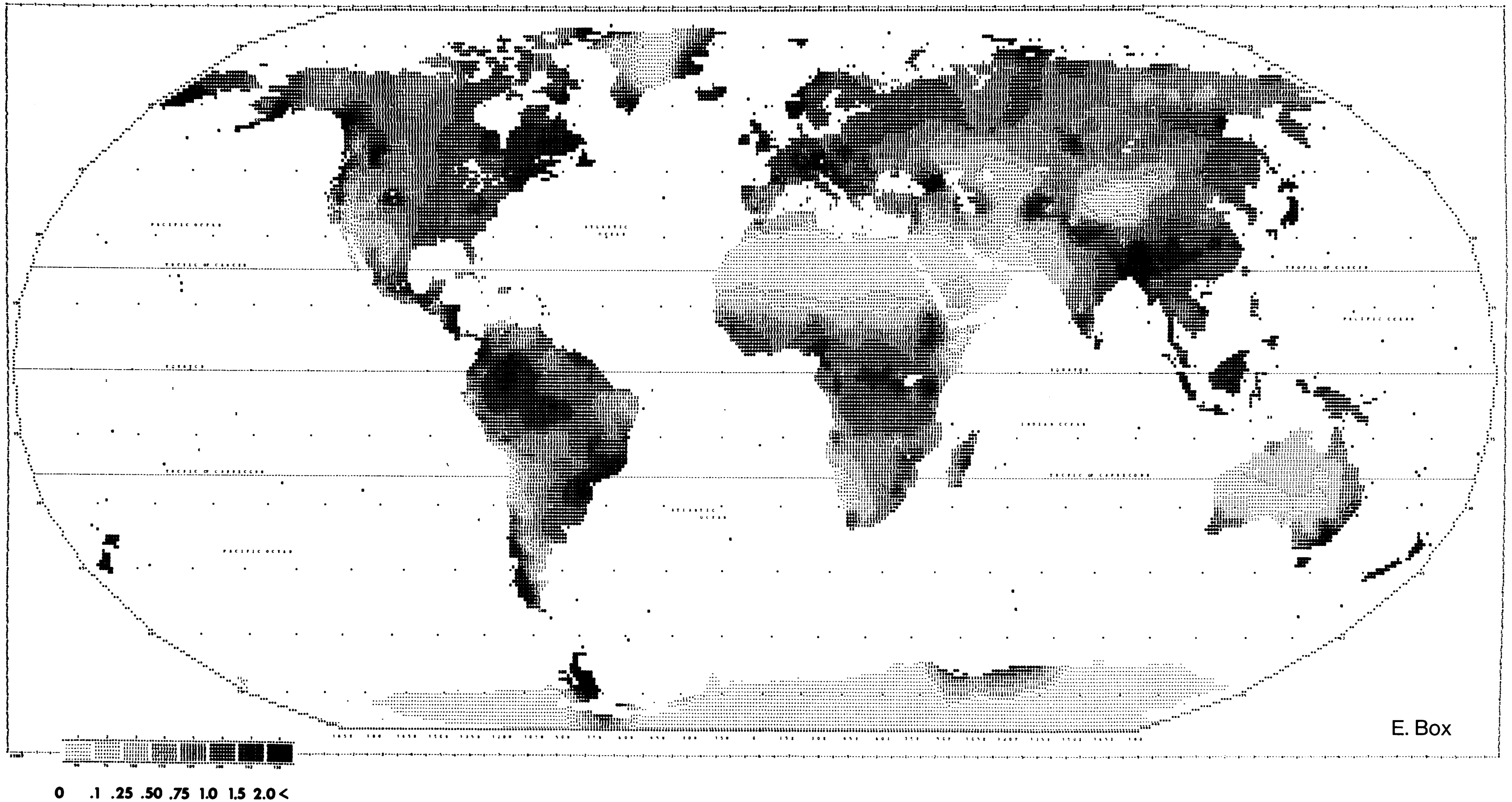
Map 3. World terrestrial pattern of annual range of mean temperature, DTY.
Annual temperature range, represented here by the range of mean temperatures, provides the main mechanism for separating tropical forms with little temperature seasonality from forms adapted to seasonal cycles. It is probably less important in the current model than in the first version.



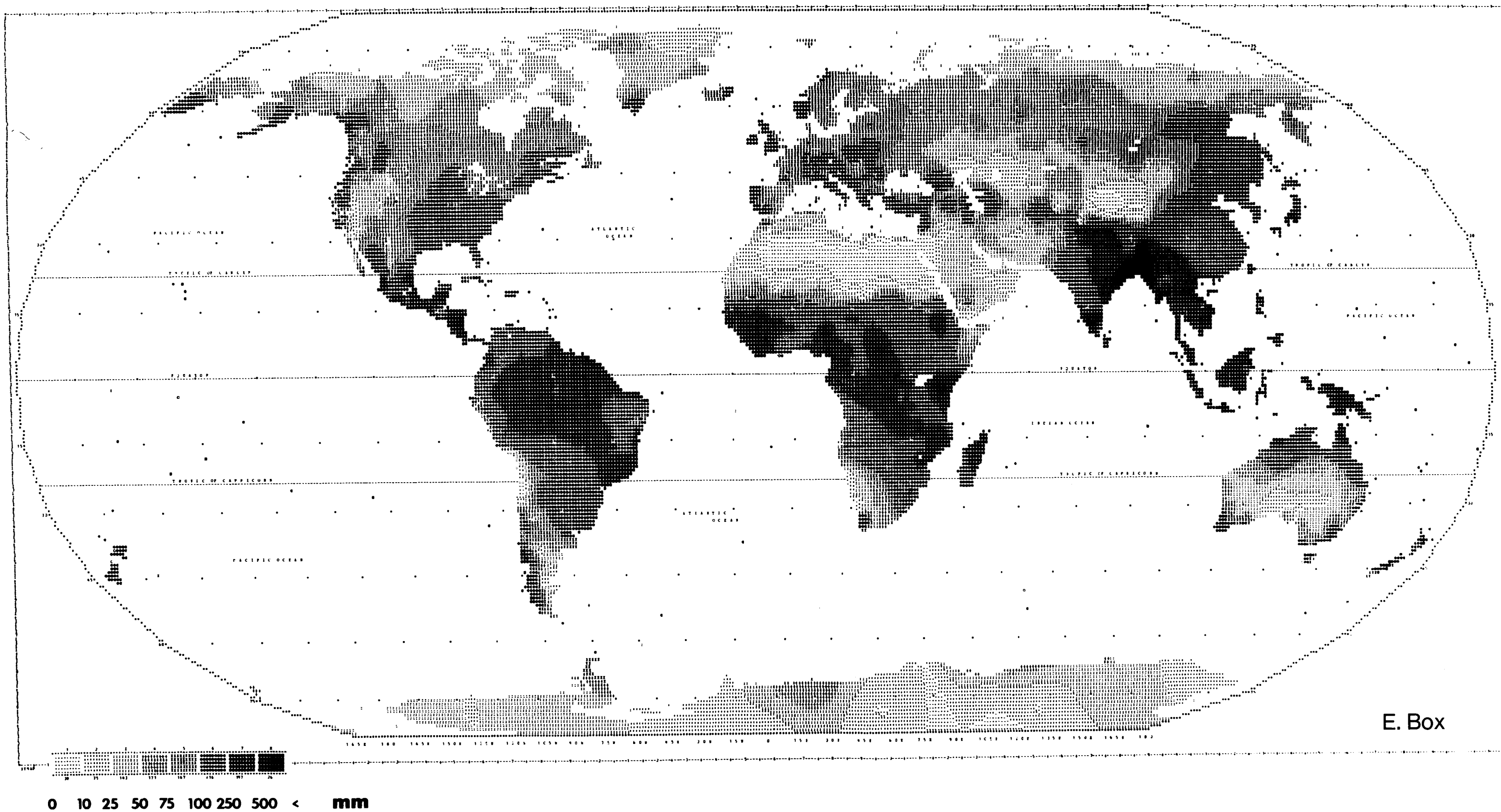
Map 4. World terrestrial pattern of average annual precipitation, PRCP.
Average annual precipitation represents the total amount of water which is (climatically) available for storage in the soil and use by plants. For a given temperature regime, plant production and vegetation structure generally increase with increased water availability. This generalization can be modified considerably by precipitation seasonality.



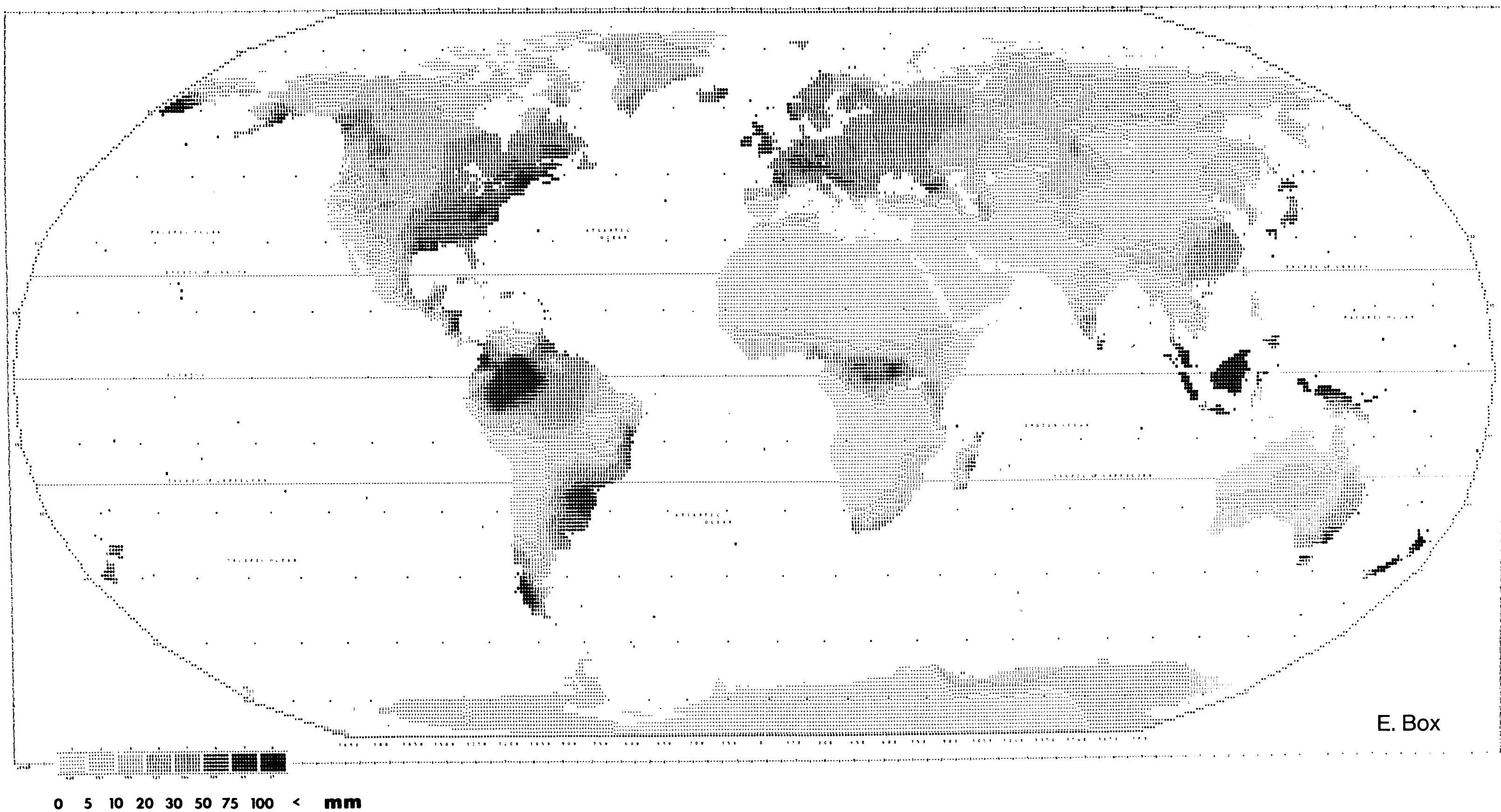
Map 5. World terrestrial pattern of average annual potential evapotranspiration (Thornthwaite estimate).
Average annual PET represents the total potential water loss by plants during a year and provides the basis for estimating annual patterns of water demand. PET over periods of at least a few weeks is generally estimated by air-temperature methods, of which perhaps the most widely used is that of Thornthwaite. The Thornthwaite estimate mapped here is based on measured monthly mean temperature values for the seasonal extrema and values interpolated for the intervening months.



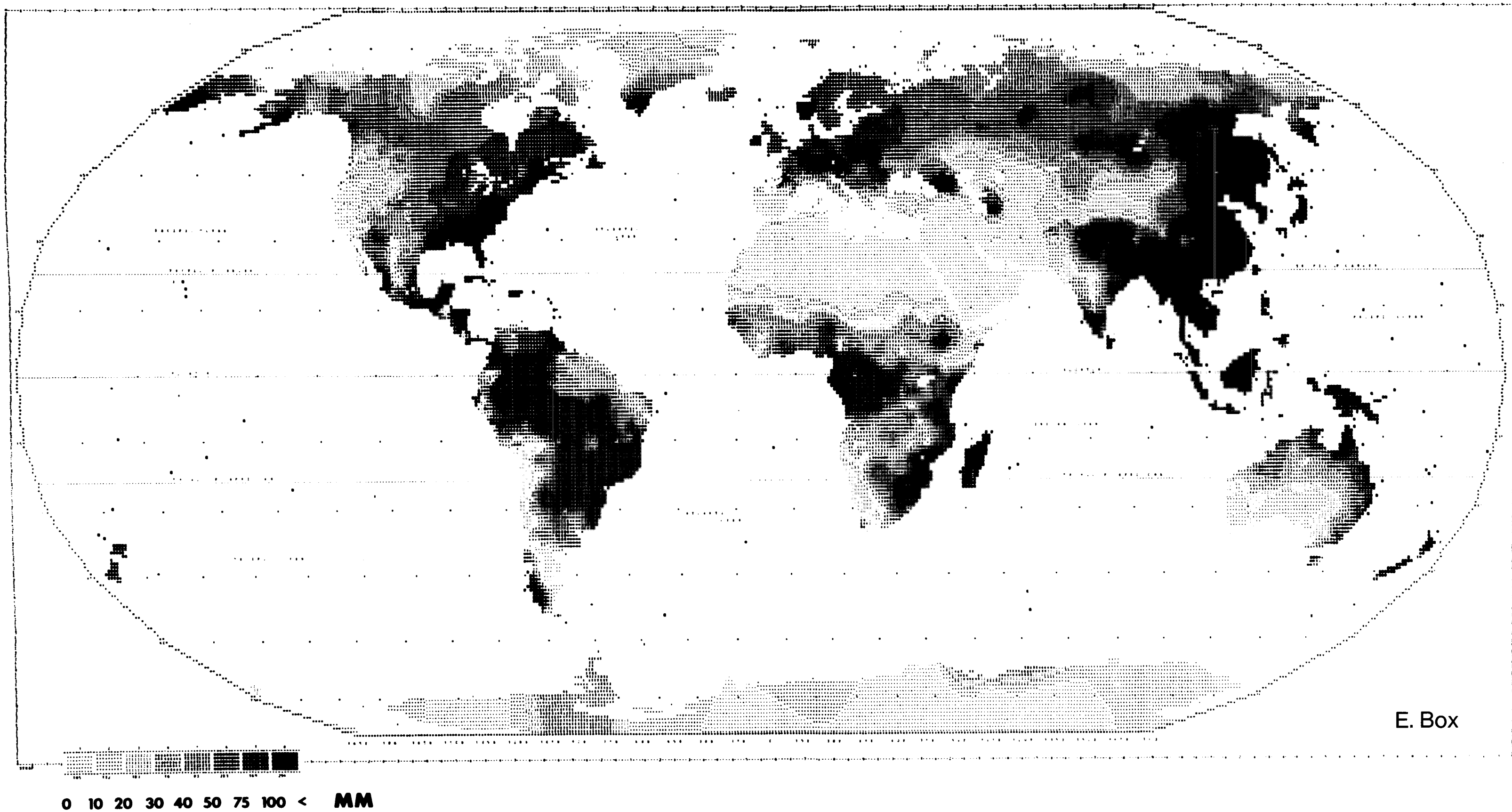
Map 6. World terrestrial pattern of the annual moisture index, MI (based on Thornthwaite's estimate of PET).
The annual moisture index MI, obtained by dividing average annual precipitation by average annual PET, serves as an index of general moisture conditions. Since it involves both energy input and available moisture, the moisture index serves as the best single indicator of the dominant growth forms, general vegetation structure, and the degree of leaf xeromorphy.



Map 7. World terrestrial pattern of highest average monthly precipitation, PMAX.
The highest average monthly precipitation provides an estimate of the amount of water which may be required, especially in drier climates, to constitute adequate growing seasons. It also indicates areas with high seasonal rainfall (seasonal rainforests).



Map 8. World terrestrial pattern of lowest average monthly precipitation, PMIN.
The lowest average monthly precipitation identifies immediately the rainforest areas, which have no significant dry season. It also constitutes the mechanism for identifying areas with raingreen forms.



Map 9. World terrestrial pattern of average precipitation of the warmest month, PMTMAX.
The average precipitation of the warmest month serves as a useful index of precipitation seasonality in relation to growing season requirements. The map clearly identifies summer-rain areas and summerdry areas with often extreme water stress. This variable is used in particular to predict mediterranean plant forms.

Table 11. World frequency distributions of important ecoclimatic variable values.

World (terrestrial) frequency distributions, based on the values of the 1225 sites in CLIMDAT1 (the computerized world climatic data-base), are shown in separate tables for each of the eight ecoclimatic variables plus the Thornthwaite estimate of annual potential evapotranspiration. The 1225 sites are not distributed perfectly evenly throughout the world's land areas but do provide a good representation of world ecoclimatic patterns since site density is lowest in Antarctica and other extreme climates with little or no vegetation. World temperatures show a bimodal pattern with frequency peaks for all three variables in the tropical and temperate ranges and lower frequencies in the subtropical and polar ranges. Annual precipitation appears to be unimodal, with a peak in the 250–500 mm range (which is typical, however, of widely differing regions and evaporation levels). The annual balance between precipitation and potential evaporation (moisture index MI) shows a peak around the value 1.0, falling off a bit more rapidly on the wet side of this value. Seasonal precipitation values suggest a mode of about 75 mm for PMAX (highest average monthly precipitation) and suggest at least one essentially precipitation-free month per year for 34% of the world. Values for precipitation of the warmest month show a peak at 0–10 mm (mediterranean plus subtropical dry areas) and suggest a slight and much lower secondary peak around 60–70 mm. The values were obtained from the mapping program SYMAP and correspond to the isoline intervals on Maps 1–9.

TMAX

Range (°C)	No. of sites	% of total
0 °C or below	15	1.2
0°–5°	37	3.0
5°–10°	34	2.8
10°–15°	107	8.7
15°–20°	308	25.1
20°–25°	197	16.1
25°–30°	425	34.7
above 30°	102	8.3
Total	1225	100.0

TMIN

Range (°C)	No. of Sites	% of total
-20° or below	121	9.9
-20° to -10°	109	8.9
-10° to 0°	197	16.1
0–5°	102	8.3
5–10°	134	10.9
10–15°	169	13.8
15–20°	149	12.2
above 20°	244	19.9
Total	1225	100.0

DTY

Range (°C)	No. of sites	% of total
0–5°	213	17.4
5–10°	213	17.4
10–15°	154	12.6
15–20°	200	16.3
20–30°	244	19.9
30–40°	138	11.3
40–50°	54	4.4
above 50°	9	0.7
Total	1225	100.0

PRCP

Range (mm)	No. of sites	% ot total
0–100	91	7.4
100–250	135	11.0
250–500	267	21.8
500–750	209	17.1
750–1000	137	11.2
1000–1500	193	15.8
1500–2000	95	7.8
above 2000	98	8.0
Total	1225	100.0

PET

Range (mm)	No. of sites	% of total
0–100	15	1.2
100–250	23	1.9
250–500	236	19.8
500–750	350	28.6
750–1000	202	16.5
1000–1250	117	9.7
1250–1500	135	11.0
above 1500	147	12.0
Total	1225	100.0

MI

Range	No. of sites	% of total
0.0 –0.10	94	7.7
0.10–0.25	76	6.2
0.25–0.50	108	8.8
0.50–0.75	178	14.5
0.75–1.00	189	15.4
1.00–1.50	300	24.5
1.50–2.00	142	11.6
above 2.00	138	11.3
Total	1225	100.0

PMAX

Range (mm)	No. of sites	% of total
0–10	30	2.5
10–25	75	6.1
25–50	143	11.7
50–75	171	14.0
75–100	167	13.6
100–250	416	34.0
250–500	197	16.1
above 500	26	2.1
Total	1223	100.0

PMIN

Range (mm)	No. of sites	% of total
0–5	420	34.3
5–10	151	12.3
10–20	199	16.2
20–30	121	9.9
30–50	144	11.8
50–75	109	8.9
75–100	44	3.6
above 100	37	3.0
Total	1225	100.0

PMTMAX

Range (mm)	No. of sites	% of total
0–10	185	15.1
10–20	112	9.1
20–30	103	8.4
30–40	74	6.0
40–50	83	6.8
50–75	203	16.6
75–100	169	13.8
above 100	296	24.2
Total	1225	100.0

D. Life-form prediction frequency

Application of the model to the world climatic data-base provides, among other things, predictions of life-form frequency throughout the world. These frequencies were tabulated by ECOSIEVE and are listed as raw occurrences and as percentages (based on 1225 sites) in Table 12. The numbers do not represent accurate estimates of area because site density varies in different parts of the world. General estimates of area can be obtained, however, by multiplying the percentage value (last column of Table 12) by the earth's land area, about 149×10^6 km^2. Such estimates of area covered, where these can be interpreted as dominant forms and thus formation types (e.g. 16.4×10^6 km^2 for tropical rainforest trees, excluding montane), generally are close to the area estimates by Golley (1972), Lieth (1975) and Whittaker (1975) for biome-level vegetation units (e.g. 17.0×10^6 km^2 for tropical rainforest).

The highest prediction frequencies belong to the thallophytes, which can occur in most environments. The highest frequencies among the higher plant types belong to short bunch (82%) and sward (55%) grasses, summergreen forbs (52.5%), needle-leaved shrubs (43%, e.g. *Juniperus*), tall grasses (41%), and bush stem-succulents (41%, e.g. *Opuntia*). These plant types do not dominate large areas (except the grasses) but are well adapted to a wide range of largely temperate to subtropical environments, including drier situations. Next in prediction frequency is a group of forms some of which have special edaphic or other non-climatic relationships and must be interpreted differently: wintergreen epiphytes (37%), xeric cushion-herbs (34%), phreatophytic summergreen (36%) and evergreen (30%, e.g. mallee) arborescents, plus tall cane-grasses (32%) and raingreen forbs (30%). As with the first group, these forms are tolerant of various drier situations.

The most frequently predicted tree forms are the tropical sclerophyll (27%, e.g. eucalyptoid), microphyll (27%), and palmiform (24%) types, plus summergreen (30%), palmiform (26%) and raingreen (23%) small trees. Again, these forms usually are not dominants but tolerate wide ranges of conditions. Typically dominant forms which were predicted most frequently include boreal/montane evergreen needle-trees (20%), boreal summergreen needle-trees (19%), and summergreen broad-leaved trees (18%).

The least frequently predicted forms, apart from the physiographically limited tropical montane-alpine forms, include the subantarctic broad-evergreen trees (0.6%) and tree ferns (1.6%) of extremely perhumid, stenothermal climates (also physiographically limited) plus a variety of other forms: short tussock-grasses (2.6%), mediterranean broad-evergreen trees (2.9%), hydrophilic summergreen needle-trees (*Taxodium*, 3.1%), needle-leaved treeline krummholz (3.7%), evergreen cushion-shrubs (3.8%), and broad (3.9%) and narrow-leaved (3.7%) temperate rainforest trees. All of these latter forms, except krummholz, represent climates which are distinctly maritime if not perhumid.

E. Predicted plant-form distributions

Distributions of selected plant life forms and growth forms are shown on the following Maps 10–22*. Production of these maps is discussed in section 6.B. The predicted patterns shown on these maps are summarized below.

More detailed interpretations of particular patterns, including situations of co-importance and apparent discrepancy, are included in the legends for the individual maps.

Broad-leaved evergreen trees of all types (Maps 10 and 11) are especially well predicted. This is expected since these trees generally require humid, often somewhat maritime subtropical and tropical climates without extreme conditions. These situations are generally well described by the ecoclimatic variables employed.

The occurrence of broad-leaved deciduous tree types (Map 13) is generally well predicted, but the importance (Map 12) of deciduous broad-leaved trees is not always well determined in some tropical and Southern Hemisphere subtropical areas, especially relative to broad-leaved evergreen trees. Summergreen broad-leaved trees (mesophyllous variety) are predicted too far north in eastern Canada. Broad-microphyllous summergreen trees are accurately predicted in maritime subpolar areas of both hemispheres (*Betula* in northern Fenno-

*For general note on the vegetation maps, see p. 102.

scandia, Iceland, and coastal Alaska; *Nothofagus* spp. in southern Chile and New Zealand).

Narrow-leaved trees (Map 14) are less well predicted, though problems are mostly confined to particular situations. Boreal conifers appear too far north in both North America and Eurasia, though this is due to some extent to special cases and low site density. Major occurrences of the various temperate needle-leaved trees are correctly predicted on all continents (e.g. southeastern USA and adjacent Caribbean areas, southern Brazil, East Asia, sub-mediterranean Europe, the Rocky Mountains, the western Himalaya). Since envelopes for these forms were based mainly on single prototypic taxa, the results suggest, despite successional and evolutionary relationships, that these forms also possess ecophysiognomic status.

Shrubs and selected arborescents (Map 15) are well predicted in most cases. The accuracy is surprising when one considers that shrubs usually dominate in rather open stands which permit a greater variety of life forms. Shrub-dominated tundra areas are probably least well predicted and often depend as much on topography as on macroclimate.

Dominant graminoids and some other herbs (Map 16) are generally correctly located, but their areas are seldom shown to be as large as these areas are in reality. This must be due to the omission of fire, grazing, and anthropogenic influences from the model. Some problems occur in predicting dominance by sward, bunch and tussock forms. In reality, most grasslands are mixtures of these forms.

Stem and leaf-succulents (Map 17) are correctly confined to drier climates but are not well predicted, since their distributions are often determined also by topographic and historical factors. Only one stem-succulent (*Sarcostemma australis*) is reported to be native to Australia and is not important, but *Opuntia* species flourished when introduced there (e.g. Dodd 1959). Better estimation of length and extent of average and extreme dry periods might improve prediction of both these types.

Most forbs and semi-desert herbs (Map 18) are generally well predicted, though distinction between cold deserts with some scant vegetation and extreme ice or cold deserts with no vegetation is not very successful because of lack of any estimate of warm-season length or of ice and snow accumulation.

The prediction of some forms must be approached somewhat differently because of historical considerations. The most important such case is that of the warm-evergreen (eucalyptoid) sclerophyll trees. The prototypic genus was confined to Australia until transported elsewhere by man. So many eucalypts have been planted in such places as California, the Mediterranean region, and East Africa that, if introduced species can legitimately be considered in the present context, Map 19 gives a quite reasonable indication of the present worldwide distribution of eucalypts and eucalyptoids.

Palmiform and other tuft-trees (Map 20) also represent a special case because of edaphic and topographic relationships, the slow growth of the xeric forms, and other factors. Their distributions are not badly predicted by macroclimate, but dominance in seasonally flooded areas and occurrence at oases involve factors other than climate. Tropical alpine tuft-treelets are not well mapped because of the small areas and paucity of climatic data involved.

The predicted distributions of vine (Map 21) and epiphyte (Map 22) forms are special cases since these forms generally require other, usually woody and fairly large forms for support. The predicted distributions are relatively accurate and are especially interesting since one rarely sees maps for distributions of the smaller synusiae.

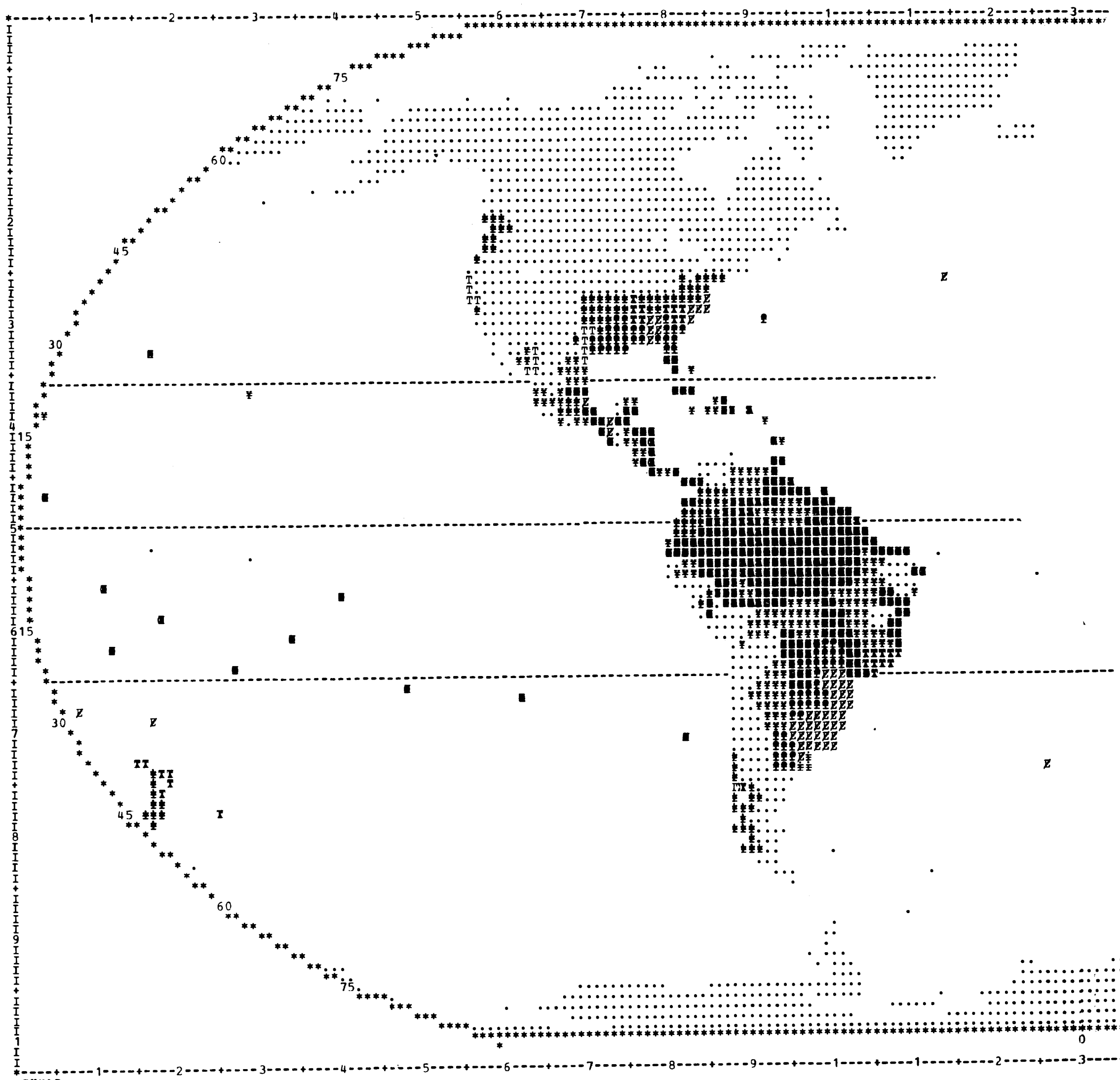
Table 12. World prediction frequencies of the terrestrial plant life forms.

The number of predicted occurrences worldwide (based on the world database CLIMDATl) and the corresponding percentage of the 1225 total sites are shown for each of the 90 terrestrial life forms of Table 2. The values were obtained by using ECOSIEVE to generate and tabulate the predicted forms at each site. The highest prediction frequencies are shown by thallophytes, short and tall grasses, seasonal forbs, bush stem-succulents, and several shrub and bush forms. The most frequently predicted tree forms are tropical sclerophyll, microphyll, and palmiform evergreens and the summergreen and raingreen small trees. Least frequently predicted are a variety of alpine, perhumid, Southern Hemisphere and mediterranean forms.

Plant type	No. of occurrences	Percentage
Tropical rainforest trees	133	10.9
Tropical montane rainforest trees	63	5.1
Tropical evergreen sclerophyll trees	333	27.2
Tropical evergreen microphyll trees	329	26.9
Warm-temperate broad-evergreen trees	58	4.7
Mediterranean broad-evergreen trees	36	2.9
Temperate broad-rainforest trees	48	3.9
Monsoon broad-raingreen trees	96	7.8
Montane broad-raingreen trees	67	5.5
Xeric raingreen trees	110	9.0
Summergreen broad-leaved trees	222	18.1
Boreal broad-summergreen trees	175	14.3
Tropical linear-leaved trees	173	14.1
Tropical xeric needle-trees	86	7.0
Temperate rainforest needle-trees	45	3.7
Heliophilic large-needled trees	97	7.9
Mediterranean needle-trees	157	12.8
Typical temperate needle-trees	180	14.7
Boreal/montane needle-trees	248	20.2
Hydrophilic summergreen needle-trees	38	3.1
Boreal summergreen needle-trees	236	19.3
Tropical broad-evergreen dwarf trees	89	7.3
Tropical broad-evergreen small trees	220	18.0
Cloud-forest dwarf-trees	28	2.3
Temperate broad-evergreen small trees	159	13.0
Sub-polar broad-evergreen small trees	7	0.6
Broad-raingreen small trees	284	23.2
Broad-summergreen small trees	364	29.7
Needle-leaved small trees	210	17.1
Palmiform tuft-trees	291	23.8
Palmiform tuft-treelets	313	25.6
Tree ferns	20	1.6
Tropical alpine tuft-treelets	8	0.7
Xeric tuft-treelets	184	15.0
Evergreen arborescents	368	30.0
Raingreen thorn-scrub	183	14.9
Summergreen arborescents	444	36.2
Leafless arborescents	255	20.8
Needle-leaved treeline krummholz	45	3.7
Tropical broad-evergreen shrubs	368	30.0
Mediterranean evergreen shrubs	150	12.2
Broad-ericoid evergreen shrubs	87	7.1
Temperate broad-evergreen shrubs	229	18.7

Table 12 (continued).

Plant type	No. of occurrences	Percentage
Hot-desert evergreen shrubs	131	10.7
Leaf-succulent evergreen shrubs	100	8.2
Cold-winter xeromorphic shrubs	116	9.5
Broad-summergreen mesic shrubs	353	28.8
Xeric summergreen shrubs	170	13.9
Needle-leaved evergreen shrubs	525	42.9
Mediterranean dwarf-shrubs	119	9.7
Temperate evergreen dwarf-shrubs	271	22.1
Maritime heath dwarf-shrubs	63	5.0
Summergreen tundra dwarf-shrubs	179	14.6
Xeric dwarf-shrubs	271	22.1
Mesic rosette-shrubs	221	18.0
Xeric rosette-shrubs	233	19.0
Evergreen cushion-shrubs	46	3.8
Xeric cushion-shrubs	216	17.6
Arborescent stem-succulents	140	11.4
Typical stem-succulents	180	14.7
Bush stem-succulents	503	41.1
Arborescent grasses	266	21.7
Tall cane-grasses	391	31.9
Tall grasses	504	41.1
Short sward-grasses	678	55.3
Short bunch-grasses	1002	81.8
Tall tussock-grasses	84	6.9
Short tussock-grasses	32	2.6
Sclerophyllous grasses	72	5.9
Desert-grasses	226	18.4
Tropical evergreen forbs	237	19.3
Temperate evergreen forbs	242	19.8
Raingreen forbs	371	30.3
Summergreen forbs	643	52.5
Succulent forbs	293	23.9
Xeric cushion herbs	412	33.6
Ephemeral desert herbs	190	15.5
Summergreen cold-desert herbs	167	13.6
Raingreen cold-desert herbs	24	2.0
Tropical broad-evergreen lianas	182	14.9
Broad-evergreen vines	292	23.8
Broad-raingreen vines	278	22.7
Broad-summergreen vines	134	10.9
Tropical broad-evergreen epiphytes	138	11.3
Narrow-leaved epiphytes	203	16.6
Broad-wintergreen epipytes	451	36.8
Evergreen ferns	123	10.0
Summergreen ferns	192	15.7
Mat-forming thallophytes	685	55.9
Xeric thallophytes	1040	84.9



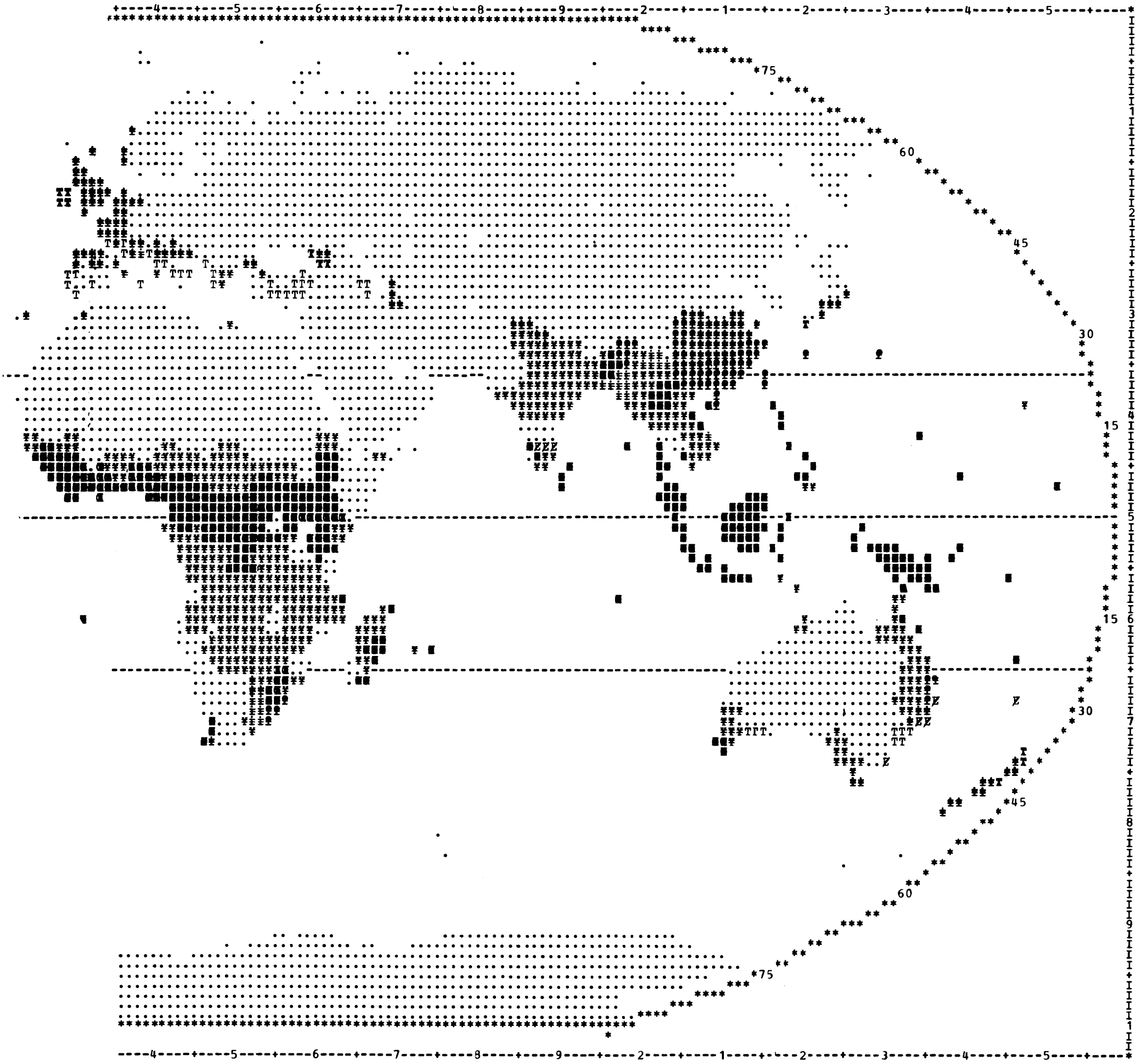
SYMAP

Map 10. Predicted distributions of most important broad-leaved evergreen tree types.

Broad-leaved evergreen trees are predicted to occur in tropical-subtropical and less extreme temperate areas with only short or no dry seasons, in mediterranean areas with sufficient total moisture, and in perhumid, stenothermal cool-temperate areas such as southern Chile (*Nothofagus*), New Zealand, and northwestern North America. The map shows the predicted dominant broad-leaved evergreen tree type in each area (except those very close to climatic limits). These types are also the formation dominants in many cases, especially in the tropical rainforest and in warm-temperate forests. Areas of predicted co-important forms (MULT) involve primarily the combinations TBRT + WTET and TBRT + TMRT (10 occurrences each). Broad-leaved evergreen trees are well predicted in general, with no major discrepancies appearing on this map. The proximity of these forms to climatic limits ('fitness') is shown on Map 11.

TRFT = Tropical RainForest Trees
EST = Evergreen Sclerophyll Trees
TEMT = Tropical broad-Evergreen Mircophyll Trees
WTET = Warm-Temperate broad-Evergreen Trees
MBET = Mediterranean Broad-Evergreen Trees
TBRT = Temperate Broad-evergreen Rainforest Trees

TEST = Tropical broad-Evergreen Small Trees (small and dwarf trees)
BEST = Temperate broad-Evergreen Small Trees (temperate, cloud-forest, and subpolar)
MULT = co-important broad-evergreen tree forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

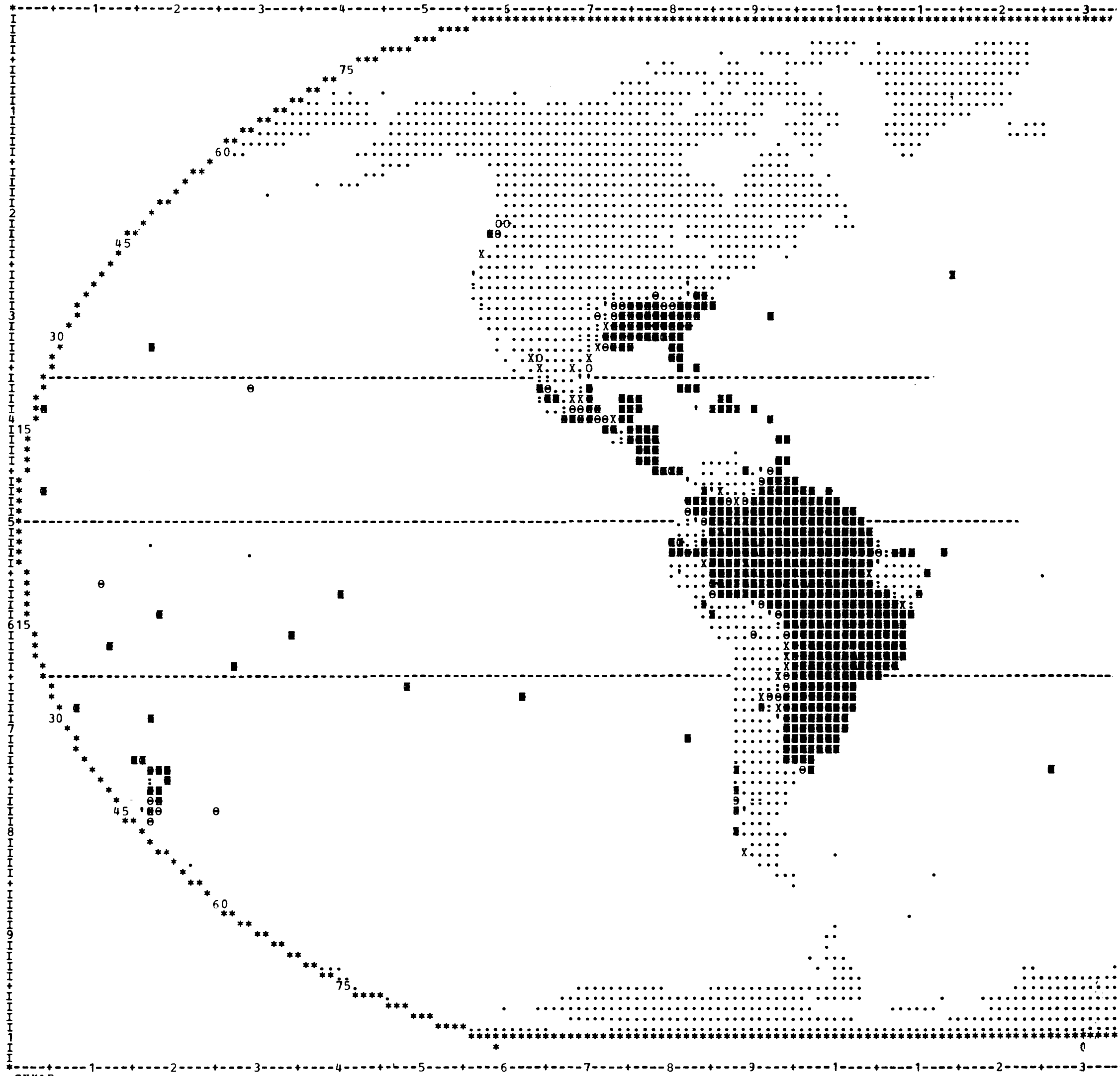
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	ABOVE
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	8.50

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

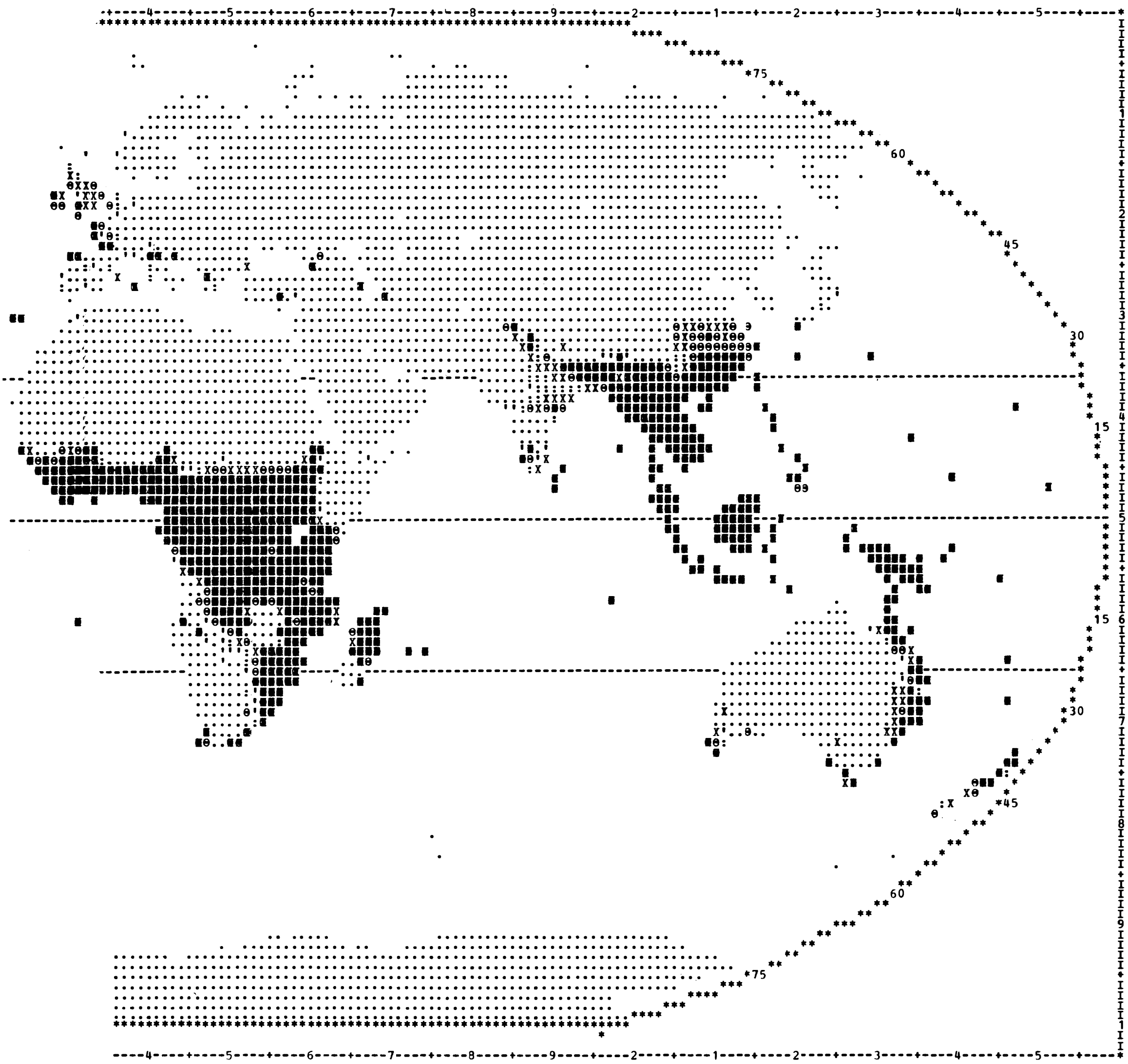
12.50 12.50 12.50 12.50 12.50 12.50 12.50 12.50

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	7	8	H
SYMBOLS	....	■■■■■■■■■	¥¥¥¥¥¥¥¥¥	‡‡‡‡‡‡‡‡‡	●●●●●●●●●	TTTTTTTTT	TTTTTTTTT	iiiiiiiii	●●●●●●●●●	ZZZZZZZZZ
FREQ.	795	161	138	7	29	23	14	0	92	22
FORMS	NONE	TRFT	EST	TEMT	WTET	MBET	TBRT	TEST	BEST	MULT



Map 11. Predicted fitness of broad-leaved evergreen tree types.
The potential 'fitness' of the locally most important broad-leaved evergreen tree types (Map 10) is suggested here by estimated proximity to respective closest climatic limit. This may also suggest potential abundance and importance in the local vegetation, although actual dominance depends also on the fitness of other tree types. The pattern shown here suggests dominance by broad-leaved evergreen trees in expected situations: tropical and warm-temperate humid climates plus some extremely maritime cool-temperate climates (e.g. southern Chile, New Zealand). The most interesting questions are suggested by the high 'fitness' values predicted in eastern African, inland southeastern USA, and southeastern South America, and the low values across northern Australia.



)ATA VALUE EXTREMES ARE -1.00 0.50

:OTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

\BSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

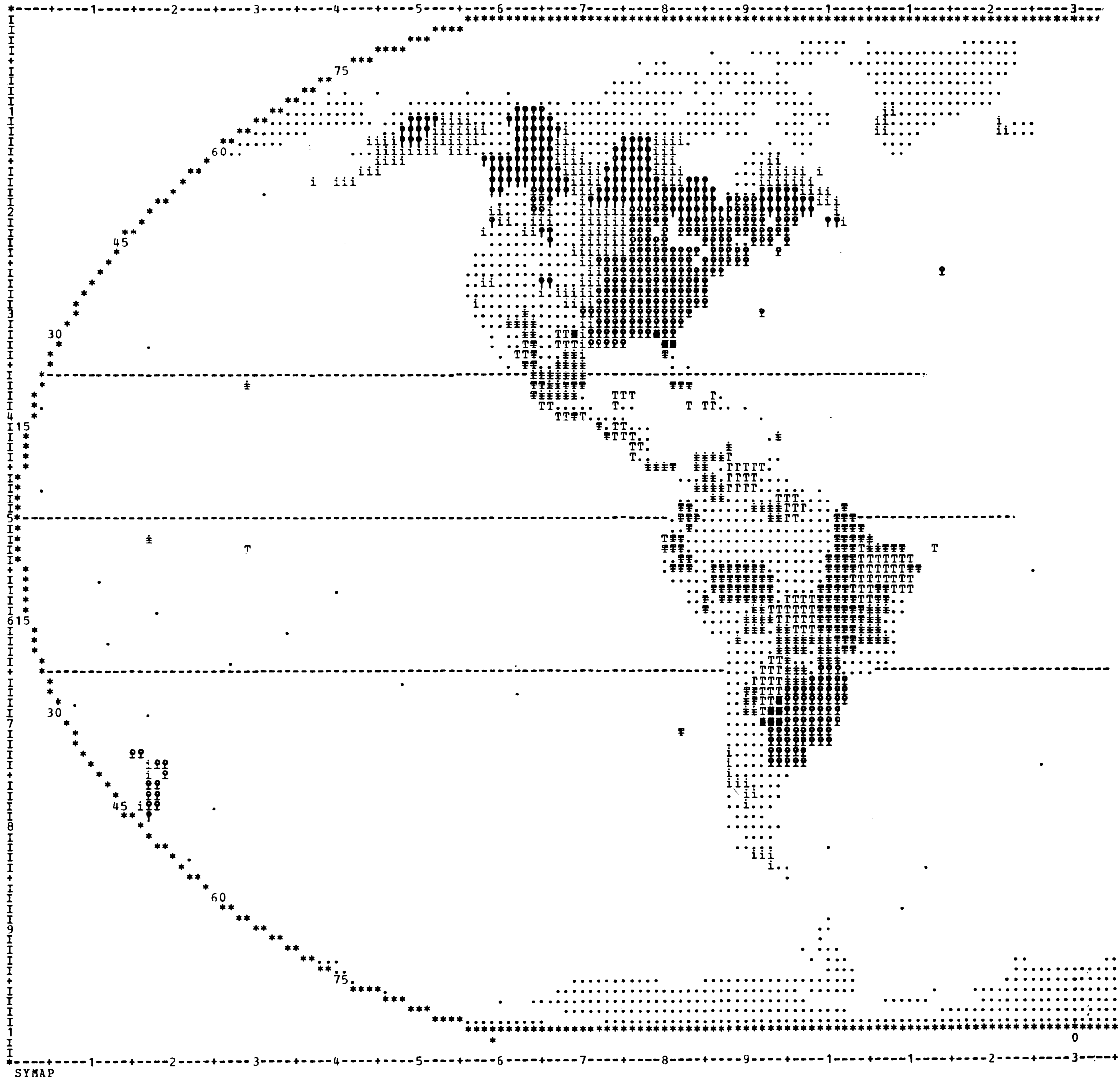
MINIMUM	BELOW	0.0	0.05	0.10	0.15	0.20	ABOVE 0.25
MAXIMUM	0.0	0.05	0.10	0.15	0.20	0.25	

'ERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00 20.00 20.00 20.00 20.00

'REQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	H
SYMBOLS	....	'''''''''	:::::::::	XXXXXXXXX	θθθθθθθθθ	■■■■■■■■■	■■■■■■■■■
FREQ.	780	39	29	27	42	73	291
FITNESS	ABSENT	< 0.05	0.05-0.1	0.1-0.15	0.15-0.2	0.2-0.25	> 0.25

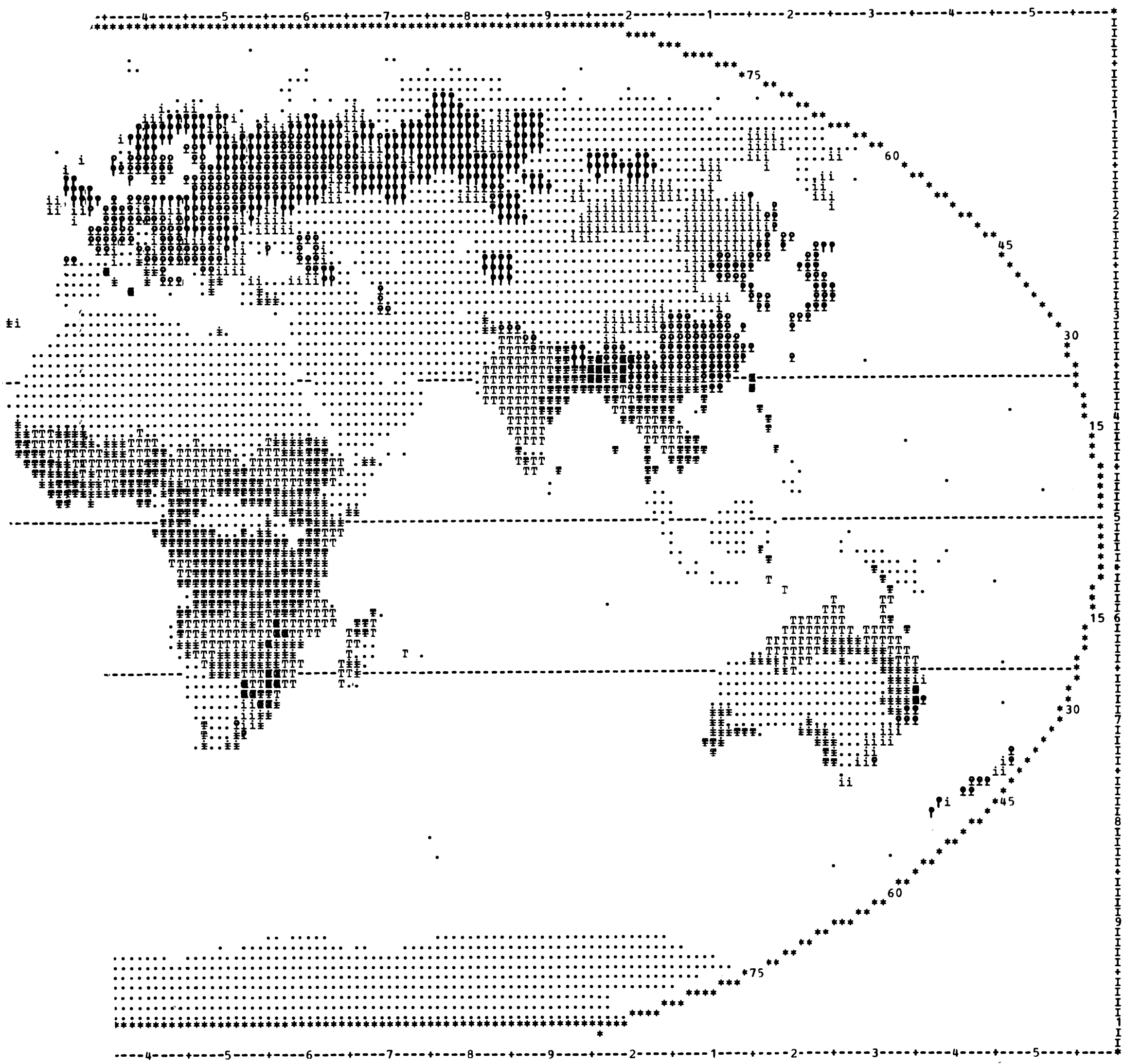


Map 12. Predicted distributions of most important broad-leaved deciduous tree types.

Broad-leaved deciduous trees, including both summergreen and raingreen types, are predicted to occur in cold/cool-winter areas of eastern North America, East Asia, and Western Europe (summergreen), in tropical summer-rain Africa, India and Southeast Asia (raingreen), and in various smaller, more scattered woodland and grassland areas. Smaller summergreen trees are also important in boreal and even some small austral climatic areas and attain formation dominance in northern Quebec, the Aleutian Peninsula and archipelago, Iceland, and Kamchatka. Smaller raingreen trees are important in dry, seasonal tropical and subtropical climates, including thorn-scrub and savanna areas mainly in Africa and tropical America. These forms are all generally well predicted. The greatest discrepancy between predicted and actual distributions involves summergreen tree types which are predicted too far north in Canada and northern Russia and probably erroneously in southern Brazil to northern Argentina and in smaller areas of southern Australia and South Africa.

RGT = mesic broad-RainGreen Trees (lowland, montane)
XRGT = Xeric broad-RainGreen Trees
SGT = SummerGreen broad-leaved Trees (temperate)
BSGT = Boreal broad-SummerGreen Trees

RGST = broad-RainGreen Small Trees
SGST = broad-SummerGreen Small Trees
MULT = co-important summergreen and raingreen tree types



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DATA VALUE EXTREMES ARE          0.0          11.00

TOTAL SUPERIMPOSED DATA POINTS IS      135.   THESE OCCUR IN   60 LOCATIONS.
```

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

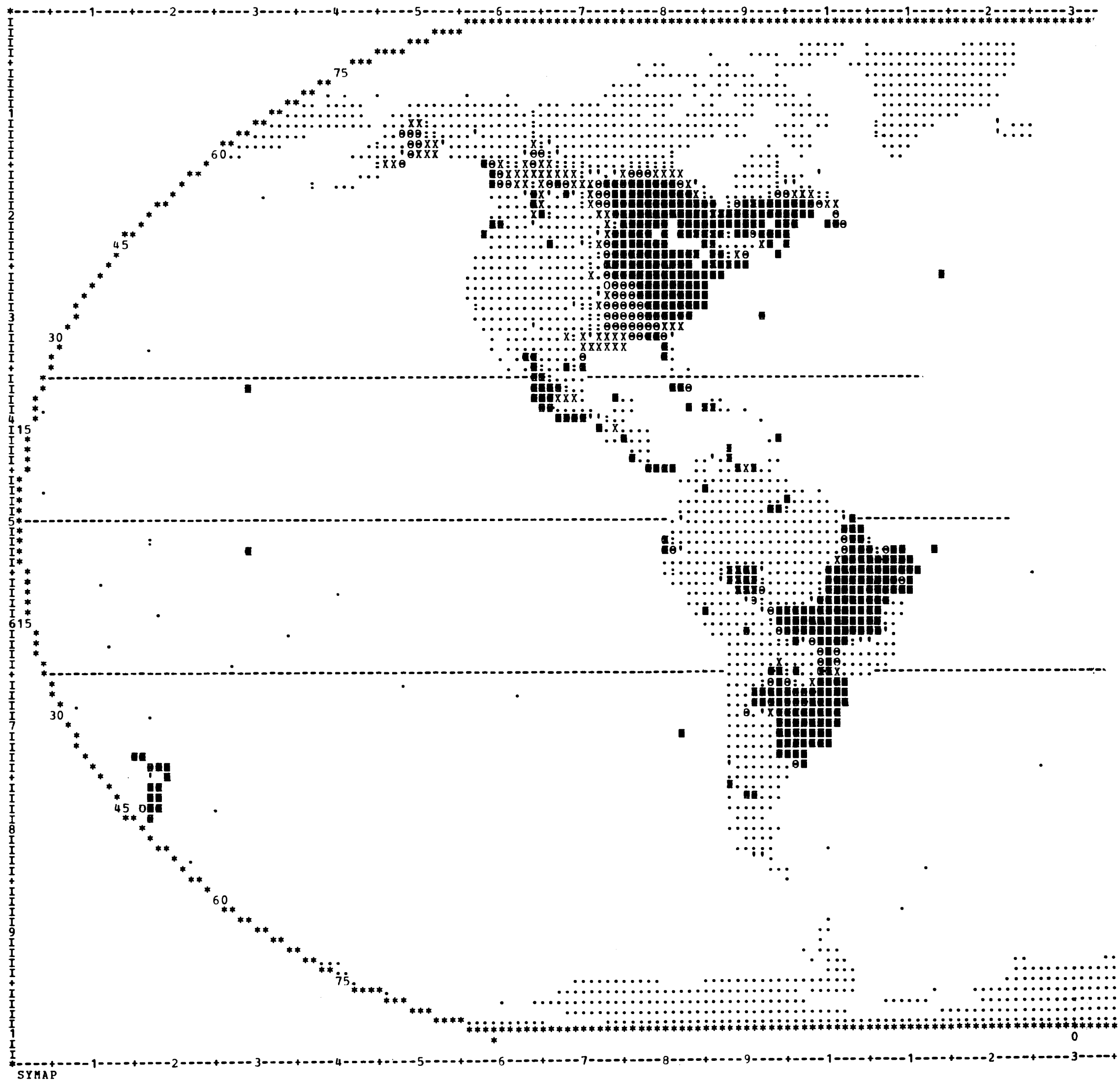
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	ABOVE
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	6.50

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

16.67 16.67 16.67 16.67 16.67 16.67

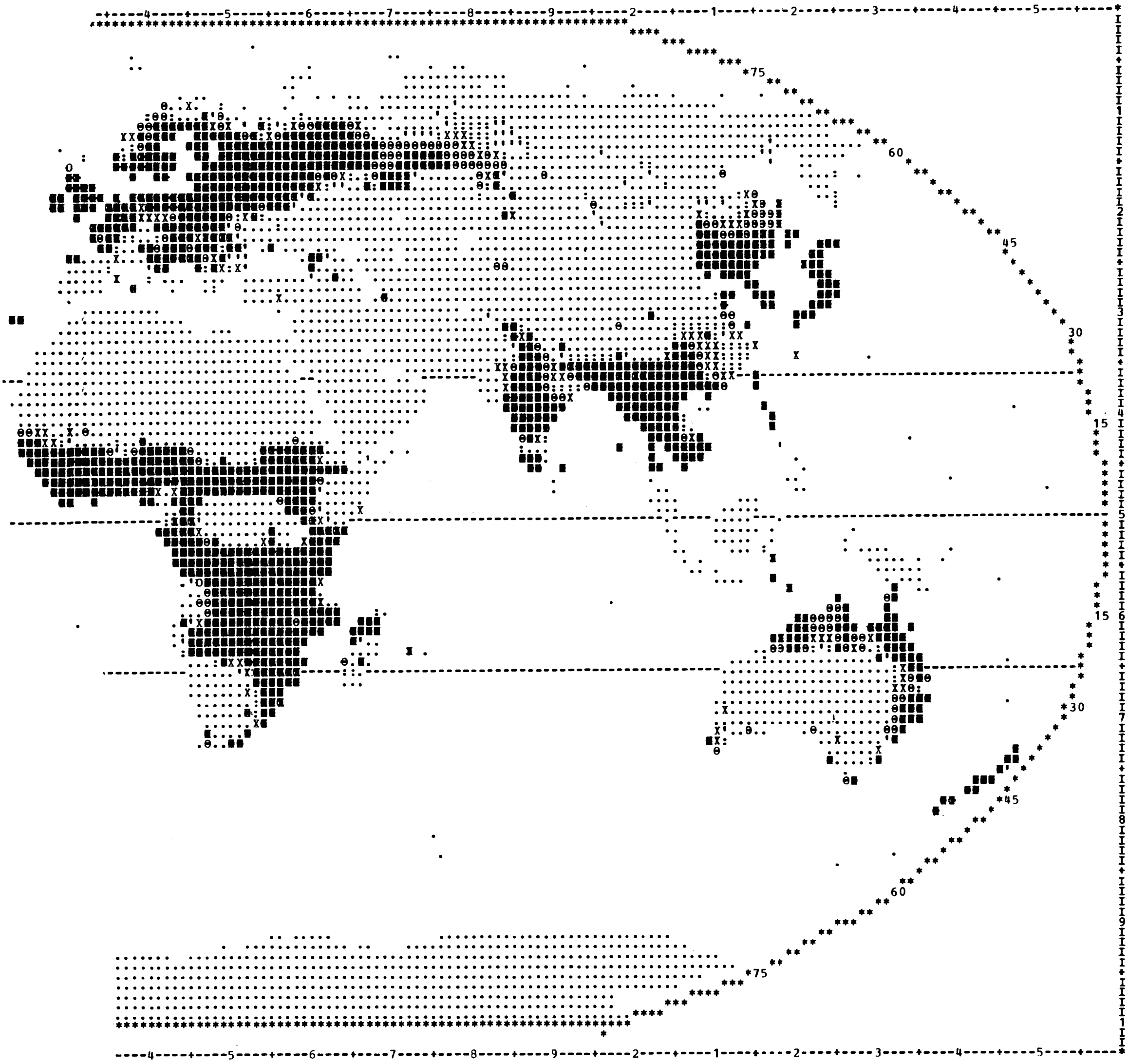
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	H
FREQ.	623	99	88	173	92	78	114	14
FORMS	NONE	RGT	XRGT	SGT	BSGT	RGST	SGST	MULT



Map 13. Predicted fitness of broad-leaved deciduous tree types.

The potential 'fitness' (i.e. distance from climatic limits) of the locally most important broad-leaved deciduous tree types (Map 12) is shown on this map. Although predicted formation dominance (Map 23) depends also on other predicted tree types, the pattern shown here reflects the actual dominance of broad-leaved deciduous trees in cool-temperate and dry-season tropical climates with sufficient wet seasons. Due to the less xeromorphic nature of (malacophyllous, generally more productive) deciduous leaves, higher fitness values for broad-evergreen tree types do not imply greater importance in a given situation. (Compare Maps 11 and 13, for example, in southeastern USA, where summergreen trees are the dominant broad-leaved form). Note also the low fitness values for small summergreen trees (e.g. *Betula, Nothofagus*) in areas such as Iceland and southern Chile, where these trees can be formation dominants.



DATA VALUE EXTREMES ARE -1.00 0.50

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

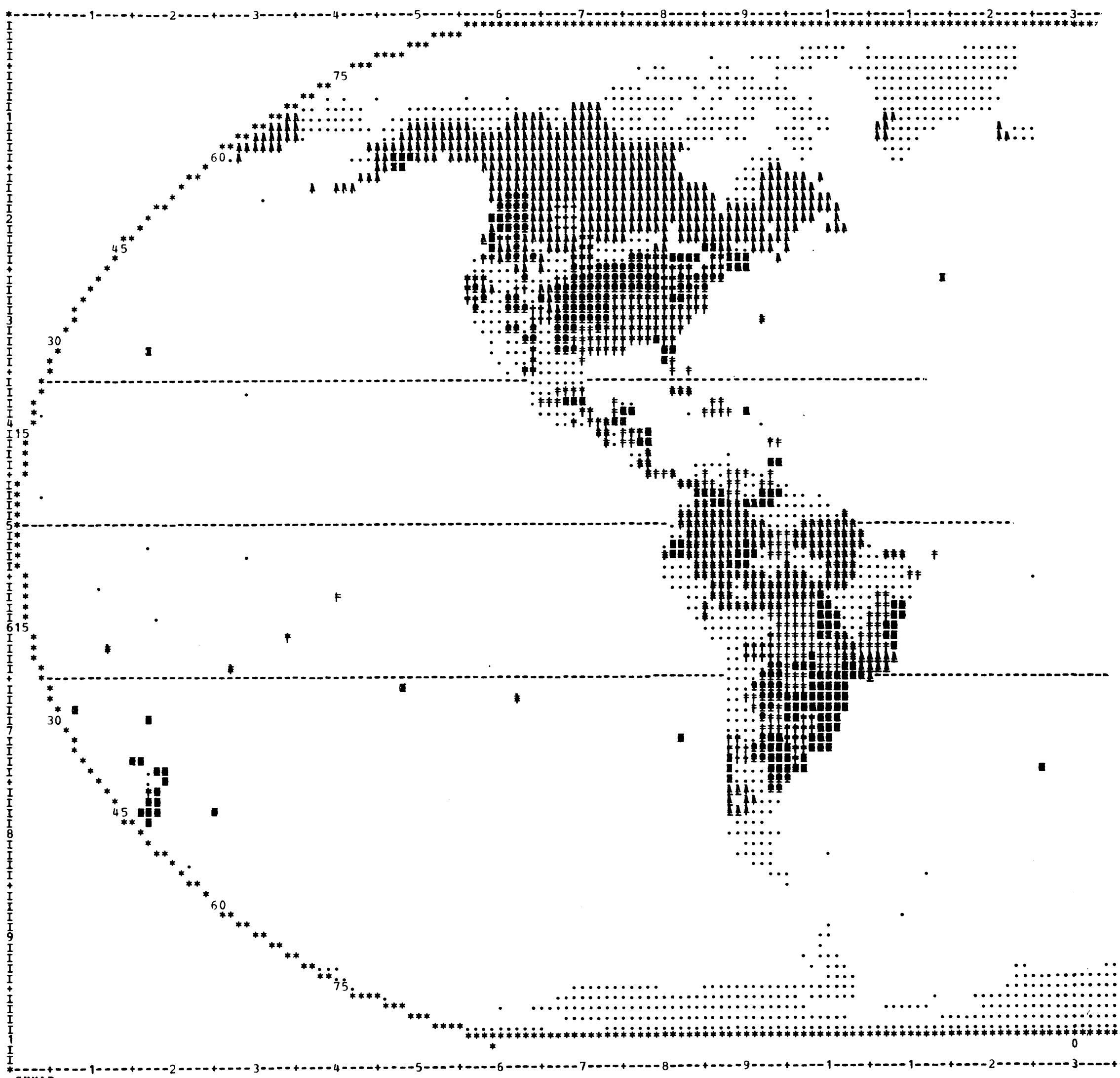
MINIMUM	BELOW	0.0	0.05	0.10	0.15	0.20	ABOVE 0.25
MAXIMUM	0.0	0.05	0.10	0.15	0.20	0.25	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

		20.00	20.00	20.00	20.00	20.00	

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

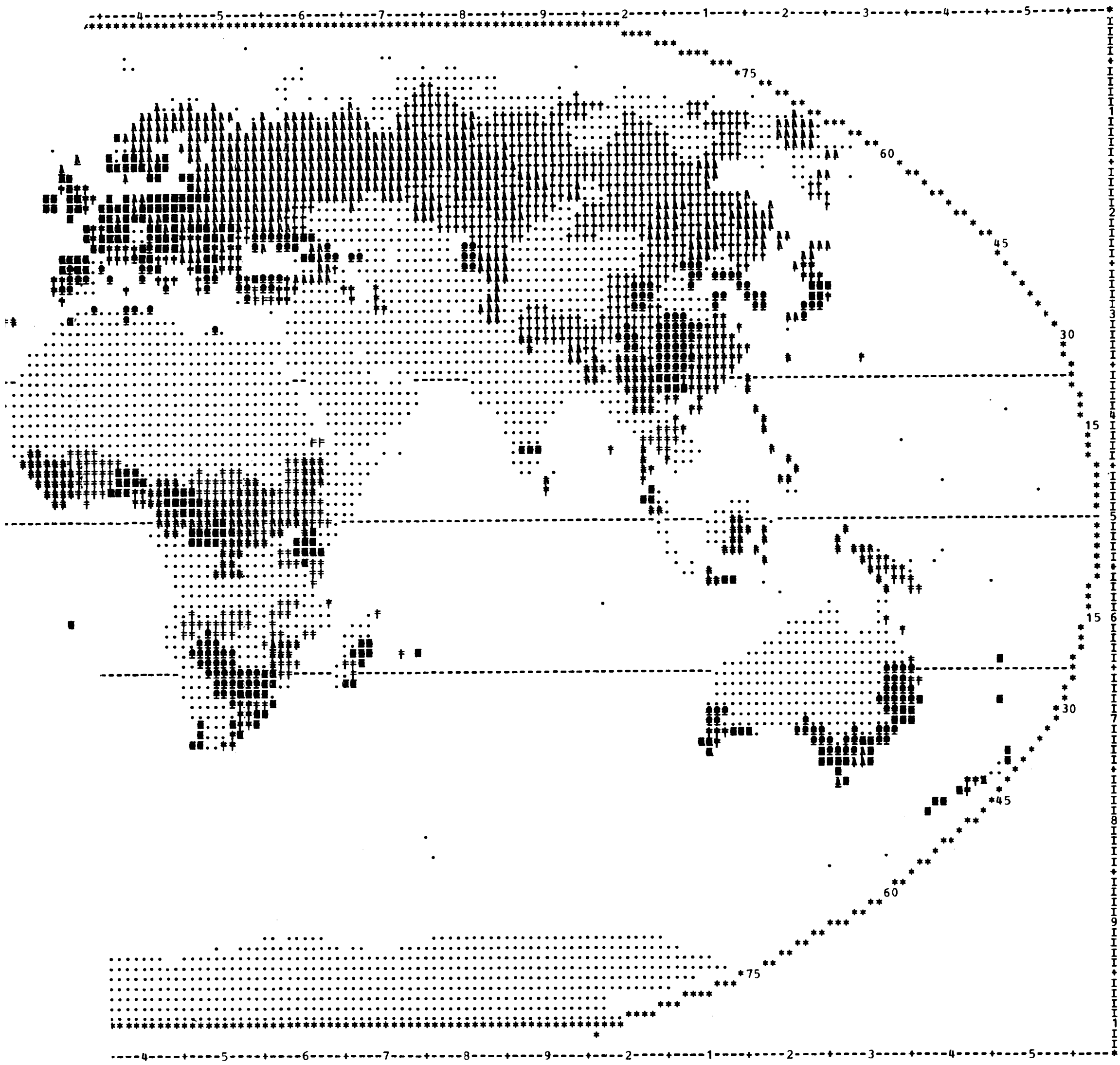
LEVEL	L	1	2	3	4	5	H
SYMBOLS	....	'''''''''	:::::::::	XXXXXXXXX	ΘΘΘΘΘΘΘΘΘ	■■■■■■■■■	■■■■■■■■■
FREQ.	623	42	61	39	56	89	371
FITNESS	ABSENT	< 0.05	0.05-0.1	0.1-0.15	0.15-0.2	0.2-0.25	> 0.25



Map 14. Predicted distributions of most important needle/narrow-leaved tree types.

Needle and narrow-leaved trees, mostly conifers, are predicted to occur in boreal and a wide variety of warmer areas. These are usually dominants in boreal areas but occur mainly as co-dominants or as other canopy forms (sometimes as emergent individuals) in warmer areas. The areas of predicted co-important needle-tree forms (MULT) represent a great variety of combinations, including TNT + BMNT (38 occurrences, mainly sub-boreal), TNT + SMNT (15 occurrences, sub-mediterranean), HLNT + TLLT (34 occurrences, sub-tropical), and various areas with three forms or more (42 occurrences, usually maritime or montane situations). Most forms are well predicted, but boreal tree forms appear too far north on the map in both North America and Eurasia. The area of suggested needle-tree importance in southern Brazil is exaggerated, probably as a result of underestimated PET in this area. Other apparent discrepancies include the importance of larches (BSNT) predicted in Alberta-Saskatchewan and the southern Rockies, and the scattered areas of tropical xeric needle-trees (TXNT) predicted outside Africa.

TLLT = Tropical Linear-Leaved Trees
TXNT = Tropical Xeric Needle-Trees
HNLT = Heliophilic Needle-Leaved Trees
TNT = Temperate Needle-leaved Trees
TRNT = Temperate Rainforest Needle-Trees
SMNT = Sub-Mediterranean Needle-Trees
BMNT = Boreal/Montane Needle-Trees
BSNT = Boreal Summergreen Needle-Trees
DNST = Dwarf-Needle Small Trees
MULT = co-important narrow-leaved tree forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

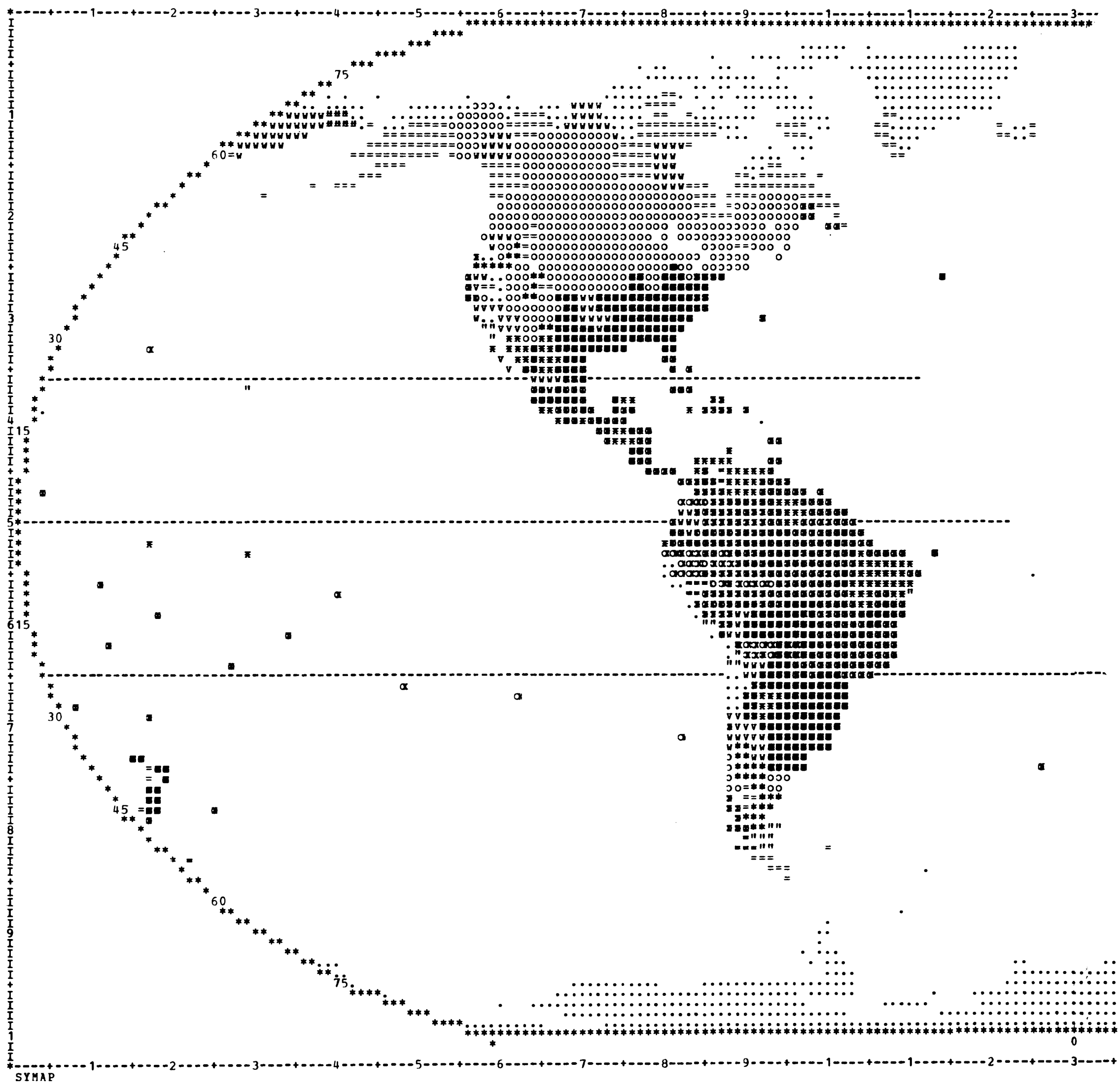
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	ABOVE 9.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

11.11	11.11	11.11	11.11	11.11	11.11	11.11	11.11	11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	7	8	9	H
SYMBOLS											
FREQ.	561	78	62	40	26	10	27	174	65	78	160
FORMS	NONE	TLLT	TXNT	HNLT	TNT	TRNT	SMNT	BMNT	BSNT	DNST	MULT

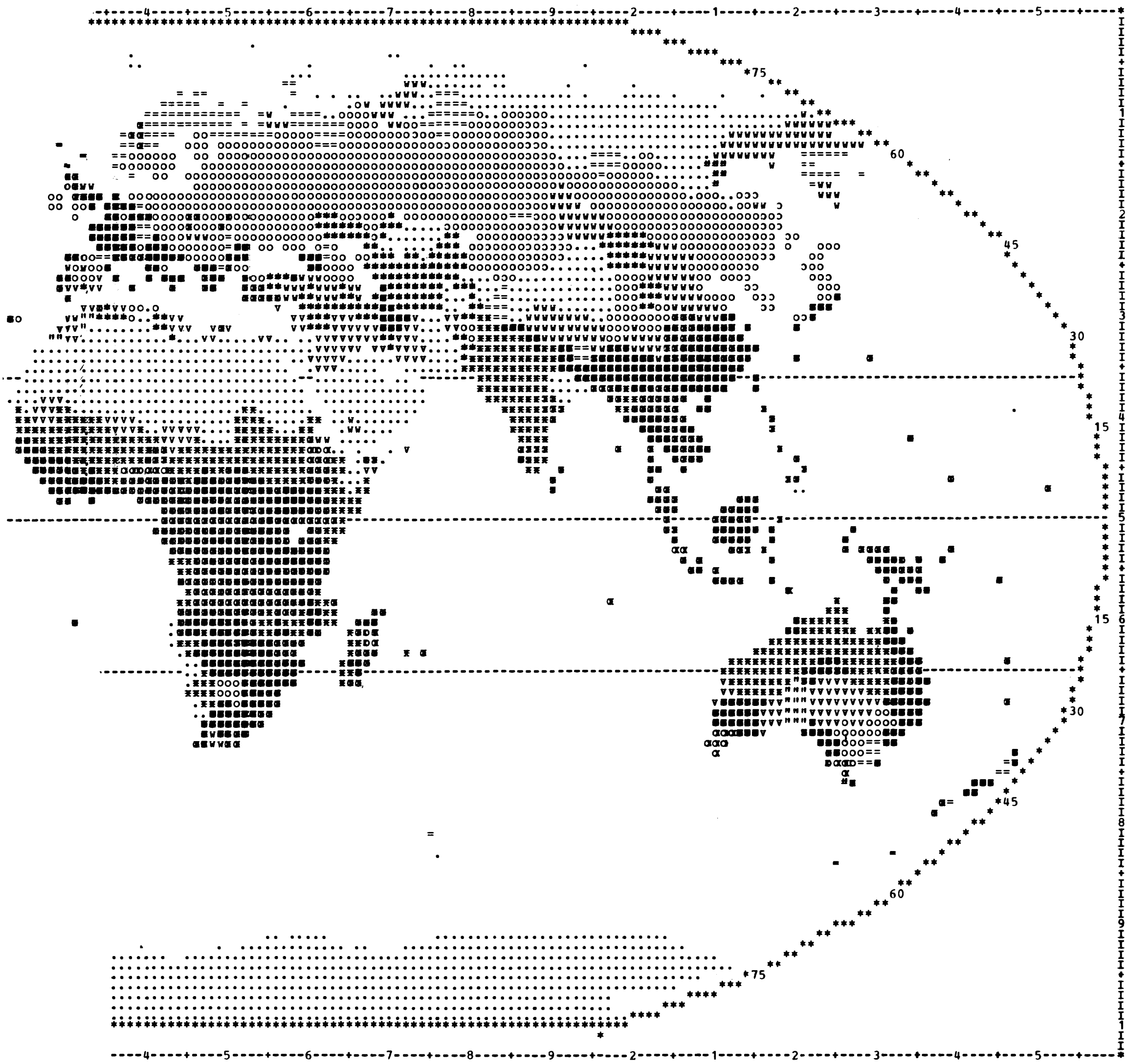


Map 15. Predicted distributions of most important shrub and similar forms.

Shrubs and similar forms, including frutescents, thorn-scrub, dwarf and cushion-shrubs, are predicted to occur over most of the non-desert world. Such forms are correctly predicted (see Map 23) to dominate large areas in western North America, Patagonia, the Middle East (including Kazakhstan), and Australia, plus smaller areas in southwestern Africa, mediterranean Europe, central Chile, Caribbean South America, Central Asia, and along the north and south borders of the Sahara desert. Shrub-tundra climates are predicted in northern Europe, southern Greenland, and in the central part of the Canadian archipelago. Of the many sites with predicted co-important shrub forms, most are combinations of evergreen and summergreen forms (127 occurrences), with raingreen plus evergreen (46 occurrences) and raingreen plus summergreen (9 occurrences) predicted less frequently. Potentially interesting occurrences of all three types were predicted in southern and southwestern Australia (3), northern Argentina (1), and the mountains of Southern Africa (2) and northern Mexico (1). Most of these areas are surprisingly well predicted when one considers that shrubs generally are most important in open stands resulting from reduction of larger forms. Predicted with least accuracy are probably the tundra forms.

BES = Broad-leaved Evergreen Shrubs
RGTS = RainGreen Thorn-Shrub
SGS = SummerGreen Shrubs
NLES = Needle-Leaved Evergreen Shrubs
HDES = Hot-Desert Evergreen Shrubs
CWXS = Cold-Winter Xeric Shrubs

TEDS = Temperate Evergreen Dwarf-Shrubs
SGDS = SummerGreen Dwarf-Shrubs
MECS = Mesic Evergreen Cushion-Shrubs
XCS = Xeric Cushion-Shrubs
MULT = co-important shrub forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

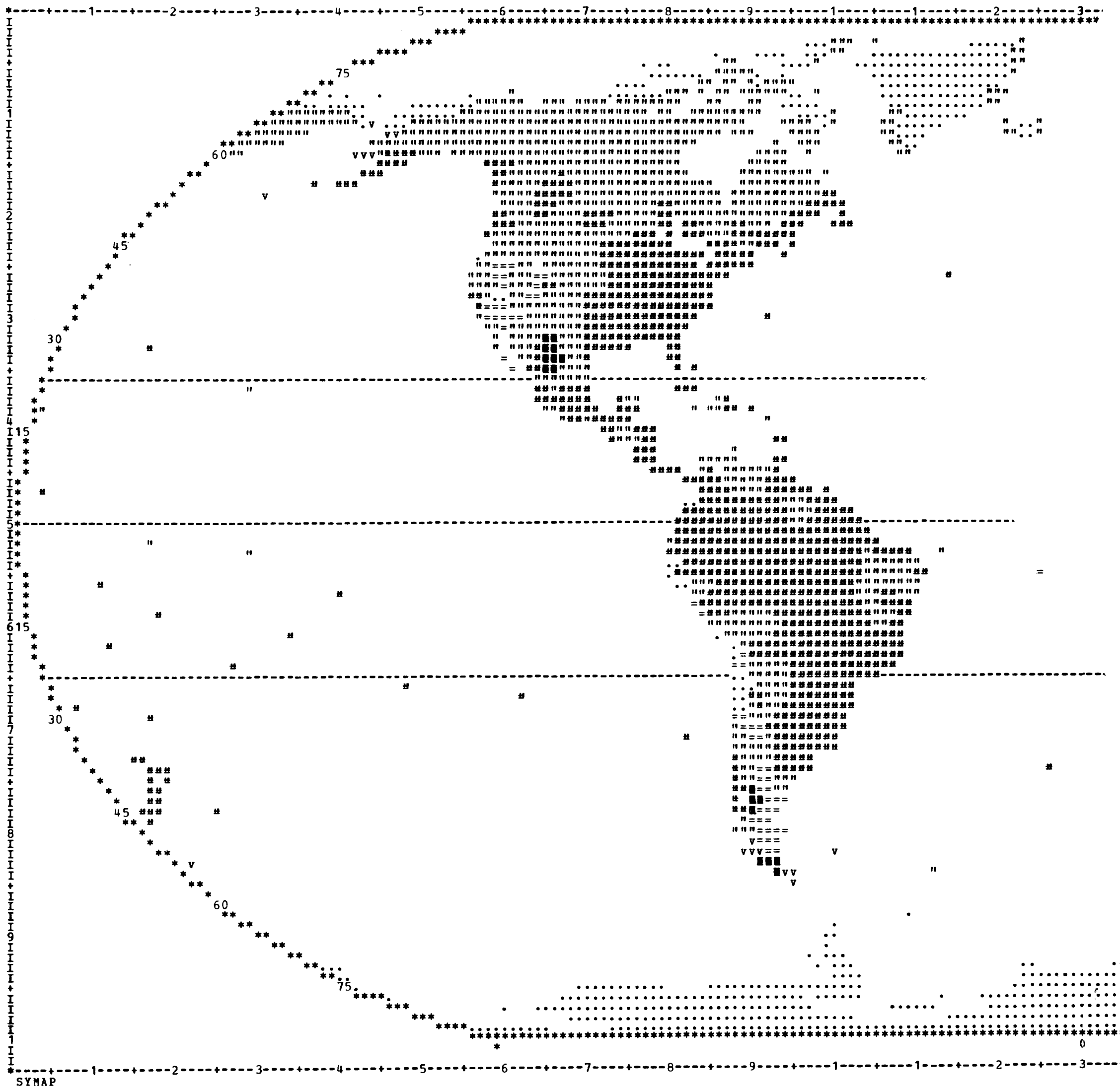
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	ABOVE 10.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

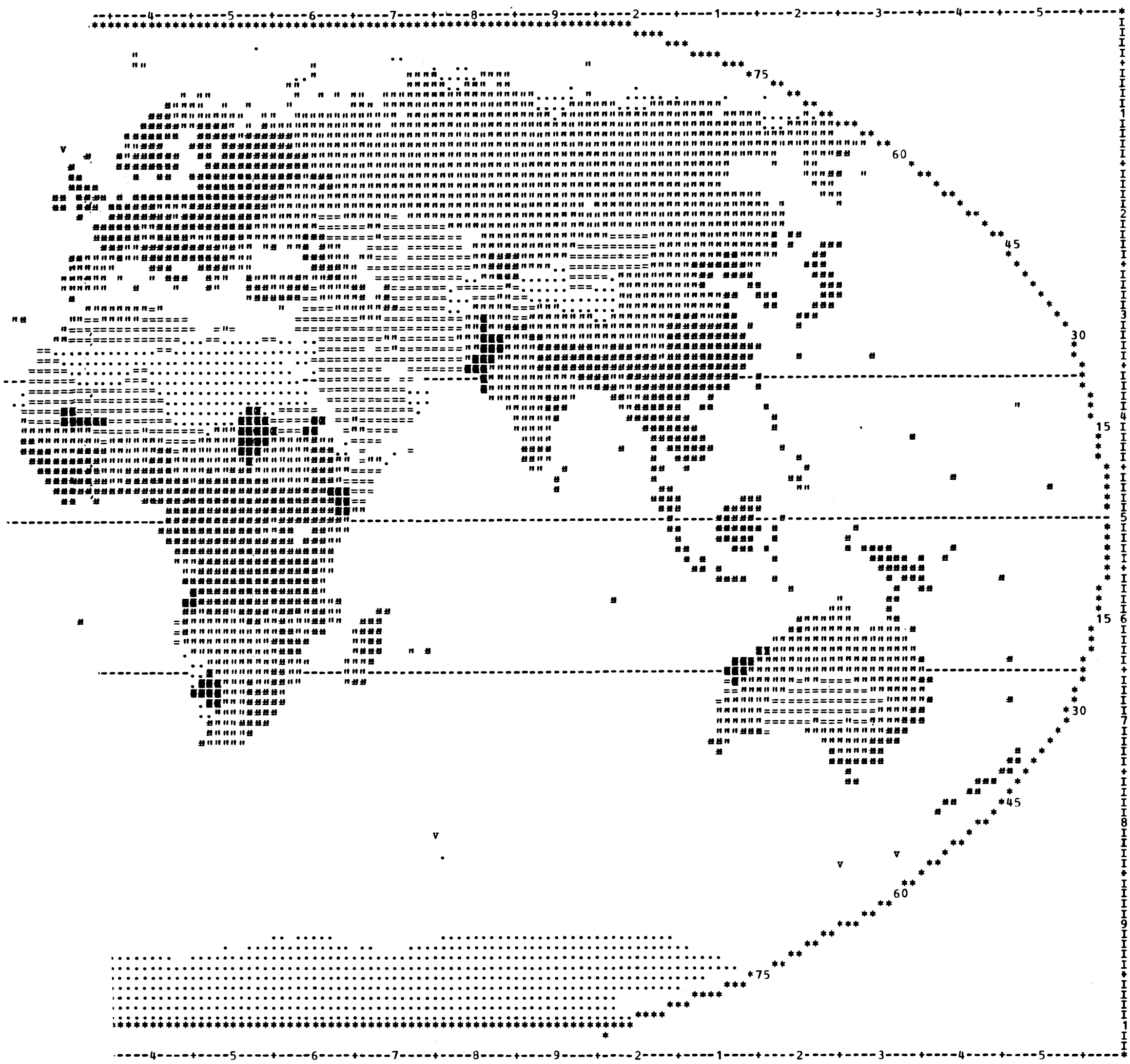
LEVEL	L	1	2	3	4	5	6	7	8	9	10	H
SYMBOLS	....	@@@@@@@@@	XXXXXXXXX	OOOOOOOOO	WWWWWWWWW	VVVVVVVVV	*********	#########	=========	---------	"""""""""	■■■■■■■■■
FREQ.	195	282	99	250	62	44	38	3	94	9	15	190
FORMS	NONE	BES	RGTS	SGS	NLES	HDES	CWXS	TEDS	SGDS	MECS	XCS	MULT



Map 16. Predicted distributions of most important graminoid types.

Graminoids (mostly grasses, with sedges also in colder climates) are predicted to occur in essentially all parts of the world except extreme deserts. Graminoids gain dominance in tropical and temperate climatic grasslands (Map 23) but may extend their areas of dominance as a result of fire, grazing, and anthropogenic influences. The areas of predicted co-important graminoid forms represent the combination DG + SCG (15 occurrences) except in southern Chile (SSG + STG). Unfortunately, no site from the Canterbury Plains short-tussock region of New Zealand is included in the data-base. The actual pattern of tall, short, and desert-grasses is shown by the predictions. Dominance by bunch, sward-forming, and tussock grass forms, on the other hand, is generally not well predicted. Because of low site density the zonal nature of the sub-Saharan grassland belts is not shown.

TG = Tall Grasses
SG = Short Grasses (bunch, sward)
TTG = Tall Tussock-Grasses
STG = Short Tussock-Grasses
SCG = Sclerophyllous Grasses
DG = Desert-Grasses
MULT = co-important graminoid forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

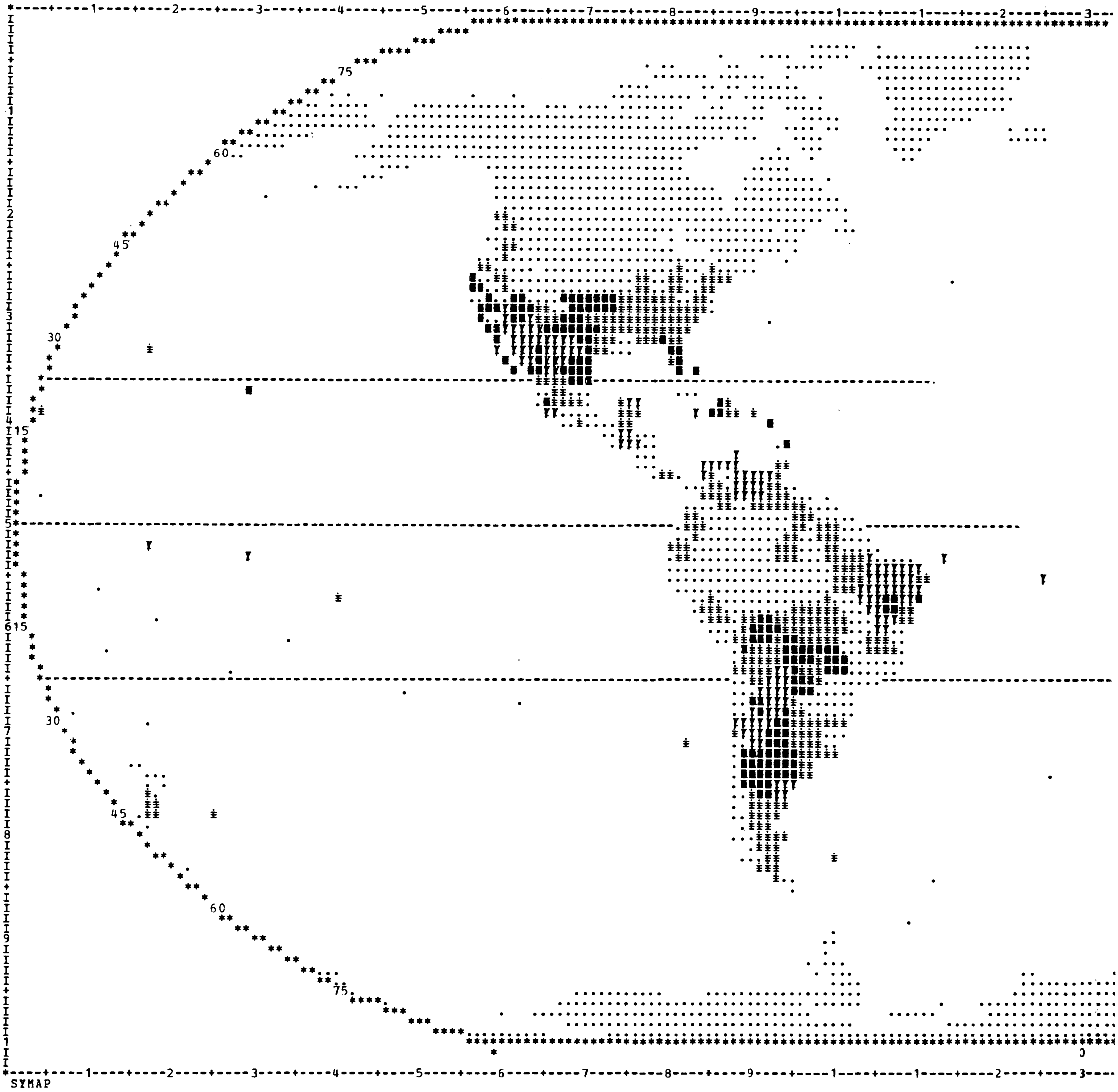
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	ABOVE
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	6.50

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

16.67 16.67 16.67 16.67 16.67 16.67

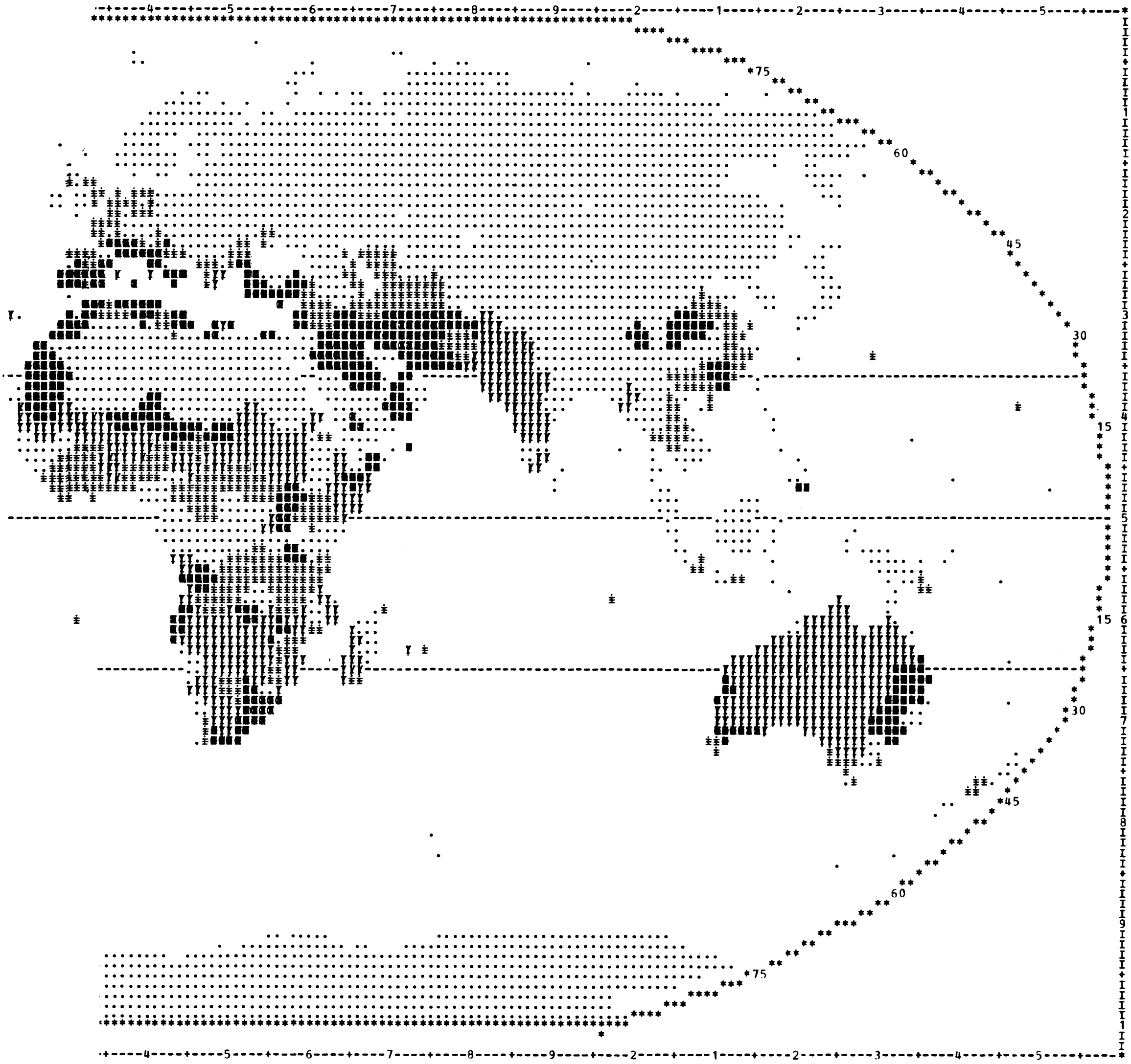
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	H
SYMBOLS	....	########	"""""""""	VVVVVVVVV	#########	=========	=========	■■■■■■■■
FREQ.	105	544	499	12	0	0	104	17
FORMS	NONE	TG	SG	TTG	STG	SCG	DG	MULT



Map 17. Predicted distributions of most important stem and leaf-succulent types.
Stem-succulents and leaf-succulent xeric rosette shrubs are predicted to occur in largely frost-free climates with exception of the 'bush' form (e.g. *Opuntia*), which can withstand severe cold in some areas. All forms prefer dry climates, but some extend their ranges into surprisingly mesic climates on drier substrates. Due to the dominance structure employed, only arborescent and bush forms are predicted alone, while the other forms appear in combinations (MULT) which do not include arborescents. All of these 162 co-occurrences involve BSS: BSS + XRS (95), BSS + TSS (40), and 27 occurrences of all three (but without arborescents), mainly in southern California, Morocco-Algeria, and scattered sites in the Middle East. The prediction of a large area of arborescent stem-succulents in Australia is completely wrong, as are the smaller areas of succulents in and around the Sahara, Arabian and Iranian deserts. Off all growth forms, succulents are probably most poorly predicted by the model.

ASS = Arborescent Stem-Succulents
TSS = Typical Stem-Succulents
BSS = Bush Stem-Succulents
XRS = Xeric Rosette-Shrubs
MULT = co-important (non-arborescent) succulent forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

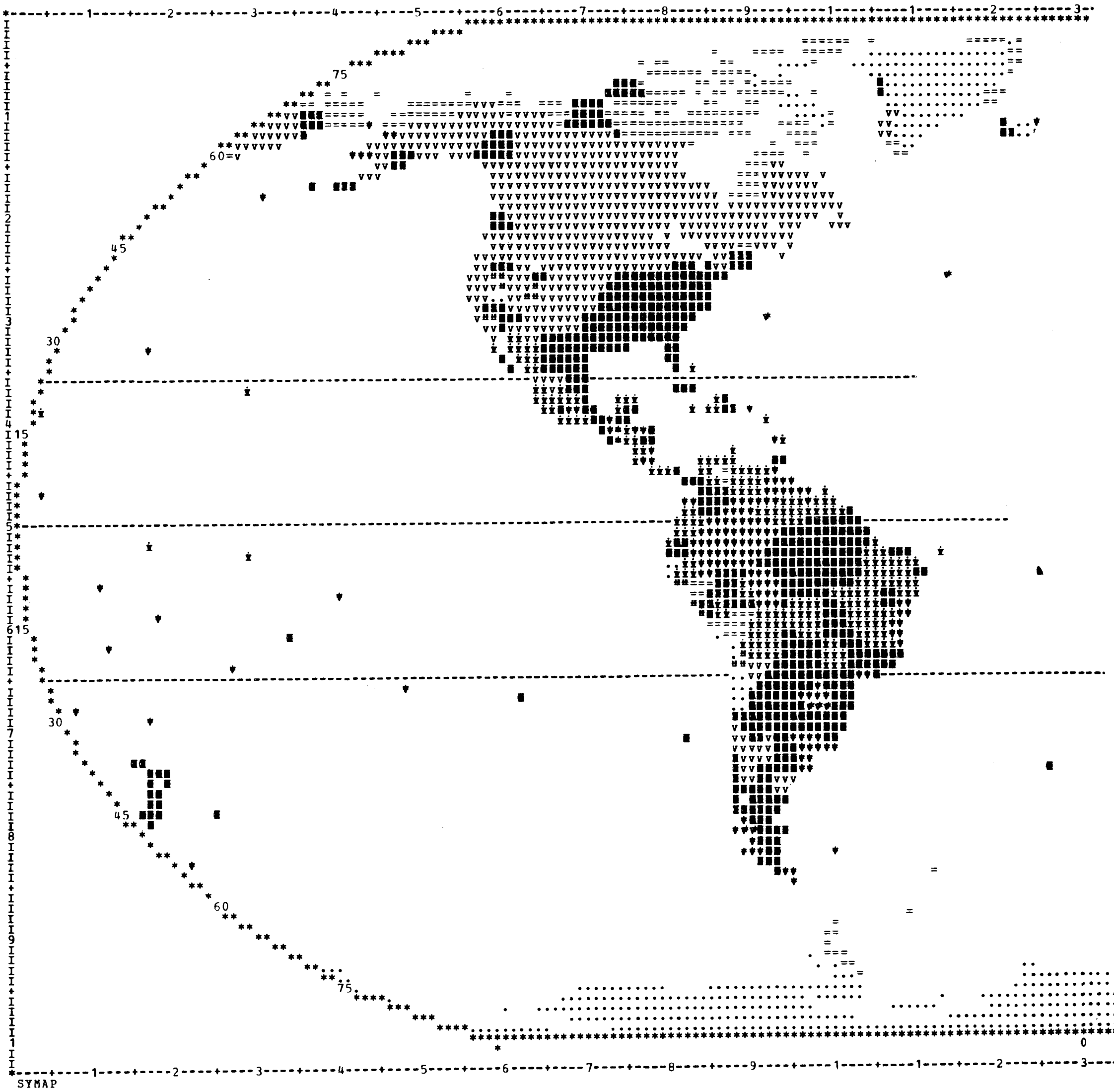
MINIMUM	BELOW	0.50	1.50	2.50	3.50	ABOVE 4.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

25.00	25.00	25.00	25.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

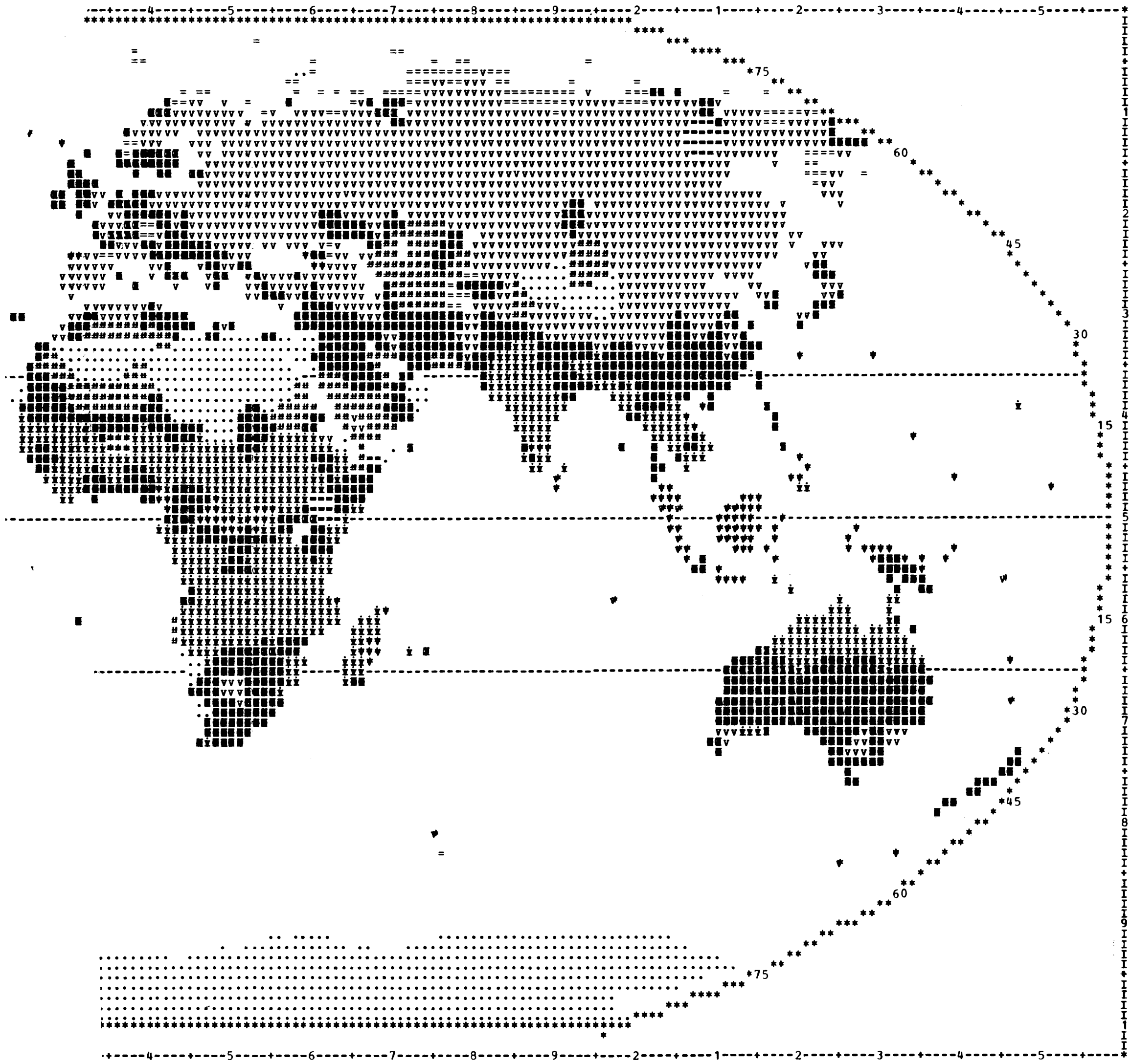
LEVEL	L	1	2	3	4	H
SYMBOLS	....	YYYYYYYYY	▪▪▪▪▪▪▪▪▪	‡‡‡‡‡‡‡‡‡	VVVVVVVVV	█████████
FREQ.	774	140	0	205	0	162
FORMS	NONE	ASS	TSS	BSS	XRS	MULT



Map 18. Predicted distributions of most important forb and semi-desert herbs types.
Forbs and/or undifferentiated semi-desert herbs, like graminoids, are predicted to occur in essentially all parts of the world except extreme deserts. They gain dominance (Map 23), however, only in dry and/or cold, usually highly seasonal semi-deserts. The large areas in which the forb component is dominated by evergreen (equatorial), raingreen (tropical), or summergreen (temperate) forms are clearly visible on the map. Transition bands (MULT) of summergreen plus evergreen and/or raingreen forms are also clearly evident in the subtropics. Ephemerals are most obvious (outside the polar areas) in Middle Asia, the Near East, and around the interior Sahara desert. Evergreen forms reappear, both alone and in combinations (MULT), in some subpolar areas (e.g. Alaska, Tierra del Fuego).

TEF = Tropical Evergreen Forbs
RGF = RainGreen Forbs
SGF = SummerGreen Forbs
SCF = Succulent Cushion-Forbs
XCH = Xeric Cushion Herbs

EDH = Ephemeral Desert Herbs
SCDH = Summergreen Cold-Desert Herbs
RGDH = RainGreen cold-Desert Herbs
MULT = co-important forb/small-herb forms



)ATA VALUE EXTREMES ARE 0.0 11.00

COTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

\BSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

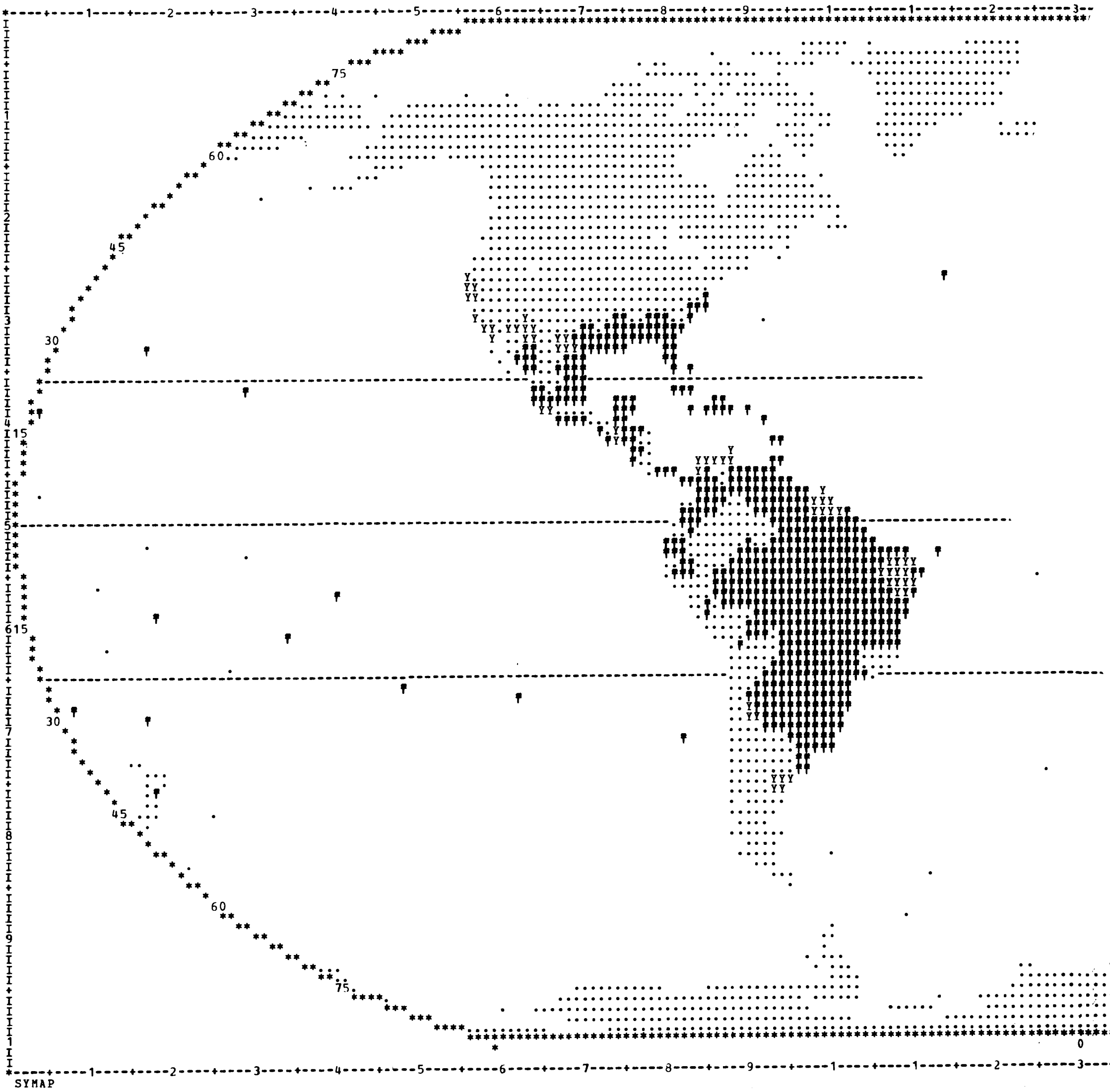
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.5)	7.50	ABOVE
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.5)	8.50	8.50

?ERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

12.50	12.50	12.50	12.50	12.50	12.50	12.5)	12.50

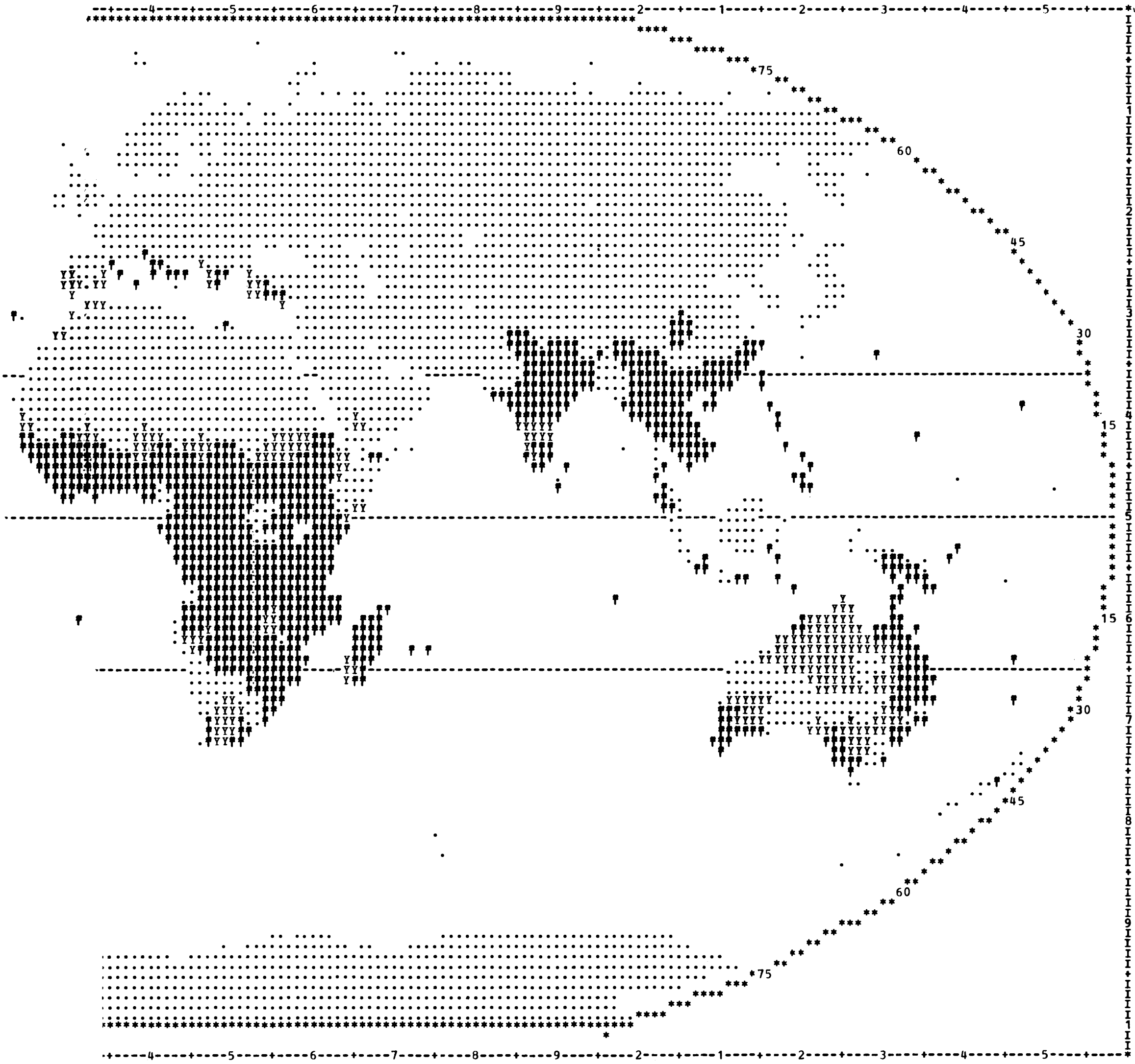
PREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	7	8	H
SYMBOLS	....	♥♥♥♥♥♥♥♥♥	XXXXXXXXX	vvvvvvvvv	########	---------	########	=========	=========	■■■■■■■■
FREQ.	70	102	173	405	2	3	35	80	4	407
FORMS	NONE	TEF	RGF	SGF	SCF	XCH	EDH	SCDH	RGDH	MULT



Map 19. Predicted distributions of eucalyptoid trees and scrub.
Eucalyptoid (evergreen sclerophyll) trees are separated from other broad-leaved evergreen tree forms because of the unique historical development of the prototypic genus, which was confined naturally to Australia. Both forest and woodland forms are predicted to be well adapted to large areas of tropical Africa, India, South America, Central America, southeastern USA, and Southeast Asia, as well as appropriate areas of Australia. The successful introduction of eucalypts in these areas outside Australia suggests that the predictions of eucalyptoid forms are generally accurate. Convergent non-eucalypt forms can also be identified in some of these other areas and appear especially well developed in eastern and southern Africa.

EST = Eucalyptoid Sclerophyll Trees
ESA = Eucalyptoid Sclerophyll Arborescents (e.g. mallee)



DATA VALUE EXTREMES ARE 0.0 2.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

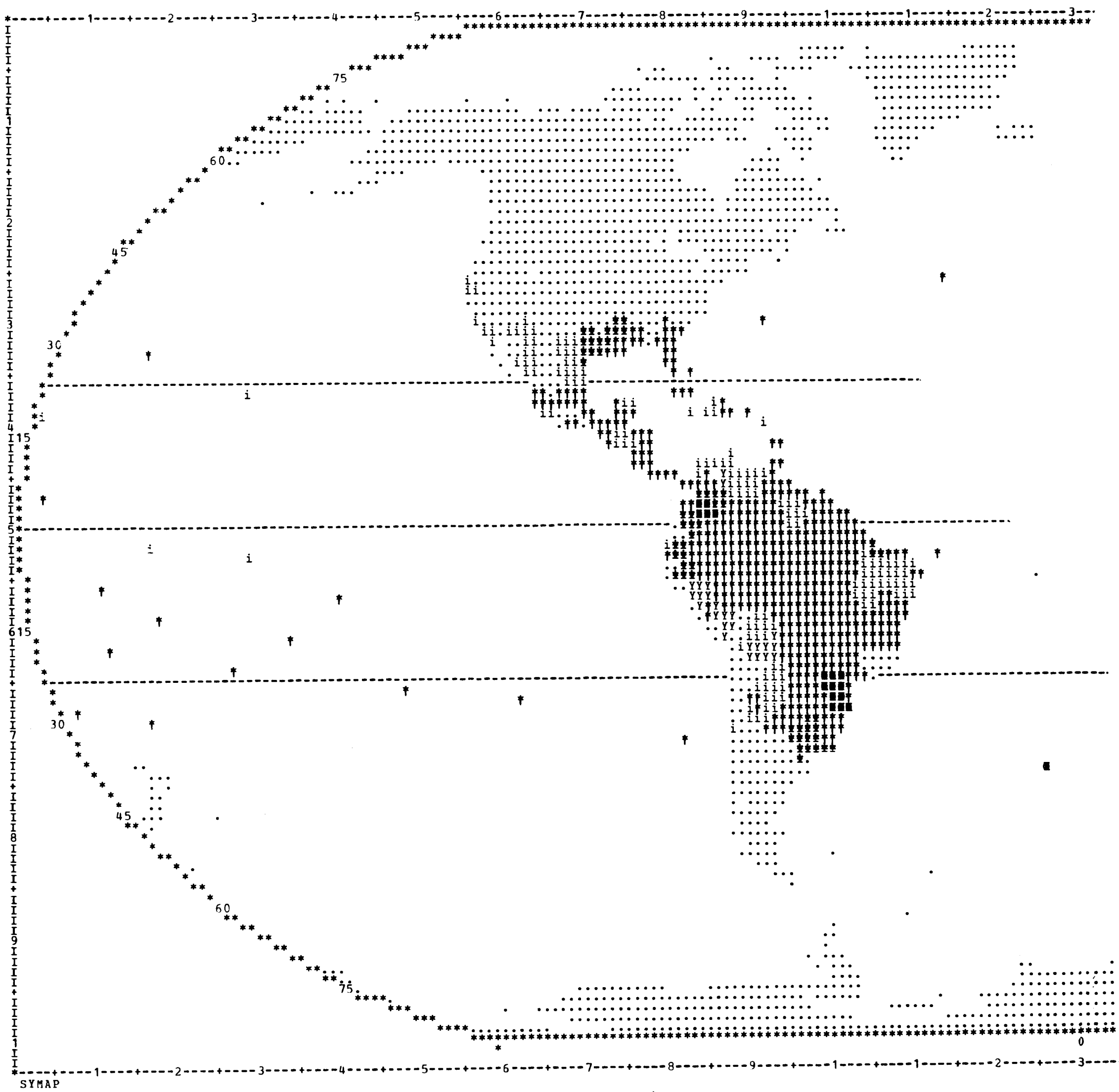
MINIMUM	BELOW	0.50	1.50
MAXIMUM	0.50	1.50	2.50

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

50.00 50.00

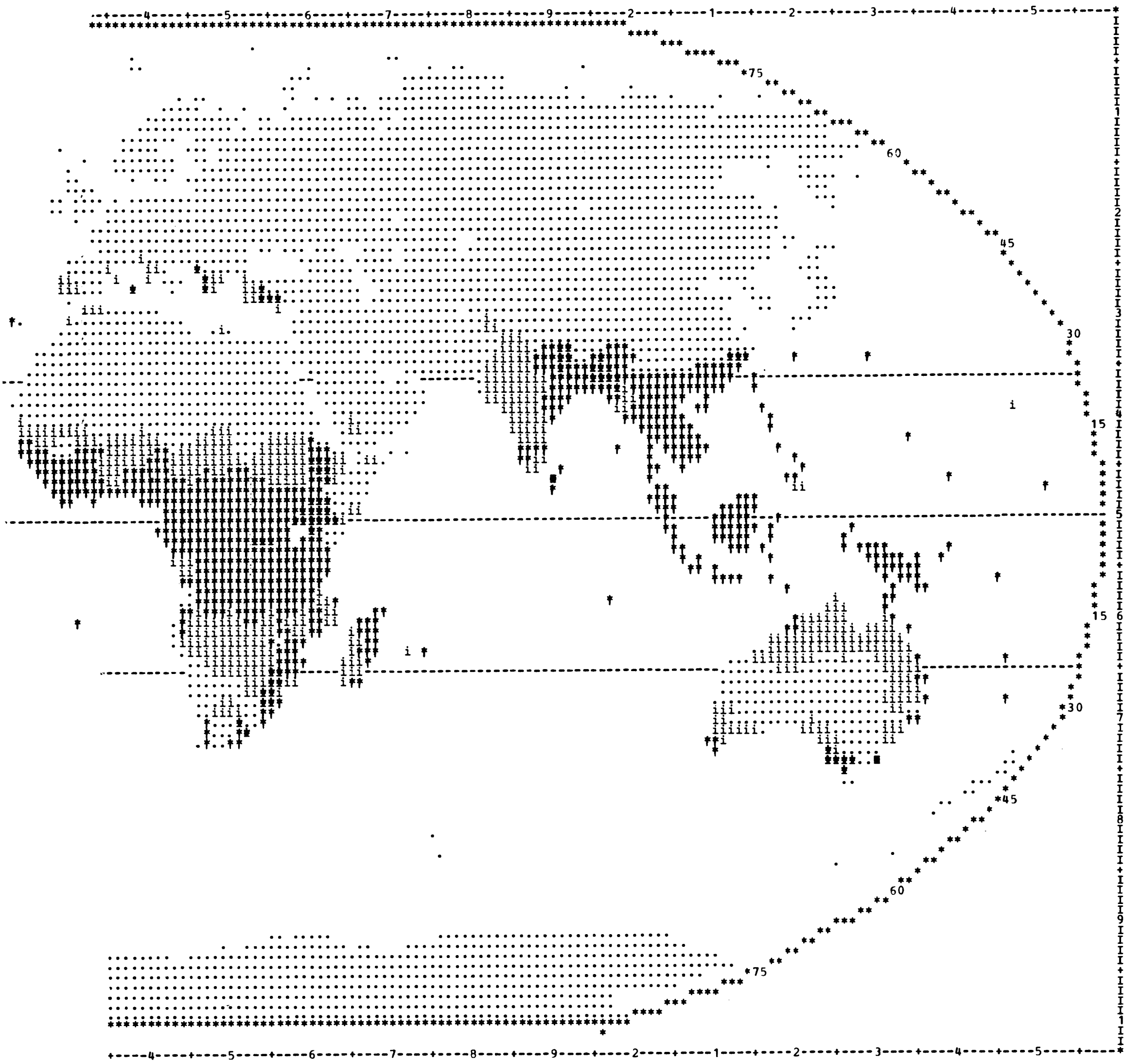
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2
SYMBOLS	....	#########	YYYYYYYYY
FREQ.	863	338	80
FORMS	NONE	EST	ESA



Map 20. Predicted distributions of most important tuft-tree and tuft-treelet types.
Evergreen tuft-trees and treelets, including tree ferns, are restricted to mostly frost-free climates of the tropics and subtropics, where sufficient water is available. More mesic forms are found in humid tropical and subtropical climates and more xeric forms (e.g. XETT) in the drier regions of the subtropics. The few occurrences of predicted co-important forms all involve the combination PTTL + TFN (conspicuously absent from New Zealand and Chile). Natural occurrences of the most important forms are generally well predicted, but these forms, especially palms, can also occur along water courses, at oases, in seasonally flooded savanna and swamp areas, and in other situations where climatic dryness is compensated by available groundwater. The single prediction of tree ferns as the most important tuft-tree form (Uraguay) is clearly erroneous. The occurrence of tropical alpine tuft-treelets is not well represented by the map because of the small mountain-top areas which they occupy and the paucity of such sites in the data-base, especially in Africa.

PTT = Palmiform Tuft-Trees
PTTL = Palmiform Tuft-TreeLets
TFN = Tree FerNs
TATT = Tropical Alpine Tuft-Treelets
XETT = Xeric Evergreen Tuft-Treelets
MULT = co-important tuft-tree forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

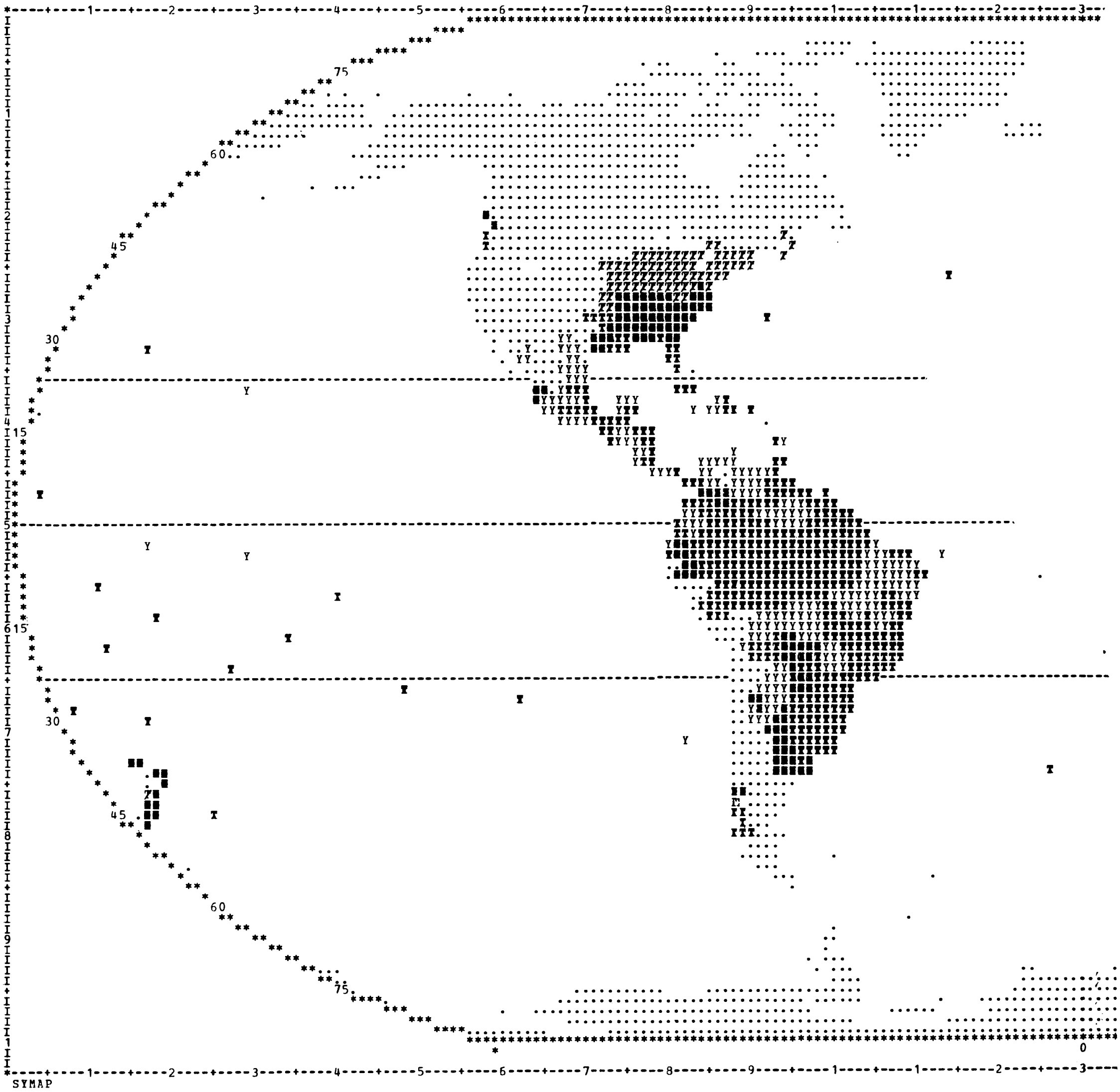
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	ABOVE 5.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

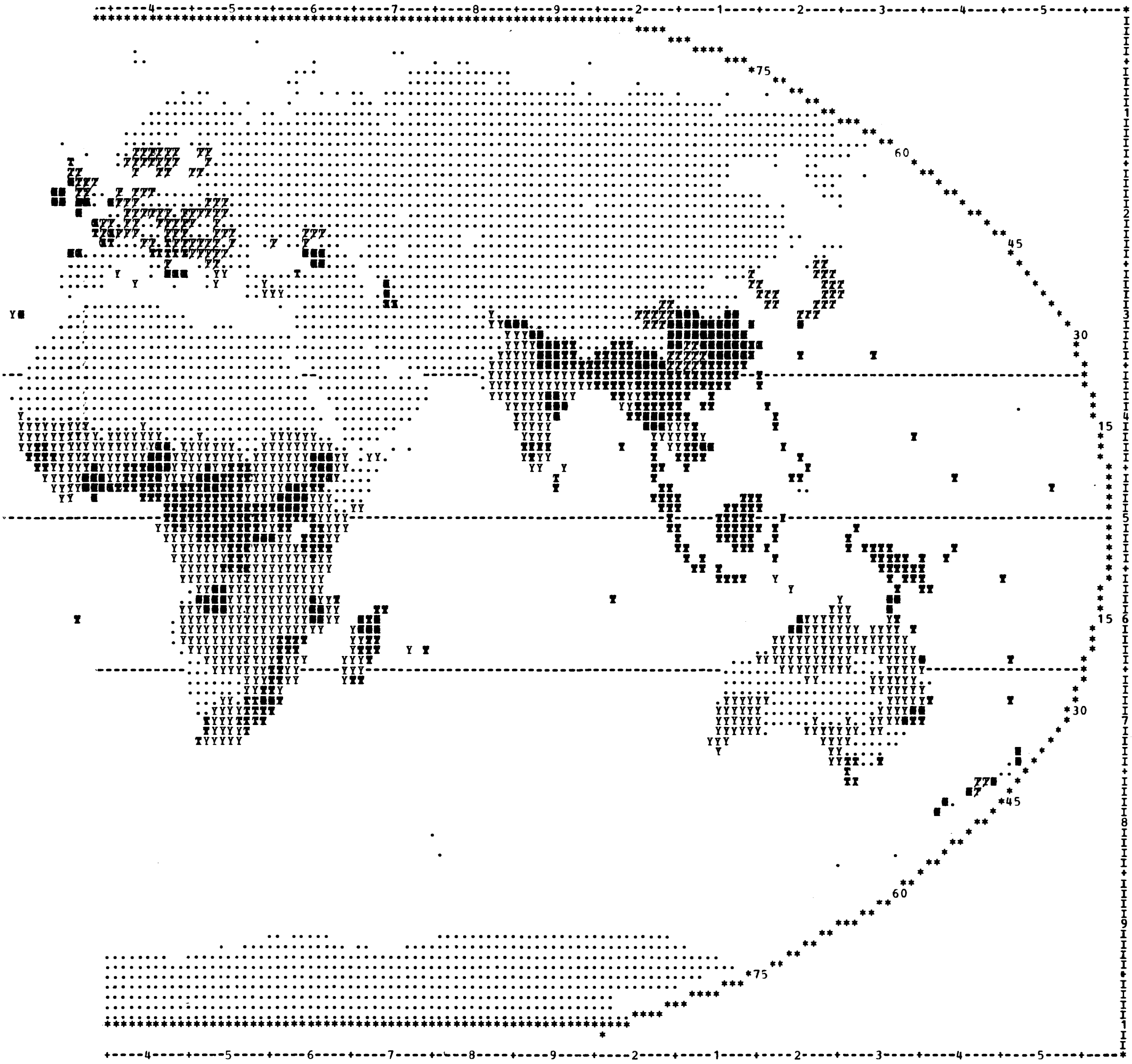
LEVEL	L	1	2	3	4	5	H
SYMBOLS	....				YYYYYYYYY	iiiiiiiii	
FREQ.	826	264	31	1	8	144	7
FORMS	NONE	PTT	PTTL	TFN	TATT	XETT	MULT



Map 21. Predicted distributions of most important vine and liana types.

Vines and lianas are generally found in wetter climates which support other woody vegetation over which the vines can climb or sprawl. Evergreen lianas (larger woody climbers) are generally restricted to the frost-free tropics where rapid growth is most easily accomplished. Smaller evergreen vines, almost always woody, occur well into the temperate zones but are largely confined to more maritime climates with moderated winter temperatures and available winter moisture. Summergreen and raingreen vines are common, respectively, in cold-winter and tropical summer-rain climates with varying degrees of total moisture. They become less important as total moisture decreases and/or the growing season becomes shorter. The areas (MULT) of predicted co-important forms represent combinations of summergreen and evergreen vines in the temperate zone (54 occurrences, e.g. southeastern USA) and of raingreen and evergreen vines in the tropics (27 occurrences, e.g. India and Africa).

TBEL = Tropical Broad-Evergreen Lianas
BEGV = Broad-EverGreen Vines
BRGV = Broad-RainGreen Vines
BSGV = Broad-SummerGreen Vines
MULT = co-important vine/liana forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

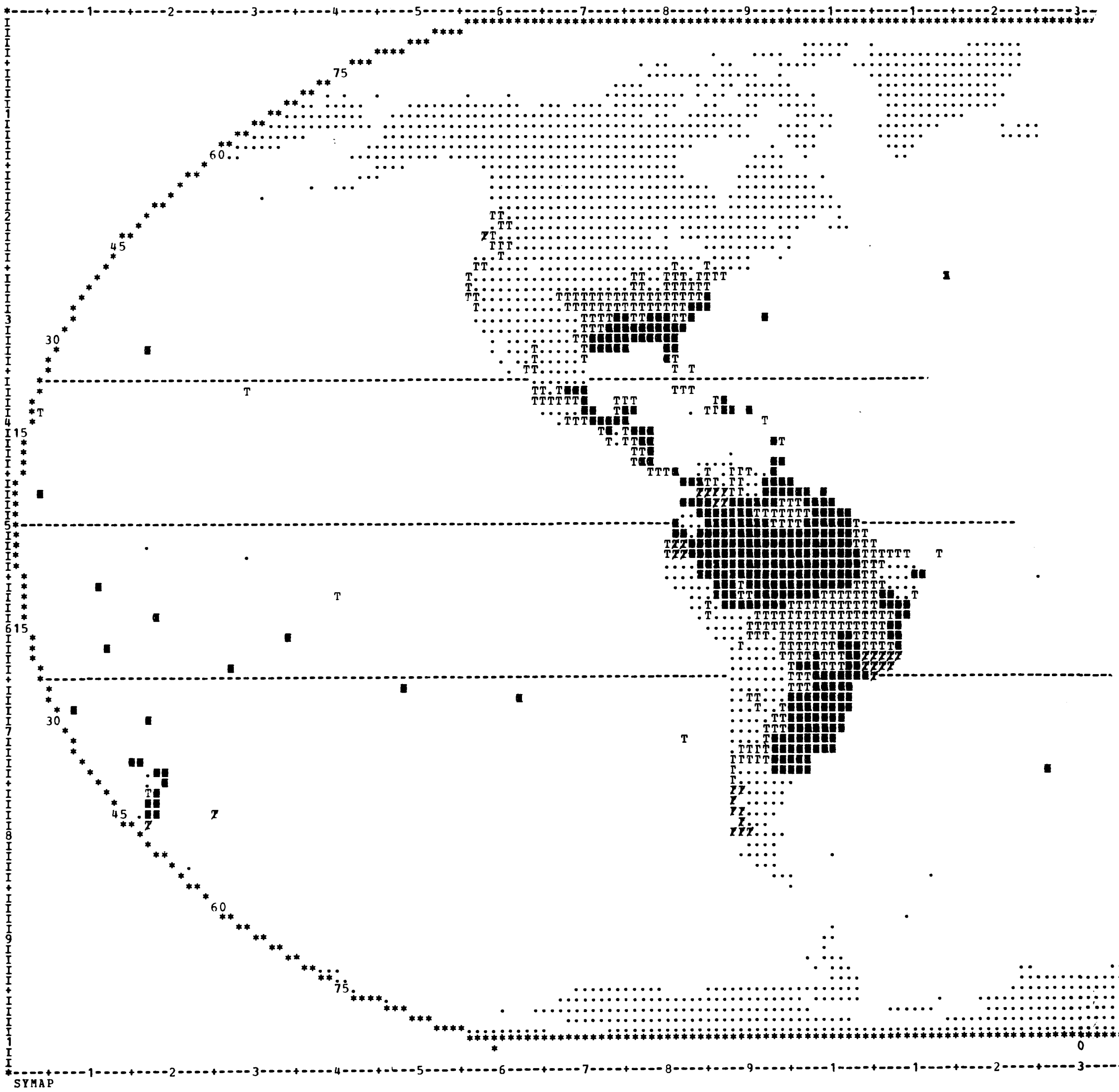
MINIMUM	BELOW	0.50	1.50	2.50	3.50	ABOVE 4.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

25.00	25.00	25.00	25.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

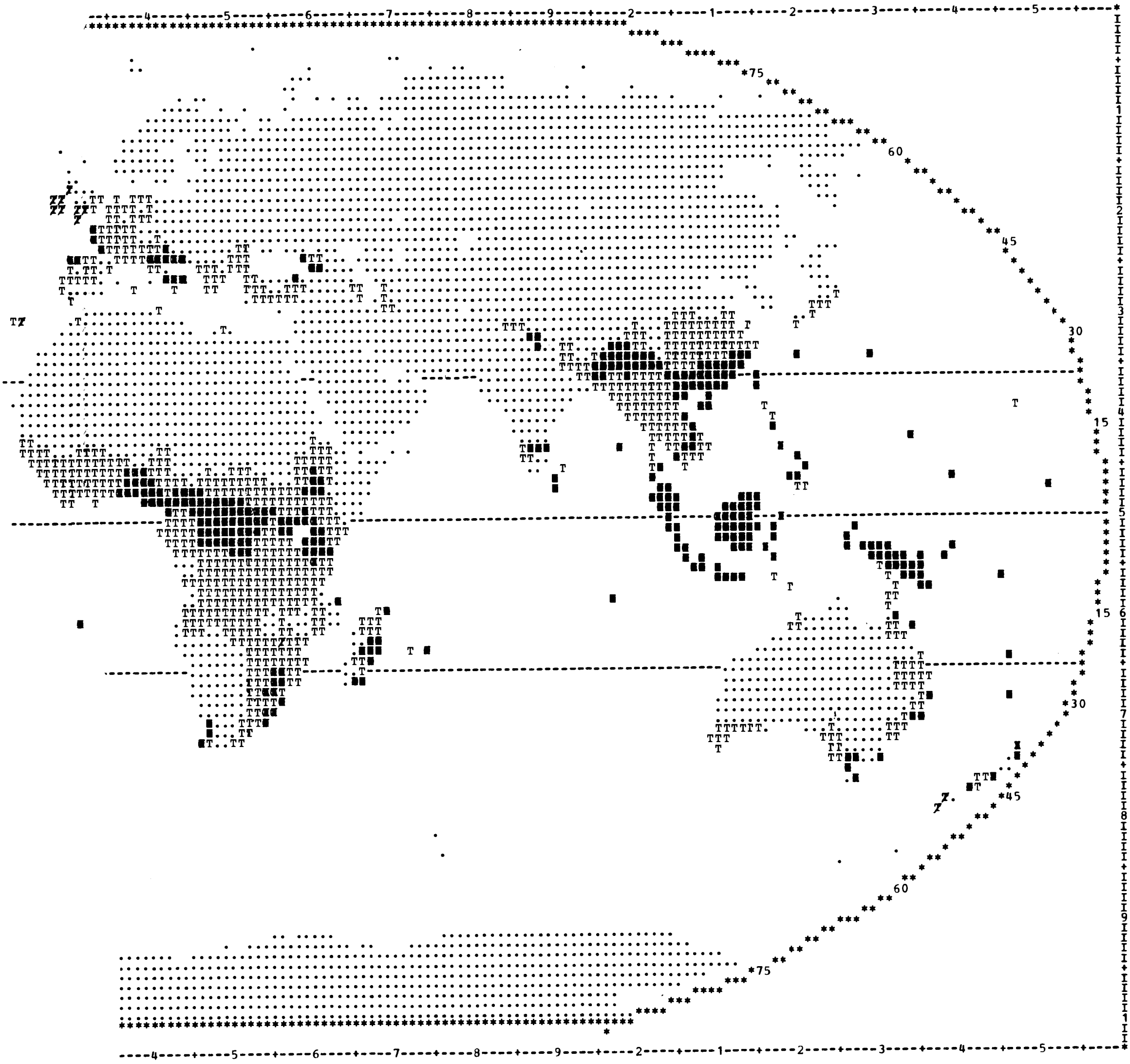
LEVEL	L	1	2	3	4	H
SYMBOLS	....	IIIIIIIII	IIIIIIIII	YYYYYYYYY	ZZZZZZZZZ	■■■■■■■■■
FREQ.	720	188	34	181	77	81
FORMS	NONE	TBEL	BEGV	BRGV	BSGV	MULT



Map 22. Predicted distributions of major epiphyte types

Epiphytes (evergreen forms only) are generally restricted to tropical and relatively mild temperate climates with sufficient moisture for woody host plants. Wintergreen epiphytes (e.g. mistletoe) extend into fairly cold and/or dry areas but continue to be active during the unfavorable period. Broad and narrow-leaved (evergreen) epiphytes occur in generally frost-free climates, the former requiring more humidity to support its larger leaf area. Tropical broad-leaved epiphytes are not shown to occur separately here because they occur in climates which generally support the other types as well. Areas of predicted co-occurrence usually involve all three forms (141 occurrences) but also NLE + BWGE (53 occurrences, generally subtropical) and only 2 occurrences of NLE + TBEE without BWGE (Bogota and Quito).

TBEE = Tropical Broad-Evergreen Epiphytes
NLE = Narrow-Leaved Epiphytes
BWGE = Broad-WinterGreen Epiphytes
MULT = co-important epiphyte forms



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	BELOW	0.50	1.50	2.50	ABOVE 3.50
MAXIMUM	0.50	1.50	2.50	3.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

33.33	33.33	33.33

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	H
SYMBOLS	....	■■■■■■■■■	ZZZZZZZZZ	TTTTTTTTT	■■■■■■■■■
FREQ.	799	0	17	268	197
FORMS	NONE	TBEE	NLE	BWGE	MULT

F. Predicting world vegetation types

Describing, predicting and mapping vegetation types can be approached in a variety of ways using (among other criteria):

1. formation classes based on dominant growth forms (the traditional approach);
2. different combinations of constituent plant types (a more complete measure of vegetation structure); and
3. the number of constituent plant types present, with some considerations of relative importance.

These last two criteria lead to the concepts of physiognomic ecotones and form diversity of vegetation, which provide information not only on plant-type diversity but also on the general structural and functional diversity of entire ecosystems.

The simplest and perhaps the only way to present the world vegetation predictions in a single map is to map the most obvious single attribute, which is usually the dominant growth form. This is done in Map 23. The dominant form or forms are determined from the dominance hierarchy in the case of closed stands and from a combination of potential dominance, cover, and fitness in open stands. As one can see by examining Map 23, the dominant structural type is well predicted in almost all ecoclimate core areas and generally becomes problematic only in transitional areas. Among the maps, Map 23 is perhaps the best single index of model accuracy.

Identification of different combinations of predicted life forms, i.e. of different life-form spectra, was approached by means of a relatively simple enumeration program called NCOMBS (Box, unpublished). Out of 1225 sites there were 853 different combinations predicted, many differing, however, only with respect to understorey synusiae. The potential usefulness of this approach is illustrated in Table 13, in which tropical montane rainforest sub-types are differentiated according to different combinations of tree life forms. Interpretation of Table 13 and the world results is limited by the fact that they reflect only predicted presence or absence, with no consideration of importance. Addition of importance criteria would permit a type of life form-based ordination which may be more closely tied to environmental conditions than are current ordination methods.

One seldom sees maps of ecotones, so the map of predicted physiognomic ecotones and other regions of multiple but less distinct physiognomic forms (Map 24) presents an interesting pattern. The darker shaded areas may involve co-dominance by different structural types (mainly the more familiar ecotones between biomes, such as forest-steppe and forest-tundra) or prediction of two or more co-dominant forms of the same structural type (e.g. broad and narrow-leaved trees). These latter indicate areas of physiognomic diversity and coexistence within areas usually recognized as more or less uniform biomal units. Such areas can be thought of as physiognomic ecotones even though they may retain considerable ecological unity, e.g. northern mixed conifer-hardwood forests.

G. Physiognomic diversity of vegetation

Since the plant types used in the model represent well defined ecophysiognomic forms, the number of forms predicted at each site represents a measure of the physiognomic diversity of the vegetation. An initial prediction of world physiognomic diversity among dominant and sub-dominant forms (using results from the earlier model, Box 1978a) is presented on Map 25. The earlier model contained only those understorey forms which do become dominant somewhere in the world (e.g. tundra shrubs in boreal forest understorey) and so is slightly biased toward the cooler regions. Since some forms differ physiognomically more than others, it was necessary to group similar forms. The groupings used are the same as those for Maps 10–22 and generally represent commonly recognized growth forms.

The increase in number of forms along gradients of increasing aridity has been documented several times (see, for example, Shreve 1936; Whittaker & Niering 1965; Whittaker 1975; Mooney & Dunn 1970), and many authors have suggested that there can always be a greater variety of forms in open vegetation stands, where light is not limiting. One thus would expect the highest form diversity in semi-deserts and open woodlands (especially those of warmer climates) and the lowest form diversity in the climatic core areas of the various physiognomic forest types.

In looking at Map 25 one can see that this is

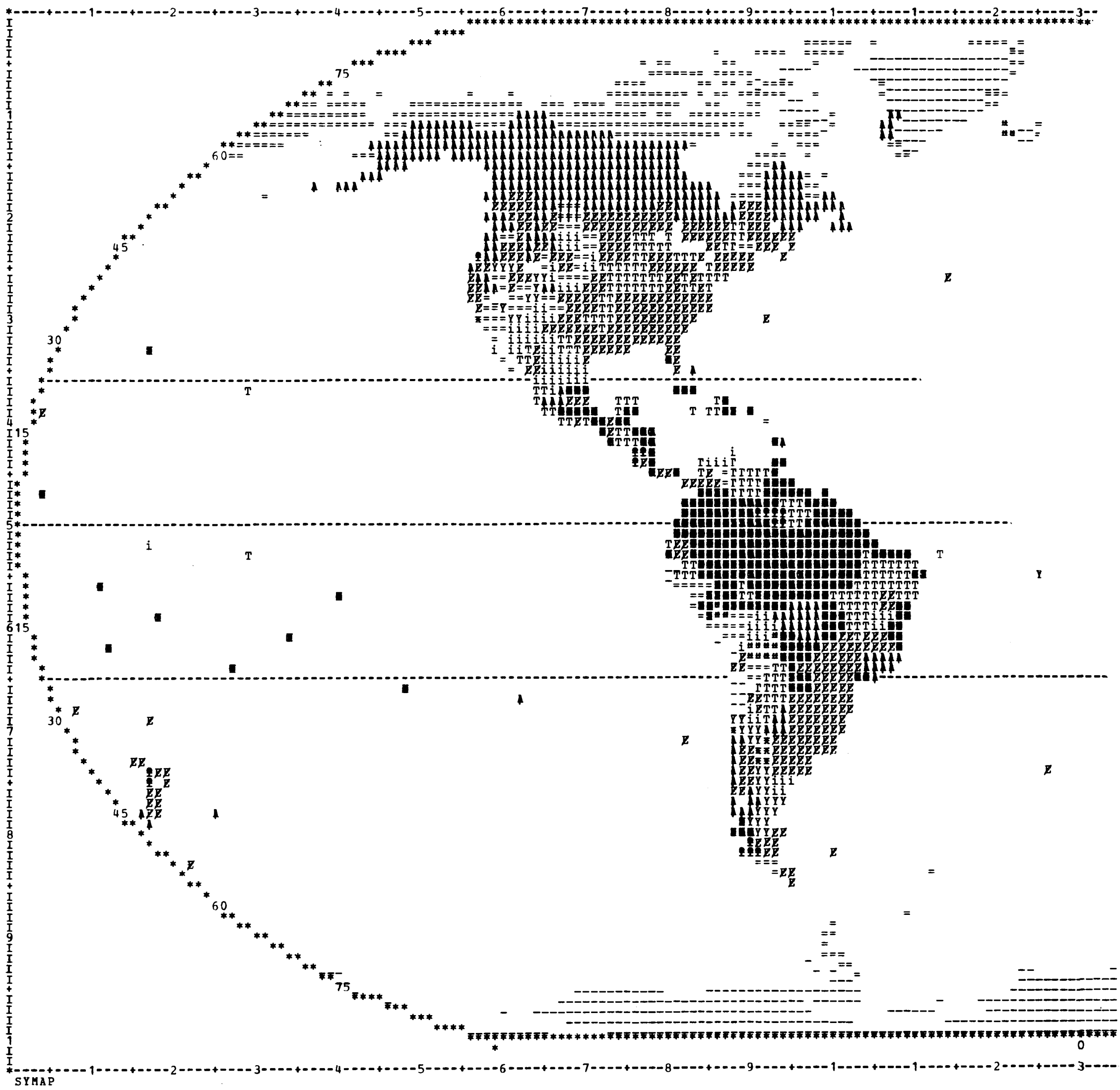
Table 13. Differentiation of tropical montane rainforest sub-types according to different combinations of constituent life forms.

The use of life-form combinations as a basis for perhaps greater resolution of vegetation types is illustrated using various predicted combinations which involve tropical montane rainforest trees. The different combinations of tree forms are shown in the left column with the corresponding vegetation types juxtaposed in the right column. The numbers in parentheses indicate the actual numbers of combinations (involving all life forms) which were predicted. (These numbers closely reflect the actual numbers of sites involved, since only two combinations occur at more than one site.) Among the 1225 sites in the world data-base, 60 different combinations of all life forms (63 sites) were predicted which involve tropical montane rainforest trees. All 60 also involve tropical evergreen microphyll and small trees. Of the 60, 16 also involve cloud-forest trees and can be called Mid-Montane Cloud Forest sites. Twelve of the 60 involve lowland rainforest trees and can be called Lower-Montane Rainforest sites. The remaining 32 sites involve neither cloud-forest nor lowland trees and represent the true Mid-Montane Rainforest. Further subdivisions are possible, as shown, involving admixtures of sclerophyll, raingreen, temperate summergreen, linear-leaved, and palmiform trees or small trees. Note that the combinations and frequencies reflect only presence or absence of the various forms but not their importance. Consideration of importance (e.g. proximity to environmental limits) will require further development of the identification program (NCOMBS).

Life-form combinations	Corresponding vegetation type
Tropical montane rainforest trees (60)	
(always with evergreen microphyll and small trees)	
with cloud-forest trees (16)	Mid-montane cloud forest
with neither cloud nor lowland trees (32)	Mid-montane rainforest
with sclerophyll trees (27)	drier mid-montane forest
with raingreen trees (13)	semi-deciduous mid-montane forest
with sclerophyll and raingreen trees (12)	
with neither sclerophyll nor raingreen trees (4)	
with summergreen trees (17)	subtropical semi-deciduous mid-montane forest
without linear-leaved trees (3)	
without palmiform tuft-trees/treelets (5)	
with lowland rainforest trees (12)	Lower-montane rainforest
(always with palmiform and linear-leaved trees)	
with sclerophyll trees (8)	drier lower-montane forest
with raingreen trees (5)	semi-deciduous lower-montane forest
with neither sclerophyll nor raingreen trees (3)	

indeed the pattern which is predicted. The highest physiognomic diversity is predicted for the subtropical-tropical semi-deserts of Australia, Chihuahua, Sonora-Arizona, and southern Africa. The lowest diversity is predicted for areas where a particular life form is well established, as in the tropical rainforests, and in the extreme climates of the dry and cold deserts, where total diversity is low.

Not so readily expected are the form-diversity levels predicted for boreal areas (generally imagined to be monotonously uniform), which are shown as higher than those of summergreen forest areas such as eastern North America and western Europe. In boreal areas one can readily identify three tree forms which occur throughout most of the region: the evergreen and summergreen needle-trees and the summergreen broad-microphyll (betuloid) trees. These tree forms are complemented by various shrub and herb forms, making a total of five forms, even though the evergreen conifers may exclude the other forms almost completely in older stands. In the nemoral (typical four-season temperate) regions the dominant summergreen broad-leaved trees are generally complemented by at most one other tree form, the temperate evergreen needle-trees. Shrubs

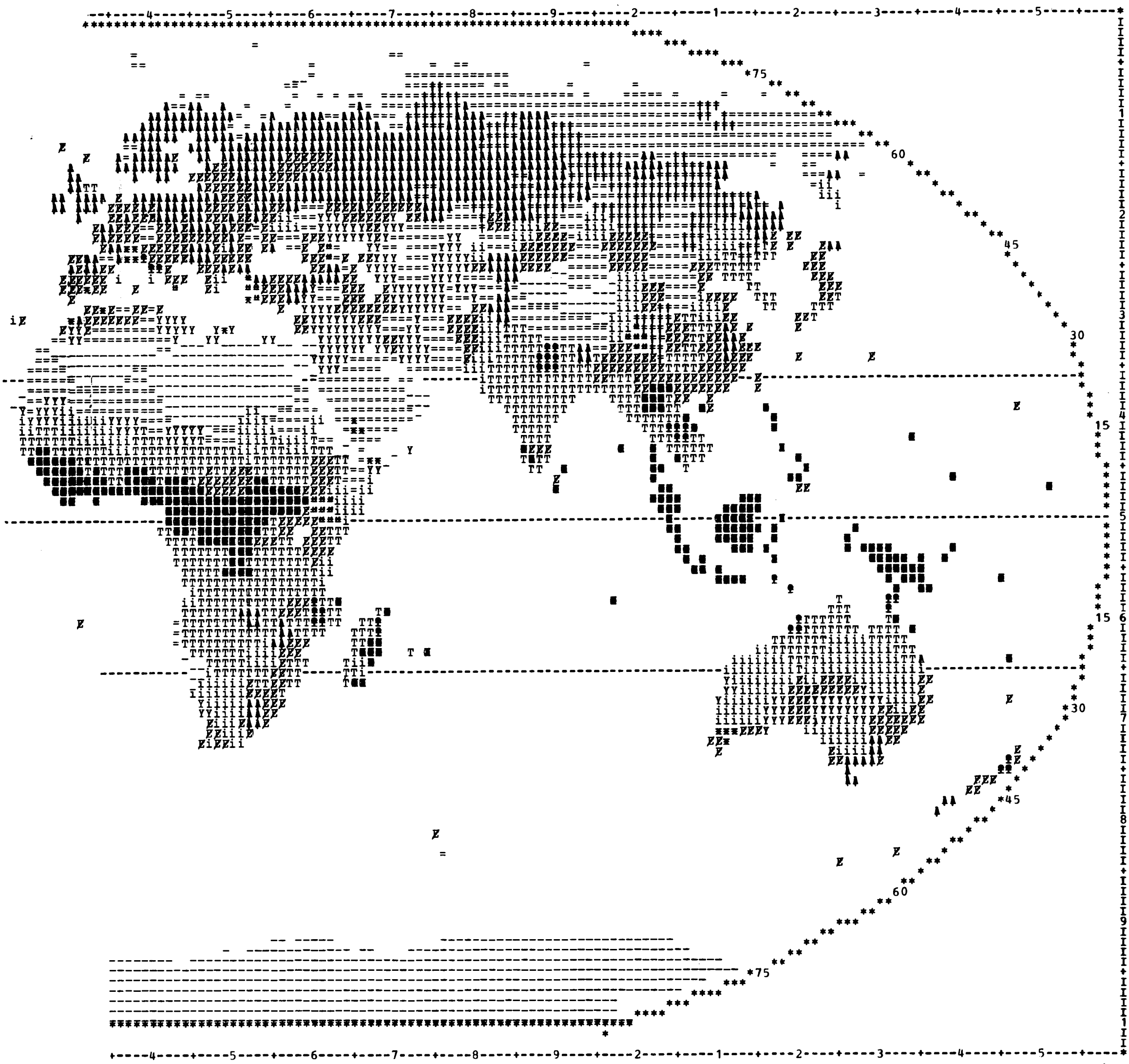


Map 23. Predicted dominant growth forms.

Tree forms are predicted as formation dominants in all humid and some moderately subhumid areas with sufficient summer warmth. Broad-leaved trees are favored in climates which are very productive at least seasonally (humid tropical and warm-summer temperate climates). Narrow and needle-leaved trees, mainly conifers and often more sclerophyllous, are favored in climates with at least seasonal stress but in which longer growing seasons must be realized to provide sufficient annual net production. In drier climates, in which transpiring leaf area and respiring biomass may need to be reduced, trees disappear and shrubs may dominate, especially where their deeper root systems provide an advantage in dry seasons over herbaceous forms. Where precipitation is low but reliable (during a sufficiently warm season), graminoids may attain dominance, with this dominance extended into adjacent areas by fire, grazing, etc. Succulent, rosette, and smaller herbaceous forms can attain dominance only in certain less favorable climates and occur more commonly as sub-dominants or understorey forms. The areas of predicted co-dominant growth forms (physiognomic ecotones) are treated in more detail on Map 24.

TRF = Tropical RainForest (broad-evergreen trees)
BEGT = other Broad-leaved EverGreen Trees
DECT = broad-leaved DECiduous Trees
NEGT = Narrow/Needle-leaved EverGreen Trees
NSGT = Needle-leaved SummerGreen Trees
T/A = small trees, Tuft-treelets and Arborescents

SCRB = xeric SCRuB (including desert shrubs and succulents)
SHRB = SHRuBs and other frutescent forms (non-desert)
TG = Tall Grasses
HERB = short grasses and other HERBaceous forms
ECOT = physiognomic ECOTones (co-dominant growth forms)



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

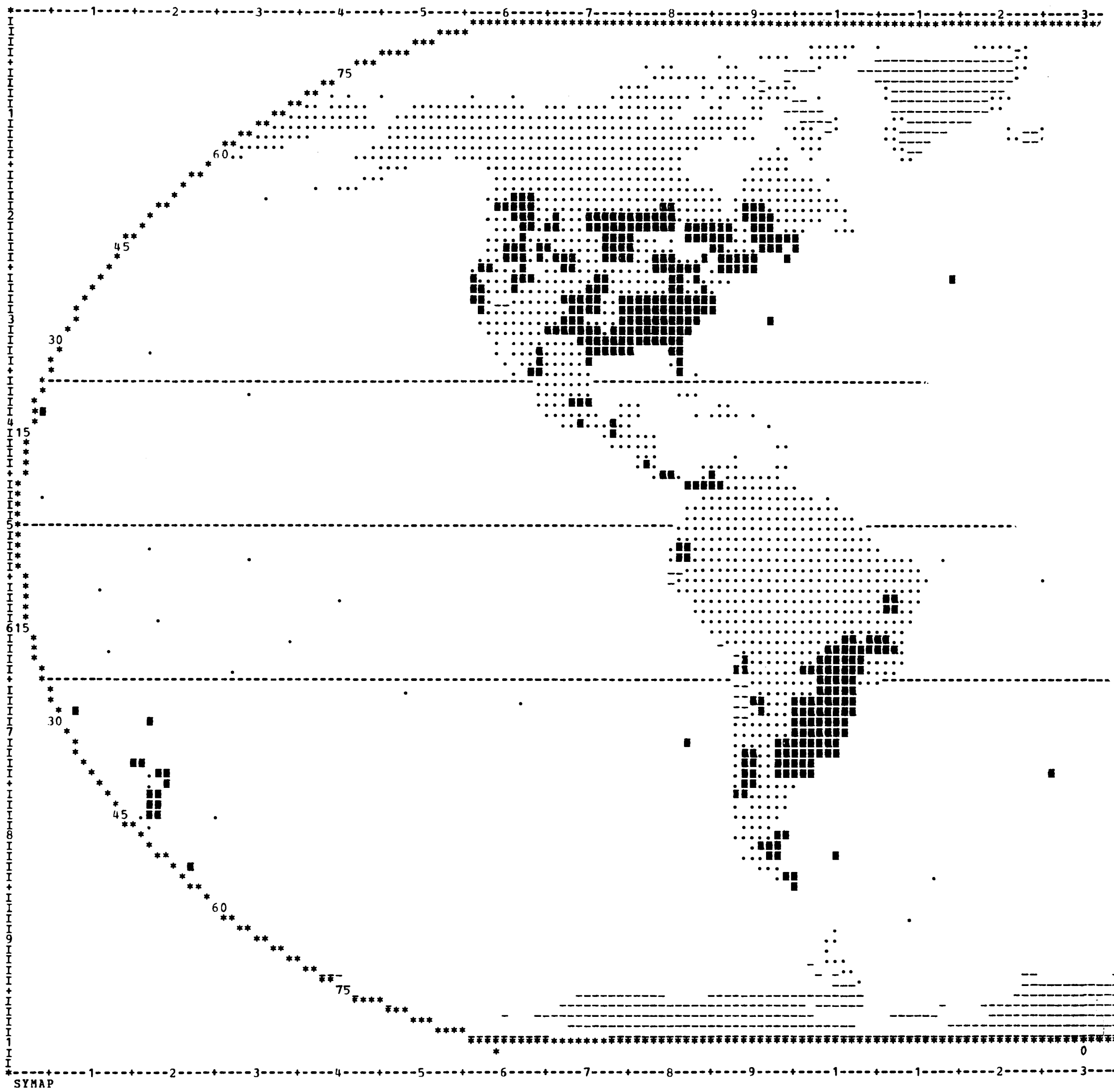
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	ABOVE 10.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

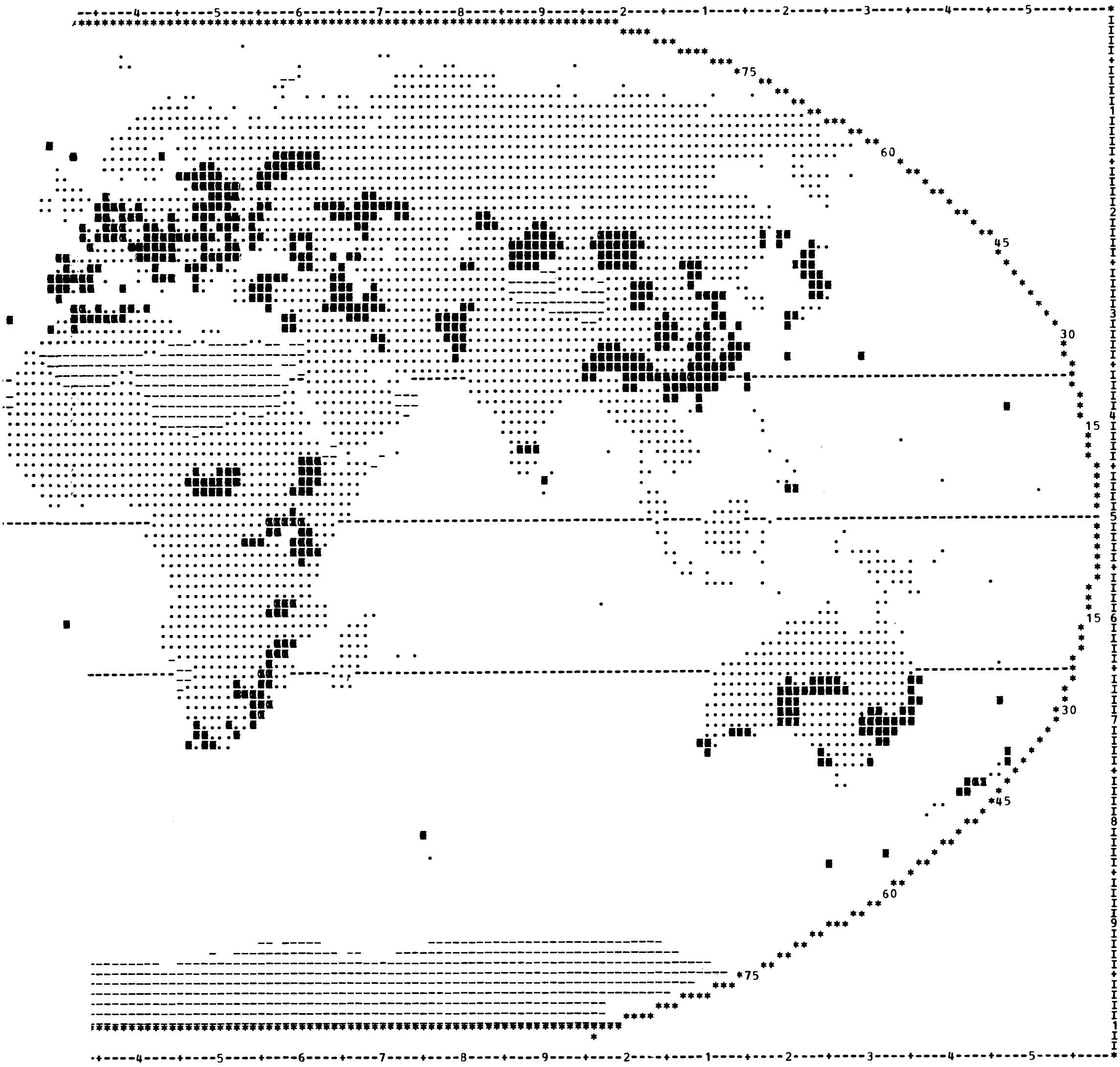
LEVEL	L	1	2	3	4	5	6	7	8	9	10	H
SYMBOLS	---------	■■■■■■■■■	♀♀♀♀♀♀♀♀♀	TTTTTTTTT	AAAAAAAAA	‡‡‡‡‡‡‡‡‡	iiiiiiiii	YYYYYYYYY	xxxxxxxxx	#########	=========	ZZZZZZZZZ
FREQ.	68	142	16	147	209	31	89	49	25	8	204	293
FORMS	NONE	TRF	BEGT	DECT	NEGT	NSGT	T/A	SCRB	SHRB	TG	HERB	ECOT



Map 24. Predicted distribution of physiognomic ecotones.

Physiognomic ecotones are areas dominated by more than one growth form. Co-dominant woody forms (usually tree forms) are predicted for large areas of eastern North America and South America, much of Europe, a belt around the African equatorial rainforest, parts of the Middle East (non-trees), eastern India, northern Japan, and large areas of East Asia and southern Australia (non-trees). The areas of co-dominant tree forms are often semi-deciduous mixed forests but may contain only subordinate admixtures of the second form. Areas of more than two co-dominant tree types (94 occurrences) are predicted especially in southeastern USA, southern Brazil, northeastern Argentina (often erroneously), western and southern Europe, southern Africa, southern China, eastern Australia, and New Zealand. Areas of co-dominant evergreen and deciduous broad-leaved trees, without narrow-leaved trees, are predicted at only a very few sites, mainly in the Far East. Areas of co-dominant broad and narrow/needle-leaved trees (91 occurrences) are predicted much more commonly, mainly in sub-boreal, sub-mediterranean, east-coast subtropical, and tropical-montane areas. Among non-tree co-dominants, areas involving more than two basic growth forms (29 occurrences, commonly xeric shrubs and bunch-grasses) are predicted especially in temperate-continental (cold-winter) semi-desert areas. Other predicted ecotones generally involve one woody and one non-woody, usually graminoid form, i.e. savannas, shrub-steppes, or very open woodlands.

SINGLE = SINGLE dominant form
ECOT = physiognomic ECOTones



DATA VALUE EXTREMES ARE 0.0 11.00

TOTAL SUPERIMPOSED DATA POINTS IS 135. THESE OCCUR IN 60 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

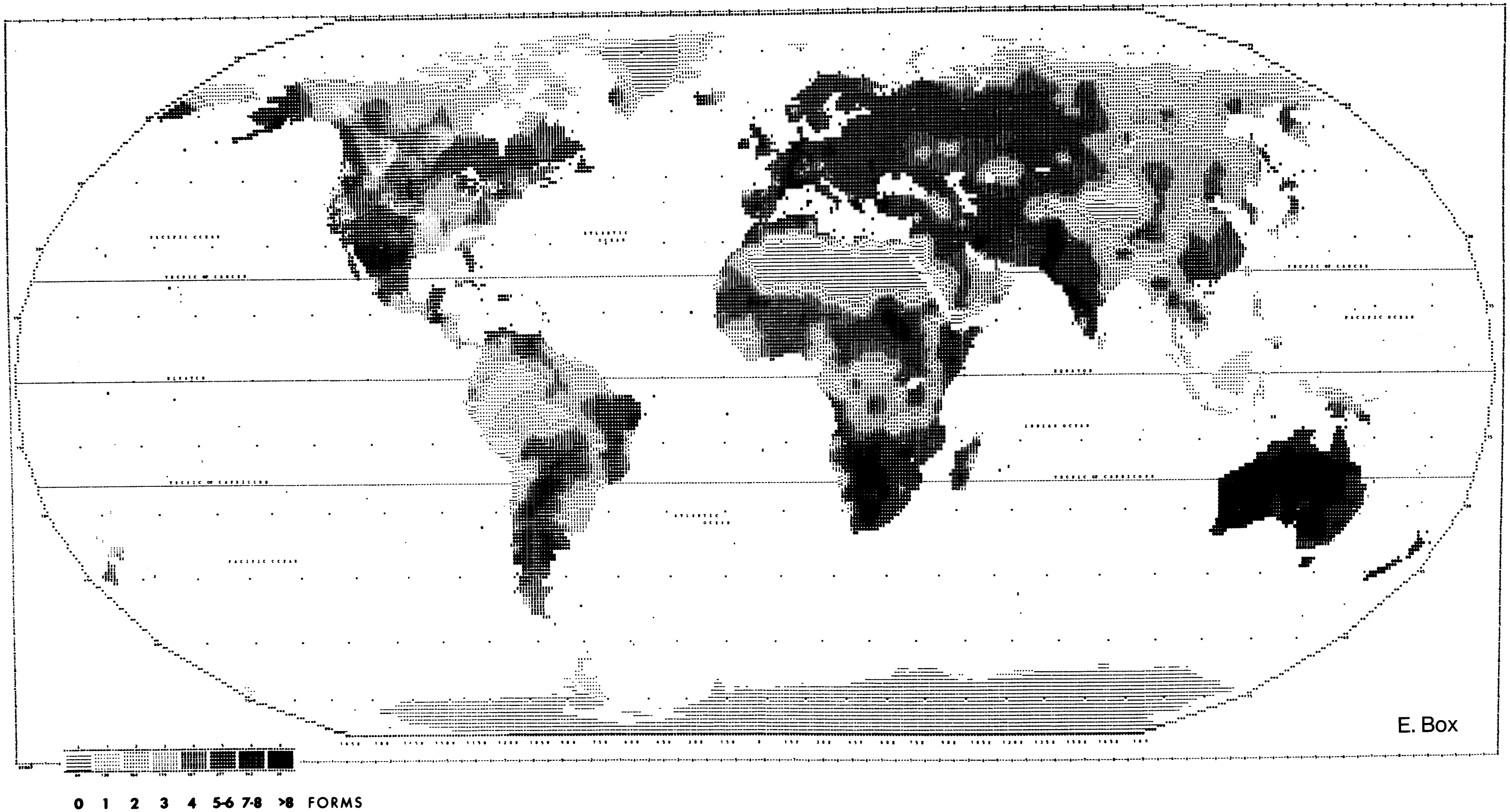
MINIMUM	BELOW	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	ABOVE 10.50
MAXIMUM	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	4	5	6	7	8	9	10	H
SYMBOLS	---------	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	:::::::::	■■■■■■■■
FREQ.	68	142	16	147	209	31	89	49	25	8	204	293
FORMS	NONE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	ECOT



Map 25. Predicted physiognomic diversity of dominant vegetation.

and forbs occur also, but the physiognomic diversity in the tree synusia is actually higher in the boreal forest.

Maps of total (all growth forms) and higher-synusial physiognomic diversity predicted by the expanded current model are being prepared. The largest numbers of life forms (not grouped into growth forms) predicted by the current model and the corresponding sites include the following:

46 at Montevideo (Uruguay)

42 at Buenos Aires (Argentina), Jonkershoek (South Africa), and Gabo Island (Victoria)

41 at Ceres (Argentina), Rio Grande do Sul (Brazil), Pilgrim's Rest and Ladysmith (South Africa), Napoli (Italy), and Santa Cruz das Flores (Azores)

40 at Porto Alegre (Brazil), Tampa (Florida), and Southport (Queensland).

These sites are characteristically subtropical, near-coastal (or montane in South Africa), and receive at least some summer rainfall. Many of these sites are in regions which are relatively poorly predicted by the model (see validation and Appendices B–D).

Attempts to study the physiognomic diversity of vegetation, including seasonal aspects, have been very few. Unfortunately, most of these studies are not directly comparable with the results in Map 25 because they are restricted to particular plant characters, vegetation synusiae, or geographic regions. Vareschi, for example, has done considerable work on leaf shapes and sizes in the tropics and has suggested (Vareschi 1973) that the greatest diversity in tropical leaf forms is to be expected in the high-montane cloud forests. One recent diversity study which suffers less from the above-mentioned restrictions is that of Givnish (1975). By plotting life-form diversity against rainfall unpredictability for various world vegetation types, Givnish suggests (as have Whittaker, May and others) that environmental variability leads to greater structural and functional diversity. The predicted pattern of physiognomic diversity shown in Map 25 seems to be consistent with this suggestion.

H. General observations and problems

One can see immediately from the vegetation maps and frequency statistics that the predicted vegetation patterns are generally reasonable. Tree, shrub and most grass forms appear to be most accurately predicted, while problems exist with slow-growing succulent forms in particular. Natural ecotones appear to cover about 30% of the earth's land area. (Lieth, personal communication, has also suggested this figure.) The expected general patterns of dominant vegetation type (Map 23) and physiognomic diversity (Map 25) are also predicted. A particular affinity between humid tropical mountains and Southern Hemisphere maritime climates is seen in the prediction of cloud-forest trees and tropical linear-leaved trees in both regions (Appendices B and C). Projection of climatic envelopes of some forms based on single-region prototypes suggests ecophysiognomic equivalents in other parts of the world. These include the Himalayan and Rocky Mountain conifer forests as equivalents and the *Araucaria* and 'Southern pine' forests (admixtures) of southern Brazil and the southeastern U.S.A.

A number of contradictions between predicted and actual vegetation can also be identified. Most can be explained by the exclusion from the model of the appropriate limiting mechanisms.

The most obvious discrepancies seem to be the following:

1. Tropical dry evergreen woodlands (e.g. 'campos cerrados' of Brazil) are not separated from dry and wet raingreen forests.
2. Raingreen trees are predicted for large areas of Australia dominated by evergreen eucalypts.
3. Arctic tundra areas are shown as dry steppes; tropical alpine areas, on the other hand, may be shown as being too wet.
4. Arborescent and other stem-succulents do not occur in all dry environments and the model does not correctly determine in which they do occur.
5. Succulents are predicted for large parts of Australia and North Africa, but few species are native there and they are unimportant.
6. Tropical subalpine cloud forests are not distinguished from the extremely maritime evergreen rainforests of southern Chile and New Zealand.

Lack of predictive mechanisms involving length and degree of dry and favorable seasons, diurnal and interannual variation, and soil water situations can be cited as responsible for most of these discrepancies. The apparent overestimation of dryness of arctic environments and underestimation of dryness in tropical mountains, however, suggests that the Thornthwaite estimate of potential evapotranspiration is not accurate in these and other extreme regions. It has already been suggested (chapter 4) that the Thornthwaite estimate generally underestimates tropical PET and may overestimate in arctic areas, at least relative to the Holdridge (1959) estimate (see also Box, in preparation).

Prediction is complicated in some areas by non-climatic factors. The actual vegetations in the first two cases above ('campos cerrados' and northern Australia) appear to be partial reflections of low soil nutrient supplies (Rawitscher 1948; Cole 1960). A number of authors (e.g. Beard 1953; Beadle 1966; Walter 1973) have pointed out the particular edaphic problems of many savanna and open-woodland areas. Anomalous evergreenness has frequently been interpreted as an adaptation to low nutrient levels (e.g. Monk 1966; Beard 1976). Various authors (e.g. Walter 1973; Beard 1976) have also observed that, within arid regions, there do not appear to be any obvious climatic correlates for the distributions of stem-succulents. They do seem to prefer arid regions with humidity or with more than one rain period per year, which would exclude most of the Sahara-Arabian-Turanian belt.

General note on the vegetation maps

Predicted vegetation distributions and structure are represented in three ways:

1. Most important life form(s) within general structural classes (Maps 10, 12, 14–22).
2. 'Fitness' (proximity to closest climatic limit) of the locally most important life form(s) (Maps 11 and 13).
3. Dominant growth form and physiognomic ecotones (Maps 23 and 24).

Predicted formation dominants are shown only on Map 23. The term 'important' refers to 'dominance' within a given structural category.

Because of low site density the patterns appearing on all climatic and vegetation maps will be unreliable in some areas. This problem is much worse on the vegetation maps because of the nearest-neighbor mapping algorithm which must be used for typological maps. Whereas the weighting effects of the contour algorithm produce generally reasonable isolines, the nearest-neighbor algorithm distorts the shapes of nearly all life-form zones, depending on the proximities of adjacent sites with different life forms. One must look at the centers of individual life-form areas and ignore the exact computer-produced boundaries.

There are at least two other computer-generated artifacts to be kept in mind:

1. What appear to be excessively large life-form areas, including extensions too far into polar or arid regions, may be due to low site density combined with nearest-neighbor interpolation. This is the case especially in northern Canada and Alaska and in Northern Russia and northeastern Siberia.
2. Apparent conflicts in the spatial extent of corresponding life-form (Maps 10 and 12) and fitness zones (Maps 11 and 13) are due to the use of the different interpolation algorithms. The nearest-neighbor algorithm reduces the reach of adjacent absence zones and causes the life-form areas of Maps 10 and 12 to appear larger.

Symbols appearing on the vegetation maps are identified by abbreviations (see symbolism strip accompanying each map) which are explained in the legend for each map. The symbols for the fitness maps (Maps 11 and 13) represent intervals for proximity to climatic limits, as explained in the main text.

CHAPTER 7

Evaluation of model results

Formal validation has not been a traditional method for evaluating geobotanical models. World-scale models have usually been designed as correlations between vegetation patterns and environmental factors, with the emphasis much more on geographic description than on prediction and verification. Geobotanists have often relied on colleagues working or visiting in other parts of the world for evaluation of world-scale classifications, maps, and rudimentary models. In order to assess both the hypothetical basis and the implications of the model presented herein, however, a systematic means of checking the accuracy of vegetation predictions is needed. This need can be met by the methodology for formal validation of complex systems models developed recently by systems ecologists (see, for example, Caswell 1976). For predictive vegetation models this sort of rigorous validation implies direct comparison of predicted and actually occurring vegetation at particular sites not used for developing the model. These validation sites should be ecologically appropriate (free of unusual non-climatic influences but not necessarily euclimatopes), and there should be enough sites in different regions and climates to test all parts of the model. Model sensitivity to unusual conditions, including climate change, should also be studied.

A. Site comparison of predicted and actual vegetation

Where both vegetation descriptions and climate data are available, the best method for evaluating vegetation predictions is to compare predicted and actual vegetation at selected actual sites. Site comparisons permit one to compare predictions with actual vegetation observed without geographic or ecologic generalization. Such comparisons can be made within the normal framework of formal validation provided that the predicted plant-form spectra can be presented in a form which can be compared directly with actual vegetation formations. This can be done by using the cover and dominance models to interpret plant-form spectra as formation types. Comparison of actual and predicted individual synusiae (life forms) can be made by comparing the full spectra (Appendix C) with species lists (Appendix D; see also Box 1978a, Table 8).

There are certain unavoidable criteria for the choice of validation sites:

1. The actual vegetation must be natural or semi-natural in the sense that it should be free of large-scale geologic or anthropogenic physical disruptions, such as pavement or agricultural use, or maintenance in a particular state, as by mowing.
2. The sites should be free of overriding edaphic or other non-climatic complications.
3. The set of sites used for validation must represent as many climatic and vegetation regions as possible, since the ecoclimatic envelopes of the individual plant forms are independent of each other. Sites from both core areas and transitional vegetation should be included.
4. An adequate vegetation description, including species lists, must be available for each site,

either from the literature or from personal observations.

5. The necessary macroclimatic data must be available for the site.
6. The site must not be included in the data-base used for developing the model.

Personal observation is the best method for assessing actual vegetation but is not possible everywhere, since few geobotanists have seen the whole world. Finding site descriptions which include complete climatic data meant that descriptions had to be obtained from a variety of sometimes less traditional botanical sources.

In order to diminish whatever bias may exist in any particular method of vegetation description, it is perhaps better to select sites from a number of sources, such as:

1. Examples of local vegetation and associated climate from books on the vegetation of large areas. This represents the best way of covering large areas and numbers of vegetation types.
2. Detailed studies of local vegetation, in which vegetation and climate are described in detail for a specific site.
3. Sites observed personally.
4. Sites selected by the availability of illustrative material such as photographs (but with the necessary climate data).

Sites of the first type may tend to represent core areas, which are often easier to predict but which can cover large areas. The other sources need not present this bias.

About 85 sites were selected initially for the attempted validation. Half were from North America but all continents except Antarctica were represented. The sites were chosen primarily from sources 1 and 3 and were supplemented by studies of local vegetation in order to include situations not otherwise included. The sites from books were selected mainly from the volumes on the vegetation of individual large land-masses by Knapp (1965, 1973), Hueck (1966), and Walter (1968, 1973). These volumes were used because, as observed earlier, they are almost the only works covering large areas which present both sufficient physiognomic information and the required climatic data. These sources are supplemented by Küchler's (1964) map and manual of the potential vegetation of the USA and by other maps in other areas (e.g. UNESCO 1969; Emberger 1938; Küchler 1977). Most sites involve at least two sources of vegetation data. More specific site descriptions were always sought but could not always be found. The initial set of sites was culled to remove sites which involve major non-climatic problems or for which sufficient information on actual vegetation could not be found. The remaining data-base of 65 sites, of which the author had observed 23 personally, was used for validation of the initial model (Box 1978a). These sites remain quite instructive for validation since development of the current model involved primarily addition of new forms and only widening of climatic limits and since the original 65 sites were deliberately set aside and not consulted until the current model was completed. The only reason for retaining the original 65 sites was the time required for obtaining so many new site descriptions. Nine new sites were added, however, in order to improve representation of various regions, climate types and known types of actual vegetation. The nine new sites were obtained primarily from recent journal papers (mainly *Vegetatio*) and are all in the Eastern Hemisphere.[1]

The final data-base for validation consists of 74 sites, of which 30 are in North America and 23 are in mountainous areas (excluding high plateaus). Seven pairs of neighboring sites within the same general climate type are included (all in the Western Hemisphere) in order to illustrate effects of local variation. Other distributional aspects of the validation sites are presented in Table 15.

Validation data for each site include a list of the most important species occurring at and near each site and a formation name provided by the data source but modified if necessary to conform to the nomenclature used herein (Table 8). The names of actual formations contain the names of dominant genera where possible. Of course it is easier to generalize for the less well-known sites. For a few sites where the natural vegetation has been largely destroyed (e.g. São Paolo, Nanyuki) one must rely on the description of potential vegetation. The vegetation descriptions for most sites not observed

[1]Two of these sites were obtained at the last minute from the 'Ecosystems of the World' volume on heathlands by Specht (1979), which had just appeared. This and the other volumes of this series promise to be excellent world-scale sources of both descriptive and quantitative vegetation data.

Table 14. Predicted and actual vegetation at 74 validation sites.

Probably the best way to evaluate a predictive vegetation model is to compare corresponding predicted and actual vegetation at a geographically representative set of validation sites not used in developing the model. This was done using 74 sites (from all continents except Antarctica) chosen primarily by availability of the necessary paired site or regional vegetation descriptions (with species lists) and climatic data.

The sites are listed vertically in the left column, along with general location and annual moisture index (MI), which provides the basis for naming predicted formations. (Geographic coordinates and site climatic values, as well as the complete spectra of predicted forms, are given in Appendix C).

Predicted formation type and important constituent forms are shown in the center column. Some relatively similar forms are grouped into a single line in order to conserve space. Predicted dominant forms are indicated by an asterisk in closed formations (MI $>$ 0.9) or a plus in open formations (MI $<$ 0.9). The other forms are listed generally in order of decreasing dominance and, within dominance levels, by increasing proximity to environmental limits. The predicted life-form spectra are interpreted and the corresponding formations named according to criteria described in Tables 8 and 9 (sections 5.C–5.F).

Juxtaposed in the right column is the corresponding actual vegetation, as determined from descriptions and species lists identified and summarized more completely in Appendix D. The actual vegetation shown consists of a formation name (generally with dominant species or genera) and a short list of the most important actually occurring taxa.

Sites at which the actual dominant forms and only they are predicted to occur and to dominate (i.e. the exact combination of the dominant forms, the 'strong criterion') are indicated in the left column by two asterisks before the site name. Sites at which the actual dominant forms are all predicted to occur (but at which the other conditions for the strong criterion are not met) are indicated by a single asterisk before the site name. A summary of prediction accuracy for the validation sites is presented in Table 15.

Site	Predicted vegetation	Actual vegetation
**Fairbanks (interior Alaska, 134 m) MI = 0.74	Boreal Semi-Open Needle Forest with summergreens: *Boreal/montane short-needled trees Boreal summergreen needle-trees Broad-summergreen shrubs Needle-leaved evergreen shrubs Short bunch and sward-grasses Summergreen forbs	Boreal *Picea-Betula* forest, with *Larix, Populus, Salix, Arctostaphylos, Empetrum, Vaccinium,* and various tundra herbs.
**Vancouver (British Columbia) MI = 2.25	Diverse Needle-Leaved Rainforest with summergreens: *Boreal/montane short-needled trees *Temperate needle-trees *Sub-mediterranean needle-trees *Temperate rainforest needle-trees *Summergreen broad-leaved trees Boreal summergreen needle-trees Boreal broad-summergreen trees	*Thuja-Tsuga-Pseudotsuga* Rainforest with *Pinus, Abies, Populus, Acer, Prunus, Arbutus, Berberis, Rhododendron, Vaccinium, Rubus,* forbs, ferns, etc.
**Banff (Alberta, 1397 m) MI = 0.98	Boreal/Montane Needle Forest with summergreens: *Boreal/montane short-needled trees Boreal summergreen needle-trees Broad-summergreen small trees Needle-leaved evergreen shrubs Summergreen shrubs and tundra dwarf-shrubs Tall and short grasses Summergreen forbs	Boreal-Montane transitional *Picea-Abies* forest, with *Pinus, Larix, Betula* and understorey shrubs and herbs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
*Saskatoon (Saskatchewan) MI = 0.70	Short-Grass Prairie with scattered shrubs and needle-trees: +Short bunch and sward-grasses Boreal summergreen needle-trees Boreal/montane short-needled trees Broad-summergreen small trees Needle-leaved evergreen shrubs Xeric summergreen shrubs Leafless shrubs and dwarf-shrubs Summergreen forbs	Northern Grove Belt and *Festuca* Prairie: *Festuca, Koeleria, Danthonia,* et al. with *Populus tremuloides, Rosa arkansasa,* and prairie forbs.
*Swift Current (Saskatchewan) MI = 0.71	Short-Grass Prairie with scattered needle-trees and shrubs: +Short bunch and sward-grasses Boreal summergreen needle-trees Boreal/montane short-needled trees Broad-summergreen small trees Tall grasses Needle-leaved evergreen shrubs Xeric summergreen shrubs Cold-winter and leafless xeric shrubs Summergreen forbs	Northern limit of Northern Short and Mixed-Grass Prairie, with *Bouteloua, Stipa, Buchloë* et al. plus *Atriplex, Artemisia, Opuntia* and prairie forbs.
**Sioux Lookout (Ontario) MI = 1.44	Boreal Forest with summergreens: *Boreal/montane short-needled trees Summergreen broad-leaved trees Boreal summergreen needle-trees Boreal broad-summergreen trees	Central Boreal Forest: *Picea-Abies,* with *Betula, Populus, Larix, Pinus, Vaccinium,* evergreen and summergreen herbs.
**Lac Albanel (Québec) MI = 1.60	Boreal Forest with summergreens: *Boreal/montane short-needled trees Summergreen broad-leaved trees Boreal summergreen needle-trees Boreal broad-summergreen trees	Eastern Boreal Forest: *Picea-Abies,* with *Larix, Pinus, Thuja, Betula, Populus, Vaccinium,* evergreen and summergreen herbs.
*Olympia (Washington, on Puget Sound) MI = 2.05	Temperate Mesic Needle-Forest with Broad-Evergreen Understorey: *Temperate needle-trees *Sub-mediterranean needle-trees Temp. broad-evergreen small trees Tall and short graminoids Various forbs, ferns, etc.	Tall, dense *Pseudotsuga* rainforest with *Tsuga, Thuja, Pinus, Abies, Arbutus, Acer, Berberis, Prunus, Rhododendron,* evergreen and summergreen herbs.
**Davis (central valley of California) MI = 0.49	Short Bunch-Grass Steppe with various forbs and mostly smaller shrubs: +Short bunch-grasses Bush stem-succulents Leafless and mediterranean dwarf-shrubs Summergreen forbs Xeric cushion-shrubs and herbs Succulent forbs Needle-leaved, hot-desert and mediterranean evergreen shrubs	California Bunch-Grass Prairie with many forbs: *Stipa, Aristida, Festuca,* etc. with spring ephemerals, prairie forbs, *Salvia, Artemisia,* and scattered *Opuntia.*

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
*Tanbark Flat (southern California, 863 m in San Gabriel Mtns.) MI = 0.92	Mediterranean Evergreen Shrubland with trees: *Mediterranean evergreen shrubs Needle-leaved evergreen shrubs Sub-mediterranean needle-trees Mediterranean broad-evergreen trees Dwarf-needle small trees Tropical broad-evergreen shrubs Mediterranean dwarf-shrubs Xeric evergreen tuft-treelets and scrub Tall and short grasses Bush stem-succulents Summergreen forbs	*Adenostoma* (needle-leaved) Chaparral with *Arctostaphylos, Ceanothus, Rhamnus, Quercus* scrub, *Rhus, Salvia,* grasses and forbs.
**West Yellowstone (Montana - NW Wyoming, 2035 m) MI = 1.29	Montane Needle Forest with summergreens: *Boreal/montane short-needled trees Boreal summergreen needle-trees Boreal broad-summergreen trees	Montane *Picea-Abies* forest with *Pseudotsuga, Pinus, Larix, Populus, Salix, Vaccinium, Cornus,* forbs etc.
*Logan (northern Utah, 1455 m) MI = 0.67	Mixed Semi-Deciduous Montane Shrubland: +Short bunch-grasses +Needle-leaved evergreen shrubs +Cold-winter xeromorphic shrubs +Dwarf-needle small trees +Xeric summergreen shrubs Summergreen forbs Leafless scrub	Semi-deciduous montane 'deciduous chaparral': *Cercocarpus, Quercus, Arctostaphylos, Ceanothus, Purshia, Amelanchier, Acer, Rhus,* with grasses and forbs.
**Cody (northern Wyoming, 1519 m) MI = 0.44	Short Bunch-Grass Steppe with numerous xeric shrubs: +Short bunch-grasses +Xeric summergreen shrubs +Cold-winter xeromorphic shrubs Leafless xeric dwarf-shrubs Summergreen forbs Xeric cushion-herbs Desert-grasses Ephemeral desert herbs	*Artemisia*-Short Grass Steppe, with *Agropyron, Festuca, Stipa* et al., *Purshia, Lupinus, Atriplex, Opuntia.*
*Flagstaff (northern Arizona, 2070 m) MI = 1.04	Temperate Montane Needle-Forest with summergreens: *Boreal/montane short-needled trees *Temperate needle-trees Summergreen broad-leaved trees Boreal summergreen needle-trees Boreal broad-summergreen trees	Southern Rocky Mtn. *Pinus ponderosa* forest, with other *Pinus* spp., *Populus, Ceanothus* and *Quercus* scrub, bunch-grasses and steppe forbs.
*Phoenix (southern Arizona, 339 m) MI = 0.18	Hot Semi-Desert with Stem-Succulents: +Hot-desert evergreen shrubs +Arborescent stem-succulents Xeric rosette-shrubs Other stem-succulents Succulent forbs Leafless xeric shrubs Desert-grasses Ephemeral desert herbs	Colorado Valley *Larrea-Franseria* (90–95%) Semi-Desert, with scattered desert grasses, stem-succulents, dwarf-shrubs and abundant summer and winter ephemerals. (Larger stem-succulents restricted now to surrounding mountains).

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Tucson (southern Arizona, 739 m) MI = 0.29	Hot Semi-Desert with Mixed Shrubs and Stem-Succulents: +Raingreen thorn-scrub +Xeric summergreen shrubs +Evergreen arborescents +Hot-desert evergreen shrubs +Arborescent stem-succulents Xeric rosette-shrubs Typical and bush stem-succulents Mediterranean and leafless dwarf-shrubs Xeric cushion-shrubs Xeric evergreen tuft-treelets Short bunch and desert-grasses Summergreen, raingreen and succulent forbs Ephemeral desert herbs	Upland *Larrea-Cercidium-Opuntia* Semi-Desert (diverse) with tall cacti, plus *Prosopis, Olneya, Franseria, Fouquiera, Carnegiea, Echinocereus, Ephedra,* and abundant desert grasses, summer ephemerals and fewer winter ephemerals.
*Santa Fe (northern New Mexico, 1929 m) MI = 0.60	Mixed Xeric Shrub-Steppe with Needle-Trees: +Short bunch and sward-grasses +Needle-leaved evergreen shrubs +Summergreen scrub and xeric shrubs Cold-winter xeromorphic shrubs Leafless xeric shrubs +Boreal summergreen needle-trees Dwarf-needle small trees Summergreen forbs	Open Juniper-Piñon Woodland with small shrubs, turf and bunch grasses but fewer forbs: *Juniperus, Pinus, Cercocarpus, Ceanothus, Quercus scrub, Artemisia, Chrysothamnus, Agropyron, Bouteloua, Buchloë.*
*Colorado Springs (east base of Rocky Mtns., 1855 m) MI = 0.64	Mixed Xeric Shrub-Steppe with Needle Trees: +Short bunch-grasses +Needle-leaved evergreen shrubs +Summergreen scrub and xeric shrubs Leafless xeric shrubs +Short sward-grasses Boreal/montane short-needled trees +Boreal summergreen needle-trees Dwarf-needle small trees Summergreen forbs	Southern Short and Mixed-Grass Prairie with *Bouteloua, Muhlenbergia, Aristida, Stipa, Andropogon* et al. plus scattered *Juniperus, Yucca glauca, Opuntia* and various steppe forbs.
**Custer (Black Hills/ S. Dakota, 1622 m) MI = 0.94	Open, Grassy Needle-Tree Woodland: *Boreal/montane short-needled trees Boreal summergreen needle-trees Broad-summergreen small trees Needle-leaved evergreen shrubs Broad-summergreen shrubs +Short bunch and sward-grasses Tall grasses Summergreen forbs	Black Hills Pine Forest (locally open), with *Prunus, Arctostaphylos, Juniperus, Symphoricarpus, Artemisia, Cercocarpus, Rhus trilobata, Elymus, Poa, Agropyron, Koeleria, Bouteloua* and various forbs.
*Oelrichs (S. Dakota, south of Black Hills, 1017 m) MI = 0.74	Short Mixed-Grass Steppe with Shrubs: +Short bunch and sward-grasses Summergreen forbs +Needle-leaved evergreen shrubs +Summergreen scrub and xeric shrubs Temperate needle-trees Leafless xeric shrubs	Short Mixed-Grass Steppe: *Agropyron-Stipa* with *Koeleria, Buchloë, Bouteloua* et al. plus many steppe forbs and scattered small shrubs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
*Oklahoma City (central Oklahoma) MI = 0.93	Summergreen Grassy Open Woodland: +Summergreen broad-leaved trees and small trees Sub-mediterranean needle-trees +Summergreen scrub and shrubs Needle-leaved evergreen shrubs Dwarf-needle small trees Temp. broad-evergreen small trees Temperate broad-evergreen shrubs Bush stem-succulents +Tall grasses +Short bunch and sward-grasses Summergreen forbs	Southern Tall-Grass Prairie: red-clay *Stipa-Koeleria* association with scattered *Quercus* and *Carya* spp., *Andropogon, Bouteloua, Agropyron* et al., numerous steppe shrubs and semi-shrubs (e.g. *Amorpha*) and numerous prairie forbs.
**Bartlesville (northeastern Oklahoma, 218 m) MI = 1.08	Dry Summergreen Forest (semi-open): *Summergreen broad-leaved trees Broad-summergreen small trees Dwarf-needle small trees Broad-evergreen and summergreen shrubs Tall grasses (incl. cane-grasses) Short sward-grasses Summergreen forbs	*Quercus* Woodland - Tall Grass Mosaic on fine shale, with closed oak coves: *Quercus marilandica* and *Q. stellata, Carya, Cercis, Celtis, Prunus; Andropogon, Bouteloua, Elymus* et al., plus numerous prairie forbs.
**South Bend (northern Indiana, 221 m) MI = 1.42	Summergreen Broad-Leaved Forest: *Summergreen broad-leaved trees Broad-summergreen small trees (incl. boreal) Temperate needle-trees Tall grasses Summergreen forbs	Summergreen Oak-Hickory Forest (western limit): *Quercus, Carya, Acer rubrum, Fraxinus, Tilia, Ulmus, Prunus, Cercis,* with many grasses and forbs.
**Columbus (Ohio, 243 m) MI = 1.43	Summergreen Broad-Leaved Forest: *Summergreen broad-leaved trees Broad-summergreen small trees (incl. boreal) Temperate needle-trees Tall grasses Summergreen forbs	Summergreen Beech-Maple Forest: *Fagus, Acer saccharum, Fraxinus, Quercus, Carya, Betula, Prunus, Aesculus* et al., with *Lonicera canadensis* and many forbs.
**Bar Harbor (Acadian coast of Maine) MI = 2.20	Sub-Boreal Mixed Semi-Deciduous Forest: *Temperate needle-trees *Summergreen broad-leaved trees *Boreal/montane short-needled trees Boreal broad-summergreen trees Summergreen and evergreen shrubs Tall grasses	Spruce-Northern Hardwood Forest on glacial till and sand: *Picea, Abies, Pinus strobus, Thuja, Tsuga, Betula, Populus, Acer, Quercus, Fagus,* with *Vaccinium,* other ericaceous and summergreen shrubs, grasses, sedges and forbs.
**Trenton (New Jersey, on Delaware River) MI = 1.46	Summergreen Broad-Leaved Forest: *Summergreen broad-leaved trees Temperate needle-trees Broad-summergreen small trees Boreal broad-summergreen trees Tall grasses	Appalachian Summergreen *Quercus-Castanea* Forest with *Liriodendron, Acer, Fagus* et al., plus *Pinus, Betula, Tsuga, Prunus, Cornus, Vaccinium, Kalmia,* summergreen shrubs, grasses and forbs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Mt. Mitchell (western N. Carolina, 2 miles ssw of summit, 1989 m) MI = 3.56	Montane Needle-Forest with summergreens: *Boreal/montane short-needled trees Summergreen broad-leaved trees Broad-summergreen small trees Boreal broad-summergreen trees Evergreen and summergreen mesic shrubs Tall and short grasses Summergreen and evergreen forbs	Appalachian Fir-Spruce Forest: *Abies fraseri, Picea rubens,* with *Sorbus, Prunus, Betula, Acer, Vaccinium, Rhododendron, Rubus* and mostly northern forbs and graminoids.
**Charleston (S. Carolina coast) MI = 1.20	Warm-Temperate Mixed Semi-Summergreen Forest: *Warm-temperate broad-evergreen trees *Summergreen broad-leaved trees *Heliophilic long-needled trees Temperate broad-rainforest trees Tropical sclerophyll and microphyll trees Palmiform tuft-treelets Broad-evergreen small trees Broad-summergreen small trees Swamp summergreen needle-trees Arborescent grasses Tall and short grasses Evergreen and summergreen forbs and vines Narrow-leaved and wintergreen epiphytes	Lowland Warm-Temperate Mixed Forest: *Quercus virginiana, Q. laurifolia, Q. alba, Q. phellos, Pinus taeda, Liquidambar, Nyssa, Magnolia* with *Ilex, Persea, Cornus, Sabal palmetto, Bumelia, Vaccinium, Myrica, Baccharis, Arundinaria, Tillandsia,* many vines, grasses, forbs, and *Taxodium* in swamps.
**Savannah (Georgia, 25 km from coast) MI = 1.20	Warm-Temperate Mixed Semi-Summergreen Forest: *Warm-temperate broad-evergreen trees *Summergreen broad-leaved trees *Heliophilic long-needled trees Tropical sclerophyll and microphyll trees Palmiform tuft-treelets Broad-evergreen small trees Broad-summergreen small trees Swamp summergreen needle-trees Arborescent grasses Tall and short grasses Evergreen and summergreen forbs and vines Narrow-leaved and wintergreen epiphytes	Coastal-Plain Pine-Hardwood Forest: *Quercus virginiana, Q. phellos, Pinus, Liquidambar, Nyssa, Magnolia* with *Persea, Ilex, Cornus, Prunus, Sabal palmetto, Vaccinium, Myrica, Arundinaria, Tillandsia,* many vines, grasses, forbs, and *Taxodium* swamps.
*Birmingham (north-central Alabama, 182 m) MI = 1.57	Warm-Temperate Mixed Semi-Summergreen Forest: *Heliophilic long-needled trees *Warm-temperate broad-evergreen trees *Summergreen broad-leaved trees *Temperate broad-rainforest trees Tropical evergreen microphyll-trees Temp. broad-evergreen small trees Broad-summergreen small trees Swamp summergreen needle-trees Arborescent grasses Tall and short grasses Evergreen and summergreen forbs and vines Wintergreen epiphytes	Southern Pine-Summergreen Oak Forest: *Quercus* (summergreen, with evergreen), *Pinus, Carya, Nyssa* et al., with *Cornus, Cercis, Prunus, Vaccinium, Taxodium* along rivers, and many shrubs, grasses, forbs and vines.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Xilitla (Mexico, 1035 m in Sierra Madre Oriental) MI = 2.58	Subtropical Montane Semi-Summergreen Forest with needle-trees: *Summergreen broad-leaved trees *Warm-temperate broad-evergreen trees *Tropical linear-leaved trees Tropical montane rainforest trees Tropical evergreen microphyll-trees Tropical broad-evergreen small trees Swamp summergreen needle-trees Palmiform tuft-trees Broad-summergreen small trees Broad-evergreen lianas and vines Arborescent grasses Tall and short grasses Evergreen and raingreen forbs Broad and narrow-leaved epipytes	Tropical Montane Mixed Semi-Summergreen Rainforest with Holoarctic Species: *Quercus, Carpinus, Carya, Liquidambar, Pinus, Cornus, Podocarpus,* with *Turpinia, Clethra, Vaccinium, Eugenia, Garrya, Ilex, Rhus, Parthenocissus,* and many holarctic herbs, including ferns.
**Mazatlan (Mexico, Pacific coast at Tropic of Cancer) MI = 0.70	Dry Raingreen Woodland and Dense Scrub: *Raingreen thorn-scrub *Tropical evergreen sclerophyll trees *Xeric raingreen trees *Broad-raingreen small trees Xeric evergreen tuft-treelets Bush stem-succulents Evergreen arborescents Leaf-succulent evergreen shrubs Short bunch-grasses Raingreen forbs and vines	Lowland Dry Raingreen Thorn Forest: *Ipomoea arborescens, Acacia, Zizyphus, Bauhinia, Ceiba, Prosopis, Caesalpinia, Jatropha, Cordia, Mimosa,* and many others, plus *Cassia, Croton, Fouquiera, Cereus, Pachycereus,* and many grasses, forbs and vines.
**Quibdo (Colombia, west base of Andes) MI = 6.10	Wet, Diverse Tropical Rainforest: *Tropical rainforest trees Palmiform tuft-trees and understorey Tropical evergreen microphyll-trees Tropical broad-evergreen small trees Tropical evergreen lianas and vines Broad and narrow-leaved epiphytes Evergreen forbs and ferns	Equatorial Coastal Rainforest: tall, diverse, multistorey forest with *Terminalia, Brosimum, Ficus, Hura, Hevea, Cedrela, Tabebuia* and countless others, plus riverine palm thickets and swamps, and numerous lianas, epiphytes, ferns, and smaller trees and arborescent shrubs.
*Barinas (Venezuela, east base of Cordillera de Mérida) MI = 1.14	Tropical Semi-Deciduous Forest: *Tropical evergreen sclerophyll trees Palmiform tuft-trees and treelets *Tropical evergreen microphyll-trees *Monsoon broad-raingreen trees *Tropical rainforest trees Raingreen and evergreen understorey trees, forbs, and vines	Tradewind Raingreen Forest with scattered evergreens: *Spondias, Pterocarpus, Bombacopsis, Sapium, Hura, Brosimum, Terminalia, Swietenia* et al., with understorey palms and arborescent shrubs, many grasses, forbs, and epiphytes (*Ficus, Phoradendron,* etc.).
**Obidos (Brazil, Amazon Basin) MI = 1.12	Tropical Semi-Deciduous Dry Rainforest: Tropical evergreen sclerophyll trees Palmiform tuft-trees Tropical evergreen microphyll-trees *Monsoon broad-raingreen trees *Tropical rainforest trees Raingreen and evergreen understorey trees, forbs, and vines	Dry Tropical Rainforest with Campos Cobertos (islands of drier open forest): *Curatella, Anacardium, Bowdichia, Vochysia, Byrsonima* et al., with *Cassia, Eugenia, Crotalaria,* tall and short grasses, and many other species.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Quixeramobim (Brazil, north-western Caatingas) MI = 0.43	Raingreen Thorn-Woodland: *Raingreen thorn-scrub *Arborescent stem-succulents *Broad-raingreen small trees and occasional larger trees Xeric evergreen tuft-treelets Xeric rosette-shrubs Typical and bush stem-succulents Evergreen arborescents Short and desert grasses Raingreen forbs	True Caatinga (Raingreen Thorn-Woodland with palms and tall stem-succulents): *Zizyphus, Mimosa, Cassia, Caesalpinia, Acacia, Cavanillesia* et al., with *Cocos, Copernicia,* ground bromeliads, *Cereus, Opuntia, Capparis, Euphorbia, Jatropha,* short grasses but few forbs.
*Belo horizonte (Brazil, 200 km. north of Rio de Janeiro, 857 m.) MI = 1.72	Diverse Tropical Upland Semi-Evergreen Forest: *Tropical linear-leaved trees *Montane broad-raingreen trees *Tropical montane rainforest trees Tropical evergreen microphyll trees Tropical broad-evergreen small and dwarf trees Tropical evergreen sclerophyll trees Broad-raingreen small trees Palmiform tuft-trees Tropical broad-evergreen lianas Arborescent grasses Tall and short grasses Evergreen and raingreen forbs and vines Wintergreen epiphytes	Campos Cerrados-Mixed Forest Transition: dwarf evergreen woodland (*Kielmeyera, Byrsonima, Machaerium* et al.) with dense grass cover, small palms, arborescent shrubs, and numerous forbs, plus mixed semi-raingreen forest mainly in valleys.
**São Paolo (southern Brazil, 740 m) MI = 1.63	Diverse Subtropical Upland Semi-Deciduous Forest: *Montane broad-raingreen trees *Tropical linear-leaved trees *Temperate needle-trees *Tropical montane rainforest trees *Temperate rainforest needle-trees *Warm-temperate broad-evergreen trees Heliophilic long-needled trees Tropical evergreen microphyll trees Tropical evergreen sclerophyll trees Broad-evergreen small trees Broad-raingreen small trees Palmiform tuft-trees Tropical broad-evergreen lianas Arborescent grasses Tall and short grasses Evergreen, raingreen and summergreen forbs Broad and narrow-leaved epiphytes Evergreen and raingreen vines	Subtropical Species-Rich Semi-Deciduous Forest: *Cedrela, Balfourodendron, Hymenaea, Centrolobium, Machaerium, Piptadenia,* and many others, with numerous palms, dense underbrush, and numerous lianas, vines and epiphytes.
*Villa Nougues (Tucumán province of northwestern Argentina, 1388 m) MI = 2.22	Subtropical Montane Mixed Semi-Deciduous Forest: *Tropical montane rainforest trees *Temperate rainforest needle-trees *Montane broad-raingreen trees *Tropical linear-leaved trees *Summergreen broad-leaved trees Broad-raingreen small trees	Southern Andes Subalpine Alder Belt (near lower limit): *Alnus jorullensis, Juglans, Podocarpus, Prunus, Sambucus, Ilex, Berberis,* with mainly northern shrubs and forbs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
	Tropical microphyll and sclerophyll trees Summergreen and evergreen small trees Temperate needle-trees Arborescent, tall and short grasses Evergreen and deciduous forbs and vines	
Isla Victoria (Lago Nahuel Huapi, 900 m in southern Andes, 41°S) MI = 3.22	Temperate Needle-Leaved Rainforest with summergreens: *Temperate rainforest needle-trees Broad-summergreen small trees Temp. broad-evergreen trees Boreal broad-summergreen trees Evergreen and summergreen shrubs Tall and short grasses Evergreen and summergreen forbs	Patagonian Lower-Montane *Nothofagus* Rainforest, with *Eucryphia, Drimys, Libocedrus, Podocarpus, Saxegothea,* understorey *Weinmannia, Laurelia,* and many ferns, epiphytes, and often bamboos.
*Bariloche (Argentina, 825 m, near Lago Nahuel Huapi) MI = 2.16	Temperate Montane Needle-Forest: *Boreal/montane short-needled trees Temperate rainforest needle-trees Sub-mediterranean needle-trees Evergreen and summergreen small trees Summergreen scrub and shrubs Evergreen dwarf-shrubs Tall cane-graminoids Short sward and bunch-grasses Evergreen, summergreen and raingreen forbs	Patagonian Lower-Montane *Libocedrus* Forest: *L. chilensis* (to 90%), with *Lomatia, Diostea, Schinus* and scattered *Araucaria,* plus *Berberis, Azara,* and steppe dwarf-shrubs and grasses.
**Valdivia (southern Chile, 40° S near coast) MI = 4.18	Diverse Temperate Mixed Rainforest: *Temperate rainforest needle-trees *Temperate broad-rainforest trees *Tropical montane rainforest trees *Tropical linear-leaved trees Tropical evergreen microphyll-trees Broad-evergreen small trees Arborescent grasses Tall and short grasses Evergreen forbs, vines, ferns and epiphytes	Temperate Species-Rich Broad-Macrophyll Rainforest (near transition to summergreen forest): *Aextoxicon, Eucryphia, Laurelia, Drimys* et al., with *Lomatia, Nothofagus, Fitzroya, Weinmannia, Cariaria,* plus numerous lianas, epiphytes, bamboos, forbs and mosses.
Ushuaia (mainland of Tierra del Fuego) MI = 1.23	Treeline Krummholz-Tundra Transition: *Tall turf and tussock-grasses *Summergreen tundra dwarf-shrubs *Temperate evergreen dwarf-shrubs Needle-leaved shrubs and krummholz Short bunch and sward grasses Summergreen and evergreen forbs Mat-forming thallophytes	Subantarctic Summergreen *Nothofagus* Forest (near southern limit), with scattered evergreen *Nothofagus,* plus *Berberis, Ribes, Pernettya, Escallonia, Chusquea* and other graminoids, and various, mostly summergreen forbs.
*Thingvellir (Iceland, 103 m) MI = 2.97	Herb-Dwarf Shrub Tundra with Krummholz and scattered trees: *Short sward and bunch-grasses Needle-leaved treeline krummholz Boreal/montane short-needled trees Broad-summergreen small trees Evergreen and summergreen dwarf-shrubs and forbs Summergreen ferns Thallophytes	Iceland Maritime 'Mo' Tundra (herbaceous with dwarf-shrubs and mosses): *Festuca, Carex, Agrostis, Juncus, Poa* et al., with *Salix, Empetrum, Calluna, Arctostaphylos,* various forbs and many mosses and lichens.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Abisko (northern Sweden, 388 m) MI = 0.74	Mixed Semi-Summergreen Forest-Tundra: Broad-summergreen small trees +Summergreen tundra dwarf-shrubs +Short bunch and sward-grasses Needle-leaved shrubs and krummholz Summergreen forbs and xeric herbs	Summergreen Fell-Birch Forest-Tundra: *Betula tortuosa, B. callosa,* with *Populus, Pinus* on moors, *B. nana, Empetrum, Vaccinium, Arctostaphylos, Loiseluria,* plus grasses, forbs, mosses and lichens.
*Lund (Dalby Söderskog) (southern Sweden) MI = 1.12	Sub-Boreal Mixed Semi-Deciduous Forest: *Boreal/montane short-needled trees *Temperate needle-trees *Summergreen broad-leaved trees Boreal summergreen needle-trees Boreal broad-summergreen trees Evergreen and summergreen shrubs and herbs	Summergreen *Ulmus-Quercus* Forest (undisturbed since 1916), with *Fagus, Fraxinus, Corylus, Crataegus, Prunus, Acer, Lonicera,* and various grasses and forest forbs.
*Mikulov/Weinviertel (northeastern Austria) MI = 0.95	Open Needle Tree-Mixed Shrub Mesic Woodland: +Temperate needle-trees +Boreal/montane short-needled trees +Boreal summergreen needle-trees +Broad-summergreen small trees Dwarf-needle small trees Broad-summergreen mesic shrubs Xeric summergreen shrubs Needle-leaved evergreen shrubs Temperate broad-evergreen shrubs Tall grasses Short bunch and sward grasses Summergreen forbs	Summergreen Woodland and Scrub with dry grassland mosaic: *Quercus, Carpinus, Pinus, Betula, Robinia* with *Festuca, Agropyron, Bromus, Poa, Convolvulus, Salvia, Artemisia* and various steppe forbs.
**Ain-Draham (coastal mountains of northern Tunisia, 739 m) MI = 2.01	Mediterranean Semi-Deciduous Montane Forest: *Summergreen broad-leaved trees *Mediterranean broad-evergreen trees Sub-mediterranean needle-trees Dwarf-needle small trees Broad-summergreen small trees and scrub Broad-evergreen and summergreen shrubs Tall graminoids Short sward and bunch-grasses Summergreen forbs and ferns Wintergreen epiphytes	Mediterranean Semi-Deciduous Montane Oak Forest: *Quercus faginea* ssp. *baetica* (SG), *Qu. suber* (EG), with *Sorbus, Prunus, Acer, Ilex, Crataegus, Erica arborea, Cytisus, Rubus,* and various grasses, mediterranean forbs, and epiphytic ferns and mosses.
**Azrou (Middle Atlas of Morocco, 1250 m) MI = 1.11	Mediterranean Evergreen Montane Forest: *Mediterranean broad-evergreen trees Sub-mediterranean needle-trees Temp. broad-evergreen small trees Tropical evergreen microphyll-trees Mediterranean shrubs and dwarf-shrubs Tall and short grasses Summergreen, raingreen and succulent forbs Wintergreen epiphytes	Mediterranean Montane Evergreen Oak Forest (near transition to cedars): *Quercus ilex* with *Sarothamnus, Cytisus, Crataegus, Cistus, Thymus, Rosa, Buxus, Pistacia,* and many vines (*Lonicera, Smilax,* et al.) grasses, dwarf and semi-shrubs, and forbs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Ksar-es-Souq (Saharan side of Middle Atlas, 1060 m) MI = 0.13	Hot-Desert Shrub Steppe: +Hot-desert evergreen shrubs Leafless scrub and dwarf-shrubs Typical stem-succulents Bush stem-succulents Xeric rosette-shrubs Succulent forbs Ephemeral desert herbs Desert-grasses	Sub-Saharan Plateau Shrub-Bunch Grass Steppe: *Artemisia, Anabasis, Ephedra, Stipa tenacissima, Aristida,* with other xeric shrubs and many, often yellow-flowered forbs.
**Damanhur (Egypt, area between Cairo and Alexandria) MI = 0.09	Sparse Hot-Desert Evergreen Scrub with ephemerals: Hot-desert evergreen shrubs Leafless scrub Small stem-succulents Succulent forbs Desert-grasses Ephemeral desert herbs Dry desert	*Artemisia-Thymelaea* Semi-Desert (10% cover), with *Aristida, Panicum, Zygophyllum, Asphodelus, Pituranthos* and various geophytes and ephemerals.
*Mahadday-Weyne (Somalia, 70 km north of Mogadisho) MI = 0.28	Raingreen Thorn-Scrub with Tall Stem-Succulents: *Raingreen thorn-scrub and small trees *Arborescent stem-succulents Typical and bush stem-succulents Xeric rosette-shrubs and tuft-treelets Leaf-succulent evergreen shrubs Xeric cushion-shrubs Short bunch and desert grasses Evergreen arborescents Raingreen and succulent forbs Raingreen vines Xeric cushion-herbs Ephemeral desert herbs	Dry Raingreen Thorn-Scrub: *Commiphora, Acacia, Capparidaceae, Anacardiaceae, Grewia* et al., plus short *Chrysopogon, Aristida, Sporobolus, Cenchrus,* etc., including scrub and forbs.
**Asmera (Eritrea, northern Ethiopia, 2372 m) MI = 0.59	Semi-Deciduous Scrub with some trees: +Tropical evergreen sclerophyll trees +Raingreen thorn-scrub +Broad-raingreen small trees +Short bunch-grasses Xeric evergreen tuft-treelets Bush stem-succulents Leaf-succulent and xeric cushion shrubs Raingreen forbs	Dry Thorn-Scrub, Dwarf-Shrub and Montane Grassland mosaic: *Acacia, Juniperus procera, Olea, Sanseveria, Celtis africana,* et al., *Acokanthera, Buxus, Euphorbia, Dracaena,* with *Festuca, Agrostis, Pentaschistis* and various forbs.
**Kericho (Western Kenya, 2042 m) MI = 2.31	Tropical Montane Rainforest: *Tropical montane rainforest trees *Tropical linear-leaved trees Tropical evergreen microphyll-trees Palmiform tuft-trees Tropical cloud-forest small-trees Tropical evergreen sclerophyll trees Treelets, tree ferns, shrubs, bamboos, other grasses, forbs, lianas and vines, epiphytes.	Equatorial Montane Rainforest: *Ocotea, Podocarpus,* with *Aningeria, Casearia, Ficus, Pygeum, Schefflera,* and many others, plus understorey trees, *Croton, Dracaena, Ficalhoa,* and numerous vines, forbs and epiphytes.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
**Nanyuki (central Kenya, 1947 m) MI = 0.93	Tropical Dry Montane Mixed Forest (open) with scrub: *Tropical xeric needle-trees Montane broad-raingreen trees Tropical evergreen microphyll-trees Tropical evergreen sclerophyll trees Broad-raingreen small trees Palmiform tuft-trees and treelets Raingreen thorn-scrub Tall grasses, including some bamboo Short bunch and sward grasses Bush stem-succulents Tropical broad-evergreen shrubs Palmiform mesic rosette-shrubs Tropical evergreen and raingreen forbs and vines Wintergreen epiphytes	Region of potential Dry Montane Conifer Forest (open, with thorn-scrub and savanna mosaic): *Juniperus procera, Olea, Podocarpus, Croton, Cussonia, Acacia, Commiphora, Acanthus,* with *Chrysopogon, Aristida* and other grasses, plus forbs.
**Makurdi (Southeastern Nigeria) MI = 0.83	Raingreen Savanna Woodland with evergreens: +Xeric raingreen trees Broad-raingreen small trees Tropical evergreen sclerophyll trees Raingreen thorn-scrub Tall cane-grasses Short bunch-grasses Xeric tuft-treelets and rosette-scrub Evergreen scrub and shrubs Palmiform tuft-trees and treelets Bush stem-succulents Raingreen forbs and vines	Raingreen Tree Savanna (wet savanna zone): *Daniellia, Lophira, Parinari, Terminalia, Prosopis, Gardenia* et al., *Hyparrhenia, Andropogon, Pennisetum* and other tall grasses, with numerous forbs and shrubs
*Lusaka (central Zambia, 1278 m) MI = 0.89	Raingreen Woodland-Open Forest with evergreens: +Broad-raingreen small trees +Tropical evergreen sclerophyll trees Tropical xeric needle-trees Palmiform tuft-treelets and trees Tropical evergreen microphyll-trees Xeric evergreen tuft-treelets Raingreen and evergreen scrub Xeric raingreen trees Tropical and mediterranean evergreen shrubs Bush stem-succulents Xeric rosette-shrubs Tall cane-grasses Short bunch-grasses Raingreen and xeric forbs Raingreen vines Wintergreen epiphytes	Semi-Open Raingreen Miombo Forest: *Brachystegia, Julbernardia, Isoberlinia, Berlinia* and other legumes, *Parinari, Uapaca, Diospyros, Monotes, Faurea,* various shrubs, and many grasses and especially dry-season forbs.
**Maun (Ngamiland, northern Botswana, 942 m) MI = 0.43	Raingreen Woodland and Thorn-Scrub +Raingreen thorn-scrub Broad-raingreen small and larger trees Leafless xeric shrubs Mediterranean dwarf-shrubs Xeric evergreen tuft-treelets and scrub	Raingreen Mopane Open Woodland with sparse undergrowth: *Colophospermum, Acacia, Kirkia, Terminalia,* with *Grewia, Combretum, Capparidaceae,* and relatively few grasses and forbs.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
	Bush, typical and tall stem-succulents Leaf-succulent, cushion and hot-desert shrubs Short bunch and sclerophyllous grasses Desert-grasses Raingreen and summergreen forbs	
*Kroonstad (Orange Free State, 1348 m) MI = 0.84	Diverse Savanna Woodland with Shrubs: +Short bunch and sward grasses +Tall Grasses Dwarf-needle small trees +Tropical evergreen sclerophyll trees Broad-raingreen small trees +Tropical xeric needle-trees +Temperate needle-trees +Tropical evergreen microphyll-trees Temp. broad-evergreen small trees Sub-mediterranean needle-trees Montane broad-raingreen trees Mediterranean broad-evergreen trees Xeric evergreen tuft-treelets Evergreen and deciduous arborescents Needle and broad-evergreen shrubs Summergreen shrubs Bush stem-succulents Xeric rosette and cushion shrubs Raingreen and summergreen forbs	Region of Tall, Forb-Poor High Veld: *Themeda, Heteropogon, Setaria, Eragrostis, Andropogon, Hyparrhenia* et al., plus *Elephantorrhiza, Hypoxis, Aster, Indigofera* and other forbs, and with invading shrubs if not grazed.
*Cathedral Peak (Little Berg, in Natal Drakensberg, 1860 m) MI = 2.21	Diverse Subtropical Montane Rainforest (seasonal): *Tropical montane rainforest trees *Temperate needle-trees *Montane broad-raingreen trees *Tropical linear-leaved trees Tropical evergreen sclerophyll trees Tropical evergreen microphyll-trees Broad-evergreen small trees Broad-raingreen small trees Arborescent grasses Tall cane and typical grasses Evergreen broad and needle-leaved shrubs Various forbs	Montane Heathland (Fynbos): *Passerina, Philippia, Widdringtonia, Erica, Macowania, Protea, Anthospermum, Rhus discolor,* et al., with *Asparagus, Senecio, Euphorbia, Diospyros, Stoebe,* and many other shrubs, plus *Encephalartos, Polystichum, Cymbopogon,* and *Berkheya.*
**Hell-Bourg (Réunion, 935 m) MI = 3.31	Tropical Montane Rainforest with Raingreens: *Tropical montane rainforest trees Montane broad-raingreen trees Temperate rainforest needle-trees Tropical linear-leaved trees Tropical evergreen microphyll-trees Palmiform tuft-trees Tropical cloud-forest small-trees	Montane Evergreen Rainforest: *Cassine, Diospyros, Dodonaea, Naxia, Olea, Ocotea, Sideroxylon, Terminalia, Weinmannia* and many others, with understorey trees, lianas and vines, epiphytes, etc.
*Borisovka (southern Russia, near Ukrainian border) MI = 0.94	Semi-Open Mixed Semi-Deciduous Forest: *Boreal/montane short-needled trees *Summergreen broad-leaved trees Boreal summergreen needle-trees Broad-summergreen small trees Needle-leaved evergreen shrubs	Summergreen *Quercus-Tilia* Forest (preserve) near forest-steppe transition, with *Acer, Ulmus, Malus, Crataegus,* and various shrubs, spring geophytes, summer forbs and grasses (*Poa, Festuca gigantea*).

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
	Summergreen scrub and shrubs Short and tall grasses Summergreen forbs	
**Kerki (eastern Kara-Kum, Turkmenistan, near Afghan border) MI = 0.17	Cold-Winter Xeromorphic Semi-Desert Scrub: +Leafless xeromorphic large-scrub +Cold-winter xeromorphic shrubs Xeric dwarf-shrubs Bush stem-succulents Desert-grasses Ephemeral desert herbs	Kara-Kum Leafless and Nanophyllous Semi-Desert Scrub: *Ammodendron, Haloxylon,* with *Calligonum, Salsola, Astragalus, Ephedra, Artemisia,* other shrubs and semi-shrubs, *Carex, Poa bulbosa, Allium, Aristida, Tulipa, Iris, Gagea,* and many annual herbs.
Chatkal Mtns. (Kirghiz-Uzbek border, 1433 m) MI = 1.63	Temperate Montane Steppe with Needle-Scrub: Needle-leaved evergreen shrubs Short bunch-grasses Summergreen forbs	Montane Summergreen *Juglans* Belt, with *Prunus, Acer, Malus, Crataegus* et al., *Melica, Festuca, Agropyron, Carex* and other graminoids, and various forbs.
*Najaf Depression (central Iraq, Euphrates Valley) MI = 0.06	Leafless Desert Scrub with succulents: +Leafless xeromorphic scrub +Small stem-succulents +Desert-grasses Succulent forbs Ephemeral desert herbs Dry desert	*Salsola-Zygophyllum* Shrub Steppe (5–15% cover) with saline marshes, including *Nitraria, Seidlitzia, Halocnemum, Limonium, Bienertia* and other halophytes.
Maimana (northwestern Afghanistan, 615 m) MI = 0.55	Upland Shrub-Steppe with scattered small needle-trees: +Dwarf-needle small trees +Cold-winter xeromorphic shrubs +Short bunch-grasses Bush stem-succulents Leafless shrubs and dwarf-shrubs Needle-leaved evergreen shrubs Summergreen forbs Xeric cushion-herbs	Summergreen *Pistacia* Savanna-Woodland (2–5 m, 5–40% cover), with *Amygdalus, Cerasus, Cercis, Rosa, Ephedra, Artemisia, Acantholimon, Poa bulbosa, Salvia, Compositae, Carex, Anemone, Bromus, Astragalus* and many others.
*Kotgai (eastern mountains of Afghanistan, 2450 m) MI = 0.94	Temperate Montane Dry Needle-Forest: *Temperate needle-trees *Boreal/montane short-needled trees Dwarf-needle small trees Needle-leaved evergreen shrubs Short bunch-grasses Summergreen forbs	Montane *Cedrus deodara* Forest, with *Juniperus, Pinus, Quercus, Rosa, Cotoneaster, Berberis, Lonicera, Salvia, Phlomis, Astragalus,* various grasses and forbs.
Mussoorie (northern India, 1500 m) MI = 3.32	Montane Evergreen Shrubs and Forbs: *Tropical broad-evergreen shrubs Broad-wintergreen epiphytes Summergreen forbs Mat-forming thallophytes	Montane Temperate Evergreen Oak Forest: *Quercus incana,* with *Cedrus* and *Pinus* on dry exposures, tree understorey of *Rhododendron, Lyonia, Persea,* and others, *Virburnum, Berberis, Hedera* and other climbers, *Arundinaria,* and various other grasses, forbs and ferns.

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
Yüjlin (Ordos region, central China, 1121 m) MI = 0.72	Mixed Scrub-Bunch Grass Steppe +Needle-leaved evergreen shrubs +Summergreen arborescents Broad-summergreen mesic shrubs +Short bunch-grasses +Short sward-grasses Summergreen forbs Xeric cushion-herbs	Cold-Winter Xeric Shrub Steppe (15–40% cover) on aeolian sand: *Artemisia ordosica, A. frigida, Caragana, Pycnostelma, Stipa,* with *Lasiagrostis, Carex, Allium, Peganum,* and others.
*Mitchell Plateau Camp (northwestern Australia) MI = 1.15	Monsoon Semi-Deciduous Forest: *Monsoon broad-raingreen trees Broad-raingreen small trees Tropical evergreen sclerophyll trees Tropical evergreen microphyll-trees Palmiform tuft-trees Tall cane and typical grasses Short grasses, forbs	Evergreen *Eucalyptus* Woodland with patches of raingreen monsoon forest: *E. tetrodonta, E. miniata, E. nesophila,* with *Livistona, Erythrophloeum, Terminalia, Cycas, Grevillea,* et al., plus monsoon forests of *Zizyphus, Albizia, Cochlospermum, Pouteria, Wrightia* et al.
*Wiluna (interior Western Australia, 27° S) MI = 0.25	Mixed Hot Semi-Desert Scrub: +Hot-desert evergreen shrubs +Raingreen thorn-scrub Leafless shrubs and dwarf-shrubs +Arborescent and smaller stem-succulents Xeric rosette-shrubs Sclerophyllous grasses Short bunch and desert grasses Xeric cushion-shrubs Raingreen, summergreen and succulent forbs Ephemeral desert-herbs	Evergreen Mulga Scrub: *Acacia aneura* (leafless, with polymorphic phyllodes), with other *Acacia, Eremophila, Cassia, Hakea,* smaller *Eucalyptus, Triodia, Chenopodiaceae* on saline sites, and ephemeral carpets of *Weitzia aurea* and *Helipterum.*
*Perth (coastal south-western Australia) MI = 1.14	Mediterranean-Subtropical Dry Rainforest: *Tropical evergreen sclerophyll trees *Mediterranean broad-evergreen trees *Sub-mediterranean needle-trees *Tropical linear-leaved trees Temperate needle-trees Tropical montane rainforest trees Tropical evergreen microphyll-trees Broad-raingreen small trees Broad-evergreen small trees Palmiform tuft-trees and treelets Tall cane-grasses Short bunch and sclerophyllous grasses Various evergreen shrubs Seasonal forbs Wintergreen epiphytes	Evergreen Tall Jarrah Forest: *Eucalyptus marginata,* with scattered other eucalypts, an understorey of *Casuarina* and *Banksia,* 'grass trees' (*Kingia, Xanthorrhoea*), many *Proteaceae, Myrtaceae, Leguminosae* and *Epacridaceae,* and various herbs, including orchids and insectivorous *Drosera.*

Table 14 (continued).

Site	Predicted vegetation	Actual vegetation
*Kieth (Dark Island) (South Australia) MI = 0.68	Diverse Mixed Subtropical Semi-Evergreen Scrub with scattered trees: +Needle-leaved evergreen shrubs +Xeric summergreen shrubs +Broad-raingreen small trees +Mediterranean evergreen shrubs +Dwarf-needle small trees +Raingreen thorn-scrub +Tropical evergreen sclerophyll trees +Xeric evergreen tuft-treelets Leafless scrub Evergreen arborescents Temperate needle-trees Mediterranean dwarf-shrubs Hot-desert evergreen shrubs Xeric rosette-shrubs Bush stem-succulents Xeric cushion-shrubs Short bunch-grasses Raingreen and summergreen forbs	Open Dry Evergreen Heath (1–2 m) with mallee: *Banksia ornata, Casuarina pusilla, Leptospermum myrsinoides,* and *Xanthorrhoea australis,* with scattered taller *Eucalyptus,* plus *Phyllota, Hibbertia, Leucopogon* (dwarf-shrubs), bunch-graminoids, and a variety of forbs (including *Liliaceae* and *Orchidaceae*).
*Alexandra (Canterbury Plains, South Island of New Zealand) MI = 0.63	Short Tussock and Spreading-Grass Steppe with xeric shrubs: +Short bunch-grasses +Short tussock-grasses +Short sward-grasses Needle-leaved evergreen shrubs Xeric summergreen shrubs and scrub Xeric cold-winter and cushion-shrubs Leafless dwarf-shrubs Bush stem-succulents Summergreen forbs Possible evergreen needle-trees and broad-leaved shrubs	Low-Tussock Grassland (valley site): *Festuca novae-zelandiae, Poa caespitosa,* with *Agropyron, Discaria, Aciphylla, Leucopogon, Carex, Danthonia, Agrostis,* and various meadow and steppe forbs, including European ruderals.

personally, however, are supported in their various sources by photographs taken near the sites.

After the actual vegetation had been determined for the validation sites, the site macroclimatic data were coded, other values generated, and the data put through ECOSIEVE to generate the model's predicted vegetation at each validation site. These predicted life-form spectra are listed in Appendix C. The cover and dominance models were then applied to predict a formation type for each site, which was given a name based on the predicted dominant and subdominant components and predicted cover, as described in Table 8. The predicted vegetation for each site, with predicted dominant and subdominant forms, is presented alongside the corresponding actual vegetation in Table 14. Predicted dominant forms (center column) are denoted by an asterisk, with other forms listed considered to be potentially important also. (Lesser forms are shown in the complete listing in Appendix C).

Two criteria were used for comparing predicted and actual vegetation:

1. All actually occurring dominant forms be predicted by the model.
2. All but only actually occurring dominant forms (i.e. the exact combination of dominant forms) be predicted by the model.

The latter criterion is quite strict and, if met, can be interpreted as prediction of the actual vegetation

Table 15. Summary of vegetation prediction accuracy at the validation sites.

The 74 validation sites are grouped three times in the left column according to three criteria: region, terrain type, and annual moisture index (MI). The number of sites and the prediction statistics corresponding to each grouping of sites are shown in the other four columns. For description of the strong (correct combination of dominant forms) and weak (prediction only) criteria for prediction accuracy, please refer to the text or to Table 14. Prediction accuracy appears to be highest in the Americas and Africa and in the higher and lower (but not intermediate) MI ranges. The apparently similar prediction accuracy in lowland and in mountainous areas may be misleading since all but one of the 11 mountainous sites satisfying the strong criterion also involve high MI values (>0.93). The relatively small numbers of sites in the various groupings, however, do not permit definite conclusions about relative vegetation predictability.

Site class	No. of sites	Sites meeting		
		Strong criterion (**)	Weak criterion (*)	Neither
North America	30	18	12	0
South America (incl. Central America)	13	7	4	2
Europe (excl. USSR)	4	1	3	0
Africa	14	10	4	0
USSR	3	1	1	1
Asia (excl. USSR)	5	0	2	3
Australia and Oceania	5	0	5	0
Lowland/upland sites	51	26	22	3
Mountainous sites	23	11	9	3
$MI > 1.6$	20	11	6	3
$1.2 < MI < 1.6$	9	7	1	1
$0.95 < MI < 1.2$	10	4	6	0
$0.8 < MI < 0.95$	9	3	6	0
$0.6 < MI < 0.8$	12	3	8	1
$0.3 < MI < 0.6$	6	5	0	1
$MI < 0.3$	8	4	4	0
Total	74	37 (50%)	31 (42%)	6 (8%)

formation type.[2] Sites at which only the first (weak) criterion is met are indicated in Table 14 by a single asterisk before the site name. Sites at which the strong second criterion is met are indicated by two asterisk before the site name. Sites meeting the strong criterion automatically satisfy the weak criterion also. A summary of sites meeting the criteria is presented in Table 15.

As one can see in Tables 14 and 15, the actual dominant plant form or forms are predicted by the model (weak criterion: one or two asterisks before the site name) in 68 of the 74 cases (92%). The actual vegetation formation type is predicted (strong criterion: two asterisks before the site name) in 37 of the 74 cases (50%), the number being lower because the criterion for correct prediction is much more rigorous. The actual formation type was considered to be correctly predicted only if all its dominant (and in some cases subdominant) components, and no others, were predicted both to occur and in fact to dominate. Considering these criteria and the number of environmental factors not included in the model, a figure of 50% seems remarkable. The actual dominant forms were not predicted at only 6 of the 74 sites (8%).

The distribution of correct and incorrect predictions, by region, terrain and general climatic wetness (annual moisture index MI), is summarized in

[2]Predicted forms of the highest dominance level present are excluded as predicted dominants if they are near environmental limits (fitness values well below 0.10). Other subjective considerations may also be made concerning growth rates, etc., according to criteria described in section 5.F.

Table 15. The small total number of sites in each grouping precludes definite conclusions, but the results do suggest greater correspondence between actual vegetation and normal climatic relationships (greater prediction accuracy) in the Americas and Africa. The smaller number of correct predictions in Asia and Australia reflect to at least some extent various site peculiarities at some Asian sites (e.g. aeolian sand) and the more isolated and unique development of the Australian vegetation (e.g. the importance of *Eucalyptus* and the lack of stem-succulents). Several sites were included because of their unusual seasonal patterns (e.g. Mussoorie, Yüjlin, Chatkal Mountains) or climatic extremes (e.g. Najaf, Quibdo, Damanhur). Three of these are in Asia and a fourth in the USSR.

At first glance it may appear that there is little difference in predictability between lowland and mountainous sites, each showing roughly the same pattern as for all sites. Of the 11 mountainous sites for which actual formation (strong criterion) was predicted, however, only one has an annual moisture index (MI) below 0.93. Those nine sites meeting only the weak criterion include six transitional or drier sites ($0.6 < MI < 1.1$). The other three, plus the three mountainous sites meeting neither criterion (Isla Victoria, Chatkal Mountains, Mussoorie), all have MI values above 1.6 (to over 3). Mountainous areas, both those which are climatically drier and those with accentuated seasonal orographic rainfall, appear to represent special problems for interpreting macroclimatic control on vegetation type, due primarily to greater availability of soil water.

The distribution of prediction results by moisture class (MI range) is perhaps most instructive since it considers vegetation stands by (potential) degree of openness. The highest prediction accuracy (>75% satisfying the strong criterion) is suggested for climates characterized by typical closed forests ($1.2 < MI < 1.6$, i.e. not extreme rainforests) and by rather open steppes and woodlands (including typical raingreen thorn-scrub). More interesting, however, is the decreased accuracy for the transitional climates (MI values from 0.6 to 1.2), reflecting the greater importance of fire, site characteristics, and particular biotic factors in determining the actual vegetation structure and dynamics in these areas. These results correspond to the general occurrence of vegetation core areas in the climatic ranges of humid forest (MI of 1.2–1.6) and dry open woodland-steppe (MI of 0.3–0.6). The vegetation of the driest ($MI < 0.3$) and perhaps also the wettest ($MI > 1.6$) climates may show greater influence by local vegetation history and/or by environmental factors (including climate) which were not expressed in the current model, such as soil water and topography.

B. Vegetation and climate at unusual sites

Perhaps the most can be gained from the evaluation of results by examining unusual sites, such as those at which the actual vegetation is not correctly predicted. Of the 74 validation sites, neither prediction criterion was satisfied at six sites: Isla Victoria, Ushuaia, Chatkal Mountains, Maimana, Mussoorie, and Yüjlin (see Table 14 for locations and predicted and actual vegetation). These include several sites which were deliberately chosen for the validation because of their unusual climates (Ushuaia, Mussoorie), unusual topographic situation (Yüjlin) or particularly interesting vegetation (Chatkal Mountains, Maimana). All of these sites except Ushuaia are located above 600 m. All but Maimana and Yüjlin have MI values above 1.2.

The dominant vegetation at Isla Victoria (in a lake in the southern Andes) is *Nothofagus dombeyii* plus other broad-leaved evergreen trees which can be considered rainforest trees (Hueck 1966). These were rejected by three model variables: TMIN, PMIN, PMTMAX. Temperate broad-evergreen small trees were predicted to occur and perhaps could represent *Nothofagus* in this case. At Ushuaia (Tierra del Fuego), the other site in southern South America, it is the summergreen *Nothofagus pumilio* and *N. antarctica,* plus scattered evergreen *Nothofagus,* which are not predicted (Hueck 1966). The mean temperature of the warmest month in the extremely maritime Ushuaia climate is only 10°, while the corresponding lower limit for broad-summergreen small trees was set in the model at 11°, based on conditions in Iceland, northern Fennoscandia, and Alaska. Other less extreme problems also occurred in predicting the vegetation of southern South America, some due to the extreme windiness of the region, with consequent underestimation of potential evapotranspiration. Compared with other comparable climatic regions, however, the minimum summer temperature requirements of most tree forms are unusually low in southern South America (e.g. some evergreen *Nothofagus* spp. surviving at TMAX = 7°).

The other four unsuccessful sites are in mountainous or upland regions in or around Central Asia. Each has a highly seasonal precipitation regime with at least one month of essentially no rainfall. Two of the sites are monsoonal, but the Chatkal Mountains site (Kirghiz-Uzbek border area in the USSR) and Maimana (Afghanistan) have continental mediterranean climates with little rainfall in summer. The actual vegetation at the Chatkal site and in similar elevational belts throughout the mountains of Middle Asia (USSR) and some of Central Asia (China-Mongolia) is an open woodland with *Juglans fallax* and a variety of wild fruit trees, e.g. *Prunus, Amygdalus, Malus,* plus *Crataegus, Pistacia* and others. The vegetation at Maimana is similar but without *Juglans* and much more open. These open woodlands (parklands) apparently survive the dry summers (with TMAX around 20–24°) on groundwater and some overland runoff from higher elevations. If this water subsidy could be expressed in the model, the predicted vegetation could be a summergreen woodland at Chatkal and a more open summergreen woodland/shrubland at Maimana.

The montane monsoonal site at Mussoorie, with MI = 3.32 but PMIN = 7 mm, well illustrates the shortcomings of the model design. The actually occurring evergreen trees (*Quercus incana,* with *Cedrus* and *Pinus*) and evergreen understorey (*Rhododendron, Persea, Lyonia,* etc.) are all rejected by the PMIN value. A model involving actual soil water, accumulated from the high-rainfall months, would certainly predict the rainforest which occurs.

The Chinese site Yüjlin, in the Ordos region of aeolian sand, illustrates a different problem. Although the MI value of 0.72 is not extremely low, there is very little precipitation except in summer, and spring can be very dry, especially on a sand substrate. The actually occurring cold-winter xeric shrubs (*Artemisia,* plus *Caragana,* et al.) generally occur in continental dry-summer climates and are not predicted at Yüjlin because of the summer rainfall peak. An aeolian sand substrate can easily reduce by half the water available from precipitation, however, which would then result in a reasonable simulation of the Yüjlin xeric shrub-steppe with 15–40% cover.

Mountainous areas, azonal soils, unusually extreme or seasonal climates, as well as wetlands and floodplains, are all areas where the macroclimatic approach may not provide useful results. This does not necessarily mean that the vegetation of these areas shows different environmental relationships but only that a macroclimatic model is insufficient to express the controlling environmental factors. Where water is the problem, precipitation and MI values can often be adjusted to express available water more accurately, resulting in a reasonable simulation of the actual vegetation composition and structure. Foggy mediterranean coastlines may remain problematic. Temperature, as illustrated by southern South America, may be a less easily circumvented problem. Temperature influences generally are not greatly changed by substrate or topographic factors, except in the cases of protected microclimates in mountains, insulating snow covers, and extremely low-growing vegetation in cool climates. For deciduous (seasonal) vegetation air temperature is usually the controlling temperature factor, but for some evergreen vegetation, such as the *Polylepis* treelets of the equatorial Andes, which can occur individually several hundred meters above treeline, soil temperature seems to be the controlling (enabling) factor. Wetlands can often be considered as equivalent to MI >> 1.0, though some forms may be eliminated by anaerobic soil conditions. Simulation success can also be improved, of course, by considering other environmental conditions, such as substrate peculiarities and the site's history of fire and anthropogenic influences.

C. Vegetation sensitivity to climatic variation

The sensitivity of plant and vegetation types to climatic variations can be studied in a number of ways. Some information was provided in the validation results by multiple sites in the same vegetation region. Additional information can be provided by changing climatic values (by amounts within the normal range of interannual variation) and comparing the new world vegetation predictions with those of the standard model. Perhaps most importantly, since there is some question about the accuracy of any single potential evapotranspiration estimation method worldwide, the model can be re-run with different estimates of PET in order to estimate the effects of this source of potential error. Such re-running of the model with altered environmental values represents a sort of sensitivity analysis, a technique which can be quite useful to the development and understanding especially of predictive ecological models (Caswell 1976). Results generated by modifying PET will always be difficult to interpret, however, since the model's MI limits were derived using PET values based on the Thornthwaite estimate. Interpretation of results is also complicated by difficulty in separating model sensitivity from the actual climatic sensitivity of existing vegetation.

The other PET estimation method which is widely used over large parts of the world is that of Holdridge (1959). It is also perhaps the best alternative to compare with the Thornthwaite values since Holdridge estimates consistently higher PET values throughout most of the tropics and Southern Hemisphere and consistently lower values north of about 40° N (Box, in prep.). The model represented by Table 7 was re-run with the world climate data, using the Holdridge estimate of PET, and the results were compared with those of the standard model by means of a simple program called NCHANGES (Box, unpublished). The resulting changes in prediction frequency of selected important plant forms (without dominance or other importance considerations) are shown in Table 16.

Table 16. Changes in selected life-form prediction frequencies using the Holdridge estimate of annual potential evapotranspiration (PET).

The occurrence frequencies (see also Table 12) of selected plant life forms, as predicted by the model (Table 7) for the 1225 world climatic data-sites, are shown in the first column of numbers (Std. freq.). The numbers of sites gained and lost using Holdridge's (1959) estimate of potential evapotranspiration (PET) are shown in the remaining columns, with the corresponding percentages of the original frequencies given in parentheses. Most forms gained and lost fewer than 20% of their original sites, with net gains or losses generally closer to 2–10%. The most significant changes occur in tropical and subtropical (including mediterranean) areas.

Plant type	Std. freq.	Holdridge PET	
		Gained (%)	Lost (%)
Tropical rainforest trees	133	1 (0.8)	5 (3.8)
Tropical evergreen sclerophyll trees	333	10 (3.0)	17 (5.1)
Warm-temperate evergreen trees	58	0	5 (8.6)
Mediterranean evergreen trees	36	0	13 (36.1)
Monsoon raingreen trees	96	3 (3.1)	13 (13.5)
Xeric raingreen trees	110	13 (11.8)	2 (1.8)
Summergreen broad-leaved trees	222	4 (1.8)	7 (3.2)
Tropical linear-leaved trees	173	0	28 (16.2)
Tropical xeric needle-trees	86	43 (50.0)	32 (37.2)
Heliophilic needle-trees	97	2 (2.1)	15 (15.5)
Sub-Mediterranean needle-trees	157	1 (0.6)	36 (22.9)
Temperate rainforest needle-trees	45	2 (4.4)	10 (22.2)
Boreal/Montane needle-trees	248	13 (5.2)	0
Broad-summergreen small trees	364	37 (10.2)	15 (4.1)
Palmiform tuft-trees	291	2 (0.7)	23 (7.9)
Raingreen thorn-scrub	183	23 (12.6)	1 (0.5)
Mediterranean evergreen shrubs	150	5 (3.3)	25 (16.7)
Broad-ericoid evergreen shrubs	87	23 (26.4)	7 (8.0)
Xeric summergreen shrubs	170	2 (1.2)	61 (35.9)
Tall cane-grasses	391	8 (2.0)	31 (7.9)
Short bunch-grasses	1002	7 (0.7)	65 (6.5)
Xeric cushion-herbs	412	24 (5.8)	113 (27.4)

The greatest percentage of changes occurred among tree forms, especially in the tropics. However, only one form, Tropical Xeric Needle-Trees (with only 86 occurrences out of 1225 sites originally), showed more than a 30% gain or 40% loss of predicted occurrences. Only four other forms (not all shown in Table 16) gained more than 20%, while only nine other forms lost as many as 20% of their original sites. Only three forms were not affected at all: the nothofagoid Cool-Temperate Broad-Evergreen Trees, the Tall Tussock-Grasses, and the Summergreen Cold-Desert Herbs, all from cool-temperate or polar climates. The greatest percentage changes in predicted sites were often by forms with restricted ranges and fewer occurrences among the original results, e.g. Tropical Alpine Tuft-Treelets. In general, the substitution of the Holdridge estimate of PET did not result in dramatic changes in predicted vegetation patterns, though it clearly can have a major effect at certain sites. The

Table 17. Predicted effect on selected extra-tropical plant-form distributions of 5 °C reduction in peak summer temperature.

The standard world vegetation model (Table 7 applied to climatic data for 1225 sites worldwide) was re-run with actual mean temperature of the warmest month (TMAX) reduced by 5 °C for each site (with recomputation of the remaining monthly temperatures to preserve an annual sinusoidal pattern and recomputation of the corresponding PET and MI values). The occurrence frequencies predicted by the standard model for selected extra-tropical forms (based on 1225 sites, see also Table 12) are shown in the first column of numbers (Std. freq.), along with the predicted changes in the remaining columns (sites gained or lost, with corresponding percentages of original frequency in parentheses). Only extra-tropical forms are shown, since results may be misleading where the annual variation of mean temperature is not clearly greater than 5 °C. Boreal needle-trees are seen to be reduced by 15–40% net while being displaced equatorward (14–19% new sites). Krummholz, tussock-grasses, and cool-mesic dwarf-shrubs make the largest net gains, with generally 10–16% of old sites lost except for krummholz, which is displaced completely (all old sites lost but many more gained). Large net decreases are evident for most typical-temperate and warm-temperate forms.

Plant type	Std. freq.	TMAX→TMAX-5°	
		Gained (%)	Lost (%)
Warm-Temperate evergreen trees	58	2 (3.4)	31 (53.4)
Summergreen broad-leaved trees	222	17 (7.7)	136 (61.3)
Boreal broad-summergreen trees	175	31 (17.7)	102 (58.3)
Temperate needle-trees	180	77 (42.8)	108 (60.0)
Boreal/Montane needle-trees	248	46 (18.5)	83 (33.5)
Boreal summergreen needle-trees	236	33 (14.0)	123 (52.1)
Dwarf-needle small trees	210	11 (5.2)	110 (52.4)
Needle-leaved treeline krummholz	45	130 (289)	45 (100)
Cold-winter xeromorphic shrubs	116	0	38 (32.8)
Broad-summergreen mesic shrubs	353	18 (5.1)	200 (56.7)
Temperate evergreen dwarf-shrubs	271	94 (34.7)	44 (16.2)
Summergreen tundra dwarf-shrubs	179	75 (41.9)	26 (14.5)
Mesic evergreen cushion-shrubs	46	13 (28.3)	10 (21.7)
Tall grasses	504	12 (2.4)	178 (35.3)
Short bunch-grasses	1002	10 (1.0)	237 (23.7)
Tall tussock-grasses	84	36 (42.9)	10 (11.9)
Summergreen forbs	643	8 (1.2)	152 (23.6)
Summergreen cold-desert herbs	167	165 (98.8)	27 (16.2)
Summergreen vines	134	8 (6.0)	72 (53.7)
Ice desert	58	39 (67.2)	0

main results appears to be a slight shifting of predicted ranges toward more mesic areas, especially in the tropics. The need for an improved, single, world-applicable estimation method for annual potential evapotranspiration remains evident.

World vegetation predictions were also generated by three other model modifications, each involving modification of a single climatic factor:

1. a 5° decrease in summer temperature (TMAX);
2. a 50% increase in annual potential evapotranspiration (reduction of MI by one-third); and
3. a 50% reduction of summer rainfall (PMTMAX).

Implied changes to values of related variables were also computed, such as recomputation of PET under the altered annual temperature regime. Each of these climatic modifications focuses on particular plant forms in certain regions of the world and is less instructive elsewhere.

The 5° reduction of mean summer temperature is not really meaningful where the annual range is 5° or less, as in most of the tropics. In boreal (austral) and polar areas, however, reduction of summer temperature resulted in the expected equatorward shift of most plant types, as shown in Table 17. Boreal evergreen and summergreen needle-trees are reduced in predicted frequency by 15% and 38% respectively, while treeline krummholz loses all its old sites and gains nearly three times as many new ones. Tussock-grasses and evergreen and summergreen dwarf-shrubs make net gains of 18–30%. In the temperate zones most forms show dramatic decreases.

The 50% increase in potential evapotranspiration is probably interpretable everywhere and has a much greater effect than the use of Holdridge PET, which generally differs from Thornthwaite by not more than 20–30%. Only the xeromorphic forms show net increases (see Table 18), while reductions of 20–60%, with no sites gained, are common for most tree, vine, epiphyte, mesic-shrub, and tall-grass forms. In terms of familiar vegetation formations, tropical rainforest, mediterranean forest, summergreen forest and temperate rainforest are all reduced by at least about 40%. The greatest net (percentage) gains are by short tussock (75%) and desert grasses (67%), ephemeral desert herbs (35%), xeric shrubs and scrub (13–21%), and stem-succulents (10–22%). Some xeric forms, however, show net losses, e.g. hot-desert evergreen shrubs (4.6%). No form is completely eliminated. Cool-temperate broad-evergreen trees (7 sites) and summergreen cold-desert herbs (167 sites) were unaffected by the increased PET.

The 50% reduction of summer rainfall is significant in most areas and also results in much greater (often dramatic) loss of predicted sites than gain (see Table 19). Again no form is completely eliminated. The greatest net losses are suffered (excluding the topographically limited swamp trees, 74%) by summergreen ferns (59%), temperate broad-leaved rainforest trees (52%), maritime cushion-shrubs (50%), heliophilic needle-trees (48%), and certain other mesic forms, while others, however, are only slightly affected. The only real gains are made by mediterranean and sub-mediterranean forms. Nineteen forms were totally unaffected, including short bunch-grasses, tropical alpine and xeric tuft-treelets, various xeric scrub forms (including hot-desert evergreen shrubs), the non-arborescent stem-succulents, and most forb forms. The apparent relative indifference of summergreen and raingreen forms, as well as mesic tropical evergreen forms, to reduced summer rainfall is perhaps the most interesting of the sensitivity results. It suggests either that rainfall is still high after 50% reduction (which is often the case in the tropics) or, mainly in summergreen areas, that the plants are well adapted to high variability in summer rainfall. Temperate evergreen forms appear to be more sensitive than the corresponding summergreen forms.

Table 18. Predicted effect on selected plant-form distributions of 50% increase in annual potential evapotranspiration (PET).

The standard world vegetation model (Table 7 applied to world climatic data) was re-run with annual potential evapotranspiration (PET) increased by 50% for each site. This is equivalent to a one-third reduction of the annual moisture index (MI). The occurrence frequencies predicted by the standard model for selected, generally more important forms (based on 1225 sites, see also Table 12) are shown in the first column of numbers (Std. freq.) along with the predicted changes in the remaining columns (sites gained or lost, with corresponding percentages of original frequency in parentheses). Most mesic forms are reduced by at least 25%, with no sites gained and the effect apparently greatest among trees and mesic evergreen forms. Some xeric forms show net gains and are shifted toward the more mesic areas. Even some xeric forms show net losses (e.g. hot-desert evergreen shrubs), suggesting that they are occurring close to dryness limits. No form is eliminated completely, but tropical xeric needle-trees are displaced by 85–90%.

Plant type	Std. freq.	PET→1.5 × PET	
		Gained (%)	Lost (%)
Tropical rainforest trees	133	0	52 (39.1)
Tropical evergreen sclerophyll trees	333	10 (3.0)	66 (19.8)
Mediterranean broad-evergreen trees	36	0	22 (61.1)
Monsoon raingreen trees	96	0	60 (62.5)
Summergreen broad-leaved trees	222	0	100 (45.0)
Tropical xeric needle-trees	86	73 (84.9)	78 (90.7)
Temperate needle-trees	180	0	49 (27.2)
Temperate rainforest needle-trees	45	0	22 (48.9)
Boreal/Montane needle-trees	248	0	65 (26.2)
Cloud-forest trees	28	0	10 (35.7)
Palmiform tuft-trees	291	0	79 (27.1)
Xeric evergreen tuft-treelets	184	48 (26.1)	20 (10.9)
Raingreen thorn-scrub	183	35 (19.1)	4 (2.2)
Broad-ericoid evergreen shrubs	87	0	50 (57.5)
Hot-desert evergreen shrubs	131	14 (10.7)	20 (15.3)
Broad-summergreen mesic shrubs	353	0	132 (37.4)
Xeric summergreen shrubs	170	45 (26.5)	12 (7.1)
Temperate evergreen dwarf-shrubs	271	0	124 (45.8)
Typical stem-succulents	180	51 (28.3)	11 (6.1)
Tall grasses	504	0	119 (23.6)
Short tussock-grasses	32	26 (81.3)	2 (6.3)
Tropical broad-evergreen lianas	182	0	88 (48.4)
Tropical broad-evergreen epiphytes	138	0	70 (50.7)
Evergreen ferns	123	0	58 (47.2)
Dry desert (no vegetation)	77	1 (1.3)	0

Table 19. Predicted effect on selected plant-form distributions of 50% reduction of summer precipitation. Precipitation.

The standard world vegetation model (Table 7 applied to world climatic data via ECOSIEVE) was re-run with average warmest-month precipitation (PMTMAX) reduced by 50% at each site (with re-estimation of the other monthly precipitation values in order to preserve the same annual total and moisture index). The occurrence frequencies predicted by the standard model for selected, mostly temperate-zone or raingreen forms (based on 1225 sites) are shown in the first column of numbers (Std. freq.) along with the predicted changes in the remaining columns (sites gained or lost, with corresponding percentages of original frequency in parentheses). Mediterranean forms show clear gains (often with no losses), but all other forms show mild to more serious reductions. The losses are greatest for temperate summer-rain rainforest forms and heliophilic needle-trees (40–60%) but are generally much less (8–22%) for summergreen and raingreen trees and shrubs, suggesting that these forms, despite malacophylly, are well adapted to withstand wide year-to-year variations in growing-season rainfall. Xeric scrub forms are also reduced (generally 15–30%), as are the graminoids (20% or less, except for sclerophyllous grasses). Wintergreen epiphytes are only slightly affected, and nineteen forms are not affected at all (not shown but identified in the main text).

Plant type	Std. freq.	PMTMAX→PMTMAX/2	
		Gained (%)	Lost (%)
Tropical rainforest trees	133	0	2 (1.5)
Warm-temperate evergreen trees	58	0	12 (20.7)
Mediterranean evergreen trees	36	22 (61.1)	0
Temperate broad-leaved rainforest trees	48	0	25 (52.1)
Monsoon raingreen trees	96	0	8 (8.3)
Summergreen broad-leaved trees	222	0	33 (14.9)
Heliophilic needle-trees	97	0	47 (48.5)
Temperate rainforest needle-trees	45	0	5 (11.1)
Boreal summergreen needle-trees	236	0	51 (21.6)
Cool-temperate broad-evergreen trees	7	0	3 (42.9)
Raingreen Thorn-scrub	183	0	33 (18.0)
Mediterranean evergreen shrubs	150	35 (23.3)	0
Temperate broad-evergreen shrubs	229	0	51 (22.3)
Broad-summergreen mesic shrubs	353	0	27 (7.6)
Xeric summergreen shrubs	170	0	29 (17.1)
Cold-winter xeromorphic shrubs	116	20 (17.2)	0
Arborescent stem-succulents	140	0	33 (23.6)
Tall grasses	504	0	88 (17.5)
Short sward-grasses	678	0	123 (18.1)
Sclerophyllous grasses	72	18 (25.0)	22 (30.6)
Raingreen vines	278	0	21 (7.6)
Summergreen vines	134	0	50 (37.3)
Wintergreen epiphytes	451	0	9 (2.0)
Summergreen ferns	192	0	114 (59.4)

CHAPTER 8

Conclusions and next steps

Plant form and function, vegetation structure, environmental factors, and ecosystemic functions are of course highly complex phenomena interrelated by perhaps countless constraining and generative feedback mechanisms. The particular species composition of a system depends not only on physical conditions and evolutionary adaptations but also on complex biotic interactions. These complex interrelationships represent one of the primary and most intriguing foci of ecology. As is generally the case with feedback systems, however, certain processes are more immediately limiting or otherwise more important than others, resulting in a hierarchical ordering of both processes and effects, with subordination of much detail.

The first observation to be made from the foregoing results is that even a rather simplistic model with considerable ecological generalization can predict the general features of vegetation structure and world vegetation distributions with surprising accuracy. Despite the complexity of ecological systems, species interactions, and plant-environment relations, the results suggest that the basic features of plant form and world vegetation (in the absence of overwhelming non-climatic complications) are determined primarily by the general levels and mean seasonal patterns of temperature and the climatic water balance, with relatively little reliance on other factor interactions. The spectrum of life forms composing a vegetation appears to vary much less with climate than does species composition, and it is the particular combination of basic life forms, not the detailed species composition, which provides the basic structural and functional framework of an ecosystem.

More specific conclusions include the following:

1. Fairly specific plant forms and vegetation structures, including seasonal aspects, can usually be determined from the most basic, readily available climatic data. Sites on which this may not hold include waterlogged, foggy or windy, extremely rocky, agricultural, mechanically disrupted, fire-maintained, heavily grazed, chemically disrupted, mobile-substrate, oasis and some coastal and riverine sites. Climate, however, usually determines many of the forms found even on these sites, with actual vegetation corresponding either to shifted climatic conditions or to a subclimax stage with climatic dominants excluded. Except for agricultural and other maintained lands, these non-climatically controlled sites cover small fractions of the earth's land area.

2. Since occurrence of the ecophysiognomic forms is well described by their macroclimatic envelopes, it appears that climate not only 'determines' physiognomy but that plant forms are limited to their particular ecoclimates to a considerable degree. This corresponds to a certain degree of what can be called ecophysiognomic status. Well-known forms which have not always been accorded such status include, in particular, various groups of pines and other conifers. The evolutionary and successional status of such forms does not preclude ecophysiognomic status.

3. Despite climatic variation and differing configurations of climatic values, the macroclimatic limits of the plant forms of Table 2 appear to be similar throughout the world. In some situations,

however, related factors not explicitly included in the model seem to set the actual limits. These include soil moisture, absolute temperature range, growing-season length and total thermal input, and wind.

4. Most vegetation types appear to be well adapted to their local climatic regimes, with the inherent variabilities, and not extremely sensitive to minor modifications. Interannual climatic variability does not appear to be a major determining factor for plant form in most climate types. (Some exceptions to both these generalizations were suggested.)

5. Natural life-form ecotones appear to cover about 30% of the earth's land area. Some mixes of life forms show considerable consistency and merit formation-type status.

6. Physiognomic diversity of vegetation appears to increase as tree forms disappear and to be negatively related to warm-season precipitation. The highest form-diversity (excluding less important understorey forms) is to be expected in the warm semi-deserts.

7. There appears to be little difference in ecophysiognomic significance between some widely separated and apparently dissimilar climates, such as:

(a) tropical high-mountain (cloud-belt) and temperate perhumid (extremely maritime) climates.
(b) correspondingly wet polar and temperate alpine climates.
(c) temperate summergreen climates and the montane summer-rain climates (with frost) of tropical margins.

These parallels have been recognized for some time through species and phenological similarities but should be studied also using integrative ecophysiognomic indices.

8. The generally good results of the site comparisons relative to full life-form spectra support further the suggestion that biotic interactions (among plants) are not as important to general vegetation structure as to species composition.

The results emphasize the importance of ecophysiognomic form in plant-environment relations and suggest that ecophysiognomy may provide a theoretical and geographical framework for studying plant-environment relations. One of the most useful results of such general geographic studies is that they often effectively point out areas where more data or research is needed. Tropical mountains, windy and maritime environments are suggested by the current study. Additional climatic data should express some aspects of windiness, diurnal temperature variations, absolute temperature extremes, and interannual variations.

As a methodology the model demonstrates the following:

1. A combined life form-environmental limitation approach to the study of vegetation structure, function and geography.
2. A general computer-based framework and methodology for simulating vegetation and ecosystem phenomena and their spatial and temporal variations.
3. A quantitative but at the same time descriptive, analytical (as opposed to purely statistical), and validation-oriented approach to ecological modeling.
4. A framework for world-scale environment based modeling which may be of some use in fields other than botany and ecology.

As one can see from the relatively large amount of model output, the life-form approach to vegetation geography provides a combinatorial basis for greater resolution in formation description without requiring long lists of species. The environmental basis permits extrapolation, prediction and hypothesis-testing under conditions of changing macro- or micro-climate. Applications range from prediction of vegetation under different climatic conditions (e.g. during the Ice Ages or after greenhouse-effect climatic change) to geographic testing of ecophysiological hypotheses. The geographical basis provides the necessary feedback for iterative refinement of estimates of environmental limits. Subsequent models, however, should seek to relate vegetation to fewer, more integrative environmental variables in order to identify more critical mechanisms and general patterns of environmental limitation. Environmental-limitation and other such discrete models can be coupled with continuous process models in order to provide more complete descriptions of system structure and function and more insight into ecological strategies. This combined structural-functional approach, with geoenvironmental basis, begins to get at what Innis (1975) and Haefner (1978) have called 'ecological grammars.'

True ecophysiognomic studies and models require a more analytical (mechanismal) approach which seeks to simulate quantitatively and to integrate the metabolic, transport, and other physiological processes of particular life forms (plant or animal). Five major environmental factors not included in the present model were identified earlier as being necessary to eliminate the main discrepancies between actual vegetation and that predicted by the macroclimatic approach. These factors are:

1. soil moisture regime
2. seasonal freezing and thawing of the soil
3. solar declination
4. annual ranges of absolute temperatures
5. delimitation of the growing season, including some measure of total solar input and warmth.

In the course of developing the model, other models and submodels of various environmental phenomena (for use within an ECOSIEVE framework or independently) were also developed. These include in particular a soil moisture simulator (SOLWAT) and a simple routine (PERIOD) for delimiting favorable and unfavorable seasons which can be used, along with more complete data on temperature extremes and climatic variabilities, for a more integrative approach to modeling life-form ecology. Refinement of the current model may well represent diminishing returns, but estimating the life-form limiting values for more integrating variables, such as soil moisture level or actual evapotranspiration, might provide interesting insights.

Models predicting ecological phenomena from environmental conditions have a variety of applications in other areas. The geographical framework provided by ECOSIEVE and an adequate climatic data-base permit application of the study of plant-environment relations over large areas and under conditions of changing climate. Two applications were immediate. The primary energetics of ecological systems involves not only primary productivity but also the caloric equivalent of the biomass. A similar ECOSIEVE-based model was used to generate a world vegetation model (using vegetation units for which values of biomass energy content were available), which was then used as the basis for maps of estimated average annual energy fixation by natural vegetation (Box 1976) and of estimated average annual photosynthetic efficiency (Box 1977). The second application involves estimating changes in global terrestrial vegetation patterns, including agricultural implications, which might result from likely changes in the earth's climate. The main problem here is estimating spatial variations in the course of climatic change. Other potential applications are to be found in biogeochemistry, environmental management and various fields of geography. Such applications require geographic descriptions of more general aspects of vegetation and often require area estimates. When computer-maps can be produced with sufficient resolution, they can also be quantified by computerized planimetry (Box 1978b, 1979a) to provide estimated world or regional budgets or inventories.

APPENDIX A

Descriptions of the plant types

The plant life forms employed in the model are listed, with examples, in the main text (Table 2). They are described in this appendix in more detail, including environmental relations, physiognomic characters, prototypic and other characteristic taxa, and relevant literature. A list of the forms, with physiognomic characters, is included. Sources of vegetation data relevant to particular life forms are cited with the respective forms in the text of the appendix. General references, especially descriptions of regional vegetation, are listed by region at the end of the appendix.

Plant form	Plant size	Leaf size	Leaf (Stem) structure
Trees (Broad-leaved)			
Evergreen			
1. Tropical Rainforest Trees (lowland, montane)	tall, med.	large-med.	cor.
2. Tropical Evergreen Microphyll Trees	medium	small	cor.
3. Tropical Evergreen Sclerophyll Trees	med.-tall	medium	scler.
4. Temperate Broad-Evergreen Trees			
a. Warm-Temperate Evergreen	med.-small	med.-small	scler.
b. Mediterranean Evergreen	med.-small	small	scler.
c. Temperate Broad-Leaved Rainforest	medium	med.-large	scler.
Deciduous			
5. Raingreen Broad-Leaved Trees			
a. Monsoon mesomorphic (lowland, montane)	medium	med.-small	mal.
b. Woodland xeromorphic	small-med.	small	mal.
6. Summergreen Broad-Leaved Trees			
a. typical-temperate mesophyllous	medium	medium	mal.
b. cool-summer microphyllous	medium	small	mal.
Trees (Narrow and needle-leaved)			
Evergreen			
7. Tropical Linear-Leaved Trees	tall-med.	large	cor.
8. Tropical Xeric Needle-Trees	medium	small-dwarf	cor.-scler.
9. Temperate Rainforest Needle-Trees	tall	large-med.	cor.
10. Temperate Needle-Leaved Trees			
a. Heliophilic Large-Needled	medium	large	cor.
b. Mediterranean	med.-tall	med.-dwarf	cor.-scler.
c. Typical Temperate	medium	medium	cor.
11. Boreal/Montane Needle-Trees	medium	small	cor.-scler.

Plant form	Plant size	Leaf size	Leaf (Stem) structure
Summergreen			
12. Hydrophilic Summergreen Needle-Trees	tall-med.	large-med.	mal.-cor.
13. Boreal Summergreen Needle-Trees	medium	medium	mal.-cor.
Small and dwarf trees			
14. Tropical Broad-Evergreen Small Trees	small	med.-small	cor.
15. Tropical Broad-Evergreen Dwarf-Trees	dwarf	large-med.	cor.
16. Cloud-Forest Small Trees	small	small	cor.-scler.
17. Temperate Broad-Evergreen Small Trees	small	small	scler.
18. Broad-Raingreen Small Trees	small	small	mal.
19. Broad-Summergreen Small Trees	small	small-med.	mal.
20. Needle-Leaved Small Trees	small	dwarf	cor.-scler.
Rosette-trees (evergreen)			
21. Palmiform Tuft-Trees	medium	large	cor.-scler.
Rosette-Treelets (evergreen)			
22. Palmiform Tuft-Treelets	small	large-med.	cor.-scler.
23. Tree Ferns	small	med.-small	cor.-mal.
24. Tropical Alpine Tuft-Treelets	small-dwarf	large-med.	cor.-scler.
25. Xeric Tuft-Treelets	small-dwarf	large-med.	scler.
Arborescents			
26. Evergreen Arborescents	med.-tall	small	scler.
27. Raingreen Thorn-Scrub	medium	small	mal.
28. Summergreen Arborescents	med.-small	small	mal.
29. Leafless Arborescents	med.-small	–	(lign.)
Krummholz			
30. Needle-Leaved Treeline Krummholz	medium	small-dwarf	scler.
Shrubs			
31. Tropical Broad-Evergreen Shrubs	med.-tall	large-med.	cor.
32. Temperate Broad-Evergreen Shrubs			
a. Mediterranean	medium	small	scler.
b. Typical Temperate	medium	small-med.	scler.
c. Broad-Ericoid (perhumid)	med.-tall	large	scler.-cor.
33. Hot-Desert Evergreen Shrubs	small	small	scler.
34. Leaf-Succulent Evergreen Shrubs/Treelets	small-dwarf	med.-small	succ.
35. Cold-Winter Xeromorphic Shrubs	small-dwarf	small-dwarf	pub.-mal.
36. Summergreen Broad-Leaved Shrubs			
a. mesomorphic	medium	med.-large	mal.
b. xeromorphic	med.-small	small-med.	mal.-cor.
37. Needle-Leaved Evergreen Shrubs	med.-small	dwarf	scler.
Dwarf-shrubs			
38. Mediterranean Dwarf-Shrubs	dwarf	small-dwarf	pub.-mal.
39. Temperate Evergreen Dwarf-Shrubs	dwarf	small-dwarf	scler.-cor.
40. Summergreen Tundra Dwarf-Shrubs	dwarf	small	mal.
41. Xeric Dwarf-Shrubs	dwarf	dwarf, –	mal., (lign.)
Cushion-shrubs			
42. Perhumid Evergreen Cushion-Shrubs	dwarf	small-dwarf	scler.
43. Xeric Cushion-Shrubs	dwarf	dwarf, –	mal., scler., (lign.)

Plant form	Plant size	Leaf size	Leaf (Stem) structure
Rosette-shrubs (evergreen)			
44. Mesic Rosette-Shrubs	medium	large	cor.-scler.
45. Xeric Rosette-Shrubs	small	med.-large	scler.-succ.
Stem-succulents (evergreen)			
46. Arborescent Stem-Succulents	tall	–	(succ.)
47. Typical Stem-Succulents	med.-small	–	(succ.)
48. Bush Stem-Succulents	med.-small	–	(succ.)
Graminoids			
49. Arborescent Grasses	tall	large	mal.
50. Tall Cane-Grasses	tall-med.	med.-large	mal.
51. Typical Tall Grasses	medium	medium	mal.
52. Short Sward-Grasses	small	small	mal.
53. Short Bunch-Grasses	small	small	mal.
54. Tall Tussock-Grasses	medium	med.-large	mal.
55. Short Tussock-Grasses	small	small-med.	mal.
56. Sclerophyllous Grasses	small	medium	scler.
57. Desert Grasses	dwarf	small	mal.
Forbs			
58. Tropical Evergreen Forbs	tall-dwarf	large-med.	cor.-scler.
59. Temperate Evergreen Forbs	med.-dwarf	med.-small	scler.
60. Raingreen Forbs	med.-dwarf	large-small	mal.
61. Summergreen Forbs	med.-dwarf	large-small	mal.
62. Succulent Forbs	small-dwarf	med.-small	succ.
Undifferentiated small herbs			
63. Xeric Cushion-Herbs	small-dwarf	small	mal.-cor.
64. Ephemeral Dry-Desert Herbs	small-dwarf	small	mal.
65. Summergreen Cold-Desert Herbs	dwarf	small	mal.
66. Raingreen Cold-Desert Herbs	dwarf	small	mal.
Vines and lianas			
67. Tropical Broad-Evergreen Lianas	tall	large-med.	cor.
68. Broad-Evergreen Vines	med.-small	large-small	cor.-scler.
69. Broad-Raingreen Vines	med.-dwarf	large-small	mal.
70. Broad-Summergreen Vines	med.-dwarf	large-small	mal.
Ferns			
71. Evergreen Ferns	med.-small	med.-small	cor.
72. Summergreen Ferns	med.-small	med.-small	mal.-cor.
Epiphytes (evergreen)			
73. Tropical Broad-Evergreen Epiphytes	large-med.	large-med.	cor.
74. Narrow-Leaved Epiphytes	med.-small	small	cor.
75. Broad-Wintergreen Epiphytes	medium	medium	cor.
Thallophytes (poikilohydrous)			
76. Mat-Forming Thallophytes	med.-large	med.-small	mal.-cor.
77. Xeric Thallophytes	small-dwarf	small-dwarf	cor.-crust.

cor. = coriaceous
scler. = sclerophyllous
mal. = malacophyllous
lign. = ligneous

pub. = pubescent
succ. = succulent
crust. = crustose

Trees

True trees (as opposed to rosette-trees) are tall woody phanerophytes with a single main stem (trunk) and usually well developed lateral branches forming a more or less characteristic crown. Typical branching and crown forms may range from multi-stemmed 'overgrown bushes' (treated separately below) through typically 'dendritic' (see de Laubenfels 1975) to the highly monopodial columnar or umbrella-like growth forms of most conifers. Trees can grow to over 100 m in height, but heights of 10–30 m are typical. Trees shorter than 5–10 m may be called treelets, and certain scrubby but very tree-like forms of 1–5 m may be called dwarf-trees (e.g. 'campos cerrados' of Brazil, trunk-succulent euphorbs of Africa). Some understorey trees taller than 10 m, mainly in the tropics, may also be called treelets in order to distinguish them from much taller canopy trees.

Trees may have broad, narrow (linear), or needle/scale leaves, or may have no leaves at all (e.g. *Haloxylon ammodendron*). Tree leaves may be large to quite small and may be evergreen (always present, without regard initially to actual length of tenure), deciduous (summergreen or raingreen), or semi-evergreen (persistent depending on degree of cold and/or drought).

Trees generally have well-developed underground root systems, but these may be deep in drier environments or quite shallow in environments with high water tables and permanently saturated soil (e.g. not more than 50 cm in many equatorial rainforests, necessitating the characteristic aboveground buttressing). Trees generally have significantly more standing biomass above ground than below. Since trees generally have the largest transpiring surface area of any growth form, they are more important in wetter climates of the world. Because of their size trees require more time to develop but then generally attain dominance by shading shorter growth froms and by more effective water uptake from greater area and depth around them. Trees occur but do not attain dominance only where water is too limited for sufficient canopy development or where tree invasion is prevented in the seedling stage by well developed grass covers.

Stands of trees in which adjacent tree crowns overlap to form a more or less closed canopy are called forests (except for artificial plantations). Formations which do not present at least a seasonally closed canopy are called (open) woodlands and generally have better developed, more diverse understoreys. The term rainforest generally refers to closed, mesic evergreen forests which also have at least one closed understorey.

Broad-leaved trees

Broad-leaved trees have leaves which are generally of at least microphyll size and are produced in order to make maximum use of at least seasonally favorable growing conditions. Where evergreen, these trees are often dominants. Where leaves are produced anew seasonally, broadleaved trees can dominate but may be outcompeted in marginal areas (e.g. boreal mixed forests) by evergreen sclerophyll trees better able to utilize a short growing season. Leaves produced seasonally often attain higher photosynthetic rates but are generally softer (malacophyllous) than evergreen leaves and have less control over water loss. Deciduous trees generally transpire freely during their growing seasons and evade drier conditions by shedding their leaves. Leaves produced for longer tenure (generally one year for semi-evergreens and at least one year for true evergreens) become harder and are described as coriaceous (leathery, i.e. still pliable) or sclerophyllous. Such leaves usually photosynthesize more slowly but control water loss better.

General references: Kozlowski 1962, 1971; Gates & Schmerl 1975; Kramer 1962; Larcher 1976; Levitt 1972; Mooney 1974; Leathart 1977; Lieth 1974; Lieth & Whittaker 1975; Thoday 1931; Tranquillini 1979; Cooper 1975; Elton & Meentemeyer 1979.

1. Tropical Rainforest Trees are the tall, evergreen canopy-trees of equatorial regions with abundant, often daily rainfall, high humidity, and short if any dry seasons. The leaves of these trees are generally fairly large, entire, and most often described as coriaceous. Such leaves are designed to withstand short daily periods of water stress around midday but do not require stronger reinforcing, as against protracted drought or winter cold. Because of the climatic differences at canopy level and within the rainforest, trees typically show distinct morphologic differences between their more xeromorphic canopy leaves and more mesomorphic lower leaves.

Tropical rainforest trees are typically 30–50 m tall. Although the great canopy height is the result of generally favorable year-round growing conditions, the heights of individual trees are controlled also by competition for light. This can be seen easily where terrain undulates but canopy level remains relatively constant. Tropical rainforest tree crowns usually have a characteristic rounded appearance. Brünig (1970) has described a number of crown forms characteristic of different radiation environments. Because tropical rainforest soils are often saturated to within 1–3 decimeters of the surface, the trees root laterally and form dense networks of roots within the top 3 dm of the soil. Above-ground prop-roots and buttressing are common in order to provide additional support. Tropical rainforest trees have been described as lauraceous in appearance, but the actual diversity in species and even families is overwhelming. Many species still have not been identified. The list of characteristic families is very long but includes especially *Lauraceae* (s.l.), *Rubiaceae, Anacardiaceae, Moraceae, Dipterocarpaceae, Sapindaceae, Sapotaceae, Meliaceae, Vochysiaceae, Myrtaceae,* and some *Leguminosae* and *Compositae.*

As one ascends from lowland equatorial rainforests one finds that the adjacent montane rainforests are often even wetter and luxurious. Epiphytes and some other forms increase, but the canopy trees generally decrease gradually in height, and the number of distinct strata generally decreases from as many as 5–6 to 2–3 at mid-mountain. Tropical montane rainforest trees are much like the lowland trees but become less tall and gradually show somewhat smaller leaves. Diversity is often greatest at the base of windward mountain slopes and decreases upward.

References: Whitmore 1975; Richards 1952; Brünig 1970; Aubert de la Rüe et al. 1957; Walter 1973; Hueck 1966; Lind & Morrison 1974; Shreve 1914; Schnell 1970–77; Troll 1959; Hallé et al. 1978; UNESCO 1978; Vareschi 1968; Fosberg 1960; Bünning 1956; Meggers et al. 1973; Hargreaves & Hargreaves 1965; Knapp 1965, 1973; Daubenmire 1978.

2. Tropical Evergreen Microphyll Trees include a wide variety of tropical evergreen trees with either compound leaves consisting of numerous small leaflets (prototypically *Leguminosae*) or small simple leaves. The leaves are typically coriaceous. These trees occur widely in closed forests and in open woodlands throughout the tropics, both as canopy trees and as understorey forms, but they almost always represent admixtures or at best co-dominants. Characteristic taxa include not only *Leguminosae* but also a variety of other families with typically compound leaves, such as *Meliaceae, Rutaceae,* and *Simaroubaceae,* plus small-leaved eucalypts, etc. Specific examples include *Grevillea robusta* (silky oak of Australian rainforests), *Swietenia* (mahogony), *Butea frondosa, Schleichera trijuga* (*Sapindac.*), *Caesalpinia coriaria,* and *Crescentia cujete* (calabash tree). Tropical evergreen microphyll trees can be important rainforest components but become more important toward the drier margins of tropical evergreen forests, which Vareschi (1968) preferred not to call true rainforests. His comparison of leaf sizes (biótipos) in an evergreen 'selva eupluvial' in Borneo and a largely raingreen 'selva alisia' in Venezuela shows the generally smaller size of the evergreen leaves in the drier Venezuelan environment. Tropical evergreen microphyll trees are often shorter than canopy trees and form evergreen understoreys in tropical 'semi-evergreen forests' which have largely deciduous canopies (see, for example, Eyre 1968). Such semi-evergreen tropical forests are well developed on Trinidad (Beard 1946), as belts around the tropical rainforests of South America and southern-southeastern Asia (Eyre 1968; Stamp 1924), in northern Australia, in scattered parts of West Africa ('dry evergreen forest', Eyre 1968), and in Indo-Malaysia (Eyre 1968; Schimper 1898). The tropical evergreen microphyll trees of northern Australia are mainly eucalypts.

References: Eyre 1968; Vareschi 1968; Richards 1952; Whitmore 1975; Beard 1946, 1955, 1967; Stamp 1924; Ogawa et al. 1961; Milton Moore 1970; Brockman 1968.

3. Tropical Evergreen Sclerophyll Trees include prototypically the tall, more mesic, tropical and subtropical eucalypts of Australia plus a variety of similar trees in other areas. These occur in moderately humid to distinctly subhumid environments, extending well into subtropical Australia. Such eucalypts have been successfully introduced into similar tropical and subtropical

climates, including highlands, throughout the world. The leaves are classified as broad but are typically elongate, often somewhat curved (*Eucalyptus*), and may be broadly linear in some species. Eucalypt leaf textures range in a continuum from coriaceous in more mesic situations to sclerophyllous in drier situations, with any division being probably arbitrary and not really important. The sclerophylly characteristic of Australian evergreen trees is considered (e.g. Webb 1959) to be an adaptation to erratic rainfall, an attribute which serves well also when these trees are introduced outside Australia. Total leaf area also varies with conditions but is typically low for such tall trees. *Eucalyptus* wood is often lightweight, and the trees can grow quickly. Tropical evergreen sclerophyll trees occur most commonly in the semi-evergreen and sclerophyll forests of northern and eastern Australia and as admixtures in the Australian rainforsts (Milton Moore, 1970; Webb 1959; Eyre 1968). Though extending to 35 °S in mediterranean climates, the leathery-leaved Jarrah (*Eucalyptus marginata*) can be included also. (The more mesic and much taller *E. diversicolor,* Karri, is more problematic.) Equivalent sclerophyllous trees can be found especially in East Africa (Burtt 1942; Lind & Morrison 1974), but the success with which eucalypts have spread after introduction into other tropical and subtropical areas suggests a particular ecological strategy superior to that developed in similar climates elsewhere.

References: Milton Moore 1970; Keast et al. 1959; Beard 1955, 1965, 1967; Eyre 1968; Walter 1968, 1973; Knapp 1973; Burtt 1942; Lind and Morrision 1974; Webb 1959; Gentilli 1960; Aubert de la Ruë et al. 1957; Specht 1972; Min. Agric. Rabat 1960.

4. Temperate Broad-Evergreen Trees include several types of tall and shorter trees which occur in milder, generally maritime temperate-zone climates with a variety of rainfall regimes. The broad leaves of these trees can be large or small but are generally harder than those of tropical trees (i.e. sclerophyllous) since they must withstand winter cold as well as varying degrees of periodic drought. Temperate evergreen trees are often co-dominants but are also often outcompeted in mixed stands by faster-growing, softer-leaved and taller summergreen trees. At least three distinct subtypes occur, namely those of warm-temperate summer-rain, winter-rain and maritime-perhumid climates. The eucalypts of Australia present a special problem because of their height and lack of major physiognomic differences in different climates. The tall, broad-leaved eucalypts of mesic southern Australia and Tasmania can be grouped with the temperate broad-leaved rainforest trees of other areas, while the more xeromorphic majority of the tall eucalypts are classified as Tropical Evergreen Sclerophyll Trees, even in subtropical areas.

4a) Warm-Temperate Evergreen Trees are the evergreen broad-sclerophyll trees of subtropical areas with summer rainfall, mild winters with some frost, and some summer moisture stress due to high potential evaporation rates. Such climates occur primarily near the east sides of land masses in the subtropical belts, namely in southern China and Japan, West Indies and southeastern USA, southern Brazil, southeastern Australia, southeastern South Africa and northern New Zealand. The leaves of these trees are typically mesophyllous to microphyllous in size. Some resist saltwater spray, as in coastal southeastern USA (e.g. *Quercus virginiana,* see Boyce 1954). Typical taxa include *Quercus* (USA and Far East), other *Fagaceae* in China and Japan (e.g. *Lithocarpus, Castanopsis*), *Ilex* (USA and Far East), *Persea* (USA and South America), other *Lauraceae* (USA, Far East, South America), *Nothofagus* (Australia, New Zealand, Chile-Argentina), and mainly tropical taxa in southeastern South Africa. Several of these genera (usually different species) occur also in winter-rain climates, such as *Quercus, Lithocarpus* and *Castanopsis* in California and *Quercus* in the Mediterranean area. The *Citrus* species, though cultivated most commonly in mediterranean climates, are native to summer-rain climates and appear to belong in this type.

References: Daubenmire 1978; Hueck 1966; Knapp 1965, 1973; Wang 1961; Ogawa et al. 1961; Numata 1974; Boyce 1954; Küchler 1964; Zinderen-Bakker 1973; Monk 1966, 1968; Kan et al. 1965; Wells 1928, 1942; Kusumoto 1961; Brockman 1968; Walter 1968; Holloway 1954; Webb 1959; Lindman & Ferri 1974.

4b) Mediterranean Evergreen Trees are the evergreen broad-sclerophyll trees of the warm-temperate to subtropical areas with mild and rainy winters but very dry summers. Such 'mediterranean' climates occur on the west sides of land masses at the same latitudes or slightly higher (30°–44°) than the summer-rain subtropics, namely around the Mediterranean Sea, at the southwest tip of South Africa, along the southwest coasts of Australia, in southern California, and in central Chile. Mediterranean Evergreen Trees differ little in physiognomy from many Warm-Temperate Evergreen Trees, with the exception that mediterranean trees may be shorter in stature with more spreading crowns. The leaves of mediterranean evergreen trees are usually microphyllous in size and typically quercoid. Many of these leaves may be shed during especially dry summers. Leaf tenure is commonly one year, the old being shed in spring as the new are produced. Many taxa resist saltwater spray. The most characteristic genus in the Northern Hemisphere is *Quercus*, including *Q. suber* and *Q. ilex* around the Mediterranean and *Q. chrysolepis* and *Q. wislizenii* in California-Arizona. Other typical taxa include *Olea*, *Ceratonia siliqua*, and *Arbutus unedo* around the Mediterranean and *Arbutus menziesii*, *Castanopsis chrysophylla*, *Umbellularia californica* (*Laurac.*) and *Lithocarpus densiflorus* in California. *Leucadendron argenteum* (*Proteaceae*) appears to be the only important mediterranean tree of South Africa, its relatives all being shrubs (Walter 1968). Australia is problematic, since it has produced tall eucalypts in its mediterranean areas rather than more typical mediterranean tree forms. Mediterranean evergreen trees of central Chile include *Lithraea caustica* (*Anacardiac.*), *Quillaja saponaria* (*Rosac.*) and *Peumus boldus (Monimiac.)*.

References: Walter 1956, 1968, 1975; di Castri & Mooney 1973; Hueck 1966; Cooper 1922; Brockman 1968; Oppenheimer 1932; Larcher 1961, 1970, 1972; Sauvage 1961; Horvát et al. 1974; Zohary 1973; Zohary & Orshan 1966; Pisek & Rehner 1958, 1960; Braun-Blanquet & Walter 1931; Rouschal 1939; Grieve 1955; Lange & Lange 1963; Ern 1966; Lüdi 1935; Schmithüsen 1956; Adamson 1927; Specht 1969, 1972; Knapp 1965, 1973.

4c) Temperate Broad-Leaved Rainforest Trees are the often larger-leaved but still sclerophyllous trees of warm-temperate maritime climates with year-round rainfall. Such 'rainforest' climates can occur on temperate-zone windward west coasts (e.g. southern Chile, southern New Zealand, Atlantic Europe, northwestern USA) and on subtropical east coasts which get summer rainfall from tropical systems (e.g. southern China and Japan, southeastern USA, southeastern Australia, northern New Zealand, southern Brazil). Such areas differ climatically from adjacent mediterranean areas by having no summer drought and from summer-rain areas by having higher annual rainfall and humidity. Temperate broad-leaved rainforest trees can have much larger leaves, especially in Chile and the warmer east-coast areas (e.g. *Magnolia grandiflora*), or can have the microphyll-mesophyll leaves most typical of *Nothofagus* in the Southern Hemisphere (see Webb 1959). Typical taxa include *Magnolia grandiflora* and *Gordonia lasianthus* (*Theaceae*) in southeastern U.S.A.; *Laurelia* (*Monimiaceae*), *Eucryphia* (*Eucryphiac.*), and the shorter *Aextoxicon punctatum* (*Aextoxicac.*) and *Drimys winteri* (*Magnoliac.*) in southern Chile; a variety of *Apocynaceae* (e.g. *Aspidosperma*) and *Lauraceae* (e.g. *Phoebe, Nectandra*) plus many others in southern Brazil (see Hueck 1966); *Nothofagus* in Australia and New Zealand, plus very tall *Eucalyptus* spp. in Australia (e.g. *Eu. regnans, Eu. saligna, Eu. diversicolor*); and various *Lauraceae* (e.g. *Machilus, Actinodaphne*) and *Magnoliaceae* in southern China and Japan.

References: Daubenmire 1978; Hueck 1966; Knapp 1965, 1973; Wang 1961; Ogawa et al. 1961; Numata 1974; Monk 1968; Kan et al. 1965; Radford et al. 1968; Brockman 1968; Walter 1968, 1974; Kusumoto 1961; Webb 1959; Holloway 1954; Lindman & Ferri 1974; Veblen 1979.

5. Raingreen Broad-Leaved Trees are generally tropical trees with larger or smaller, usually malacophyllous broad leaves which are lost in response to a pronounced, regularly occurring dry season. Tropical climates with such dry seasons are found mainly along the tropical margins in each hemisphere, where the seasonal shift of the global atmospheric circulation patterns causes dry, subsiding air masses during the low-sun period of the year. This tropical 'winter' is not cold (except in highlands) and in many areas is in fact the warmest season, due to the lack of a cloud cover. The raingreen leaves may be shed at the beginning of the dry season (suggesting some degree of adaptation to seasonal drought) or may be lost more gradually as the drought progresses. Experiments performed with raingreen trees in various botanical gardens, in which water was provided throughout the dry period, have suggested that leaf-fall in tropical trees (raingreenness) is facultative, as opposed to the more obligatory leaf-fall and winter dormancy in temperate deciduous (summergreen) trees (see Walter 1973). The length of the dry season normally increases as one goes toward the subtropical arid margins of tropical summer-rain climates, causing length of wet season and generally also total precipitation (both annual and wet-season monthly) to decrease correspondingly. As this happens the character of the vegetation changes also, from quite mesomorphic raingreen 'monsoon forests' which resemble rainforests during the wet season (e.g. southern Asia) to much more open, xeromorphic 'dry forests' with less undergrowth (e.g. East Africa). Although the change in physiognomy is primarily a property of the vegetation stand, there are also some changes in the form and physiology of the constituent raingreen trees. As a result, two subtypes are distinguished.

5a) Mesic Raingreen Trees are generally taller and closely resemble rainforest trees except for their deciduousness. Leaves may be either large or small, the latter often occurring as compound leaves in *Leguminosae*. The leaves are designed to produce optimally during the wet season and then be lost. Their size and structure are thus affected only indirectly by the relative lengths of wet and dry seasons. There is a great variety of raingreen trees, but typical taxa include *Tectona* (teak), *Terminalia, Shorea, Xylia* and various *Dipterocarpaceae* in southern and southeastern Asia; various *Anacardiaceae, Bombacaceae, Moraceae* and *Leguminosae* in Central America and northern South America; a great number of *Leguminosae* in Brazil; and a variety of scattered taxa, including many *Leguminosae* in Africa. Mesic raingreen forests and semi-evergreen forests (with many mesic raingreen canopy trees) are best developed in southern and southeastern Asia (including Indonesia) and are also important in Caribbean America and in the mountains of the summer-rain tropics.

5b) Xeric Raingreen Trees include a somewhat greater variety of both tall (enormous, e.g. *Adansonia*) and shorter (e.g. *Acacia*) trees which in one way or another have a more xeromorphic structure. Leaves may be either entire mesophylls (e.g. *Colophospermum mopane*) or the more common soft, often compound (e.g. *Leguminosae*) microphylls. Two important and quite characteristic subtypes are the trunk-succulent 'bottle trees' of Africa (e.g. *Adansonia digitata*) and Brazil (e.g. *Cavanillesia arborea*) and the spreading, flat-topped umbrella acacias of the African savannas. More typical, dendritic taxa include above all the many *Leguminosae* of the open 'miombo' woodlands of Africa (e.g. *Brachystegia, Isoberlinia, Julbernardia*), the 'alisio' and similar forests of Caribbean America, and scattered other woodlands and savannas on all tropical continents. Dry raingreen forests and open woodlands are best developed in eastern (highlands) and south-central Africa, in a sub-Saharan belt across northern Africa, in the Caatingas and 'chaco' regions of Brazil, along the Pacific coast of Mexico and Caribbean coast of Venezuela, through much of central and western India, and in the 'dry belts' of Southeast Asia. Xeric raingreen trees are the main trees in the extensive African and other savannas, with the exception of Australia. Even among the typically evergreen eucalypts of Australia, however, there are several raingreen species (e.g. *Eu. alba, Eu. brachyandra*) which occur in the savannas and open woodlands of the summer-rain northern sections (Walter 1973; Keast et al. 1959), especially in the Kimberley Plateau area.

References: Walter 1939, 1973; Hueck 1966; Knapp 1965, 1973; Eyre 1968; Daubenmire 1972, 1978; Lind & Morrision 1974; Bhatia 1958; Beard 1944a, 1944b, 1953, 1955, 1967; Boaler 1966; Lauer 1952; Burtt 1942; Ernst 1971; Mani 1974; Malaisse 1974; Owen 1974; Stocker 1970, 1971; Keast et al. 1959; Müller 1977; Werger 1977; UNESCO 1978; Aubert de la Ruë et al. 1957; Meggers et al. 1973; Schmidt 1973; Sreedhara 1978; Shrimal & Vyas 1977; Misra & Gopal 1968; Mata et al. 1972; Schnetter 1968; Scholz 1967; Fanshawe 1969; Stamp 1924; Ogawa et al. 1961; Champion & Seth 1968; Ewel & Madriz 1968; Golley & Medina 1975; Lawson et al. 1970.

6. Summergreen Broad-Leaved Trees are generally temperate-zone trees (tropical in some mountains but never equatorial) with large to small, generally malacophyllous leaves which are lost in response to winter cold. Since the leaves are usually soft and designed for high productivity during the warm season, broad-summergreen trees are typical of temperate areas with summer rainfall and extend into dry and summerdry climates only on moist sites, such as along rivers. Summergreen trees are the characteristic dominants of the typical four-season (nemoral) temperate climates of eastern North America, much of Europe, and eastern Asia. For a variety of reasons, summergreen trees in the Southern Hemisphere are restricted to small areas in New Zealand and the southern Andes. Summergreen leaves are generally 'killed' by autumn frost and gradually fall off. Before falling they typically turn bright yellow and/or red (orange, violet) for a 2–4 week period in mid-autumn, the intensity of coloration being greatest in areas with many warm, sunny autumn days but cool, clear nights (i.e. North America and East Asia more than Europe). Refoliation occurs when springtime temperatures are sufficient and frost has subsided. Both leaf-fall and sufficient winter cold (vernalization) are apparently required by summergreen trees. This can be seen from the fact that summergreen species shed their leaves even in the mild winters of south-central Florida (January mean temperatures around 15° C) and by the fact that summergreen trees grown in the winterless tropics suffer from confused flowering cycles and gradually die. Summergreen tree taxa are mostly holarctic and common to the three major Northern Hemisphere formations of summergreen forest, as well as to more local formations. These taxa include *Quercus, Fagus, Castanea* (all *Fagaceae*), *Acer, Tilia, Fraxinus, Ulmus, Carya* and *Carpinus*. As summers become cooler and shorter, summergreen leaves tend to become softer and smaller and do not survive protracted drought (e.g. Neuwirth & Polster 1960). The main taxa from these cool boreal and montane areas are *Betula, Salix, Populus* and *Alnus*, plus *Nothofagus* in the Southern Hemisphere. Whereas the more shade-tolerant, malacophyllous summergreens are generally climatic-climax species in temperate areas, the boreal summergreens are usually successional species, being shaded out by the dense canopies of the taller boreal conifers. Transition zones of mixed forest are well developed in North America, Europe and East Asia, and Eyre (1968) notes that many historical cultural capitals of Europe (e.g. London, Stockholm, Moscow, Berlin) plus Boston and Beijing (Peking) all developed within this narrow belt. Smaller areas of summergreen forest and/or open woodland occur in northwestern U.S.A. (Küchler 1946), in southern Chile (Hueck 1966), in New Zealand, and across Russia and the mountains of Central Asia (Walter 1974). Summergreen forests composed of holarctic species also penetrate into the summer-rain tropics along the mountain ranges of eastern Mexico (Miranda & Sharp 1950; Leopold 1950), Bolivia-Argentina (Hueck 1954, 1966), and Southeast Asia (Ogawa et al. 1961; Walter 1968).

References: Walter 1956, 1968, 1974; Daubenmire 1978; Knapp 1965; Braun 1950; Wang 1961; Ellenberg 1963; Horvát et al. 1974; Eyre 1968; Hueck 1954, 1966; Ogawa et al. 1961; Leopold 1950; Schweinfurth 1957; Küchler 1946, 1964; Brockman 1968; Cockayne 1958; Godley 1960; Grebenshchikov 1974; Hamet-Ahti et al. 1974; Hartmann & Schnelle 1970; Lieth 1974; Miranda & Sharp 1950; Numata 1974; Radford et al. 1968; Axelrod 1966; Jäger 1968; Reichle 1970; Elton & Meentemeyer 1979; Reed 1971; Veblen 1979.

Narrow-leaved trees

Narrow-leaved trees have either flat linear leaves (e.g. *Podocarpus*) or needle-leaves, which may be reduced to even smaller scale-leaves (e.g. *Cupressaceae*). Most narrow-leaved trees are conifers (gymnosperms), which implies further that most narrow-leaved trees have strongly monopodial growth forms and tend to be tall. In general the smaller, harder leaves or needles of conifers provide greater protection during unfavorable periods than do broad leaves. As a result, narrow-leaved trees are mostly evergreen and occur, in one form or another, in all tree climates except the drier tropical summer-rain areas. In addition, the smaller, harder leaves (needles) and tall stature at maturity permit maintenance of greater total leaf areas than those of broad-leaved trees. In some areas, such as boreal and wet mediterranean climates, this provides a definite competitive advantage, and tall needle-leaved trees become the dominant form, despite relatively slow growth rates. Narrow-leaved trees are rarely climatic dominants in the tropics and subtropics but remain important as canopy constituents and often as individually taller emergents. In all areas where evergreen plants can survive unfavorable periods they have two important advantages over deciduous and other seasonal forms:

1. Evergreens have effectively longer growing seasons since their leaves are already deployed.
2. Evergreens survive poorer nutrient supplies since they waste less on seasonally discarded leaves.

General references: Dallimore & Jackson 1966; Krüssmann 1972; Tolmatschew 1954; Tranquillini 1979; de Laubenfels 1953, 1969; Hare 1954; Hustich 1953; Tranquillini & Holzer 1958.

7. Tropical Linear-Leaved Trees are tall (often emergent), monopodial, frost-sensitive evergreen trees with flat, linear leaves and stately, somewhat conical growth. The combination of height, high leaf area and coriaceous to sclerophyllous linear leaves makes these trees well suited to any warm humid climate with only short stress periods. As a result, such trees (primarily species of *Podocarpus, Agathis* and *Araucaria*) are found not only throughout the humid tropics but also throughout the largely frostless maritime climates of the Southern Hemisphere subtropics and temperate zone. The similarity between the Southern Hemisphere maritime climates and the climates of humid tropical mountains has been well recognized (Troll & Lauer 1978), and many genera and forms are common to both (Troll 1961, 1970). Tropical linear-leaved trees occur in moist tropical lowlands primarily as individuals but become more important in adjacent mountains, where they can become dominants in montane and cloud forests. Montane *Podocarpus* forests are best developed, within the tropics, in Africa (Knapp 1973; Lind & Morrison 1974) and in the East Indies (Whitmore 1975; van Steenis 1962; de Laubenfels 1969). In the southern temperate zone podocarps form important forests in New Zealand (Dawson 1962; Robbins 1962) and mix with other, more temperate conifers in mesic forests of various areas. Some podocarps and araucarias have been successfully introduced as ornamentals in northern warm-temperate and subtropical areas.

References: Troll & Lauer 1978; Dallimore & Jackson 1966; Whitmore 1975; Knapp 1973; Hueck 1966; Lind & Morrison 1974; Walter 1960, 1968, 1973; Troll 1959, 1961, 1970; van Steenis 1962; Robbins 1961, 1962; Dawson 1962; de Laubenfels 1969; Costin 1957; Kuschel 1975; UNESCO 1978; Krüssmann 1972; Godley 1975; Webb 1959.

8. Tropical Xeric Needle-Trees include a very small number of needle or scale-leaved but still relatively tall, evergreen trees which occur primarily in the drier montane forests of Africa. Because they are the tallest trees in these drier areas, these trees are generally dominants or co-dominants, but they occur also as individuals in more mesic montane forests. The main taxa are *Juniperus procera* (East Africa and Arabia), certain needle-leaved podocarps (e.g. *Podocarpus gracilior*), and *Widdringtonia* (*Cupressaceae*) in southern Africa. These taxa form dry coniferous montane forests (Knapp 1973: Trocken-Koniferen-Bergwälder) in drier mountain areas from Arabia (von Wissmann 1972) to South Africa. In general the *Cupressaceae* form the driest forests, with needle-leaved podocarps and then linear-leaved podocarps (e.g. *Podocarpus latifolius*) forming the gradient to more mesic broad-leaved montane forests (Knapp 1973). Equivalent forests from other tropical or subtropical areas have not been described, but some subtropical pine forests may be similar.

References: Knapp 1973; von Wissmann 1972; Kerfoot 1960–61; Zohary 1973; Lind & Morrison 1974; Troll 1959.

9. Temperate Rainforest Needle-Trees are tall, magnificent, monopodial trees with a variety of evergreen needle types and sizes which all add up to the same ecological significance, namely the highest leaf area indices of any plant form in the world and many of the world's tallest tree species. The needle-leaves of these trees may be flattened linear needles (as in *Taxus, Tsuga, Cunninghamia, Sciadopitys* and *Abies*), flattened scales (as in *Thuja* and *Chamaecyparis*), small falcate needles (as in *Cryptomeria, Sequoiadendron* and some species of *Araucaria*), or the equivalent of compound needles with generally flattened linear leaflets (as in *Sequoia*). The density of individual needles is always high. Most needle types are flattened for greater surface area, even in otherwise round-needled genera (e.g. *Picea sitchensis* and *P. breweriana*). Leaf area indices of 8–18 are typical (e.g. Tadaki 1977), and values as high as 50 (!) have been reported (Waring et al. 1978). Other taxa include temperate, smaller-leaved podocarps, scale-leaved *Dacrydium*, and *Saxegothaea*, all from the Southern Hemisphere. *Sequoia sempervirens* (to 110 m) and *Sequoiadendron giganteum* (to over

100 m) are the tallest trees in the world, occurring respectively along the north coast and in the Sierra Nevada of California. Temperate needle-leaved rainforest trees occur, in general, in perhumid temperate climates with mild winters and no severe frost. Such situations and the corresponding rainforests are best developed in the windward, often foggy marine west-coast climates of northern California to British Columbia, southern Chile, northwestern Europe, the west coast of New Zealand, and western Tasmania. The greater dominance of needle-leaved trees in the North American rainforest may be due to the greater mediterranean influence there, to which the needle-trees may be better adapted than broad-leaved trees. It is interesting to note that the tallest trees occur in the more mediterranean southern part of the American rainforest area, where potential evapotranspiration rates are higher. The world's tallest broad-leaved tree, *Eucalyptus regnans* of southwestern Australia, occurs in a similar climate. Elton & Meentemeyer (1979) found, on the other hand, that the tallest summergreen trees (in North America) tend to occur near the low-evaporation ends of their species ranges.

References: Daubenmire 1978; Walter 1960, 1968; Tadaki 1977; Waring et al. 1978; Hueck 1966; Leathart 1977; Eyre 1968; de Laubenfels 1953, 1969; Brockman 1968; Küchler 1964, 1977; Franklin & Dyrness 1973; Shelford 1963; Schmithüsen 1956, 1960; Numata 1974; Costin 1957; Davis 1964; Webb 1959; Cockayne 1958; Holloway 1954; Godley 1975; Troll & Lauer 1978; Williams 1974; Krajina 1969; Schuler 1977; Kilgore & Taylor 1979.

10. Temperate Needle-Trees include both generally round-needled and scale-leaved evergreen trees from a variety of temperate-zone climates with varying degrees of winter cold but generally warm, sunny summers or at least long growing seasons, as in more maritime climates. These trees are generally monopodial and of more normal height than the tall rainforest and mesic tropical conifers. The needles are generally long or of medium length (e.g. *Pinus*) or occur as tightly overlapping scales (e.g. *Cupressaceae*) which render the entire branchlet photosynthetic. Though somewhat xeromorphic in appearance, these trees can present moderately large leaf areas. The hardness of the needles, however, makes them well adapted to withstand both moderate freezing temperatures and summer water stress. 'Harder' photosynthetic surfaces generally result in lower photosynthetic and growth rates. In this respect the pines (*Pinus*) represent an anomaly, as many pine species grow quite rapidly and dominate successional vegetation until finally shaded out by more shade-tolerant but not significantly taller broad-leaved trees. Many *Pinus* species have extremely high light-saturation levels. The *Cupressaceae,* on the other hand, generally grow more slowly. Temperate needle-trees can be grouped into warm-temperate (summer rain), mediterranean (winter rain), and cold-winter subtypes, based on physiologic and morphologic adaptations to the climates they inhabit. The fact that they usually occur in corresponding but disjunct regions on the different continents reinforces their status as distinct subtypes.

10a) Heliophilic Long-Needle Trees are, prototypically, the monopodial, somewhat xeromorphic 'southern pines' of the humid subtropical and warm-temperate climates of southeastern U.S.A. and adjacent Caribbean Islands. In the U.S.A. this type includes only 'hard pine' species (Brockman 1968), which generally have fewer needles per bundle, harder needles and harder wood. The climatic limits of a prototypic species, *Pinus taeda* (loblolly pine), have been studied in detail by Hocker (1956), Mather & Yoshioka (1966), and the American commercial forestry industry. Other species from the same region include *P. palustris* (longleaf pine), *P. echinata* (shortleaf pine, with needles of only 8–12 cm in length), and *P. elliottii* (= *P. caribbea,* slash pine or Caribbean pine). Although these trees are mainly successional on sites with better soil and are often considered to be relicts, similar needle-tree forms are important and sometimes dominant in other east-coast subtropical areas with similar climates. These include *Araucaria angustifolia* in southern Brazil (Hueck 1966) and other species of *Pinus* in eastern Mexico and Central America (Leopold 1950; Parsons 1955), in Southeast Asia (Stamp 1924; Ogawa et al. 1961; Wang 1961), and in southernmost Japan (Numata 1974). Ecologically similar species of *Casuarina* (Australian pine, a leafless non-conifer) occur in subtropical-tropical eastern Australia but are frost-sensitive. *Pinus elliottii* has been widely introduced for reforestation in Australia, New Zealand and South Africa. Heliophilic needle-trees are not winter-dormant and are active whenever winter temperatures are high enough. Hocker's (1956) study suggested that *Pinus taeda* is limited both to the north and west (i.e. toward more continental climates) mainly by inability to take up sufficient water from cold or frozen soil during the winter.

References: Hocker 1956; Dallimore & Jackson 1966; Brockman 1968; Hueck 1966; Leopold 1950; Parsons 1955; Küchler 1964; Daubenmire 1978; Shelford 1963; Knapp 1965, 1973; Mather & Yoshioka 1966; Ogawa et al. 1961; Milton Moore 1970; Wells 1928, 1942; Braun 1950.

10b) Mediterranean Needle Trees include both needle and scale-leaved trees which occur in maritime winter-rain climates with greater summer moisture stress and which, as a result, are more variable in size and shape and generally grow more slowly. Included are the true cedars (*Cedrus*) of less severe montane climates, various mediterranean pines of lower and middle elevations (e.g. *Pinus pinea, P. maritima, P. halepensis*), and certain scale-leaved *Cupressaceae* from California (e.g. *Libocedrus decurreus, Cupressus macrocarpa*), Chile (*Libocedrus chilensis*), the Mediterranean region (*Cupressus* and *Juniperus* spp.), and South Africa (*Widdringtonia*). Mediterranean needle-trees are generally restricted to coastal or montane areas which have somewhat moderated summer temperatures, higher humidity, and occasional light summer rainfall and/or runoff inputs. These trees tolerate some frost but remain active in winter whenever temperatures permit. Many of these trees show characteristic flattened crowns with well developed lateral branches, as often occur in windy and water-stressed environments. The needles of *Cedrus* and the mediterranean pines are generally shorter than those of heliophilic needle-trees but longer than those of boreal conifers.

References: Dallimore & Jackson 1966; Walter 1968; Brockman 1968; Leathart 1977; Hueck 1966; Mayer & Sevim 1958; Zohary & Orshan 1966; Zohary 1973; Beals 1965; de Wilde 1961; Emberger 1939; Schmithüsen 1956, 1960; Knapp 1965, 1973; Jenny et al. 1969; Kilgore & Taylor 1979.

10c) Typical Temperate Needle-Trees are the cold-winter needle-leaved trees which occur in a variety of temperate-zone climates with extended periods of sub-freezing temperature. Such climates are probably restricted to the Northern Hemisphere, and the main taxon is the northern genus *Pinus*, including *P. ponderosa* and similar species from the drier western U.S.A., *P. strobus* and *P. rigida* from eastern U.S.A., *P. roxburghii* from the Himalaya, and *P. yunnanensis* from higher elevations in southern China. *Pinus sylvestris,* the most wide-spread tree species in Eurasia, spans the temperate and boreal zones, functioning in Europe largely as a typical temperate-zone needle-tree. These trees are largely successional species on better soils in the more mesic climates of Europe and eastern U.S.A. Despite this and the taxonomic poverty of the form, these trees can be very numerous, dominating with nearly pure stands in various montane belts, successional areas, and on sites with edaphic problems.

References: Walter 1968, 1974; Daubenmire 1943, 1978; Ern 1974; Shelford 1963; Knapp 1965; Schweinfurth 1957; Wang 1961; Numata 1974; Brockman 1968; Küchler 1964; Mather & Yoshioka 1966; Kilgore & Taylor 1979.

11. Boreal/Montane Needle-Trees are the tall, monopodial, conical to columnar evergreen trees of the boreal forest and subarctic forest-tundra, and upper montane belts of temperate-zone mountains. All are relatively short-needled conifers, mainly from the genera *Picea, Abies,* and *Pinus.* The compact evergreen needles have the ability to withstand temperatures down to −60 °C when cold-hardened and to withstand long periods of sub-freezing temperature with almost no respiration (Larcher 1976; Pisek & Rehner 1958, 1960; Polster & Fuchs 1963; Tranquillini 1963, 1964; Tranquillini & Holzer 1958). Yet when springtime or even mid-winter temperatures are high enough (air temperature around the freezing point) the leaves are quickly ready to resume photosynthesis. Boreal and montane needle-trees have dense, thick canopies with high leaf area indices (8–15 in closed forests). They attain dominance in the extensive boreal forests of Canada-Alaska and northern Scandinavia-Russia but become less important in the drier and coldest winters of Siberia, where only deciduous larches survive as important trees. At its northern edge the boreal forest opens into the forest-tundra woodland, with tall, cylindrical trees well spaced to take advantage of the low sun angle. The northernmost limit of boreal needle-trees closely follows the 10 °C isotherm for July mean temperature in most areas (Hare 1950, 1954; Hustich 1953; and many others). Closed forest generally requires 2–3 months with mean temperatures above 10 °C. Boreal/montane needle-trees also dominate characteristic montane and subalpine belts in most temperate-zone mountain ranges of the Northern Hemisphere, and there are some fairly similar montane forests in New Zealand (Walter 1960, 1968). The montane trees are generally tall and cylindrical, but a subalpine equivalent of the open forest-tundra woodland is usually absent due to greater topographic influence in mountains. Walter (1974) and others have listed equivalent North American and Eurasian species in both boreal and montane areas.

References: Walter 1960, 1968, 1974; Hare & Ritchie 1972; Hare 1950, 1954; Hustich 1953; Dallimore & Jackson 1966; Brockman 1968; Daubenmire 1943, 1978; Knapp 1965; Rowe 1959; Jäger 1968; Tranquillini 1963, 1964, 1979; Tranquillini & Holzer 1958; Pisek & Rehner 1958, 1960; Larcher 1976; Reiners & Lang 1979.

12. Hydrophilic Summergreen Needle-Trees include only three species from two genera of *Taxodiaceae* which occur in quite moist temperate environments with cool winters. The species are *Taxodium distichum* (bald cypress) and *T. ascendens* (pond cypress) of swamps and mesic forests (including hammocks) in the southeastern U.S.A. and *Metasequoia glyptostroboides* of China, which was identified from fossils and discovered living only in 1948. These trees have compound leaves consisting of relatively soft needle-leaflets. They grow slowly and require large amounts of water but attain impressive height and age, becoming dominant where sufficient water is available. *Taxodium* grows most commonly in standing water.

References: Penfound 1952; Wharton 1978; Brockman 1968.

13. Boreal Summergreen Needle-Trees are tall, monopodial boreal conifers with summergreen deciduous needles, as found in the genera *Larix* and *Pseudolarix*. Because they must first produce new leaves these trees have a shorter effective growing season than the evergreen boreal conifers. The larches have softer needles with less inactive sclerenchyma and photosynthesize rapidly at first, especially at the beginning of the growing season. After ten years or more, however, the evergreens begin to grow faster than the larches and eventually attain dominance (Walter 1968). Larches survive as individuals, both in the boreal forest and in montane forests, but dominate only in the driest and coldest winters of Siberia where it is too cold and there is too little protective snow cover for evergreen trees. Much of Siberia has relatively low rainfall and dry summers. The trees in such areas probably could not survive without the deeply frozen soil, which thaws slowly and spreads the meltwater more evenly over the course of the summer. Because of dryness and low sun angles, *Larix* stands in Siberia are often quite open. The main *Larix* species are *L. decidua* in Eurasia (including Siberia), *L. dahurica* in Siberia, *L. leptolepis* in Japan, and *L. laricina* and *L. occidentalis* in North America. *Pseudolarix* occurs only in China.

References: Walter 1968, 1974; Tranquillini 1963, 1979; Knapp 1965; Brockman 1968; Numata 1974.

Small and dwarf trees

Small trees (treelets) are most commonly simply smaller versions of larger trees. Smaller stature means less leaf surface and less standing biomass, which (other factors being more or less the same) means reduced water requirements and some reduction of photosynthetic requirements due to reduced respiration. Smaller size can thus be advantageous in forest understoreys with reduced light, in drier climates, on shallow soils with reduced water-holding capacity, and in windy environments with higher potential evapotranspiration. Smaller size can also be an advantage where saturated soil prevents the deeper root systems needed by larger trees. The term 'dwarf tree' is reserved for even smaller treelets (generally not exceeding 5 m) whose stunted growth form results from some form of more pronounced stress. Dwarf-trees and krummholz may not always be mutually exclusive, but dwarf-trees include forms such as the stunted treelets of the 'campos cerrados' of Brazil, where wind is not a factor. Increasing dryness, requiring some reduction in transpiring surface area, can be met by reduction in above-ground vegetation cover (e.g. open woodlands instead of closed forests), by reduction of plant size, or, most commonly, by some combination of these responses and others. As canopies open up and more light is available to lower strata, smaller trees become more important and can attain dominance. In fact, only in Australia (*Eucalyptus*) and in the forest-tundra (low sun angle) is it common for open woodlands still to be dominated by taller trees.

General references: Walter 1968, 1973; Milton Moore 1970.

14. Tropical Broad-Evergreen Small Trees include rainforest-understorey, seasonal forest-understorey, thicket, open-woodland and even savanna species but without obvious boundaries between subtypes. Most forms are coriaceous, with leaf sizes ranging from megaphyllous in the shade of tropical rainforests to the nanophyllous leaflets of more xeric *Leguminosae*. The diversity in rainforest understorey forms is enormous, but it is only in thickets (usually edaphic climaxes) and open woodlands or scrublands that small evergreen trees gain dominance or co-dominance in the tropics. Both usually occur locally or in mosaics. Since they do not dominate large areas, tropical small evergreen trees have been studied very little as a group. Important taxa include *Leguminosae, Eucalyptus, Myrtaceae* and *Sapotaceae.*

References: Richards 1952; Beard 1953, 1955, 1967; Milton Moore 1970; Brockman 1968.

15. Tropical Broad-Evergreen Dwarf-Trees are, prototypically, the stunted, fire-resistant, large-leaved evergreen treelets of the 'campos cerrados,' which occur in a tropical wet-dry climate on the deep soils of central Brazil, south of the Amazon rainforest. The dry season of the 'campos cerrados' is not as extreme as is more common in much of Africa, but the deep soil also appears to be necessary for the development of an evergreen woodland in Brazil. The treelets are typically 2–4 m tall, often with twisted trunks, and make a strikingly xeromorphic impression (see, for example, Hueck 1966) which Walter (1973) and others consider to be 'oligotrophic scleromorphy'. As a well developed formation, the Brazilian 'campos cerrados' appear to be unique, though similarly stunted and xeromorphic treelets occur also in other areas, including the llanos of Venezuela and (azonally) on laterite soils in the Congo basin in central Africa (Walter 1973). The most important taxa in the 'campos cerrados' include *Kielmeyera, Byrsonima, Erythroxylum, Hancornia, Xanthoxylum, Machaerium* (*Leg.*) and many others.

References: Ferri 1973; Rawitscher 1948; Ferri & Coutinho 1959; Walter 1973; Hueck 1966; Cole 1960; Goodland 1971; Eiten 1972; Knapp 1973.

16. Cloud-Forest Small Trees include a variety of both broad-microphyll and narrow-leaved smaller trees growing in and above the cloud-belts of tropical and subtropical mountains and in similarly perhumid climates down even to sea-level along windward coasts in the Southern Hemisphere. The trees may be visibly stunted and gnarled, both near alpine treeline or other exposed sites and along windy coastlines. In the montane cloud-forests and subalpine 'elfin woodlands', however, the trees are often almost obscured by their dense coverings of mosses and other epiphytes. *Podocarpus* species are especially important in the cloud-forests of both the Andes and East Africa (as well as the southern temperate zone), while holarctic taxa such as *Quercus* and *Pinus* are important in both Mexico and Southeast Asia. *Eucalyptus* and *Nothofagus* are important in the Southern Hemisphere. *Ericaceae* are generally important as shrubs, but *Erica arborea* and *Philippia excelsa* are important small trees in African subalpine forests, along with *Hagenia abyssinica* (*Rosac.*), *Olea chrysophylla, Ilex witis* and *Juniperus procera. Ericaceae* and *Melastomaceae* are important as small trees in Central America. Despite the constantly high humidity, large leaves are not an advantage in the cloud forest because of the constantly cool temperatures and possibility of light frost. The leaves are commonly hard.

References: Troll & Lauer 1978; Troll 1959, 1966, 1968, 1970, 1973; Walter 1968, 1973; Richards 1952; Lind & Morrison 1974; Whitmore 1975; Hueck 1966; Knapp 1965, 1973; Vareschi 1973; Costin 1957; Daubenmire 1978; van Steenis 1962; Shreve 1914.

17. Temperate Broad-Evergreen Small Trees include a variety of both understorey and low-canopy trees with generally mesophyllous or slightly smaller (e.g. notophyllous, see Webb 1959) sclerophylls designed to withstand some winter cold. These trees occur most commonly as slow-growing understorey trees (e.g. *Ilex,* some *Quercus* spp., some *Prunus* spp.) but can form the upper stratum in drier forests and open woodlands (e.g. *Quercus*) and in coastal and moist montane forests of the cooler Southern Hemisphere (e.g. *Nothofagus*, montane *Eucalyptus* spp.). These trees are perhaps most important as dominants in the extremely stenothermal, perhumid, windward-coastal climates of southern Chile (*Nothofagus dombeyi, N. betuloides*), subalpine Tasmania and Australia (*N. cunninghamii, Eucalyptus coccifera, Eu. subcrenulata*), and southern New Zealand (*N. menziesi, N. fusca* et al.). In colder areas these trees do not always form closed stands, even in very moist climates.

References: Walter 1960, 1968; Hueck 1966; Schmithüsen 1956; Costin 1957; Cockayne 1958; Godley 1960; Webb 1959; Veblen 1979.

18. Broad-Raingreen Small Trees include many taxa of deciduous forest, woodland and savanna trees but most typically small or compound-leaved forms such as the *Leguminosae*. In more open areas these trees tend to be low, spreading and flat-topped, as are the familiar scattered acacias of the African savannas. In more wooded but scrubby areas these trees may occur as individual emergents or simply as part of the more amorphous thorn-scrub. Small raingreen trees can also form understoreys in raingreen forests or occur as less conspicuous understorey components in semi-evergreen forests. Important taxa include *Acacia, Albizia* and a great number of other *Mimosaceae, Papillionaceae* and *Caesalpinaceae* (legumes), plus such others as *Bulnesia sarmientoi* (a raingreen zygophyll) and *Zizyphus mistol* (*Rhamnac.*) from the South American 'chaco' and *Commiphora* (*Burserac.*) from Africa and India. The leaves (leaflets) of many *Leguminosae* can be extremely small.

References: Walter 1973; Knapp 1973; Hopkins 1962–70; Hueck 1966.

19. Broad-Summergreen Small Trees include mesic understorey and more xeric open-woodland taxa of the temperate zone, both of which most typically have leaves of mesophyll size. Particularly important taxa include *Prunus* and other fruit trees, the colorful *Cornus florida* (dogwood) of eastern North America, *Cercis*, and certain species of *Quercus* in more open, scrubby woodlands and of *Nothofagus* in Chile and New Zealand. This form occurs most commonly in mesic forest understoreys but gains dominance in degraded vegetation (e.g. the šibljak of the Balkans), in drier areas (e.g. the summergreen scrub-oak woodlands of intermontane western U.S.A.), and in cooler, windier forest areas of southern Chile (*Nothofagus pumilio* and, more typically, *N. antarctica*) and New Zealand. A particularly interesting occurrence of smaller summergreen trees as dominants is in the widespread open parklands of mountains from the Caucasus and Iran to Mongolia and northwestern China. These parklands are composed mainly of fruit and nutbearing trees, including *Malus, Pyrus, Prunus, Amygdalus, Cerasus, Armeniaca, Crataegus, Pistacia* and the generally larger *Juglans fallax* (Walter 1974; Walter & Box, in press). The trees of the montane parklands occur in both summer-rain and winter-rain climates but receive additional water in summer from runoff. Small summergreen trees are also important in submediterranean transitional climates (e.g. southern Europe) where they form low, mixed woodlands with mediterranean shrubs.

References: Walter 1956, 1968, 1974; Horvát et al. 1974; Zohary 1973; Schweinfurth 1957; Hueck 1966; Küchler 1964; Walter & Box, in press; Reichle 1970; Veblen 1979; Reich & Hinckley 1980.

20. Needle-Leaved Small Trees are small, generally slow-growing, xeromorphic evergreen trees which include primarily certain arborescent junipers, certain smaller pines (e.g. the piñon pines of southwestern U.S.A.) and certain convergent forms in other areas (e.g. *Callitris* and *Actinostrobus* in Australia). These trees can have either true needles (e.g. *Pinus*) or scale-leaves (e.g. *Juniperus*). They occur most commonly in dry climates and generally become dominants only there, but can also occur in quite mesic climates (e.g. the widespread *Juniperus virginiana* of eastern North America and *J. communis* of both Europe and North America). These trees are particularly conspicuous as individuals in heaths and similar vegetation on sandy substrates. In the western U.S.A. small junipers and piñon pines occur together in characteristic low, quite open woodlands covering large areas. *Actinostrobus* and even some *Proteaceae* (e.g. *Banksia ericifolia* and *B. spinulosa*, the latter with long 'needles'), *Leguminosae* (phyllodious *Acacia* spp.), and *Casuarina* spp. are similar in Australia, particularly in the 'sand heath' areas. *Juniperus* and

Pinus are common in the mountains of drier parts of Asia.

References: Walter 1968, 1974; Küchler 1964; Shelford 1963; Knapp 1965, 1973; Milton Moore 1970; Zohary 1973; Specht 1972; Brockman 1968.

Rosette-trees

Rosette-trees are trees which grow from a single terminal bud to produce, typically, a monopodial, unbranched bole carrying a terminal rosette (tuft) of usually large, often compound evergreen leaves. Such 'trees' are also called tuft-trees (e.g. Küchler 1967). The trunk grows not by adding a new layer each year, as true trees do, but rather from the inside by adding new cells within the expanding trunk-like structure formed originally from remnants of earlier parts of the terminal rosette. Trunks are most commonly unbranched but may be clustered, entirely underground (appearing only later in some taxa), missing altogether (rosette-shrubs), or moderately branched. True rosette-trees are monocots. Palms are the most common taxon, but other taxa have also produced rosette-tree or equivalent forms, such as the Joshua tree (*Yucca brevifolia*) of the Sonora-Mojave desert region, the tree-ferns, the 'grass trees' of Australia, other *Liliaceae,* and certain equivalent tropical-alpine dicots (e.g. *Senecio keniodendron*). The leaves, morphologically, may be either simple or compound (pinnately or palmately), but the ecological unit, i.e. the simple leaf, leaf segment, or frond segment, generally has a characteristic linear or broad-graminoid shape and may be hardened or even succulent to reduce water loss. All species are evergreen and discard older leaves only as new ones are produced. Many rosette-tree forms (though not the tree-ferns and not all palms) are associated with high-insolation situations. Rosette-trees are also associated with generally frost-free climates or at least with situations (e.g. tropical alpine areas) where frost does not last longer than overnight.

General references: McCurrach 1960; Langlois 1976; Moore 1973; Hallé et al. 1978; Aubert de la Ruë at al. 1957; Corner 1966.

21. Palmiform Tuft-Trees are the typical tall, monopodial evergreen 'palm trees' of the tropics, most of which are palms. Most are unbranched and carry terminal tufts of strikingly large compound leaves borne on stout, often green branches. The leaves are generally sclerophyllous and may be pinnately or palmately compound. Physiognomically similar nonpalm taxa which may attain tree height include *Phenakospermum, Ravenala* and *Strelitzia* (*Musaceae*), *Carica papaya* and other *Caricaceae,* some arborescent *Xanthorrhoeaceae* and *Bromeliaceae* (more commonly treelets), and some *Pandanaceae* (usually branched and more commonly treelets or non-trees). Palmiform tuft-trees occur in a wide range of generally frost-free tropical climates with sufficient water provided by rainfall and/or groundwater. Because palms are mostly quite tolerant of saturated soil they are often the only tree forms found in such places as tropical coastlines (also salt spray-tolerant), desert oases, and seasonally (or irregularly) flooded floodplains and savannas. The sclerophyllous leaf structure of palms apparently provides quite adequate protection against water loss in even the driest desert climates, provided that groundwater is available. Palms grow rapidly and are most often successional species, in many ways the tropical ecological equivalent of pines. Palmiform trees can dominate in a variety of situations, both dry and mesic, where other trees are excluded. Palmiform trees generally require high light intensity, however, and occur in forests mainly as successional species or where climatic-climax trees are precluded by soil or other conditions (as opposed to many palmiform treelets which are understorey forms). Because of the milder, more maritime winter climates, palmiform trees extend further poleward in the Southern Hemisphere than in the Northern.

References: McCurrach 1960; Langlois 1976; Moore 1973; Walter 1973; Hueck 1966; Knapp 1973; Richards 1952; Lind & Morrison 1974; Whitmore 1975; Hallę et al. 1978; Aubert de la Ruë et al. 1957; Fosberg 1960; Corner 1966.

Rosette-treelets

Rosette-treelets (tuft-treelets) are small rosette-trees which do not attain tree proportions (generally at least 5–8 m) and which generally show a somewhat greater variety of forms and ecological relations. Like rosette-trees, the rosette-treelets are evergreen, most typically monopodial and unbranched (with a variety of exceptions), and grow with a terminal tuft of large leaves. Rosette-treelets, however, also occur as less light-demanding understorey forms, as groundwater-independent xeric forms, and include the ecophysiognomically similar but taxonomically unrelated tree-ferns and tropical-alpine tuft-dicots.

22. Palmiform Rosette-Treelets are smaller equivalents of Palmiform Rosette-Trees but can occur in a greater variety of forms and habitats. Palmiform rosette-treelets can be either light-demanding or understorey forms, xeric sclerophylls or quite mesic forms with softer leaves. Clumped trunks and some degree of branching may be more common, and some forms can take on the appearance of huge palmiform bushes (i.e. with very short trunks but yet with fronds reaching heights of 8 m). Palmiform treelets are much more common in climatic-climax tropical forests than are palmiform trees, and they are also important in certain temperate maritime climates of the Southern Hemisphere. Palmiform treelets tolerate saturated soil well and can be important in periodically flooded or waterlogged areas. The true palms are the main representatives but cycads and some palmiform *Musaceae, Pandanaceae,* etc. also occur as rosette-treelets.

References: McCurrach 1960; Langlois 1976; Moore 1973; Walter 1973; Hueck 1966; Knapp 1973; Richards 1952; Lind & Morrison 1974; Whitmore 1975; Hallé et al. 1978; Aubert de la Rüe et al. 1957; Fosberg 1960.

23. Tree-Ferns are woody, arborescent ferns which are quite similar in growth form to palmiform treelets but more demanding ecologically, requiring cool, very moist, typically mesic-understorey conditions. Tree-ferns are found most commonly in the cloud-belt forests of tropical mountains and in extremely maritime, generally frost-free perhumid climates of the Southern Hemisphere. The trunks of tree-ferns are normally unbranched and carry large, rosette-like terminal crowns of usually compound, moderately soft, evergreen leaves. Tree-ferns can grow to about 10 m. True tree-ferns are found in the family *Cyatheaceae* (plus *Dicksoniaceae*), but the monocotyledonous family *Velloziaceae* contains some equivalent forms. Climatic requirements and the world distribution of tree-ferns are described by Troll (1970).

References: Troll 1959; 1968, 1970, 1972b; Kroener 1968; Christ 1910; Troll & Lauer 1978; Shreve 1914; Richards 1952; Whitmore 1975; Cockayne 1958.

24. Tropical Alpine Tuft-Treelets are the short but erect, xeromorphic, often pubescent non-palm woody tuft-plants of the alpine and subalpine belts of the Andes, the mountains of East Africa and some mountains in Central America and elsewhere. The climates of these equatorial areas are diurnal rather than seasonal, with high insolation and warm surface temperatures during the day and freezing temperatures most nights of the year. The leaves of the plants are generally either sclerophyllous or thickly white-pubescent. The plants rarely exceed about 6 m in height and are reduced to stocky, almost trunkless tuft-scrub as temperatures decrease with altitude. The most common taxa include *Lobelia* and *Senecio* in Africa, *Espeletia* and *Lupinus* in the Andes, *Argyroxiphium sanwicensis* in Hawaii, and *Anaphalis* in Indonesia. Most of these dicot genera are known for erect, often weedy species in the northern temperate zone. Their assumption of a caulirosette (stemmed-rosette) growth form in tropical alpine areas is an often-cited example of convergent evolution, though the step is probably not so great here as in some other cases.

References: Cuatrecasas 1968; Coe 1967; Hedberg 1951; Salt 1954; Weber 1958; Walter 1973; Troll 1959, 1968; Vareschi 1970; Daubenmire 1978; Van Steenis 1962; Sturm 1978; Knapp 1973; Lind & Morrison 1974; Baruch 1979.

25. Xeric Tuft-Treelets include various evergreen, mostly unbranched, monocotyledonous treelets with smaller sclerophyll tufts and generally xeromorphic appearance, as occur in the semi-deserts and other drier areas of the tropics and subtropics. Characteristic forms include the stem-yuccas (*Liliaceae*) in the Western Hemisphere, the tuft-treelet species of *Dracaena* in Africa, and the familiar 'grass trees' of Australia (*Kingia* spp. and *Xanthorrhoea* spp.). A striking but less characteristic form, due to its arborescent branching, is the Joshua Tree (*Yucca brevifolia*) of the Sonora and Mojave deserts, which becomes a significant tree with sufficient age. The leaves of xeric tuft-treelets are always evergreen and generally sclerophyllous.

They may be either stiff and succulent as in *Yucca* or more graminoid (but still large) as in *Kingia* and some dracaenas. Though partly succulent some taxa can extend into quite mesic climates on drier sites (e.g. *Yucca aloifolia* in the sandy coastal plain of the southeastern U.S.A.). Xeric tuft-treelets tolerate some winter frost but suffer whenever temperatures remain below freezing. They prefer high insolation and occur throughout the world's warm, dry climates.

References: Walter 1968, 1973; Shreve & Wiggins 1964; Whittaker & Niering 1965; Knapp 1965, 1973; Keast et al. 1959; Orians & Solbrig 1977; Werger 1977; Richard-Vindard & Battistini 1972; Turage & Hinckley 1938; MacDougal 1912.

Arborescents

The nouns 'large bush' and 'arborescent' (used here almost interchangeably) were suggested by de Laubenfels' (1975) 'overgrown bush form' and are used to refer to woody plants which branch near or even under ground-level but grow to tree height. Arborescents are thus an intermediate form between trees and shrubs, for which the exact branching pattern is not as important as general plant size. Arborescents, as a category, can therefore include a variety of intermediate forms, notably sprawling xeric 'large scrub' (e.g. thorn-scrub), clumped-stem forms associated with underground tubers (e.g. the mallee form), and other rather indeterminate but slowly low-arborescent forms characteristic of drier areas (e.g. the leafless 'trees' of Middle Asian semi-deserts). Because their growth form is not monopodial, arborescents can never become truly tall trees. They are typically open-woodland forms which, for various reasons, assume some intermediate combination of height and leaf area as appropriate for a generally intermediate water supply. Some quite malacophyllous forms also occur, however, in quite wet situations (including standing water), where they co-exist with larger trees but may better tolerate the largely anaerobic soil conditions.

26. Evergreen Arborescents include prototypically the tall, lignotuberous, phreatophytic 'mallee' (i.e. multi-stemmed) species of *Eucalyptus,* which form extensive open woodlands in southern Australia further into semi-arid climates than any other forms of comparable size. These are consistently the tallest of the 'overgrown bushes' and can maintain heights of 10 meters right up to their distributional limits. Heights of mallee eucalypts range from one meter in mallee heaths to 12 meters in woodlands (Barrow & Pearson 1970). The shorter mallee shrubs are called marlocks, have more poorly developed underground woody stocks (Burbidge 1952), and are best represented simply as shrubs. Lignotubers, promoting multi-stemmed growth, are fairly common in drier climates and in various eucalypts. Burbidge (1952) seems to ascribe 'the significance of the mallee habit' entirely to the (genetic) existence of lignotubers and does not offer an ecological explanation. He does suggest that the multi-stemmed habit is a late evolutionary development within *Eucalyptus,* restricted primarily to the sections *Dumosae* and *Subulatae.* He lists the following mallee species: *E. morrisii, E. diversifolia, E. leptophylla, E. gracilis, E. eneorifolia,* and most commonly *E. dumosa* and *E. oleosa.* Pryor (1959) states that all *Eucalyptus* species of the 'highly successful xerophytic Mallee communities' display the multi-stemmed growth form, which suggests a climatic (water supply) role even though the mallees are strongly associated with calcareous soils. Certainly the phreatophyte's connection with a relatively constant groundwater supply would permit taller growth with greater leaf area. And certainly multiple stems from a rootstock with many dormant buds will be favored by any processes (e.g. grazing, fire, cold, drought) which damage the main meristem of existing shoots, as has been noted in connection with *Prosopis* (Simpson 1977). Similar multi-stemmed, phreatophytic growth forms are found in other taxa in other similarly dry climates (e.g. *Prosopis, Acacia*) and in some wet situations (e.g. riparian *Salix*), but these taxa are deciduous. Other multi-stemmed evergreen taxa which can be groundwater-connected and may be ecologically similar include *Myrica cerifera* (sandy coastal areas of southeastern U.S.A.) and various riparian taxa throughout the tropics.

References: Burbidge (1952), Pryor (1959), Barrow & Pearson (1970), Keast et al. 1959; Milton Moore 1970; Walter 1968, 1973; Simpson 1977.

27. Raingreen Thorn-Scrub includes various forms of larger and smaller, non-phreatophytic, often sprawling bushes with usually soft, often quite small raingreen leaves (often compound) and often definite thorns. This form is very widespread in the summer-rain tropics, often dominating large areas which are too dry for forest or taller woodland. It is perhaps best represented by many non-phyllodious species of *Acacia* and many other legumes (e.g. *Mimosa, Caesalpinia, Cassia, Albizia, Brachysema*). Raingreen scrub forms often have evergreen, photosynthetic stems and may show other variations, such as the virgate *Fouquiera splendens* (ocotillo) of Arizona-Sonora and even some dwarfed but 'bottle tree'-like treelets (e.g. *Idria columnaris,* also *Fouquieriaceae,* and certain *Burseraceae* in southwestern Africa, Sonora, and elsewhere). Raingreen thorn-scrub has been well recognized as a formation type for a long time (e.g. von Humboldt 1807, Rübel 1930). It is important on all continents except Europe and Antarctica.

References: Walter 1973; Knapp 1965, 1973; Hueck 1966; Shantz & Marbut 1923; Beard 1944, 1955, 1967; Leopold 1950; Daubenmire 1978; Milton Moore 1970; Lauer 1952; Boaler 1966; Burtt 1942; Lind & Morrison 1974; Mani 1974; Stocker 1970; Orians & Solbrig 1977.

28. Summergreen Arborescents include prototypically the phreatophytic, readily re-sprouting species of *Prosopis, Salix* and other holarctic and tropical genera which arise from woody rootstocks in both wet areas (e.g. carr) and most importantly in dry areas along streambeds and wherever else groundwater contact can be maintained. The ecology of this form appears to be much like that of the mallee eucalypts, at least in dry areas, but the summergreen forms occur in areas with colder winters or involve tropical taxa (e.g. *Prosopis*) which have a deciduous habit. The rootstocks of these plants contain many dormant buds. Whenever the terminal meristem of existing shoots is destroyed, as by fire, winter cold, grazing, or felling, dormant buds are activated and new shoots form. Summergreen *Prosopis* woodlands are especially well developed in Texas but occur in similar areas of the Americas, Africa and Asia where rainfall is low but sufficient groundwater can be reached by the extensive root systems, especially along washes and canyons. *Prosopis* can also function as a non-phreatophyte and assume normal tree form where water is sufficient. The observed decrease (*Prosopis*) of tree forms and increase in bush forms in the southwestern U.S.A. has been related to the increased use of the area for livestock grazing (Simpson 1977). Similar *Prosopis* and other summergreen woodlands are found in much of northern and Pacific Mexico, in Argentina and Uruguay ('algarrobos'), in sub-Saharan Africa (where *Prosopis* is raingreen, i.e. raingreen scrub), and in much of the Middle East, including Iran, the Arabian Peninsula, and Middle Asia. Other taxa which form multi-stemmed summergreen large bushes include various acacias (*Acacia greggii* and *A. constricta* in North America, *A. aroma* and *A. furcatispina* in Argentina), *Celtis spinosa* (Argentina), and various holarctic genera such as *Salix, Betula* and *Populus,* which occur as phreatophytic bushes in both dry and wet climates.

References: Simpson 1977; Orians & Solbrig 1977; Walter 1968, 1973, 1974; Hueck 1966; Zohary 1973; Eyre 1968.

29. Leafless Arborescents include both arborescent and shrubby, generally phreatophytic woody scrub with evergreen photosynthetic stems and either no leaves at all or at most soft, semi-ephemeral nanophylls. These are much like Xeric Dwarf-Shrubs in their ecology but are larger. Leafless arborescents occur in a variety of dry climates but are best developed in the cold-winter, continental-mediterranean semi-deserts of Middle Asia (Kazakhstan, Uzbekistan, Turkmenistan, and adjacent areas), where they can form the dominant vegetation. Summers are hot and dry, and winters can be very cold, which leaves only a very short period in spring during which leaves are advantageous. Rainfall coming in the spring, plus snowmelt, provides a brief spring growing season (up to two months), but growth is often made possible well into the summer and perhaps to autumn by the extensive root systems and the extremely low, resistant transpiring surface. Water-loss rates are comparable to those of cuticular transpiration. Growth is slow, but plants reach ages of 100 years or more. This form grows especially well in the extensive sand-deserts of Middle Asia, where lack of a more extensive vegetation cover permits groundwater to accumulate close to the surface. Typical taxa in Middle Asia and the Middle East include above all the arborescent saksa'ul species *Haloxylon aphyllum* (to 12 m.) and *H. persicum* (to

8 m.), similarly arborescent *Ammodendron* spp. (to 6 m.) and *Calligonum* spp. (to 8 m.), and a larger variety of shrubby taxa (and morphs), e.g. *Salsola, Anabasis, Astragalus, Eremospartum.* Several of these taxa are used extensively in reforestation. Similar forms occur in other semi-desert areas (e.g. *Bulnesia retama,* a nearly leafless zygophyll growing to 8 m. in northwestern Argentina, see Hueck 1966), but with some exceptions they are generally not arborescent.

References: Walter & Box, in press; Walter 1968, 1973, 1974; Zohary 1973; Hueck 1966; Bobrovskaya 1971; Petrov 1966–67; Korovin 1961–62; Nechayeva et al. 1973; Nikitin 1966.

Krummholz

Krummholz ('crooked wood') is wind-stunted woody scrub occurring primarily at treeline and other exposed sites in mountains and along some windy seacoasts. It is the result of constantly strong winds, often from one direction, which kill new growth on the windward side and/or reduce most upward growth. Krummholz forms resulting from these conditions are usually classified as:

1. flagged (upward growth but sheared on windward side)
2. flag-matt combination
3. matt (reptant or pulvinate with no emergent growth).

Along gradients of increasing climatic severity (e.g. increasing elevation on a mountain), one can often observe a sequence of krummholz forms, from flagged only at treeline through flag-matt islands to espalier-like reptant matt forms well above treeline. The height of the matt forms is generally delimited by the thickness of the winter snow cover, since winter, with its ice-blasting just above the snow level represents the most severe environmental limit. Certain other forms can also be called krummholz but are somewhat different and treated separately, notably the cushion-shrubs of more exposed, generally snowless windy areas (see Rauh 1939) and the large 'butt-sweep' forms produced by the alternating seasonal pressures of downward snow-creep and tree orthotropy (see Tranquillini 1979).

30. Needle-Leaved Treeline Krummholz is the most common form of treeline krummholz in mountains and includes all three of the morphs described above, as well as the butt-sweep form further downslope. Of the needle-leaved treeline krummholz taxa only *Larix* is not evergreen, but it is also rather uncommon at treeline. More typical taxa include the familiar boreal-montane forest genera *Picea* and *Abies* plus *Juniperus* in the Northern Hemisphere and *Podocarpus, Dacrydium* et al. in the tropics and Southern Hemisphere. Species from these genera all form tall trees under better conditions downslope but are gradually reduced to reptant forms at treeline and above. Reptant treeline krummholz is uncommon on tropical mountains, being replaced largely by stunted rosette-treelets and by cushion-shrubs. The subalpine 'elfin woodland' within the cloud belt of many tropical mountains is usually wind-sheared on top and stunted but generally maintains a closed forest canopy. The physiological and population ecology of woody treeline species has been studied in detail in many parts of the world, but simple explanations for the cause and location of treelines in general remain elusive.

References: Tranquillini 1959, 1963, 1964, 1967, 1979; Troll 1960, 1968, 1972b, 1973; Walter 1968, 1974; Wardle 1965, 1971; Michaelis 1932–34; Schiechtl 1966; Allg. Forstz. 1966; Sharpe 1970; Ives & Barry 1974; Marchand & Chabot 1978; Hansen (in prep.); Webber 1978; Costin 1957; Gersmehl 1973; Brockmann-Jerosch 1919, 1928; Yoshino 1973; Ellenberg 1966; Holtmeier 1974; Larcher 1957, 1972; Pisek & Rehner 1958, 1960; Pisek & Winkler 1958.

Shrubs

Shrubs are woody plants with multiple stems arising from a common base at or near ground level. Because they lack a single main trunk shrubs do not grow as tall as trees. This reduction in height generally also means a reduction in total leaf area, the area of greatest potential water loss. As a result, shrubs are found both in tree climates and in climates too dry for trees. Although shrubs can form as dense a ground cover as can trees, shrubs are more commonly found, especially when dominant, in more open stands in drier areas. In such situations the shrubs often have greater below-ground 'cover' (i.e. area of lateral rooting and water uptake) than they have above ground, which accounts for their often regular spacing. Many woody plants, unlike monopodial trees, begin as shrub forms but grow with age into small trees (by developing a main trunk) or into what de Laubenfels (1975) has called 'overgrown bushes'. Those forms which sprout profusely but then grow to tree size, such as phreatophytes growing from laterally elongated rootstocks, have been included as arborescents (treated previously). Those forms and taxa with more determinate fruticose growth form, even if they grow later into larger bushes or small treelets, are not so different ecologically and are included as shrubs.

31. Tropical Broad-Evergreen Shrubs include a wide variety of generally large, frost-sensitive shrubs, typically with normal or larger coriaceous leaves. A familiar example might be *Coffea arabica,* which can also grow into a small tree. Since competition for light can be much greater in humid tropical environments, making vertical growth of greater urgency, the distinction between true shrub forms and more ascending forms probably is less clear in the tropics. Shrubs are generally not as common in humid tropical forests as in their temperate counterparts. Broad-leaved evergreen shrubs are often more important as understoreys in transitional and raingreen forests and in more open woodlands. Broad-evergreen shrubs in humid areas come typically from families such as *Rubiaceae, Anonaceae* or *Euphorbiaceae*, while the taxa in drier areas are generally more diverse. Though many broad-evergreen shrub taxa occur in tropical and subtropical Australia, they are perhaps better designated as mediterranean sclerophyll shrubs. Evergreen shrubs become more important on some equatorial mountains, such as *Erica arborea* and *Philippia excelsa* in the subalpine ericaceous belt of East Africa. These species, however, can also grow as trees to 10 meters. Tropical evergreen shrubs have not been studied as a geoecological type, and their ecology remains poorly understood.

References: Walter 1973; Knapp 1973; Lind & Morrison 1974; Whitmore 1975; Richards 1952; Milton Moore 1970.

32. Temperate Broad-Evergreen Shrubs (excluding the xeric types) are normal to large shrubs with somewhat harder, cold-resistant leaves than the typically coriaceous leaves of tropical evergreens. Though smaller evergreen forms can occur under snow even in the tundra, typical broad-leaved evergreen shrubs are restricted to regions where winter temperatures are not so extreme. Three subtypes are readily apparent.

32a) Mediterranean Evergreen Shrubs are typically medium to large shrubs with generally small, sclerophyllous broad or linear leaves, as found in the mediterranean climates of the Mediterranean borderlands, the Cape region of South Africa, south-coastal Australia, southern California, and central Chile. The consistent occurrence of this form, arising in quite unrelated taxonomic groups to form more or less dense, extensive shrublands in the world's five widely separated mediterranean climates, has long been cited as the classic example of convergent evolution in physiognomy. Since temperature stress and water stress fall in different seasons in mediterranean climates, the vegetation must be evergreen (or very nearly so) in order to make use of all favorable periods as best it can to maintain a positive annual production-respiration balance. In order to reduce water loss the shrubs may lose half their leaves during either the winter cold or summer drought, but they remain evergreen and resume more active growth in spring (new growth and flowering) and in autumn (additional net production, with new growth in some taxa). Characteristic taxa include *Quercus coccifera, Arbutus unedo, Myrtus communis, Rhamnus alaternus* and *Nerium oleander* in the maquis and similar shrublands of the Mediterranean area; *Protea grandiflora,* other *Protea* species, *Leucospermum conocarpum,* and *Mimetes* spp. in the fynbosch of South Africa; a variety of often more linear-leaved *Proteaceae, Myrtaceae, Pittosporaceae* and phyllodious legumes (mainly *Acacia*) in southern Australia; *Quercus dumosa, Rhus ovata, Arctostaphylos, Ceanothus,* and *Rhamnus* in southern California and Arizona chaparral; and *Kageneckia (Rosac.), Colliguaja (Euphorbiac.),* and *Escallonia (Saxifragac.)* in the matorral and, more commonly, sclerophyll woodlands of central Chile.

References: Walter 1968; di Castri and Mooney 1973; Cooper 1922; Mooney & Dunn 1970; Mooney et al. 1974; Specht 1969, 1979; Schmithüsen 1956; Adamson 1927; Milton Moore 1970; Grieve 1955;

Larcher 1970, 1972; Oppenheimer 1932; Pisek & Rehner 1958; Daubenmire 1978; Vogl & Schorr 1972; Hellmers et al. 1955; Horton & Kraebel 1955; Hanes 1971; Polunin 1972; Ng & Miller 1980.

32b) Temperate Broad-Evergreen Shrubs include a variety of less xeromorphic, large to small shrubs with cold-resistant but often larger and less sclerophyllous, often shiny leaves, as appear to be more appropriate for summer-rain temperate climates without extremely cold winters. Such climates are found in southern China and Japan, in the southeastern and eastern U.S.A., in southern Brazil and adjacent Uruguay-Argentina, in much of Europe west of the Soviet Union, in New Zealand, and in eastern South Africa, plus smaller mountainous areas. Winter-rain climates with only moderately dry summers may also support such shrubs, and such occur in southern Australia, southern Chile, and the Pacific Northwest of North America. Characteristic taxa include *Ligustrum, Pittosporum* and *Osmanthus* (East Asia but widely introduced elsewhere), *Gardenia* (originally from Africa), *Ilex, Berberis,* certain species of *Rhododendron* and other *Ericaceae, Buxus sempervirens* (submediterranean Europe), *Daphne* spp. (Europe), *Hypericum calycinum* (Europe), and a wide variety of others, many of which are well known and widely planted as ornamentals. New leaves appear in the spring and may replace older leaves, but generally very few leaves are lost during the cold winter.

References: Walter 1968, 1974; Polunin 1972; Knapp 1973; Radford et al. 1968; Horvát et al. 1974.

32c) Perhumid Broad-Ericoid Evergreen Shrubs are an especially mesic subtype of the typical broad-evergreen shrubs, differing mainly by having generally larger leaves and by being restricted typically to the mesic conditions found in humid to perhumid temperate-zone montane and tropical subalpine belts. Broad-ericoid evergreen shrubs typically form dense understoreys, especially along streambanks and other forest edges, and often attain dominance in characteristic subalpine 'heath' or ericaceous belts and/or on exposed sites (e.g. 'heath balds' in the Appalachians). The most characteristic taxa are the evergreen montane species of *Rhododendron* and other *Ericaceae,* which occur in humid montane and subalpine belts in North America, Europe, Africa and Asia. Equivalent forms (largely *Epacridaceae*) occur in the humid mountains of Australia and New Zealand, and mesomorphic *Cunoniaceae* and *Myrtaceae* occur in southern Chile. The world's various ericaceous and ericoid montane belts have been especially well interpreted by Troll (1959, 1966, 1972b) and by Specht (1979).

References: Walter 1968, 1973, 1974; Troll 1959, 1966, 1968, 1972a, 1972b; Hedberg 1951; Schweinfurth 1957; Whittaker 1956, 1963; Salt 1954; Specht 1979; Weberbauer 1911; Knapp 1973; Daubenmire 1978; Van Steenis 1962.

33. Hot-Desert Evergreen Shrubs are moderate-sized, generally virgate shrubs with small hard leaves or phyllodes, as found in the warm semi-deserts of southwestern U.S.A. and adjacent Mexico (e.g. *Larrea tridentata, = divaricata*), the shrub-steppe region of northwestern Argentina (also *Larrea* primarily), and large regions of the Middle East, interior Australia, and southern Africa. Typical taxa, other than *Larrea* (*Zygophyllaceae*), include the equivalent mulga (*Acacia aneura*) and other acacias of Australia, various other *Zygophyllaceae* (Middle East, Australia and Africa), and a variety of ecologically similar taxa in Australia such as *Eremophila, Hakea* and *Rhagodia.* The leaves (or phyllodes) are generally small and hard, often grayish-green (e.g. *Larrea*), and cast little shade. Many leaves are shed during extreme periods and replaced after sufficient rainfall. These shrubs generally have large underground uptake areas and thus form quite open, regularly spaced stands.

References: Walter 1968, 1973; Hueck 1966; Zohary 1973; Specht 1972, 1979; Shreve & Wiggins 1964; Shreve 1942; Cannon 1911; Cunningham & Strain 1969; Mabry et al. 1977; Orians & Solbrig 1977; Werger 1977; Knapp 1973; Keast et al. 1959; Milton Moore 1970; Chew & Chew 1965; Cunningham & Reynolds 1978.

34. Leaf-Succulent Shrubs are woody shrubs (or miniature treelets) with broad, succulent, evergreen leaves and woody but sometimes semi-succulent stems. This form is best developed in the cooler, fog-moderated Namib and Karroo arid regions of southern Africa. The most familiar example is perhaps the jade-tree (*Crassula argentea*); other examples from southern Africa include *Aloë* *asperifolia* and *A. littoralis* (*rubrolutea*), and *Sansevieria pearsonii*. Leaf-succulent shrubs occur also in other dry areas, e.g. *Simmondsia chinensis* (= *californica*) in southern California and Sonora-Arizona, but are nowhere else as important as in southwestern Africa. Leaf-succulent shrubs have a somewhat larger transpiring area than stem-succulents and thus usually require moderated desert conditions, as in coastal deserts.

References: Walter 1973; Innes 1977; Al-Ani et al. 1972.

35. Cold-Winter Xeromorphic Shrubs include a variety of usually small, often heterophyllous, xeromorphic shrubs and suffrutescent semi-shrubs which are found mainly in the cold-winter, continental-mediterranean steppes and semi-deserts of interior Eurasia and interior western North America. The most common taxon is *Artemisia* and the prototypic species *A. tridentata* (sagebrush) of the American Great Basin and various *Artemisia* species in the semi-deserts of the area the Russians call Middle Asia (primarily Kazakhstan and the adjacent lowland areas). The plants have woody bases and either completely woody branches or annual, partially lignified branches. Though many species can be called evergreen, the plants die back to varying degrees in the cold winters, grow mainly in the spring, hold on through the hot, dry summers, and may show renewed growth in the autumn (Walter and Box, in press). The leaves are generally quite small and often white-pubescent and/or grayish-green in color. Other taxa characteristic for Middle Asia and adjacent regions include a wide variety of *Chenopodiaceae, Leguminosae,* and *Zygophyllaceae* (Walter 1974). Other taxa from western North America include *Chrysothamnus, Tetradymia, Grayia,* and also various *Leguminosae* and *Chenopodiaceae* (e.g. *Atriplex*). Similar forms are less important in the Middle East, in southern interior Australia, and in southern South America. *Artemisia* generally does not regenerate quickly after fire.

References: Walter 1968, 1974; Walter & Box, in press; Billings 1949; Shreve 1942; Fautin 1946; Daubenmire 1978; Zohary 1973; Bobek 1951; Popov 1940; Korovin 1961–62.

36. Broad-Summergreen Shrubs are the seasonally green, broad-malacophyllous shrubs of temperate climates with cool to cold winter and at least some summer rain. Such shrubs range from generally larger-leaved mesic types to generally smaller-leaved forms found mainly in drier climates. Because of the differences in both form and strategy between plants from favorable and stressful environments, the summergreen shrubs can be divided into two basic types.

36a) Mesic Summergreen Shrubs are the larger-leaved shrubs of typical four-season temperate climates with precipitation in all seasons. Conditions for growth are generally good throughout the warm portion of the year, though potential evapotranspiration may exceed precipitation in summer causing mild stresses as soils dry out. Dry years can cause greater stress, but the vegetation normally recovers by the following year. Climatic requirements are essentially the same as those for summergreen trees since the reduced transpiring surface of shrubs is usually offset by shallower root systems. During dry years shrubs can be affected by drought before trees because of the shallower roots. Mesic summergreen shrubs rarely form the dominant vegetation and occur most commonly in forest understoreys, along forest edges, and in opened agricultural land. Typical taxa include *Rosa, Vaccinium, Ribes, Rubus, Spiraea* (all *Rosaceae*), *Viburnum, Astragalus, Aesculus,* and others from a wider variety of families. Many are planted as ornamentals, and many other taxa include species which can be either shrubs or small trees.

36b) Xeric Summergreen Shrubs are generally smaller-leaved shrubs which sometimes also show other traits of xeromorphy, such as somewhat harder leaves, leaf pubescence, or smaller overall plant size. These shrubs are found especially in cold-winter temperate climates with less total rainfall (generally an annual deficit, meaning that soil moisture is rarely at field capacity or above) and pronounced summer moisture stress, such as in more continental mediterranean and grassland or even semi-desert climates. In mediterranean-type climates the shrubs may lose their leaves before autumn. Xeric summergreen shrubs are often widespread in such climates but attain dominance in generally small areas such as the 'deciduous chaparral' of western Colorado and northeastern Utah, drier parts of the Balkan Peninsula (e.g. šibljak, actually a degradation form), and some mountainous areas of Middle Asia and the Middle East. Typical taxa from the 'deciduous chaparral' include *Symphoricarpos oreophilus, Amelanchier alnifolia, Cercocarpus montanus, Rhus trilobata* (also from evergreen California chaparral), and *Prunus virginiana* (also a small tree). Taxa from other areas include a large number of *Leguminosae* and some *Compositae* plus *Pistacia terebinthus, Cotinus cogyria, Thymelaea, Cistus,* etc.

References: Daubenmire 1978; Walter 1968, 1974; Radford et al. 1968; Polunin 1972; Buchanan 1974; Walter & Box, in press; Horvát et al. 1974; Zohary 1973; Ellenberg 1963; Küchler 1964.

37. Needle-Leaved Evergreen Shrubs include a relatively small number of generally sclerophyllous needle or linear-leaved shrubs of varying sizes from a variety of environments. Some species, such as *Juniperus communis* have wide environmental tolerance ranges and extremely wide distributions. Others, such as *Adenostoma fasciculatum* from the California chaparral, certain linear-leaved dwarf-shrubs (e.g. *Chenopodiaceae*) from semi-deserts, and various needle-shrubs from Australia (e.g. *Banksia ericifolia, B. spinulosa*) have much more restricted distributions. All, however, have a similar response to generally drier conditions, namely the reduction of plant size and leaf surface area to restrict water loss. Such shrubs (and some small, shrubby trees, e.g. *Tamarix*) occur in drier climates, generally in the temperate and subtropical regions, but can also penetrate well into more mesic areas, as does *Juniperus communis* (though often on sandy soil).

References: Walter 1968, 1973, 1974; Daubenmire 1978; Horton & Kraebel 1955; McPherson & Muller 1969; Brockman 1968; Knapp 1973; Blombery 1967.

Dwarf-shrubs

Dwarf-shrubs are woody, generally small-leaved chamaephytes not taller than 50 cm and more commonly 30 cm. Included are also the suffrutescent semi-shrubs, which have woody bases and largely herbaceous, annual upper branches. The smaller size of drawf-shrubs offers several advantages over larger forms, including reduced transpiring surface and greater bud protection near the ground during the cold season (usually within a litter or snow cover). Dwarf-shrubs are uncommon in the winterless tropics, where they would be outcompeted by larger forms, but become more important in cool and/or drier temperate climates and other temperate areas where trees and larger shrubs are excluded (e.g. by poor or excessive drainage, by anthropogenic factors). Dwarf-shrubs may have broad, narrow (including needle), or no leaves and can be evergreen, summergreen, or have less obvious seasonal habits, as in mediterranean and maritime-heath climates. Because the plants and their leaves are small, differences between broad and even needle leaves are less important.

38. Mediterranean Dwarf-Shrubs include a variety of xeromorphic, generally shallow-rooted and fire-sensitive, typically aromatic semi-shrubs and dwarf-shrubs found mainly in the world's mediterranean climates with insufficient rainfall for more demanding vegetation. These plants are typically suffrutescent semi-shrubs which gradually lose their small, malacophyllous, usually grayish and often pubescent leaves during the dry summer but may produce new ones (though usually fewer) after autumn rains begin. Certain aromatic evergreen sclerophylls (e.g. *Rosmarinus*) could also be included, however, because of their similar size and ecology. Mediterranean dwarf-shrubs occur in maritime and more continental mediterranean climates where some growth is possible throughout the winter. This includes woodland and some steppe areas, but the form attains dominance only in drier areas, such as the 'coastal sage' of southern California (e.g. *Eriogonum fasciculatum, Artemisia californica*), and in degraded areas, such as the *garrigue* of southern France and similar Mediterranean borderlands. Mediterranean dwarf-shrubs are generally ousted by larger, deeper rooting, fire-resistant sclerophyll shrubs where rainfall and soil water storage permit. Typical dwarf-shrub taxa include many familiar mediterranean cooking 'herbs' such as *Thymus* and *Salvia,* mostly *Labiatae;* other aromatics such as *Lavandula;* and similar semi-shrub taxa from other mediterranean areas, such as *Pelargonium* (South Africa and Australia), *Olearia* and *Calocephalus* (Australia), *Stoebe* and *Felicia* (South Africa), and *Encelia farinosa* and *Franseria* spp. (Arizona-Sonora).

References: Walter 1968, 1973; Daubenmire 1978; Zohary 1973; Horvát et al. 1974; Kirkpatrick & Hutchinson 1977; Milton Moore 1970; Küchler 1964; di Castri & Mooney 1973; Oppenheimer 1932; Quézel 1965; Schreve 1936; Polunin 1972; Harrison et al. 1971; Epling & Lewis 1942.

39. Temperate Evergreen Dwarf-Shrubs include a relatively small number of broad and narrow-leaved, generally sclerophyllous and typically ericoid dwarf-shrubs which occur in a variety of mesic cold-winter situations, most notably the extensive heaths of western Europe plus certain polar and alpine areas. Many of the species are *Ericaceae* in the Northern Hemisphere. These plants are much like the typical temperate broad-evergreen shrubs in their ecology, but their smaller size and leaves permit them both to endure much colder winters under a protective snow cover and to thrive, at least in cool-maritime climates, on sandy, well drained, and often degraded heath sites, where they can become the dominant form over large areas. Ericoid dwarf-shrubs also occur with graminoids in peaty, poorly drained moors and other wetlands, on more exposed tundra and alpine sites, and in micro-communities in polar and alpine snowbanks (Schneetälchen). The heaths of Atlantic Europe are dominated most often by *Calluna vulgaris* (heather) and extend from near Gibraltar (*Erica cinerea, Lavandula stoechas, Cistus* spp.) along the Atlantic coast and throughout the British islands to Norway and the Faeroes (Walter 1968). The distributions of both *Calluna vulgaris* and the Atlantic heaths are delimited closely by the 0 °C isotherm for January and the 22 °C isotherm for July (Böcher 1940). Rübel (1930) states that monthly rainfall in heath areas of Europe always varies between 5% and 11% of the annual total. The climate is thus cool and quite maritime. Some species of *Erica* (e.g. *E. herbacea,* Schneeheide) even bloom in January. In polar and alpine tundra many of the dwarf-shrubs are also evergreen or at least semi-evergreen (i.e. with overwintering lower leaves), since this permits the plants to react quickly and make use of the full snow-free period. Evergreen (and semi-evergreen) dwarf-shrubs occur also in similar climates outside Europe, both as dominants in dwarf-shrub heaths and as important components of other treeless formations (Specht 1979). Typical taxa include *Vaccinium, Gaylussacia, Gaultheria* and *Arctostaphylos* in Nova Scotia; *Vaccinium vitis-idaea, V. uliginosum, Cassiope tetragona, Rhododendron lapponicum, Rh. ferrugineum, Phyllodoce, Arctostaphylos uva-ursi,* and *Empetrum* in circumpolar arctic heaths and tundra; *Empetrum rubrum* et al. on Tierra del Fuego and the subantarctic islands; *Erica* and *Philippia* spp. in African alpine belts; and *Epacris* and *Kunzea* spp. in the mountains of New Guinea, eastern Australia, and New Zealand (Gimingham 1972). Many species (including *Calluna vulgaris*) occur in both temperate-heath and arctic-alpine situations.

References: Gimingham 1972, 1975; Walter 1960, 1968, 1974; Böcher 1938, 1940; Lötschert 1962–65; Rübel 1930; Tansley 1949; Stocker 1923; Adamson 1927; Sorenson 1941; Grieve 1955; Specht 1972, 1979; Daubenmire 1978; Hanson 1953; Costin 1957; Tieszen 1978; Ulmer 1937; Tranquillini 1964; Cartellieri 1935; Larcher 1976; Aleksandrova 1960; Bliss 1956; Hansen 1930; Rosswall & Heal 1975; Preusser 1975; Polunin 1926.

40. Summergreen Dwarf-Shrubs are primarily boreal and tundra/alpine species which can be either typical shrub taxa (e.g. *Vaccinium*) or dwarf-shrub forms (morphs or species) from typically tree taxa (e.g. *Salix, Betula*). Most species have both high water requirements (malacophyllous) and low optimum temperatures and, as a result, are easily outcompeted by trees and larger shrubs in warmer areas. In tundra and alpine areas these shrubs are most common in maritime or other mesic situations which reduce winter cold and/or provide sufficient snow for protection against desiccation, cold, and ice-blasting. The ecology of this form is otherwise much like that of the Scandinavian dwarf-birch scrub (treelets or larger shrubs), and indeed the genus *Betula* provides both forms, across North America and Eurosiberia as well as in Scandinavia. The most common arctic species include *B. nana* and various *Salix* species, such as *S. artica* and *S. reptans.* Some *Salix* species in particular also have somewhat more reinforced leaves, e.g. *S. reticulata* and *S. retusa* of European mountains.

References: Walter 1968, 1974; Daubenmire 1978; Böcher 1938; Aleksandrova 1960; Bliss 1956; Wielgolaski et al. 1975; Hansen 1930; Tieszen 1978; Rosswall & Heal 1975; Preusser 1975; Sorenson 1941; Hanson 1953; Polunin 1926.

41. Xeric Dwarf-Shrubs include a variety of leafless and nanophyllous, seasonally leafless dwarf-shrubs and semi-shrubs which generally have green, photosynthetic stems and can remain at least partially active even during unfavorable cold and dry seasons. These shrubs are especially characteristic of the cold-winter semi-deserts of Middle Asia, the Middle East, and the intermontane western U.S.A. The leaves, if present at all, usually are produced in the autumn or spring and remain for a few months at most. The leaves are typically malacophyllous and permit greater productivity during short favorable seasons. The remaining evergreen woody stems are very resistant to both winter cold and desiccation. Zohary (1952, 1973) has outlined the following 'hydro-economic' types from the warmer-winter, dry-summer Middle Eastern deserts:

1. Semi-deciduous dwarf-shrubs, which reduce their leaf surface drastically at the beginning of the dry season (e.g. *Reaumuria palaestina, Salsola villosa, Suaeda palaestina, Artemisia monosperma, Zygophyllum dumosum*).
2. Heterophyllous dwarf-shrubs, which lose their lower, mesomorphic winter leaves and retain smaller xeromorphic leaves (e.g. *Artemisia herba-alba*).
3. Semi-evergreen virgate shrubs, which lose their leaves during winter but retain active, evergreen woody shoots (e.g. *Retama retam, Calligonum comosum*).
4. Bud-evergreen dwarf-shrubs, which lose their green winter shoots but retain evergreen buds located in the axils (e.g. *Reaumuria*).
5. Thorny, ephemeral-leaved dwarf-shrubs, which produce small, early-summer leaves and lose them gradually (e.g. *Noaea*).
6. Leafless semi-shrubs, which lose some evergreen shoots during the summer (e.g. *Ephedra*).
7. Leafless, modular semi-shrubs with green bark, which shed in summer the bark of the previous year's shoots (e.g. *Anabasis articulata, Haloxylon articulatum*).

Other variations occur also in other areas. *Ephedra, Artemisia,* and various *Zygophyllaceae* are also important in the American semi-deserts, while *Zygophyllacae, Casuarina humilis* and others are important in Australia. Some species are definitely halophytes (non-succulent).

References: Walter 1968, 1973, 1974; Walter & Box, in press; Zohary 1952, 1973; Orshan 1953; Korovin 1961–62; Nechayeva et al. 1973; Nikitin 1966; Petrov 1966–67; Milton Moore 1970.

Cushion-shrubs

Cushion-shrubs are small krummholz forms occurring where nearly constant desiccating, often cold winds completely limit vertical branch extension, resulting in an extremely dense mass of short branches forming a flat or rounded, almost hemispheric dwarf-shrub. The definitive treatment of cushion-plants in general remains the exhaustive monograph by W. Rauh (1939), who describes cushion-plants initially, woody or herbaceous, as follows (translated from the German):

> 'The cushion-plants are perennial evergreen plants with barely emerging main (vertical) axis and numerous, radially oriented shoots, deployed in tiers, whose tips, as a result of equal longitudinal extension, produce a common, more or less compact surface with the shape of a hemisphere or a flat mat'.

As a definition, Rauh (1939) later states that cushion-plants are 'perennial herbaceous or woody, mostly evergreen plants (chamaephytes) with well developed allorhizal root systems'. He lists a number of basic growth forms, including 'true cushion-plants', creeping cushions, sward cushions, rosette cushions, succulent cushion-plants, cushion-mosses, hapaxanthous cushion-plants, and pseudo-cushion forms. Most of these forms are included elsewhere in the current classification under Succulent Forbs, Xeric Cushion-Herbs, cold-desert herbs, and Mat-Forming Thallophytes. Cushion-shrubs include primarily the woody 'true cushion-plants' and some woody creeping forms. The 'true cushion-plants' exhibit radial growth and are divided physiognomically into radial spherical cushions (Radialkugelpolster), including treelet, shrub, hollow-cushion, and full-cushion subforms, and radial flat cushions (Radialflachpolster), including hollow and full-cushion subforms. Leaf forms are classified as needle-leaves, spatulate leaves (e.g. *Aretia, Azorella* types), calyciform leaves (Keulenblätter), and rolled leaves (revolute and involute). Leaves are invariably quite small, regardless of form.

Although Rauh did not consider convergent evolution alone to be the best explanation for cushion-plants, they are generally considered to be an adaptation to extremely windy conditions, as found on high mountains, in the polar regions, and in certain deserts. The world distribution of all 'cushion species' is given by Rauh as follows:

South America (primarily Andine)	50.5%
Central Asia and Asia Minor	16%
Subantarctic and New Zealand	13.6%
Europe (primarily alpine)	11.9%
Arctic	2.7%
Africa (primarily North Africa and alpine)	2.9%
North America (primarily alpine)	2.4%

Rauh also lists a variety of site types for cushion-plants, including:

1. wet sites (e.g. moors, streambanks, snow-valleys, periodically flooded gravel terraces, rainy maritime areas, saline soils);
2. intermediate sites (e.g. rock crevices and surfaces, moraine soils, mats); and
3. dry sites (e.g. snowless windy sites, steppes, dry alpine areas, volcanic soils, dry deserts, wind deserts).

Considering the world distributions of cushion-plants and common site types, typical cushion-plant climates could be considered to include those of the equatorial alpine páramo (wet and windy), the tropical alpine puna (seasonally wet-dry and windy), Patagonia (dry and windy), the Asian cold-winter deserts (dry and windy), subpolar islands (wet and windy), dry deserts, the arctic tundra and cold-desert, and wet alpine areas. Cushion-plants are reported as important in all of these areas (see, for example, Cuatrecasas 1968; Cabrera 1968; Walter 1968, 1973, 1974; Soriano 1956; Wace 1961; Godley 1960; Ozenda 1958; Jani 1969; Quézel 1965; Zohary 1973; Tieszen 1978). The climates of these alpine, lowland-desert, and maritime areas have little in common except wind. In considering ecological types of cushion-shrubs, the first important distinction appears to be between those of wet climates (generally also cool) and those of dry climates.

General references: Rauh 1939; Schröter & Hauri 1914; Weberbauer 1931; Heilborn 1925; Reiche 1893; Troll 1937–38; Walter 1968, 1973, 1974; Hodge 1946.

42. Perhumid Evergreen Cushion-Shrubs are compact rounded and flat cushion-shrubs found primarily in the cool, extremely windy, maritime climates of the subantarctic islands, southern Patagonia and Tierra del Fuego, some subarctic islands, some other cool-perhumid windward coasts, and some similarly perhumid páramo climates of equatorial mountains. Perhaps the most characteristic taxon is *Azorella,* which forms very dense, compact, hemispheric cushions in all of the Southern Hemisphere areas just mentioned. *Azorella selago* forms the dominant vegetation over large portions of the subantarctic islands (Wilhelmy 1963; Werth 1928; Walter 1968). Cushion-shrubs of wet climates are most commonly full-cushion forms.

References: Rauh 1939; Werth 1928; Wilhelmy 1963; Walter 1968; Weberbauer 1931; Cuatrecasas 1968; Schröter & Hauri 1914; Heilborn 1925.

43. Xeric Cushion-Shrubs are small rounded and flat cushion-shrubs found in a variety of windy and at least seasonally dry climates, which may otherwise be quite dissimilar. Such situations are found most commonly in the subtropical and temperate-continental regions, especially on mountains, and are probably best represented by the puna regions of the middle Andes and the rain-shadow of windy Patagonia. Xeric Cushion-Shrubs can differ physiognomically from Perhumid Evergreen Cushion-Shrubs by being generally more xeromorphic in structure (e.g. smaller, fewer and harder leaves) and by involving more flat and hollow-cushion forms. Xeric cushion-shrubs are represented in the moist puna by hard-cushion taxa such as *Azorella compacta, Opuntia atacamensis, Adesmia* ssp., and *Pycnophyllum* spp. (Cabrera 1968), and in Patagonia by often larger and thorny taxa such as *Mulinum spinosum* (Umbellif.) and *Chuquiraga aurea* (Walter 1968). Similar forms in other areas include *Anabasis aretioides* in North Africa (Hauri 1912); *Astragalus* and *Acantholimon* spp. in Anatolia (Walter 1968; Gams 1954); *Alyssum* (= *Ptilotrichum*) *spinosum, Arenaria pungens* and others (from a variety of families) in the Atlas Mountains (Walter 1968) and other drier Mediterranean mountains; *Aizoanthemum dinteri* and *Zygophyllum simplex* in southwestern Africa (Walter 1973); and *Acantholimon* and *Artemisia* spp. in Iran (Walter 1968). Walter (1974), considering the vegetation of Pamir, distinguishes five types of xeric, mostly woody cushion-plants characteristic of the dry Central Asian highlands: hard cushions with taproot (e.g. *Acantholimon hedini, Potentilla pamiroalaica*), firm cushions with rooting lateral branches (e.g. *Sibbaldia tetrandra*), loose cushions without adventive roots (e.g. *Oxytropis* spp., *Astragalus myriophyllus*), loose cushions with adventive roots (e.g. *Artemisia rapestris* f. *alpina*), and air-cushions without adventive roots (e.g. *Acantholimon pamiricum*).

References: Rauh 1939; Walter 1968, 1973, 1974; Cabrera 1968; Hodge 1946; Hauri 1912; Gams 1954; Schröter & Hauri 1914; Weberbauer 1931; Reiche 1893; Heilborn 1925.

Rosette-shrubs

Rosette-shrubs are trunkless analogs of the various forms of rosette-trees and treelets. Included are a variety of ground forms, leaf-succulent rosettes, bunch-palms, etc. Some forms consist of basal rosettes with taller flowering stalks (e.g. certain species of *Yucca* and *Agave*), while others are terminal rosettes (often with underground trunks, e.g. many palms). Although palms and agaves, for example, are quite different in many respects, both are monocots, can have trunkless rosette growth forms, occur in largely frost-free climates with high insolation, can be of similar size, have similar leaf (or pinna) shapes and sizes, and are evergreen.

44. Mesic Rosette-Shrubs include primarily the trunkless palms, which occur as understorey forms in most tropical evergreen forests and elsewhere as often dense ground covers. Both palmate (fan) and pinnate leaf types are included. All taxa are evergreen. These plants may grow to several meters in height in tropical rainforests or can occur as smaller ground forms, such as the familiar *Serenoa repens* and *Sabal minor* of the southeastern U.S.A. and *Chamaerops humilis* of North Africa. The trunkless shrub-palms have been studied very little as an ecological type. Some palms grow for many years as rosettes from underground trunks before developing short trunks above ground. Palms are often early successional species because of their rapid reproduction and growth rates and their tolerance of poorer soil conditions. In this respect they often represent tropical ecological equivalents to temperate-zone pines.

References: McCurrach 1960; Moore 1973; Langlois 1976; Knapp 1973; Kurz 1945; Monk 1968; Daubenmire 1978; Walter 1973; Lind & Morrison 1974; Whitmore 1975.

45. Xeric Rosette-Shrubs include primarily the leaf-succulent, basal-rosette agaves, aloes, and similar forms found in the world's tropical and subtropical dry climates. Because of the dryness these plants usually occur as scattered or well-spaced individuals in open woodland, savanna or semi-desert landscapes. The leaves are evergreen, generally more or less succulent (often with spiny or denticulate edges), and characteristically shaped like large, stiff blades arranged in a basal rosette. Common taxa include *Agave* spp. and stemless yuccas (e.g. *Yucca glauca*) in the Americas, ground *Tillandsia* spp. and *Puya chilensis* (both *Bromeliaceae*) in coastal Chile-Peru, *Aloë* spp. (e.g. *A. ferox*) in Africa and the Mediterranean region, and others. These plants generally do not penetrate into humid climates because of their vulnerabilty to rotting.

References: Walter 1968, 1973; Daubenmire 1978; Knapp 1973; Innes 1977; Shreve & Wiggins 1964; Whittaker & Niering 1965.

Stem-succulents

Stem-succulents are moderately large plants with fleshy stems (trunks) capable of holding large amounts of water over long periods of time. (Shrubs and forbs with fleshy leaves are included elsewhere.) Stem-succulents are evergreen and generally leafless (some exceptions), with moderate branching in most larger forms. Columnar and barrel-shaped forms usually have ribbed surfaces which can expand to store whatever water is available (Spalding 1905). Other forms, such as many species of *Opuntia*, have stems flattened into expandable cladodes. The root-systems of stem-succulents typically are shallow but spread laterally over several meters in order to intercept quickly whatever rain penetrates the soil surface, even from short showers (Cannon 1911).

Most large stem-succulents are restricted to mostly frost-free, high-insolation, semi-arid to arid climates, especially those with two rain seasons per year (e.g. Arizona-Sonora, equatorial East Africa). Only the bushier stem-succulents with more lignified bases (e.g. *Opuntia*) penetrate into more mesic climates, where rotting can be a problem. Some stem-succulents do penetrate, however, to colder climates, such as *Opuntia frigida* in Canada and *Oreocereus celsianus* in the Andine puna (Cabrera 1968).

Stem-succulents include most *Cactaceae* of the Americas, the stem-succulent euphorbs of Africa, plus endemics in southern Africa and elsewhere. Related are the more lignified, dendroid trunk-succulent treelets of southern Africa (e.g. *Commiphora, Aloë dichotoma, Cyphostemma, Pachypodium*), Socotra (e.g. *Adenium socotranum, Dracaena cinnabari*), and Arizona-Sonora (e.g. *Idria*) (Walter 1973; Popov 1957). It appears that these can be included in the same climatic envelope with the Arborescent Stem-Succulents, though the trunk-succulent treelets represent a somewhat different growth form.

46. Arborescent Stem-Succulents are tall, columnar, usually branched forms best represented by the saguaro (*Carnegiea gigantea*) of the Sonoran Desert, by many freely branching species of *Cereus* and related cacti in Mexico and South America (Caatingas, Chaco, Caribbean thorn-scrub), and by the large 'candelabra euphorbs' of East Africa. When branched, these forms may have individual branches (e.g. *Carnegiea*), clustered branches from a main trunk (true tree form, as in *Euphorbia*), or branches clustered at the base (bush form, as in *Lemaireocereus* and *Lophocereus*). As already mentioned, various trunk-succulent treelets seem to be closely related ecologically. Arborescent stem-succulents generally require dry to arid climates in which frost, if it occurs (even nightly as in the puna), does not last more than 24 hours (Turage and Hinckley 1938; Shreve 1911). Arborescent stem-succulents can also penetrate to some extent into woodland areas and occur in the thick thorn-scrub of northern Venezuela, East Africa, and the Caatingas and even in the dry forests of southern Florida. Because of the long time required to reach arborescent size, arborescent stem-succulents are almost always found as individuals.

Being evergreen, large stem-succulents require a certain regularity of precipitation and for this reason are largely replaced in areas with longer dry periods (e.g. Saharan Africa) by deciduous and/or ephemeral forms.

References: Shreve & Wiggins 1964; Shreve 1911; Shelford 1963; Walter 1973; Niering et al. 1963; Hueck 1966; Knapp 1973; Turage & Hinckley 1938; Kausch 1965; MacDougal 1912; Marloth 1908; Spalding 1905; MacDougal et al. 1915; Popov 1957; Innes 1977; Nobel 1980a.

47. Typical Stem-Succulents include the variety of cylindrical, barrel, spherical, and cushion forms best developed in the New World cacti, especially in the semi-deserts of Arizona-Sonora. These are not as tall as other succulents (seldom over 1–2 meters) and thus generally occur more often in formations more open than the dry woodlands of the tropics. Because more of the biomass may rest on the ground, these succulents may also be confined to drier sites where the danger of rotting is reduced. Separation of arborescent and non-arborescent stem-succulent climates, however, is very problematic. Common taxa include *Ferocactus* (short columns and barrels), *Echinocereus* (often cushion-like), *Mammillaria* (cushion-form), *Opuntia* (cylindrical forms), *Trichocaulon* (small spherical forms from rocky sites in the Namib Desert), and *Euphorbia* (small cylinders). These forms generally are not branched. Other small stem-succulents, generally even smaller and with succulent leaves, are included as Succulent Forbs.

References: Shreve & Wiggins 1964; Shelford 1963; Walter 1973; Kausch 1965; MacDougal 1912; MacDougal et al. 1915; Innes 1977; Rawé 1968.

48. Bush Stem-Succulents are branched, more externally reinforced stem-succulents which tolerate both colder and wetter conditions. These include primarily certain species of *Opuntia,* which occur as shrubs in the dry regions of the Americas (and well into wetter climates on dry sites) and as smaller forms in the drier grasslands as far north as southern Saskatchewan. (Branched opuntias can grow into significant treelets in the dry tropics and subtropics, but these are included more properly as Arborescent Stem-Succulents). Similar forms from the Old World are not as widespread, though certain branched species of *Opuntia,* notably *O. stricta* in Australia (Dodd 1959), have expanded rapidly after introduction to become pest species.

Though often reported to have no important native stem-succulents, Australia does have many bushy, semi-succulent, salt-tolerant native *Chenopodiaceae* (e.g. *Atriplex, Kochia*) which appear to occupy the same climatic ranges as certain bush-opuntias.

References: Walter 1973; Shelford 1963; Shreve & Wiggins 1964; Daubenmire 1978.

Graminoids

Graminoids are narrow-leaved herbs (*Graminiae, Cyperaceae,* and various ecological equivalents) growing from generally well developed underground rootstocks which may be either perennial (e.g. rhizomes) or annual. Graminoid growth forms may be classified as bunched (caespitose), spreading (sward-forming), and rooting (Bews 1929), though intermediate forms may be more common. Leaves may be flat-linear (typical-graminoid), revolute, or even spiny-revolute. Ecologically it seems appropriate to distinguish three basic climatically related types:

1. spreading graminoids, which are favored by any process which kills vertical shoots (e.g. cold winter temperatures, herbivory) and in sandy areas with very low vegetation cover but available soil moisture (e.g. rooting psammophilic grasses);
2. typical bunch-graminoids, which may occur almost anywhere but tend to dominate in areas too dry for spreading graminoids; and
3. tussock-graminoids, an extreme case of bunched growth which provides protection in cool (but not extremely cold) climates for new shoots arising from the middle of the tussock.

In general tall grasses (except tall tussock-grasses of the Southern Hemisphere) can be considered to be spreading, since they usually require more mesic habitats with sufficient moisture for a continuous ground cover. Arborescent bamboos, however, though spreading, are restricted to particular localities by peculiarities of their flowering and seed-production patterns. Bunch-grasses (and cold-climate sedges) often maintain a larger below-ground water-uptake area to support a smaller above-ground transpiring surface area, as is the strategy of many plants in drier environments. This contributes to their apparent spacing in drier areas. Tussock-grasses (and some sedges) occur in many maritime climates which appear to be quite humid but which often have high evaporation rates due to constantly strong winds, as in Patagonia and on many isolated islands.

Graminoids (mainly grasses) can occur wherever there is sufficient light and a sufficient growing season. As climates become cooler and/or drier, however, both graminoids and forbs have several advantages over larger woody forms (Daubenmire 1978, p. 59):

1. Herbs can devote a greater proportion of their production to seed formation.
2. Herbs can migrate faster because of shorter time required to begin flowering.
3. Herbs can aestivate or survive as seeds (annuals) during unfavorably dry periods.

One might also add that:

1. Herbs can occur in climates too cold for woody plants, such as polar and alpine tundra areas.
2. Spreading graminoids, once established in a continuous ground cover, can very effectively prevent the survival of woody seedlings because of the speed with which graminoids can produce a taller, effective canopy.

Graminoids occur in some form in almost all types of climates, though natural dominance may be confined to particular subhumid 'grassland climates' (Thornthwaite 1952). Graminoids are usually seasonal (especially in climates where they are important components) but actually respond quickly to almost any occurrence of adequate growing conditions. Their seasonal physiognomy can perhaps best be described as marcescent.

49. Arborescent Grasses are tall (1–8 m), partially lignified or otherwise reinforced grasses which occur in both warm and relatively cool environments with sufficient moisture. The main taxon is the bamboos (*Bambuseae*), though some bamboos are not so tall. Bamboos can form locally dense thickets and even dominant montane belts in the tropics, but otherwise do not dominate large areas because of their dependence on vegetative propagation. Bamboos generally flower only after several years (sometimes decades), but when they do, huge areas of genetically identical plants can flower simultaneously. Arborescent grasses generally tolerate cool, moist winter conditions well into the temperate zones, especially in the more maritime Southern Hemisphere where they reach as far poleward as southern Chile. Arborescent grasses generally have broader leaf blades, greater total leaf area, and require rather mesic conditions.

References: Arber 1934; Bews 1929; Whyte 1968; French 1979; Walter 1973; Numata, in press; Coupland 1979; McClure 1966; Knapp 1973; Hueck 1966; Troll 1959, 1966, 1972b.

50. Tall Cane-Grasses, the grasses of tropical tall-grass savannas, are tall (2–6 m), reinforced (often slightly lignified), generally broader-leaved grasses which occur in climates with at least seasonally coincident warm temperatures and abundant rainfall. These conditions are met throughout much of the tropical and subtropical zones, but such grasses are best developed in the summer-rain tropics and dominate as savannas in climates with long dry seasons and insufficient total moisture for forest or woodland. Such savannas can also occur where sufficient water is available but where tree growth is suppressed by any combination of fire, herbivory, or water loss from a pre-existing grass cover. Tall Cane-Grasses begin growing at the beginning of the favorable season and grow quickly to a height of several meters. At the end of the wet season, however, they die back to ground-level, leaving the standing dead stalks. If fire occurs during the dry season the dead stalks (and any living woody seedlings) are eliminated, but the grasses regenerate quickly at the beginning of the next rainy season and often benefit from the removal of the dead debris. Tall cane-grasses can be either perennial or annual, C_3 or C_4, but are more commonly C_4 perennials. Typical taxa are *Hyparrhenia, Imperata, Pennisetum, Tristachya, Arundinaria* (a bamboo), and tropical species of *Andropogon*. Tall cane-grasses, including *Arundinaria,* also grow in forest understoreys both in the tropics and well into the warm-temperate zone. They are also found commonly as aquatics or semi-aquatics in swamps and marshes, along shorelines, and in periodically flooded areas.

References: Beard 1953, 1967; Eyre 1968; Rattray 1960; Shantz & Marbut 1923; Bews 1929; Arber 1934; Whyte 1954, 1968; Knapp 1973; Coupland 1979; Goodland 1971; Walter 1939, 1973; Hueck 1966; Wilhelmy 1957.

51. Typical Tall Grasses differ from Tall Cane-Grasses in that they are shorter (seldom over 2 meters), generally not reinforced (more pliable), and have generally softer, narrower leaves. These are typically the grasses of the temperate tall grasslands and of montane meadows but can occur also in the tropics. The same genera as in the tropics can be involved (e.g. *Andropogon*), but the particular species are less tall, due to less total warmth and moisture during the (often shorter) growing season and to the fact that more species are C_3, with lower net production rates. Typical tall grasses occur in many areas but are best developed in the temperate continental interiors with early-summer rainfall maxima and cold winters, i.e. the true prairies of North America and the meadow-steppe of southeastern Europe. Common taxa include *Andropogon, Agropyron, Stipa, Festuca,* and many others.

References: Walter 1967, 1968, 1974; Weaver & Albertson 1956; Bews 1929; Coupland 1979; French 1979; Shelford 1963; Daubenmire 1978; Eyre 1968; Knapp 1965, 1973; Küchler 1964.

52. Short Sward-Grasses are spreading grasses usually less than 50 cm in height which produce the smooth, continuous short-grass swards of the northern Great Plains (into Canada) and similar but less homogeneous swards in parts of the Ukraine. Their growth form is the result of quite cold winter, grazing, and insuffcent summer warmth and/or moisture for taller growth. The result is a thick, dense sod so firm that early settlers built their houses with it. Rain falls primarily in early summer, but late-summer drought is often less severe because of the shorter warm season, lower transpiration levels, and greater soil moisture (chernozem soils) than in warmer grasslands. Typical taxa include *Buchloë dactyloides* and *Bouteloua gracilis* in the northern Great Plains; *Poa* spp. in Europe, eastern North America, and East Asia; *Kobresia, Poa, Deschampsia,* and sedges in mesic montane swards of western North America; *Festuca* (more normally a bunch-grass) in the Ukraine; the common lawn-grass *Cynodon dactylon,* common throughout the winterless tropics; and the same or similar taxa, plus more sedges, in arctic and alpine mesic tundras.

References: Walter 1968, 1974; Weaver & Albertson 1956; Küchler 1964; Daubenmire 1978; Bews 1929; Eyre 1968.

53. Short Bunch-Grasses (graminoids) are the common, caespitose grasses usually less than 50 cm in height which can occur in most parts of the world and which dominate most short grasslands, from the tropics to the polar regions, in areas too dry (or cold) for taller grasses. Typical taxa are too numerous to mention but include most sedges as well as true grasses. This form occurs wherever there is an adequate growing period. It dominates most typically in tropical dry savannas and temperate steppes, in the tropical alpine puna and similar montane-alpine grasslands, in the dry montane grasslands of temperate mountains (e.g. Asia, southern Africa, Andes), and in drier tundra areas. Though seasonal growth is normally in the spring and early summer, short bunch-grasses also dominate the winter-rain grasslands of the eastern Mediterranean region (Anatolia, Iran) and the western U.S.A. (Central Valley of California, Palouse region).

References: Eyre 1968; Walter 1968, 1973, 1974; Weaver & Albertson 1956; Bews 1929; Beard 1953, 1967; Knapp 1965, 1973; Shanz & Marbut 1923; Troll 1959; Rattray 1960; Rawé 1968; Daubenmire 1978.

54. Tall Tussock-Grasses are the 1–3 meter tall tussocks of the windy, maritime Southern Hemisphere grasslands, including the wetter areas of the Argentine pampas, the montane grasslands of New Zealand, and the sub-antarctic islands, as well as similar climates on islands, in moors, and in tropical mountains in other parts of the world. The tussock growth form is thought to protect the active shoots in the center against near-freezing temperatures. Tall-tussocks are generally found in areas too cool or dry for tree growth, as well as in exposed areas along forest borders. The most important genera are quite familiar from other grasslands but have developed the characteristic tall-tussock growth form only under certain conditions, e.g. *Stipa brachychaeta* in the pampas, *Danthonia* (*Chionochloa*) spp., *Festuca matthewsii,* and *Poa colensoi* in New Zealand.

References: Connor 1961; Zotov 1947; Walter 1968; Cockayne 1958; Drummond & Leatham 1959; Eyre 1968.

55. Short Tussock-Grasses differ from tall tussock-grasses only in size but are much more widespread, both in Southern Hemisphere grasslands and throughout the world. The short-tussocks extend into drier areas than do tall-tussocks, including most of the pampas and Patagonia, the lowland grasslands of New Zealand, alpine and montane grasslands of Australia and New Zealand, and the subantarctic islands. Short tussock-grasses are also a dominant form in the Andine puna, in moors throughout the world, and are important in a variety of cool island or montane grasslands where winters are not too cold or there is a sufficient winter snow cover, as in much of Europe. Typical genera are again familiar from other areas but form short-tussocks only where winter conditions are not too extreme: *Stipa trichotoma* in the pampas, *S. speciosa* and *Festuca pallescens* in Patagonia, *F. novae-zelandiae* and *Poa caespitosa* in New Zealand, and *P. flabellata* on the Falkland Islands.

References: Walter 1968; Zotov 1947; Cockayne 1958; Bews 1929; Wilhelmy 1963; Drummond & Leatham 1959; Coupland 1979; Eyre 1968.

56. Sclerophyllous grasses are xeromorphic grasses with permanently revolute, often spine-like leaves, as best suggested by the Australian 'porcupine grass' (*Triodia* spp.). Sclerophyllous grasses can occur as individual bunch-grasses or as large tussocks, the hummocks of *Triodia* measuring up to several meters across. *Triodia* hummocks dominate large areas of interior Australia. Sclerophyllous grasses are generally evergreen, though the active shoots are usually all but hidden by the mass of brownish old (dead) shoots. Sclerophyllous grasses are especially common in mediterranean climates (e.g. *Stipa tenacissima* in North Africa) and in dry areas with irregular rainfall.

References: Burbidge 1945–46, 1953; Beard 1969; Bews 1929; Walter 1973; Specht 1972.

57. Desert-Grasses generally represent an extreme form of bunch-grass in which a large root network supports a much smaller above-ground bunch of shoots. The spreading psammophilic grasses could perhaps also be included. Desert-grasses grow as well spaced individuals and do not form a dense ground-cover. Above all, desert-grasses represent a growth form necessitated by aridity. Many desert-grass taxa could be short bunch-grasses under better conditions. Desert-grasses occur throughout the world's arid areas and often form the only permanent vegetation in the driest areas, especially if these involve sandy substrates. *Aristida* is a common genus in many dry areas, including the 'desert plains' of Texas-New Mexico and the drier steppes of Middle Asia. The most important dry-puna species is *Stipa jehu*. Both perennial and annual species can be involved.

References: Walter 1968, 1973, 1974; Walter & Box, in press; Weaver & Albertson 1956; Küchler 1964; Shelford 1963; Bews 1929; Eyre 1968; Rattray 1960; Knapp 1965, 1973; Daubenmire 1978; Nobel 1980b.

Forbs

Forbs are herbs which are not graminoids and not ferns, i.e. all herbaceous dicots plus all herbaceous monocots except the graminoid families *Graminiae, Cyperaceae, Juncaceae,* and various ecologically equivalent forms. Physiognomically, forbs are more or less broad-leaved herbs, although erect, linear-leaved forms (e.g. many *Compositae*) are included with the leafier, more mesic forest forms. Forb form and strategy can be classified into many subtypes, most of which are not easily relatable to climate since forbs occur most commonly as understorey components. Ellenberg & Mueller-Dombois (1967b) classify forb types based on the following:

1. life form (Raunkiaer): phanerophytes, chamaephytes, hemicryptophytes, geophytes, therophytes.
2. general structure: caespitose, scapose (with or without basal rosette), reptant, pulvinate.

In addition one can easily make other ecologically useful distinctions based on:

1. leaf shape and size: broad, linear, needle.
2. leaf and stem structure: hard, soft, succulent.
3. plant size (height).
4. seasonality: evergreen, summergreen, raingreen, ephemeral (for annuals: springgreen, summergreen, raingreen, winter annuals).
5. regional affinity: tropical, temperate, polar.
6. other attributes, such as carnivorousness, reproductive strategy (e.g. r or K-strategists), propagation mechanisms.

Herbaceous phanerophytes (e.g. *Musa*) and chamaephytes are generally restricted to the humid tropics; more typically forbs are either perennial hemicryptophytes or geophytes or annual therophytes. Since all three generally occur in the same climates, the most ecologically useful initial distinction seems to be that based on seasonality plus regional affinity.

Outside the favorable climates of the humid tropical and temperate forests, both forbs and graminoids have several advantages over woody plants, as already noted in the section on graminoids. Although the geoecology of graminoids, as a life form and a synusia, has been studied extensively worldwide, the same has not been true for forbs, mainly because forbs do not form the dominant vegetation of large areas as do some graminoids. The worldwide geography and comparative ecology of forbs as a group remains one of the more neglected areas of plant ecology and biogeography.

58. Tropical Evergreen Forbs include an enormous variety of forms and strategies which cannot really be separated climatically and which occur throughout the tropical region. Classification of such forms and subforms, both taxonomically and ecologically, remains a largely untouched field of plant ecology. Certain taxa such as *Musa* (banana, a phanerophyte), *Begonia* and *Coleus* from rainforest understoreys, and the herbaceous dwarf-palms are familiar types, but they do not begin to suggest the variety of forms which actually exists. Forbs are often not as important in tropical forests as in temperate forests because of the greater number of larger woody competitors. To some extent forbs have been replaced by epiphytes, which overcame the reduced light on the rainforest floor by moving upward onto the trees. In other tropical areas evergreen forbs may be more important components of the vegetation, as in high mountains (e.g. the tall, often white-pubescent rosette-forbs of the páramo, plus more familiar-looking members of temperate-zone taxa), in open woodlands, and around rainforest margins. The most common subtypes of Tropical Evergreen Forbs probably include the familiar leafy dicots, leafy monocots, herbaceous palms and other rosette-forbs, and (outside rainforest areas) familiar erect, single-stemmed forbs (e.g. *Compositae*) and succulent forms. Annual but aseasonal forbs can be considered evergreen if they produce evergreen stands.

References: Walter 1973; Cuatrecasas 1968; Richards 1952; Cabrera 1968; Schnell 1970; Löhr & Müller 1968; Everard & Morley 1970.

59. Temperate Evergreen Forbs include a variety of often smaller, sometimes harder-leaved (sclerophyllous) forms which occur most commonly in the understoreys of mesic forests. Temperate Evergreen Forbs are generally hemi-cryptophytes, as geophytes and therophytes are usually seasonal in the temperate zone and temperate herbaceous phanerophytes and chamaephytes, except for graminoids, generally do not occur. Most temperate evergreen forbs are small dicots, such as *Pyrola, Chimaphila, Gaultheria, Hexastylis,* and *Plantago.* Included also are many taxa which remain green in milder temperate winters but would be considered summergreen elsewhere, for example *Taraxacum, Duchesnia, Stellaria,* and other prostrate, often weedy herbs with softer leaves. Many carnivorous temperate forbs are semi-evergreen (e.g. *Drosera*). Temperate succulent forbs are usually evergreen but are included as a separate type elsewhere. Temperate Evergreen Forbs occur both in evergreen forests and woodlands and well into areas with colder winters, where they are often protected in winter by coverings of fallen leaves and snow. These forbs are especially important in temperate coastal rainforests, where they can form continuous evergreen ground-covers.

References: Walter 1968, 1974; Radford et al. 1968; Polunin 1972; Everard & Morley 1970; Reichle 1970; Penfound 1952; Ellenberg 1963.

60. Raingreen Forbs are seasonal forms which sprout anew at the beginning of the tropical rainy season, grow and reproduce, and generally die back to ground-level as the dry season progresses. Of the five seasonal types of forb described in this model, raingreen forbs are probably the least studied and are certainly the least known in the temperate zone. Raingreen forbs may be phanerophytes, chamaephytes, hemi-cryptophytes, geophytes, or therophytes, though the first is generally uncommon. Most raingreen forbs are small, since larger plants in the winterless tropics generally tend to become woody. Many raingreen forbs are familiar-looking broad-leaved dicots (e.g. *Leguminosae, Compositae, Rubiaceae, Labiatae*), and many are considered weeds. Annuals are common. Raingreen forbs are found in both forested and more open tropical summer-rain regions. Except in the extreme case of desert ephemerals, raingreen forbs generally do not attain dominance in formations. They may, however, form significant and even continuous understoreys in open areas where rainfall is concentrated in short periods but where grasses are not totally dominant. In the Sonora Desert and other dry areas with two distinct rain periods both summer-rain and winter-rain forb covers are common, each involving different sets of species. The distinction between Raingreen Forbs and Ephemeral Desert Herbs is not well defined, except that the former are generally seasonal and the latter more irregular. Some taxa which taxonomically are forbs could be better classified ecologically as graminoids, e.g. certain *Eriocaulaceae, Xyridaceae.*

References: Walter 1973; Beard 1953; Eiten 1972; Knapp 1973; Everard & Morley 1970.

61. Summergreen Forbs include a great variety of seasonal forms which sprout anew in spring or early summer, grow and reproduce, and generally die back to ground-level as summer or autumn progresses. The end of the growing period may be brought on either by summer heat and desiccation or by autumn cold. Summergreen forbs involve hemi-cryptophytes, geophytes, and therophytes, which may be leafy or nearly scapose, single-stemmed or highly branched, or of a number of other basic forms. The potential variety in subtypes is suggested by a few well known and typical families such as *Liliaceae, Compositae, Leguminosae, Ranunculaceae, Araceae, Umbelliferae,* and *Violaceae.* Three common ecological subtypes are mesic forest 'wildflowers', spring-ephemeral geophytes, and summer-blooming 'weeds'. Summergreen forbs are well developed in all but the driest temperate-zone and boreal-polar climates (with sufficient summer warmth) and extend along mountain ranges well into the summer-rain tropics. Many individual summergreen species, however, have soft leaves and high transpiration and respiration rates, and are limited toward warmer climates, especially in colder areas, by increased respiration which may be too much for a positive net production. Summergreen forbs generally are not dominants but do constitute important forest synusiae and often subdominant components of mesic meadows and 'meadow-steppes', as in southeastern Europe and the former true prairies of the U.S.A. Summergreen tall-forbs growing to 2–3 meters can be locally dominant on small, mesic, well fertilized pasture sites ('Läger') in the Alps and Caucasus (Rübel 1930, Walter 1968), as well as on more natural wet-montane, warmer-tundra, and floodplain sites. Of the five forb types described herein, the summergreen temperate forbs are by far the best studied.

References: Walter 1968, 1974; Rübel 1930; Anderson 1964; Lieth 1960; Kojić 1966; Bethke et al. 1965; Goryshina 1972; Ellenberg 1963; Daubenmire 1978; Radford et al. 1968; Polunin 1972; Daxer 1934; Mudrack 1935; Walter & Box, in press; Schemske et al. 1978.

62. Succulent Forbs are small, generally evergreen, herbaceous leaf-succulents which may also have succulent stems and/or root-systems. The most common forms are rosulate (e.g. *Sedum, Echeveria*) and prostrate (e.g. *Portulaca*). Many more exotic forms can also be included, however, such as the caudex-succulent 'living stones' (*Lithops*) of south-western Africa, the well known, non-rosette *Kalanchoë* of dry tropical areas, and many *Mesembryanthemaceae* (*Aizoaceae, Ficoidaceae*) of southern Africa. Some quite succulent species are annuals, e.g. *Mesembryanthemum cryptanthum* (South Africa) and many species of *Portulaca.* The variety in forms is quite striking (especially in southern Africa), but all have in common the requirement of moderately wet to dry sites, since they are limited both by extreme aridity and by the danger of rotting in excessively wet areas. Succulent forbs are especially common in mediterranean, warm semi-desert, and warm woodland climates and on other drier and saline sites such as coastal sands.

References: Innes 1977; Walter 1973; Polunin 1972; Shreve & Wiggins 1964; Rawé 1968; Hueck 1966; Zemke 1939.

Small herbs

The term 'small herb' is used to refer to groups of both small forbs and graminoids occurring in extreme environments. In such situations the differences in leaf shape, plant structure, and taxonomy are of much less importance than the fact that the plants are quite small and herbaceous. Generally they are also highly seasonal, which forms the most important ecological basis for further differentiation. Such plants may be either annual or perennial (usually geophytes) but generally must complete seasonal growth and seed production during the short periods in which water and warmth are available.

63. Xeric Cushion-Herbs are usually small, often rosette or mat-forming herbs found in dry and often windy (exposed) areas which may be either cold or warm. The xeromorphy of such plants may be temporal as much as morphologic, in that leaves may be quite soft but life-cycles appropriately short to be completed using the small amount of water and/or warmth seasonally available. The best examples are perhaps the rosette, mat, and cushion-herbs of exposed polar and alpine tundra sites, such as certain species of *Draba, Dryas, Cerastium, Stellaria, Silene* (the last three *Caryophyllaceae*), and above all *Saxifraga.* The ground-hugging form provides protection against desiccation, even on exposed sites, both by reducing the transpiring surface and by remaining within the calmer near-surface air layer. In cold climates the cushion form also permits better use of near-surface warmth during the active period. Larger but otherwise similar cushion forms can be found in most warmer xeric environments. Most Xeric Cushion-Herbs are summergreen (or raingreen in tropical summer-rain areas).

64. Ephemeral Desert Herbs are small, generally malacophyllous raingreen ephemerals which can grow quickly and complete their life cycles using the small amounts of water provided by short rainy periods or even individual showers. As little as 15 mm of rainfall or less may be sufficient (Tevis 1958). Both perennials with underground storage organs and annual therophytes are included, the latter probably requiring less water for survival (Walter 1973). Both types of plants can quickly develop ephemeral carpets and can attain dominance in at least two distinct environmental situations: (1) the warm deserts with no permanent vegetation, and (2) the continental spring-ephemeral semi-deserts of Middle Asia, which have a 4–8 week growing season in March-May provided by some spring rainfall and melting snow. This latter type (see Walter and Box, in press, and Walter 1974) is dominated by mini-geophytes such as *Poa bulbosa, Tulipa biflora,* and *Carex pachystylis,* and occurs on loess, which has a relatively high water-holding capacity in the upper few centimeters. The warm deserts and semi-deserts may support winter and/or summer ephemerals, depending upon the rainfall regime. The ephemeral semi-desert and desert carpets of *Weitzia aurea* in Australia (Walter 1973), of *Nolana* and *Calandrinia* species in the Atacama Desert (Kohler 1967), and of both summer and winter ephemerals in Arizona-Sonora (Shreve and Wiggins 1964, Tevis 1958, Walter 1973, Ehleringer et al. 1979) are especially well known, as well as some spring-ephemeral carpets of less arid regions (e.g. the bluebonnets, *Lupinus subcarnosa*, of Texas woodlands).

65. Summergreen Cold-Desert Herbs include a variety of often quite small graminoids and forbs (usually mini-geophytes with some therophytes) which grow in the shortest, most extreme growing seasons of the polar cold-deserts and temperate-zone subnival belts. Their main distinguishing characteristics are small size and the ability to grow rapidly and complete their life-cycles within favorable periods sometimes as short as two weeks in midsummer (Caldwell et al. 1978; Billings et al. 1978; Bliss 1956). Because soil may be scarce in such environments, and water thus limiting as well as warmth, the plants are often found only in crevices and other more mesic microsites. Each summer's photosynthate must be channelled as efficiently as possible into the production of seeds (therophytes) or into replenishing the underground storage organs (geophytes). The small size of such plants reduces potential water loss from surface areas, reduces the respiratory requirements of larger amounts of standing biomass and greater annual growth, and permits maximum use of near-surface warmth. Summergreen Cold-Desert Herbs are essentially summergreen ephemerals, as opposed to the raingreen ephemerals of arid regions. Important genera include *Eriophorum, Carex, Saxifraga, Geum, Gentiana,* and *Ranunculus.*

66. Raingreen Cold-Desert Herbs are small herbs (forbs and graminoids, annuals and perennials) which occur generally in tropical alpine areas which are both cold and subject to seasonal drought such as the Andine puna. Since mean temperatures are usually above freezing, it is the precipitation regime which delimits the growing season. Low temperatures (and nightly frost), however, limit the degree of activity even during the growing season, probably even more than in the case of the summergreen cold-desert, which receives little nightly frost and up to 24 hours of sunshine during the growing season. (The differences outside the growing season are of less importance to the vegetation). Raingreen Cold-Desert Herbs are, in form and function, much like summergreen cold-desert herbs and, at least in the Andine puna, involve many of the same taxa (e.g. *Plantago, Scirpus, Juncaceae, Poaceae, Cyperaceae*), as well as other temperate-zone taxa (e.g. *Iridaceae, Astragalus, Amaryllidaceae*) (Cabrera 1968).

Additional general references:
summergreens: Böcher 1938; Tieszen 1978; Walter 1968, 1974; Bliss 1956; Walter & Box, in press; Salisbury & Spommer 1964; Tranquillini 1978.
raingreens: Walter 1973, 1974; Went 1948–49; Shreve & Wiggins 1964; Walter & Box, in press; Zohary 1973.

Vines and lianas

Vines are weak-stemmed plants whose long, slender, fast-growing shoots rely on other plants or objects for support (Menninger 1970). Vines may be either woody or herbaceous, perennial or annual. Large woody vines are generally called lianas and occur in warmer humid climates of the tropics and subtropics. In such climates the larger vines and lianas can grow quickly to canopy height, spread out laterally, and almost completely cover the existing vegetation.

Vines germinate in the soil but then elongate rapidly, climbing or sprawling over other plants (or other objects) in order to reach more sunlight quickly and without having to invest large amounts of photosynthate in self-supporting structure. Climbing is accomplished by a variety of mechanisms, including grasping by means of tendrils, clinging by means of hooks and thorns, adventitious rooting, weaving and twining growth, and even sticking by means of adhesives. One can also distinguish photophytic vines (e.g. *Vitis, Pueraria, Ficus, Lonicera*) which grow quickly to fuller sunlight and skiophytic (shade-loving) vines (e.g. *Hedera, Parthenocissus*) which climb more slowly in the understorey, often by rooting along existing trunks. Most vines and lianas have broad leaves (or compound leaves). Hallé et al. (1978) and Cremers (1973) have recently identified a number of basic architectural types.

Because of their rapid rates of growth and need for existing vegetation for support, vines and lianas are best developed in warmer humid climates. Perhumid climates are most favorable, since vines and lianas often must compete for water with deeper-rooting trees as well as with many shallow-rooting forms.

67. Tropical Broad-Evergreen Lianas are the large, woody, perennial lianas of tropical rainforests. These are almost always photophytic vines and generally climb quickly into the existing forest canopy, where they produce their flowers, fruits, and most of their leaves. The ropelike stems can become several decimeters in diameter, and the resulting tangle at canopy level can bind trees together so that they cannot be felled by cutting at ground-level. Included in this group are the pseudo-lianas (or hemi-epiphytes), plants which germinate as epiphytes and then send down roots into the soil (see Walter 1973). Typical tropical liana genera include *Ficus* (including the stranglers), *Landolphia, Combretum, Calycobolus, Anodendron, Entada* (*Leguminosae*), and the climbing palms (e.g. *Calamus*). Included also must be taxa which commonly become self-supporting trees upon reaching the canopy (e.g. *Ceiba, Freycinetia, Bougainvillea, Securidaca*).

68. Broad-Evergreen Vines, as opposed to lianas, are smaller (perennial) vines which may be either woody or herbaceous (more commonly the former) and which may climb or sprawl in a greater variety of ways. These include both tropical taxa (e.g. *Philodendron, Vanilla*) and distinctly temperate taxa (e.g. *Lonicera, Hedera, Smilax*). In the humid tropics such smaller vines are more likely to be root-climbers and skiophytes than twining photophytes, though no sharp distinction can be made. Temperate broad-evergreen vines can be quite aggressive, however, as in the case of *Lonicera japonica* (honeysuckle), which sprawled quickly over large areas of the southeastern U.S.A. after introduction. Included are also the horizontal vines such as *Hedera* and *Pachysandra* and various climbing palms, aroids, and grasses (mainly bamboos).

69. Broad-Raingreen Vines occur in tropical and subtropical areas with pronounced dry seasons. Though little-studied, they can be particularly important in open woodlands and thorn-scrub, where they sprawl at will over existing trees and bushes. Though the leaves are deciduous, stems are often green and photosynthetically active throughout at least part of the dry season. Much of the generally impenetrable character of the tropical thorn-scrub can be due to the tangle formed by raingreen vines binding other plants together. *Leguminosae* and *Euphorbia* are important taxa.

70. Broad-Summergreen Vines occur in temperate summergreen areas with cold winters and summer rain. Included are both native taxa (e.g. *Vitis, Rhus, Parthenocissus*) and tropical invaders which already have the deciduous habit (e.g. *Pueraria lobata, = thunbergiana,* the ubiquitous Kudzu vine of the southeastern U.S.A.). Many summergreen vines are locally important and may be planted as ornamentals because of their flowers (e.g. *Wisteria, Ipomoea*) or their autumn colors (e.g. *Parthenocissus*). *Vitis* is important economically. Herbaceous vines are perhaps best represented among the summergreens (e.g. *Vicia, Ipomoea*) but woody forms are more common.

References Menninger 1970; Hallé et al. 1978; Cremers 1973; Walter 1973; Schnell 1970; Hueck 1966; Richards 1952.

Ferns

Ferns (*Pteridophyta*) are an old group of generally small plants with prostrate, even underground stems and large, erect, often compound leaves called fronds. (The larger, trunk-forming tree-ferns of the humid tropics are included, physiognomically, under rosette-treelets. Epiphytic ferns are included under epiphytes). Some ferns are quite tough and withstand drier conditions. For a variety of reasons (non-vascularized gametophytes, flagellated sperms, no protected seed-stage during reproduction), however, ferns generally grow more successfully in habitats which are at least moderately wet. Ferns are generally best developed in humid forests and, since many prefer the reduced amount of sunlight, can often form closed understoreys in both tropical and temperate rainforests. Ferns are generally poikilohydrous, the degree of hydration depending entirely on ambient moisture conditions. Included in this group are both the ephemeral ferns of rocky arid sites (e.g. *Cheilanthes lindheimeri* of Arizona, *Pellaea calomeanos* of the Namib) and many rainforest forms, both terrestrial and epiphytic (e.g. *Hymenophyllaceae*).

Ferns may be divided into evergreen and seasonal forms for ecological purposes, the latter losing its fronds seasonally but sending out new ones from a permanent rootstock or prostrate stem. Many individual fern species can be evergreen or seasonal depending on local climatic regimes.

71. Evergreen Ferns include both delicate rainforest forms which occur where there is no seasonal dryness and more xeromorphic, generally coriaceous forms whose fronds survive seasonal dryness (or winter cold). Evergreen, in this sense, means that the fronds are persistent and active (hydrated) throughout the year. Evergreen Ferns are best developed in the humid tropics and subtropics but can extend into temperate areas where winter temperatures are not too severe, such as in temperate rainforests. In areas with winter frost the evergreen fronds may become prostrate, at least during the winter. Evergreen Ferns often form luxurious closed ground-covers in cool perhumid rainforests of both tropical mountains and windward temperate coastal areas, especially in the Southern Hemisphere. Though still important in warmer tropical lowland rainforests, their understorey dominance is generally broken by larger competitors. Commonly evergreen genera include *Asplenium, Cheilantes, Pellaea, Polystichum,* and *Polypodium* (although certain species of these genera can be quite ephemeral in desert situations).

72. Summergreen Ferns sprout anew each spring after being killed back to ground-level by winter cold. Summergreen Ferns also prefer cool, perhumid or seasonally perhumid environments, though some taxa with more coriaceous foliage do grow in warmer, drier areas. The more hygrophilic summergreen ferns tolerate quite cool growing seasons and can be found as closed understoreys in cool-temperate forests all the way to alpine and subpolar forest limits. Some seasonal ferns might more properly be called raingreen, including not only the poikilohydrous desert forms but also certain ferns of mediterranean climates. Page (1977), for example, reports that *Asplenium onopteris, Davallia canariensis,* and *Polypodium macaronesicum* occur in the montane laurel forests of the Canary Islands but are summer-deciduous in response to the mediterranean summer dryness. Other species of *Asplenium* (spleenworts, including tropical rainforest nest-ferns) and *Polypodium* (often epiphytic or growing on rocks) are commonly evergreen in other tropical and temperate climates. Commonly deciduous genera (again with exceptions) include *Athyrium* and *Cystopteris* (both *Aspidiaceae*), common in North America, Eurasia, and in the Southern Hemisphere (e.g. *Cystopteris fragilis* of Australian mountains and the subantarctic islands). Different species of *Dryopteris* (also *Aspidiaceae*) tend to be summergreen in central European deciduous forests (Ellenberg 1963; e.g. *D. filix mas, D. Linnaeana, D. austriaca dilatata*) but more commonly evergreen or semi-evergreen in the milder (but more continental) summergreen climates of the southeastern U.S.A. (Radford et al. 1968: e.g. *D. marginalis, D. intermedia, D. cristata,* but summergreen *D. spinulosa* and *D. campyloptera,* both less common).

References: Christ 1910; Jermy, Crabbe, and Thomas 1973; Blombery 1967; Ellenberg 1963; Page 1977; Walter 1968, 1973.

Epiphytes

Epiphytes, strictly speaking, are plants which germinate and grow on other plants, primarily on trees and presumably as a means of obtaining more sunlight. Most have only aerial roots; those which do send roots down from their tree-branch locations into the soil are more properly called hemi-epiphytes (or pseudo-lianas). Only a few epiphytes are found in the temperate zone, most commonly the mistletoes, certain tropical invaders (e.g. *Tillandsia usneoides*), and various mosses and lichens. Epiphytes are quite common and striking in the tropics, however, especially in rainforests where rainfall is frequent and humidity is high, alleviating potential stress on the aerial roots.

Epiphyte variety is quite great, both in taxonomic groups (orchids, aroids, bromeliads, cacti, ferns, etc.) and basic forms (leafy, filiform, rosette, tussock, stoloniferous, thorny, succulent, etc.). True epiphytes are not parasitic and generally do not damage or greatly stress the trees which carry them. Most epiphytes do prefer living trees, however, often of particular taxa, possibly because of bark characteristics and because the bark of dead trees may soon fall off. Epiphytes often settle in the saddles formed by branching, since water is more readily held in these areas.

Tropical-rainforest epiphytes can be classified into sun-loving (heliophilic) photophytes, which live on upper and exposed branches, and shade-loving (ombrophilic) skiophytes, which live on lower, more protected branches. Heliophilic epiphytes are generally somewhat more xeromorphic (e.g. coriaceous, sclerophyllous, succulent) in structure but may also have larger leaves. Photophytic and skiophytic epiphytes generally occur in the same climates.

73. Tropical Broad-Evergreen Epiphytes include the wide range of generally larger, leafier rainforest forms, many of which are sun-epiphytes. The most characteristic form is perhaps the agave-like, leaf-succulent bromeliads, which sit on exposed branches and saddles and catch rainwater in their rosette bases, hence a common name 'water-cups'. Included also, however, are a variety of often mildly leaf-succulent aroids, cacti, and orchids, with leaves of varying sizes. Tropical Broad-Evergreen Epiphytes are both drought and cold-sensitive and are not common in tropical areas with extended dry seasons. They do not extend far into the temperate zone, but this is perhaps due more to seasonal dryness than to extreme frost-sensitivity, since some such epiphytes occur in the highest forested belts (cloud forests) of tropical mountains.

74. Narrow-Leaved Epiphytes involve generally smaller forms with filiform, graminoid, or other narrow leaves. These include a wider range of moisture requirements, from quite moisture-demanding, filamentous or filmy ferns (e.g. *Hymenophyllaceae*) of rainforest understoreys to certain xerophytic species of *Tillandsia,* which look more like clumps of xeric grass and may occur even in distinctly dry deciduous woodlands. The hygrophilic forms are best developed in the cloud forests of tropical mountains, where they can cover and obscure other plants almost completely. They occur also downslope and generally throughout the lowland rainforests. The more xerophytic forms extend into the seasonally-dry subtropics. *Tillandsia usneoides* (Spanish moss) extends into the temperate southeastern U.S.A., where temperatures fall below freezing on many winter nights.

75. Broad-Wintergreen Epiphytes represent the 'mistletoe habit' and include a variety of at least partly parasitic, generally somewhat more xeromorphic taxa which are found both in the tropical and the temperate zones of both the Old World and the Americas. Kuijt (1961, p. 19), in reference to *Dendrophthora,* describes the plants as 'rather small bushes of olive green or yellowish color, glabrous, parasitic on a great variety of trees and shrubs'. Wintergreen Epiphytes are seen most commonly in treetops during the season when the trees are bare. The epiphytes remain green during the foliated period, however, and can occur on evergreen trees, both in rainforests and in surprisingly dry areas (e.g. *Phoradendron juniperii,* which parasitizes *Juniperus* species in the southwestern U.S.A.). The degree of parasitism is generally not extreme and appears to fill primarily a need for nutrients. The most important taxa are *Dendrophthora* (53 spp. in tropical America, see Kuijt 1961), *Phoradendron* (found also throughout tropical America and the southern U.S.A., see Trelease 1916), *Viscum* (the common mistletoe of Europe), certain *Myzodendraceae* (which parasitize *Nothofagus* in southern South America), plus *Psittacanthus, Phacellaria,* and various *Loranthaceae* in Australia.

References: Kuijt 1961; Trelease 1916; Walter 1973; Richards 1952; Hosokawa 1954, 1967; Bünning 1956; Schnell 1970; Stanford 1969; Biebl 1964.

Thallophytes

The term thallophyte is used here in the sense of Ellenberg & Mueller-Dombois (1967b) to refer to non-vascular cryptogams, i.e. mosses, liverworts, algae and lichens. Thallophytes are always small and most are poikilohydrous, i.e. active and conspicuous only when sufficiently wet. The larger chamaephytic mosses and lichens can form significant cushions, hummocks, or mats (carpets) on both ground and biotic surfaces. Smaller thallophytes of all four taxonomic classes can form flatter coverings on a variety of surfaces (e.g. trees, rocks, ground) and are usually less apparent. Some are thero-thallophytes and escape unfavorable conditions as seeds. Epiphytic thallophytes are included here rather than as epiphytes.

76. Mat-Forming Thallophytes include the larger, relatively permanent chamaephytes, primarily pulvinate mosses and liverworts and some fruticose lichens. These can be either evergreen or seasonally active but generally maintain a permanent structure. The two habits are perhaps best represented by the evergreen carpets and hanging mats (e.g. *Selaginella*) in tropical rain and cloud forests and by the ground covering of seasonally active mosses and lichens in tundra areas. In the latter case the poikilohydrous permanent structure permits the thallophytes to compete successfully with larger but more slowly developing vascular herbs. Mat-Forming Thallophytes also occur in most closed forests, wetlands, on sufficiently moist rock and wall surfaces, and in more mesic grasslands and meadows, including lawns. In these cases the thallophytes may be more seasonal, making use of the less favorable season (e.g. humid temperate-zone winters, as in Western Europe) while being quickly outcompeted during the main growing season.

77. Xeric Thallophytes include the smaller, generally less conspicuous thallophytes, primarily flat-matted mosses and liverworts, foliose and crustose lichens, various algae (including endolithic lichens and algae), and many annual thallophytes of all groups. These may occur under quite mesic conditions but become more important as conditions become drier, as in drier forests and woodlands, on more exposed and primitive surfaces, and perhaps most importantly on drier tundra and cold-desert sites. Xeric Thallophytes can be the dominant and often the only vegetation in polar and subnival deserts, including the vegetated portions of Antarctica, and in the driest desert areas. In forests these can form epiphyllous microsystems on leaves.

References: Ellenberg & Mueller-Dombois 1967b; Walter 1968, 1973; Vogel 1955; Folmann 1965; Segal 1969; Ruinen 1961; Renner 1933; Tieszen 1978; Noerr 1974a, 1974b; Steere 1978; Watson 1913; Britton 1967; Billings & Mooney 1968; Bliss 1971; Ahmadjian & Hale 1973; Lange 1965; Wielgolaski 1972; Crum 1972; Gams 1934.

References for world and regional vegetation

World (descriptive)
Eyre (1968), Rübel (1930), Schimper & von Faber (1935), Troll (1959, 1960, 1961), Troll & Paffen (1964), Walter (1968, 1973, 1977).

World (comparative)
Beard (1967), Lauer (1952), Meggers et al. (1973), Troll & Lauer (1978), Vareschi (1968).

Tropics
Aubert de la Rüe et al. (1957), Beard (1944a, 1955), Golley & Medina (1975), Misra & Gopal (1968), Odum & Pigeon (1970), Schnell (1970–77), Troll (1959).

Mountains
Allg. Forst. (1966), Beals (1969), Cabrera (1958, 1968), Coe (1967), Cuatrecasas (1968), Daubenmire (1943), Donita (1965), Ellenberg (1975), Ern (1966), Gersmehl (1973), Gorchakovsky (1966), Grebenshchikov (1963), Hedberg (1951), Hodge (1946), Ives & Barry (1974), Michaelis (1932–34), Schweinfurth (1957), Sturm (1978), Tranquillini (1964, 1979), Troll (1959, 1966, 1968, 1972a, 1972b, 1973), Walter (1960, 1975), Wardle (1965), Webber (1978), Whittaker (1956).

Arctic/Subarctic
Aleksandrova (1960), Billings & Mooney (1968), Bliss (1956, 1971, in press), Bliss et al. (1973), Böcher (1938), Bryson (1966), Hulten (1962), Hustich (1953), Ives & Barry (1974), Rosswall & Heal (1975), Schwartzenbach (1960), Tieszen (1978), Wielgolaski et al. (1975).

North America
Billings (1949), Boyce (1954), Braun (1950), Brockman (1968), Bruner (1931), Damman (1977), Daubenmire (1943, 1978), Franklin & Dyrness (1973), Hare (1950, 1954), Hettinger & Janz (1974), Kirkpatrick & Hutchinson (1977), Knapp (1965), Küchler (1964, 1977), Livingston & Shreve (1921), Merriam (1898), Rowe (1959), Shelford (1963), Shreve (1942, 1951), Weaver & Albertson (1956), Wells (1928, 1942), Westman (1978), Wharton (1978), Whittaker (1956).

Central America and Caribbean
Asprey & Robbins (1953), Beard (1944a, 1944b, 1953, 1955), Coker (1905), Ern (1974), Graham (1973), Hargreaves & Hargreaves (1965), Lauer (1968), Lauer et al. (in press), Leopold (1950), Parsons (1955), Sarmiento (1976), Sawyer and Lindsey (1971), Shreve (1914, 1934), Weber (1958).

South America
Beard (1944a, 1953, 1955), Boelcke (1957), Cabrera (1958), Cole (1960), Cuatrecasas (1968), Eiten (1972, 1978), Ellenberg (1975), Ewel & Madriz (1968), Fittkau et al. (1969), Goodland (1971), Graham (1973), Hueck (1966), Hueck & Seibert (1972), Kummerow et al. (1961), Lescure (1978), Lindman & Ferri (1974), Lewis & Collattes (1975), Müller (1977), Rauh (1958), Rawitscher (1948), Sarmiento (1976), Schmithüsen (1956, 1960), Schnetter (1968), Solbrig (1976), Smith (1971), Soriano (1956), Sturm (1978), Veblen & Ashton (1978), Walter (1967), Walter & Medina (1969), Weinberger et al. (1973).

Atlantic Islands
Hansen (1930), Jonsson (1905), Kunkel (1976), Preusser (1975), Schmid (1954), Sunding (1972), Wace (1961), Wace & Holdgate (1976).

Europe
Acta Phytogeogr. Suecica (1965), Adamović (1933), Ahti et al. (1968), Brockmann-Jerosch (1925), Burnett (1964), Donita (1965), Eijsink et al. (1978), Ellenberg (1963), Ern (1966), Eyre (1968), Feoli-Chiapella & Feoli (1977), Gils et al. (1975), Hartmann & Schnelle (1970), Heal & Perkins (1978), Horvát (1978), Horvát et al. (1974), Lötschert (1962–65), Lüdi (1935), Malmer (1978), Markgraf (1949), Meyer (1978), Polunin (1972), Sissingh (1977), Szafer (1966), Tansley (1949), UNESCO (1969), Walter (1956, 1975), Zohary & Orshan (1966).

Africa
Ayyad and El-Ghonemy (1976), Bouxin (1975), Burtt (1942), Campbell & Moll (1977), Cannon (1934), Coe (1967), Emberger (1939), Fanshawe (1969), Frankenberg (1978), Hamilton (1975), Hedberg (1951), Holland & Hove (1975), Keay (1949, 1959), Knapp (1973), Koechelin et al. (1974), Langdale-Brown et al. (1964), Leistner (1967), Leistner & Werger (1973), Lind & Morrison (1974), Livingstone (1967), McKenzie et al. (1977), Missouri Botanical Garden (1968), Mitchell (1971), Phillips (1928), Quézel (1964), Rattray (1960), Rauh (1973), Rawé (1968), Richards (1963), Richard-Vindard & Battistini (1972), Salt (1954), Schmidt (1973, 1975), Schnell (1976), Scholtz (1966), Shantz & Marbut (1923), UNESCO (1969), Vesey-Fitzgerald (1970), Walter (1976), Werger (1977), Werger et al. (1978), Zinderen-Bakker (1970, 1973).

Indian Ocean Islands
Cadet (1974), Chastain (1958), Legris (1969), Popov (1957).

Soviet Union
Gorchakovsky (1966), Grebenshchikov (1963), Gulizashvili et al. (1975), Karpenko (1964), Keller (1927), Korovin (1961–62), Nechayeva et al. (1973), Nikitin (1966), Petrov (1966–67), Restshikov (1961), Walter (1974, 1977), Walter & Box (in press), Worobjev (1963).

Middle East
Abul-Fatih (1975), Beals (1965), Bobek (1951), Bokhari & Khan (1976), Breckle (1975), Czeczött (1938–39), Danin (1978), Davis et al. (1971), UNESCO (1969), Walter (1956, 1974), Zohary (1973).

South Asia
Bhatia (1958), Champion & Seth (1968), Champion et al. (1965), Fernando (1968), Freitag (1971), Gupta (1978), Inst. Franç. Pondichery (1961–70), Kitamura (1964), Mani (1974, 1979), Meusel & Schubert (1971), Schweinfurth (1957), Shrimal & Vyas (1977), Sreedhara Murthy (1978), Troll (1972a), Whyte et al. (1954).

Japan
Hamet-Ahti et al. (1974), Hara (1959), Lieth et al. (1973), Numata (1974), Numata et al. (1972).

East Asia
Küchler (1948), Walter (1974), Walter & Box (in press), Wang (1961), Yunatov (1950).

Southeast Asia
Ogawa et al. (1961), Stamp (1924), Vidal (1961), Whitmore (1975), Williams (1965).

Australia
Beadle (1966), Beard (1967, 1969, 1976), Blombery (1967), Costin (1957), Davis (1964), Keast et al. (1959), Milton Moore (1970), Rule (1967), Specht (1972), Webb (1959, 1964), Williams (1974).

New Zealand
Cockayne (1958), Connor (1961), Dawson (1962), Godley (1975), Holloway (1954), Kuschel (1975), Robbins (1962), Zotov (1947).

Oceania
Balgooy (1975), Brünig (1970), Fosberg (1960), Robbins (1961), Van Steenis (1962), Whitmore (1975), Wiggins & Porter (1971).

Subantarctic and Antarctica
Brockmann-Jerosch (1928), Godley (1960), Holdgate (1970), Rudolph (1966), Wilhelmy (1963).

APPENDIX B

Predicted vegetation at selected representative and well-known sites

The macroclimatic data and predicted vegetation at 111 selected sites are presented below in computer-generated form. These sites were selected as a geographically representative supplement to the list of validation sites in Appendix C. A number of university cities were included in order to encourage comparison of climatically predictable and actually occurring plant forms and vegetation structures. The format of the computer listing is described at the beginning of Appendix C. For interpretation of the predicted results refer to sections 5.F and 6.A in the main text. Since names of countries are given in representations of local languages (see Appendix E), some may not be readily apparent:

AL ‘ARABIYAH AS-SA’UDIYAH = Saudi Arabia
AL LUBNAN = Lebanon
AL MAGHREB = Morocco
BHARAT = India
CHOSON = Korea
GRUZHIJA = Georgian S.S.R. (Russian)
MAGYARORSZAG = Hungary
MISRA = Egypt
MYANMA = Burma
PRATHET THAI = Thailand
YAITOPYA = Ethiopia
ZHONGGUO = China (mainland)

These names are truncated after eight characters on the computer listing.

Appendix B. Predicted vegetation at selected representative and well-known sites.

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                                                        1
         LOCATION                                 LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI          ELEV

 7. SYDPROVEN                 GROENLAN            60.00  -45.00
    7.0  -5.0  977.  150.   30.  137.  2.32          15.
       * 1. SHORT SWARD-GRASSES                   TMAX     0.29
         2. SHORT BUNCH-GRASSES                   MI       0.30
         3. SUMMERGREEN TUNDRA DWARF-SHRUBS       TMAX     0.14
         4. TEMPERATE EVERGREEN DWARF-SHRUBS      TMAX     0.14
         5. TEMPERATE EVERGREEN FORBS             TMIN     0.0
         6. SEASONAL COLD-DESERT HERBS            MULT.    1.00
         7. MAT-FORMING THALLOPHYTES              MI       0.69

34. EDMONTON, ALBERTA         CANADA              53.55 -113.47
   17.0 -13.0  446.   77.   20.   77.  0.90          676.
       * 1. BOREAL/MONTANE SHORT-NEEDLED TREES    MI       0.33
       + 2. BOREAL SUMMERGREEN NEEDLE-TREES       TMAX     0.50
         3. BOREAL BROAD-SUMMERGREEN TREES        MI       0.11
         4. BROAD-SUMMERGREEN SMALL TREES         MI       0.22
         5. TALL GRASSES                          TMIN     0.15
       + 6. SHORT SWARD-GRASSES                   MI       0.45
         7. SUMMERGREEN GIANT-SCRUB               TMAX     0.26
         8. BROAD-SUMMERGREEN MESIC SHRUBS        TMAX     0.19
         9. XERIC SUMMERGREEN SHRUBS              MI       0.14
       +10. SHORT BUNCH-GRASSES                   TMIN     0.54
        11. NEEDLE-LEAVED EVERGREEN SHRUBS        TMAX     0.37
        12. SUMMERGREEN TUNDRA DWARF-SHRUBS       TMAX     0.08
        13. SUMMERGREEN FORBS                     TMAX     0.37
        14. TEMPERATE EVERGREEN DWARF-SHRUBS      TMIN     0.18
        15. XERIC CUSHION-HERBS                   MI       0.13
        16. MAT-FORMING THALLOPHYTES              MI       0.11
        17. XERIC THALLOPHYTES                    MULT.    1.00

54. MONTREAL DORVAL, QUEBEC   CANADA              45.47  -73.73
   21.0  -9.0  973.   93.   70.   71.  1.69          30.
       * 1. SUMMERGREEN BROAD-LEAVED TREES        TMIN     0.30
       * 2. BOREAL/MONTANE SHORT-NEEDLED TREES    TMAX     0.09
         3. BOREAL BROAD-SUMMERGREEN TREES        TMAX     0.33
         4. BROAD-SUMMERGREEN SMALL TREES         TMIN     0.45
         5. TALL GRASSES                          TMIN     0.23
         6. SHORT SWARD-GRASSES                   TMIN     0.55
         7. BROAD-SUMMERGREEN MESIC SHRUBS        TMAX     0.44
         8. SUMMERGREEN GIANT-SCRUB               TMAX     0.39
         9. BROAD-ERICOID EVERGREEN SHRUBS        TMIN     0.05
        10. SHORT BUNCH-GRASSES                   TMIN     0.57
        11. NEEDLE-LEAVED EVERGREEN SHRUBS        MI       0.19
        12. SUMMERGREEN FORBS                     TMAX     0.48
        13. SUMMERGREEN FERNS                     PMTMAX   0.29
        14. TEMPERATE EVERGREEN DWARF-SHRUBS      TMAX     0.17
        15. MAT-FORMING THALLOPHYTES              TMAX     0.39
        16. XERIC THALLOPHYTES                    MI       0.18

62. BARROW,ALASKA             USA                 71.30 -156.78
    5.0 -27.5  104.   20.    2.   20.  0.68           7.
       * 1. SEASONAL COLD-DESERT HERBS            TMAX     0.33
         2. XERIC CUSHION-HERBS                   TMAX     0.0
         3. XERIC THALLOPHYTES                    TMAX     0.17
         4. ICE DESERT                            TMAX     0.00
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                                                        2
         LOCATION                                 LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI          ELEV

66. ANCHORAGE,ALASKA          USA                 61.22 -149.88
   14.0 -11.0  360.   68.   11.   30.  0.79          36.
       * 1. BOREAL/MONTANE SHORT-NEEDLED TREES    MI       0.25
         2. BOREAL SUMMERGREEN NEEDLE-TREES       PMTMAX   0.16
         3. BROAD-SUMMERGREEN SMALL TREES         MI       0.12
         4. SHORT SWARD-GRASSES                   PMTMAX   0.16
         5. SUMMERGREEN GIANT-SCRUB               TMAX     0.13
         6. BROAD-SUMMERGREEN MESIC SHRUBS        TMAX     0.0
         7. XERIC SUMMERGREEN SHRUBS              TMAX     0.0
       + 8. SHORT BUNCH-GRASSES                   TMIN     0.55
         9. NEEDLE-LEAVED EVERGREEN SHRUBS        TMAX     0.25
        10. SUMMERGREEN TUNDRA DWARF-SHRUBS       MI       0.12
        11. SUMMERGREEN FORBS                     TMAX     0.25
        12. TEMPERATE EVERGREEN DWARF-SHRUBS      MI       0.12
        13. XERIC CUSHION-HERBS                   MI       0.27
        14. SEASONAL COLD-DESERT HERBS            TMAX     0.07
        15. XERIC DWARF-SHRUBS                    MI       0.01
        16. XERIC THALLOPHYTES                    MULT.    1.00

77. PORTLAND, OREGON          USA                 45.55 -122.65
   19.0   4.0 1062.  180.   12.   12.  1.61           9.
       * 1. TEMPERATE NEEDLE-TREES                TMAX     0.44
         2. SUB-MEDITERRANEAN NEEDLE-TREES        TMIN     0.31
         3. TEMP. BROAD-EVERGREEN SMALL TREES     TMIN     0.15
         4. TALL CANE-GRAMINOIDS                  TMIN     0.10
         5. DWARF-NEEDLE SMALL TREES              TMAX     0.08
         6. SHORT BUNCH-GRASSES                   TMIN     0.71
         7. NEEDLE-LEAVED EVERGREEN SHRUBS        MI       0.24
         8. SUMMERGREEN FORBS                     TMAX     0.43
         9. MAT-FORMING THALLOPHYTES              MI       0.51
        10. BROAD-WINTERGREEN EPIPHYTES           TMIN     0.14
        11. XERIC THALLOPHYTES                    MI       0.24

98. SANTA BARBARA,CALIFORNIA  USA                 34.42 -119.70
   18.8  11.2  471.  120.    0.    5.  0.64          37.
       * 1. MEDITERRANEAN EVERGREEN SHRUBS        TMAX     0.20
       + 2. SHORT BUNCH-GRASSES                   MI       0.70
         3. NEEDLE-LEAVED EVERGREEN SHRUBS        MI       0.38
         4. XERIC EVERGREEN TUFT-TREELETS         TMAX     0.05
         5. SUMMERGREEN FORBS                     TMAX     0.42
       + 6. XERIC CUSHION-SHRUBS                  MI       0.41
         7. BUSH STEM-SUCCULENTS                  TMIN     0.37
         8. MEDITERRANEAN DWARF-SHRUBS            TMAX     0.15
         9. XERIC CUSHION-HERBS                   TMAX     0.54
        10. BROAD-WINTERGREEN EPIPHYTES           MI       0.07
        11. SUCCULENT FORBS                       TMAX     0.04
        12. XERIC THALLOPHYTES                    MULT.    1.00
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Appendix B. *Predicted vegetation at selected representative and well-known sites.*

	LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
			3
110.	SAN DIEGO, CALIFORNIA USA	32.72	-117.15
	20.0 13.0 259. 53. 3. 4. 0.34	6.	
	* 1. SHORT BUNCH-GRASSES	MI	0.43
	* 2. XERIC EVERGREEN TUFT-TREELETS	TMAX	0.12
	3. EVERGREEN GIANT-SCRUB	TMAX	0.0
	+ 4. XERIC CUSHION-SHRUBS	TMIN	0.60
	+ 5. DESERT-GRASSES	MI	0.48
	6. BUSH STEM-SUCCULENTS	TMIN	0.43
	7. SUMMERGREEN FORBS	MI	0.43
	8. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.23
	9. MEDITERRANEAN DWARF-SHRUBS	TMAX	0.21
	10. LEAF-SUCCULENT EVERGREEN SHRUBS	TMIN	0.08
	11. TYPICAL STEM-SUCCULENTS	TMAX	0.0
	12. XERIC ROSETTE-SHRUBS	TMAX	0.0
	13. EPHEMERAL DESERT HERBS	MI	0.48
	14. XERIC CUSHION-HERBS	MI	0.43
	15. XERIC DWARF-SHRUBS	TMAX	0.36
	16. SUCCULENT FORBS	TMAX	0.09
	17. XERIC THALLOPHYTES	TMAX	0.91
130.	YELLOWSTONE PARK, WYOMING USA	44.96	-110.72
	15.5 -7.0 444. 51. 31. 34. 0.96	1899.	
	* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.38
	2. BOREAL SUMMERGREEN NEEDLE-TREES	PMTMAX	0.27
	3. BOREAL BROAD-SUMMERGREEN TREES	PMTMAX	0.13
	4. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.26
	5. SHORT SWARD-GRASSES	PMTMAX	0.27
	6. SUMMERGREEN GIANT-SCRUB	TMAX	0.20
	7. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.09
	8. SHORT BUNCH-GRASSES	TMIN	0.59
	9. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.31
	10. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.21
	11. SUMMERGREEN FORBS	TMAX	0.31
	12. TEMPERATE EVERGREEN DWARF-SHRUBS	PMTMAX	0.27
	13. MAT-FORMING THALLOPHYTES	MI	0.17
	14. XERIC CUSHION-HERBS	MI	0.05
	15. XERIC THALLOPHYTES	MULT.	1.00
140.	DENVER, COLORADO USA	39.72	-105.02
	19.0 -1.8 357. 56. 10. 43. 0.64	1592.	
	1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.07
	2. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.30
	3. SUMMERGREEN GIANT-SCRUB	TMAX	0.33
	4. XERIC SUMMERGREEN SHRUBS	TMAX	0.24
	5. SHORT SWARD-GRASSES	MI	0.22
	6. DWARF-NEEDLE SMALL TREES	TMAX	0.08
	7. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.01
	+ 8. SHORT BUNCH-GRASSES	TMIN	0.65
	9. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.38
	10. COLD-WINTER XEROMORPHIC SHRUBS	TMAX	0.24
	11. SUMMERGREEN FORBS	TMAX	0.43
	12. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.19
	13. XERIC CUSHION-HERBS	TMAX	0.52
	14. XERIC DWARF-SHRUBS	MI	0.25
	15. XERIC THALLOPHYTES	MULT.	1.00

	LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
			4
172.	HOUSTON, TEXAS USA	29.77	-95.37
	28.0 11.0 1171. 120. 77. 110. 1.12	125.	
	* 1. WARM-TEMPERATE BROAD-EVERGREEN TREES	TMAX	0.20
	* 2. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.13
	* 3. HELIOPHILIC LONG-NEEDLED TREES	MI	0.11
	4. TEMPERATE BROAD-RAINFOREST TREES	TMAX	0.0
	5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.17
	6. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.14
	7. SWAMP SUMMERGREEN NEEDLE-TREES	TMAX	0.0
	8. PALMIFORM TUFT-TREES	TMIN	0.0
	9. TALL GRASSES	TMAX	0.28
	10. TALL CANE-GRAMINOIDS	TMAX	0.28
	11. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.20
	12. TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.15
	13. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.11
	14. ARBORESCENT GRASSES	TMAX	0.10
	15. SUMMERGREEN GIANT-SCRUB	TMAX	0.30
	16. SHORT SWARD-GRASSES	TMAX	0.23
	17. TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.18
	18. DWARF-NEEDLE SMALL TREES	TMAX	0.17
	19. MEDITERRANEAN EVERGREEN SHRUBS	PMTMAX	0.14
	20. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.13
	21. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.13
	22. PALMIFORM TUFT-TREELETS	TMIN	0.05
	23. SHORT BUNCH-GRASSES	TMAX	0.40
	24. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.28
	25. EVERGREEN GIANT-SCRUB	TMIN	0.15
	26. PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.14
	27. BUSH STEM-SUCCULENTS	MI	0.34
	28. SUMMERGREEN FORBS	TMAX	0.28
	29. TEMPERATE EVERGREEN FORBS	TMAX	0.08
	30. SUMMERGREEN FERNS	MI	0.02
	31. BROAD-EVERGREEN VINES	TMAX	0.18
	32. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
	33. NARROW-LEAVED EPIPHYTES	MI	0.11
	34. BROAD-SUMMERGREEN VINES	MI	0.11
	35. MAT-FORMING THALLOPHYTES	TMAX	0.07
	36. XERIC THALLOPHYTES	TMAX	0.40

Appendix B. Predicted vegetation at selected representative and well-known sites.

5

	LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
178.	CHICAGO, ILLINOIS USA	41.88	-87.63
	23.0 -4.0 832. 100. 36. 71. 1.26	186.	
* 1.	SUMMERGREEN BROAD-LEAVED TREES	MI	0.29
* 2.	TEMPERATE NEEDLE-TREES	TMIN	0.10
3.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.17
4.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.37
5.	TALL GRASSES	TMIN	0.33
6.	SHORT SWARD-GRASSES	TMAX	0.48
7.	SUMMERGREEN GIANT-SCRUB	TMAX	0.48
8.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.44
9.	DWARF-NEEDLE SMALL TREES	TMIN	0.04
10.	SHORT BUNCH-GRASSES	TMIN	0.62
11.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.48
12.	SUMMERGREEN FORBS	TMAX	0.48
13.	SUMMERGREEN FERNS	MI	0.13
14.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.06
15.	TEMPERATE EVERGREEN FORBS	TMIN	0.04
16.	MAT-FORMING THALLOPHYTES	TMAX	0.28
17.	BROAD-SUMMERGREEN VINES	TMIN	0.06
18.	XERIC THALLOPHYTES	MI	0.59
193.	MIAMI, FLORIDA USA	25.77	-80.20
	27.5 20.0 1199. 200. 44. 145. 0.94	2.	
1.	TROPICAL RAINFOREST TREES	MI	0.04
2.	WARM-TEMPERATE BROAD-EVERGREEN TREES	MI	0.20
3.	TROPICAL XERIC NEEDLE-TREES	TMAX	0.17
+ 4.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.38
5.	PALMIFORM TUFT-TREES	MI	0.25
6.	TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.20
7.	TALL CANE-GRAMINOIDS	MI	0.25
8.	TALL GRASSES	MI	0.25
9.	ARBORESCENT GRASSES	TMAX	0.13
10.	TROPICAL BROAD-EVERGREEN SMALL TREES	MI	0.04
11.	PALMIFORM TUFT-TREELETS	MI	0.25
12.	SHORT SWARD-GRASSES	TMAX	0.25
13.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.20
14.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.17
+15.	SHORT BUNCH-GRASSES	TMAX	0.42
+16.	EVERGREEN GIANT-SCRUB	TMAX	0.38
17.	XERIC EVERGREEN TUFT-TREELETS	MI	0.09
18.	PALMIFORM MESIC ROSETTE-SHRUBS	MI	0.04
19.	BUSH STEM-SUCCULENTS	TMAX	0.42
20.	RAINGREEN FORBS	TMAX	0.30
21.	XERIC ROSETTE-SHRUBS	MI	0.29
22.	TROPICAL EVERGREEN FORBS	MI	0.04
23.	SUCCULENT FORBS	MI	0.29
24.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.18
25.	MAT-FORMING THALLOPHYTES	TMAX	0.08
26.	BROAD-EVERGREEN VINES	MI	0.04
27.	XERIC THALLOPHYTES	TMAX	0.42

6

	LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
202.	HARRISBURG, PENNSYLVANIA USA	40.27	-76.87
	24.0 0.0 914. 92. 57. 87. 1.32	102.	
* 1.	SUMMERGREEN BROAD-LEAVED TREES	MI	0.32
2.	TEMPERATE NEEDLE-TREES	TMAX	0.0
3.	SUB-MEDITERRANEAN NEEDLE-TREES	TMIN	0.06
4.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.08
5.	TALL GRASSES	TMIN	0.42
6.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.32
7.	SUMMERGREEN GIANT-SCRUB	TMAX	0.48
8.	SHORT SWARD-GRASSES	TMAX	0.42
9.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.38
10.	DWARF-NEEDLE SMALL TREES	TMIN	0.22
11.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.09
12.	SHORT BUNCH-GRASSES	TMAX	0.62
13.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.44
14.	SUMMERGREEN FORBS	TMAX	0.44
15.	TEMPERATE EVERGREEN FORBS	TMIN	0.22
16.	SUMMERGREEN FERNS	MI	0.17
17.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.0
18.	BUSH STEM-SUCCULENTS	TMIN	0.0
19.	BROAD-SUMMERGREEN VINES	MI	0.24
20.	MAT-FORMING THALLOPHYTES	TMAX	0.23
21.	BROAD-WINTERGREEN EPIPHYTES	TMIN	0.0
22.	XERIC THALLOPHYTES	MI	0.52
206.	MT.WASHINGTON,NEW HAMPSH USA	44.30	-71.40
	9.5 -14.3 1882. 178. 132. 170. 5.43	1917.	
* 1.	SHORT SWARD-GRASSES	TMAX	0.47
2.	SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.37
3.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.15
4.	MAT-FORMING THALLOPHYTES	MI	0.87
5.	SEASONAL COLD-DESERT HERBS	TMAX	0.58
207.	HOULTON, MAINE USA	46.13	-67.85
	20.0 -10.0 947. 95. 63. 85. 1.73	140.	
* 1.	SUMMERGREEN BROAD-LEAVED TREES	TMIN	0.27
* 2.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.18
3.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.42
4.	BROAD-SUMMERGREEN SMALL TREES	TMIN	0.43
5.	TALL GRASSES	TMIN	0.21
6.	SHORT SWARD-GRASSES	TMIN	0.53
7.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.38
8.	SUMMERGREEN GIANT-SCRUB	TMAX	0.36
9.	BROAD-ERICOID EVERGREEN SHRUBS	TMIN	0.0
10.	SHORT BUNCH-GRASSES	TMIN	0.56
11.	NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.17
12.	SUMMERGREEN FORBS	TMAX	0.45
13.	SUMMERGREEN FERNS	TMIN	0.31
14.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.22
15.	MAT-FORMING THALLOPHYTES	TMAX	0.45
16.	XERIC THALLOPHYTES	MI	0.16

Appendix B. Predicted vegetation at selected representative and well-known sites.

7

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
224. MEXICO MEXICO	19.40	-99.15
17.5 12.0 588. 155. 6. 53. 0.82	2280.	
* 1. TEMPERATE NEEDLE-TREES	MI	0.21
* 2. TROPICAL XERIC NEEDLE-TREES	TMAX	0.17
3. MONTANE BROAD-RAINGREEN TREES	MI	0.02
4. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.13
5. TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.08
6. PALMIFORM TUFT-TREES	TMIN	0.05
7. TALL CANE-GRAMINOIDS	MI	0.15
8. TALL GRASSES	MI	0.15
9. BROAD-RAINGREEN SMALL TREES	TMAX	0.13
10. TEMP. BROAD-EVERGREEN SMALL TREES	MI	0.08
11. ARBORESCENT GRASSES	MI	0.02
+12. SHORT SWARD-GRASSES	MI	0.39
13. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.17
14. TROPICAL BROAD-EVERGREEN SHRUBS	MI	0.15
15. RAINGREEN THORN-SCRUB	TMAX	0.13
16. MEDITERRANEAN EVERGREEN SHRUBS	TMAX	0.11
17. PALMIFORM TUFT-TREELETS	TMIN	0.10
+18. SHORT BUNCH-GRASSES	MI	0.76
19. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.38
20. BUSH STEM-SUCCULENTS	TMAX	0.38
21. RAINGREEN FORBS	TMIN	0.22
22. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.15
23. XERIC CUSHION-SHRUBS	MI	0.10
24. XERIC CUSHION-HERBS	MI	0.23
25. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.11
26. BROAD-RAINGREEN VINES	TMIN	0.10
27. MAT-FORMING THALLOPHYTES	MI	0.02
28. XERIC THALLOPHYTES	MULT.	1.00
244. LA CRUZ COSTA RI	11.07	-85.65
28.0 25.0 1450. 310. 1. 88. 0.87	246.	
* 1. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.35
* 2. PALMIFORM TUFT-TREES	MI	0.20
* 3. TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.14
4. XERIC RAINGREEN TREES	MI	0.20
+ 5. BROAD-RAINGREEN SMALL TREES	TMAX	0.35
6. TALL CANE-GRAMINOIDS	MI	0.20
7. TROPICAL BROAD-EVERGREEN DWARF-TREES	MI	0.08
8. PALMIFORM TUFT-TREELETS	MI	0.20
9. TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.18
10. RAINGREEN THORN-SCRUB	MI	0.15
+11. SHORT BUNCH-GRASSES	TMAX	0.40
+12. EVERGREEN GIANT-SCRUB	TMAX	0.33
13. RAINGREEN FORBS	TMAX	0.28
14. BROAD-RAINGREEN VINES	TMAX	0.35
15. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
16. MAT-FORMING THALLOPHYTES	TMAX	0.07
17. XERIC THALLOPHYTES	TMAX	0.40

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
249. NASSAU, NEW PROVIDENCE BAHAMAS	25.08	-77.35
28.0 22.0 1181. 180. 33. 130. 0.85	3.	
* 1. TROPICAL XERIC NEEDLE-TREES	TMAX	0.13
+ 2. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.35
3. PALMIFORM TUFT-TREES	MI	0.18
4. TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.12
5. TALL CANE-GRAMINOIDS	MI	0.18
6. TALL GRASSES	MI	0.18
7. TROPICAL BROAD-EVERGREEN DWARF-TREES	MI	0.06
8. ARBORESCENT GRASSES	MI	0.06
9. SHORT SWARD-GRASSES	TMAX	0.23
10. TROPICAL BROAD-EVERGREEN SHRUBS	MI	0.18
11. PALMIFORM TUFT-TREELETS	MI	0.18
+12. SHORT BUNCH-GRASSES	TMAX	0.40
+13. EVERGREEN GIANT-SCRUB	TMAX	0.33
14. XERIC EVERGREEN TUFT-TREELETS	MI	0.20
15. BUSH STEM-SUCCULENTS	TMAX	0.40
16. XERIC ROSETTE-SHRUBS	TMAX	0.40
17. RAINGREEN FORBS	TMAX	0.28
18. SUCCULENT FORBS	MI	0.41
19. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
20. MAT-FORMING THALLOPHYTES	MI	0.06
21. XERIC THALLOPHYTES	TMAX	0.40
252. KINGSTON JAMAICA	18.00	-76.83
27.5 25.0 800. 190. 15. 40. 0.51	34.	
1. TROPICAL EVERGREEN SCLEROPHYLL TREES	MI	0.02
2. XERIC RAINGREEN TREES	TMAX	0.22
3. BROAD-RAINGREEN SMALL TREES	TMAX	0.38
+ 4. RAINGREEN THORN-SCRUB	TMAX	0.50
5. SHORT SWARD-GRASSES	MI	0.02
+ 6. XERIC EVERGREEN TUFT-TREELETS	TMAX	0.44
+ 7. SHORT BUNCH-GRASSES	TMAX	0.42
8. EVERGREEN GIANT-SCRUB	TMAX	0.38
9. ARBORESCENT STEM-SUCCULENTS	TMAX	0.31
10. BUSH STEM-SUCCULENTS	TMAX	0.42
11. XERIC ROSETTE-SHRUBS	TMAX	0.38
12. RAINGREEN FORBS	TMAX	0.30
13. LEAF-SUCCULENT EVERGREEN SHRUBS	TMAX	0.26
14. XERIC CUSHION-SHRUBS	TMAX	0.25
15. TYPICAL STEM-SUCCULENTS	MI	0.18
16. SUCCULENT FORBS	TMAX	0.43
17. BROAD-RAINGREEN VINES	TMAX	0.38
18. XERIC CUSHION-HERBS	TMAX	0.10
19. XERIC THALLOPHYTES	TMAX	0.42

Appendix B. Predicted vegetation at selected representative and well-known sites.

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
271. CARACAS VENEZUEL	10.50	-66.93
20.8 18.0 809. 100. 10. 78. 0.93	1042.	
* 1. TROPICAL XERIC NEEDLE-TREES	TMAX	0.39
* 2. MONTANE BROAD-RAINGREEN TREES	MI	0.14
3. TROPICAL MONTANE RAINFOREST TREES	MI	0.03
4. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.29
5. PALMIFORM TUFT-TREES	TMAX	0.21
6. TROPICAL EVERGREEN MICROPHYLL-TREES	MI	0.19
7. BROAD-RAINGREEN SMALL TREES	TMAX	0.29
8. TALL CANE-GRAMINOIDS	MI	0.25
9. TALL GRASSES	MI	0.25
10. ARBORESCENT GRASSES	MI	0.14
11. TROPICAL BROAD-EVERGREEN SMALL TREES	MI	0.03
+12. SHORT SWARD-GRASSES	MI	0.47
13. TROPICAL BROAD-EVERGREEN SHRUBS	MI	0.25
14. PALMIFORM TUFT-TREELETS	MI	0.25
15. RAINGREEN THORN-SCRUB	MI	0.08
+16. SHORT BUNCH-GRASSES	MI	0.79
17. XERIC EVERGREEN TUFT-TREELETS	MI	0.09
18. EVERGREEN GIANT-SCRUB	TMAX	0.07
19. PALMIFORM MESIC ROSETTE-SHRUBS	MI	0.03
20. RAINGREEN FORBS	TMAX	0.47
21. BUSH STEM-SUCCULENTS	TMAX	0.47
22. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.18
23. XERIC ROSETTE-SHRUBS	TMAX	0.04
24. TROPICAL EVERGREEN FORBS	MI	0.03
25. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.34
26. BROAD-RAINGREEN VINES	TMAX	0.29
27. MAT-FORMING THALLOPHYTES	MI	0.14
28. SUCCULENT FORBS	TMAX	0.13
29. XERIC CUSHION-HERBS	MI	0.09
30. BROAD-EVERGREEN VINES	MI	0.03
31. XERIC THALLOPHYTES	TMAX	0.84
274. PARAMO DE MUCUCHIES VENEZUEL	8.70	-70.85
4.0 2.0 682. 150. 5. 44. 1.32	4221.	
* 1. SHORT BUNCH-GRASSES	TMAX	0.33
* 2. TROPICAL ALPINE TUFT-TREELETS	TMIN	0.20
3. MESIC EVERGREEN CUSHION-SHRUBS	MI	0.02
4. TROPICAL EVERGREEN FORBS	TMIN	0.0
5. MAT-FORMING THALLOPHYTES	MI	0.40
6. RAINGREEN COLD-DESERT HERBS	TMIN	0.38
7. XERIC THALLOPHYTES	MI	0.52

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
283. BOGOTA COLOMBIA	4.60	-74.08
15.0 14.0 1061. 165. 50. 150. 1.56	2660.	
1. TROPICAL LINEAR-LEAVED TREES	TMAX	0.0
2. TROPICAL MONTANE RAINFOREST TREES	TMAX	0.0
3. TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.0
4. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.0
5. TROPICAL CLOUD-FOREST DWARF-TREES	MI	0.36
6. ARBORESCENT GRASSES	TMAX	0.29
7. TALL CANE-GRAMINOIDS	TMAX	0.29
8. TALL GRASSES	TMAX	0.29
9. TROPICAL BROAD-EVERGREEN SMALL TREES	TMAX	0.0
10. SHORT SWARD-GRASSES	TMAX	0.59
11. TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.29
12. TREE FERNS	MI	0.23
13. PALMIFORM TUFT-TREELETS	TMAX	0.06
14. SHORT BUNCH-GRASSES	TMAX	0.76
15. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.29
16. PALMIFORM MESIC ROSETTE-SHRUBS	TMAX	0.0
17. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.53
18. TROPICAL EVERGREEN FORBS	MI	0.42
19. RAINGREEN FORBS	TMAX	0.29
20. EVERGREEN FERNS	TMAX	0.29
21. MAT-FORMING THALLOPHYTES	MI	0.49
22. NARROW-LEAVED EPIPHYTES	TMIN	0.36
23. BROAD-EVERGREEN VINES	TMAX	0.29
24. TROPICAL BROAD-EVERGREEN EPIPHYTES	TMAX	0.18
25. XERIC THALLOPHYTES	MI	0.29
295. LIMA PERU	-12.05	-77.05
24.0 16.0 48. 10. 0. 0. 0.06	158.	
+ 1. DESERT-GRASSES	TMAX	0.62
2. EPHEMERAL DESERT HERBS	TMAX	0.62
3. SUCCULENT FORBS	MI	0.11
4. DRY DESERT	TMAX	0.92
5. XERIC THALLOPHYTES	TMAX	0.62
297. CERRO DE PASCO PERU	-10.68	-76.27
7.0 5.0 885. 115. 22. 114. 1.69	4350.	
* 1. SHORT SWARD-GRASSES	TMAX	0.22
2. SHORT BUNCH-GRASSES	TMAX	0.56
3. TROPICAL ALPINE TUFT-TREELETS	MI	0.31
4. MESIC EVERGREEN CUSHION-SHRUBS	MI	0.23
5. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.11
6. TROPICAL EVERGREEN FORBS	TMIN	0.11
7. RAINGREEN COLD-DESERT HERBS	TMIN	0.62
8. MAT-FORMING THALLOPHYTES	MI	0.53
9. XERIC THALLOPHYTES	MI	0.18

Appendix B. Predicted vegetation at selected representative and well-known sites.

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                                                                 11
        LOCATION                                          LAT     LONG
     TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

313. MANAOS                        BRASIL                 -3.13  -60.02
     28.0  26.0 1771.  245.   34.   55.  1.04                45.
         * 1. TROPICAL RAINFOREST TREES                   MI       0.14
           2. TROPICAL XERIC NEEDLE-TREES                 TMAX     0.13
           3. TROPICAL EVERGREEN SCLEROPHYLL TREES        TMAX     0.35
           4. PALMIFORM TUFT-TREES                        MI       0.33
           5. TROPICAL EVERGREEN MICROPHYLL-TREES         TMAX     0.24
           6. TALL CANE-GRAMINOIDS                        TMAX     0.28
           7. TALL GRASSES                                TMAX     0.28
           8. TROPICAL BROAD-EVERGREEN SMALL TREES        MI       0.14
           9. TROPICAL BROAD-EVERGREEN DWARF-TREES        PMTMAX   0.10
          10. TROPICAL BROAD-EVERGREEN LIANAS             MI       0.04
          11. PALMIFORM TUFT-TREELETS                     MI       0.33
          12. TROPICAL BROAD-EVERGREEN SHRUBS             TMAX     0.18
          13. SHORT BUNCH-GRASSES                         TMAX     0.40
          14. EVERGREEN GIANT-SCRUB                       TMAX     0.33
          15. PALMIFORM MESIC ROSETTE-SHRUBS              MI       0.14
          16. BUSH STEM-SUCCULENTS                        TMAX     0.40
          17. RAINGREEN FORBS                             TMAX     0.28
          18. TROPICAL EVERGREEN FORBS                    MI       0.14
          19. BROAD-WINTERGREEN EPIPHYTES                 TMAX     0.14
          20. BROAD-EVERGREEN VINES                       MI       0.14
          21. MAT-FORMING THALLOPHYTES                    TMAX     0.07
          22. NARROW-LEAVED EPIPHYTES                     MI       0.04
          23. XERIC THALLOPHYTES                          TMAX     0.40

325. IGUATU                        BRASIL                 -6.37  -39.30
     29.0  26.0  786.  195.    3.   30.  0.45               208.
         * 1. XERIC RAINGREEN TREES                       MI       0.22
           2. BROAD-RAINGREEN SMALL TREES                 TMAX     0.30
         + 3. RAINGREEN THORN-SCRUB                       TMAX     0.44
         + 4. ARBORESCENT STEM-SUCCULENTS                 TMAX     0.39
         + 5. SHORT BUNCH-GRASSES                         TMAX     0.35
           6. XERIC EVERGREEN TUFT-TREELETS               TMAX     0.35
           7. EVERGREEN GIANT-SCRUB                       TMAX     0.25
           8. XERIC ROSETTE-SHRUBS                        TMAX     0.45
           9. BUSH STEM-SUCCULENTS                        TMAX     0.37
          10. TYPICAL STEM-SUCCULENTS                     MI       0.35
          11. RAINGREEN FORBS                             TMAX     0.24
          12. DESERT-GRASSES                              MI       0.12
          13. SUCCULENT FORBS                             TMAX     0.50
          14. BROAD-RAINGREEN VINES                       TMAX     0.30
          15. XERIC THALLOPHYTES                          TMAX     0.35

365. VALPARAISO                  CHILE                   -33.03  -71.63
     18.0  11.0  490.  150.    0.    1.  0.74                41.
         * 1. MEDITERRANEAN EVERGREEN SHRUBS              TMAX     0.14
         + 2. SHORT BUNCH-GRASSES                         MI       0.74
           3. NEEDLE-LEAVED EVERGREEN SHRUBS              TMAX     0.40
           4. XERIC EVERGREEN TUFT-TREELETS               TMAX     0.0
           5. SUMMERGREEN FORBS                           TMAX     0.40
           6. BUSH STEM-SUCCULENTS                        TMIN     0.37
           7. XERIC CUSHION-SHRUBS                        MI       0.21
           8. MEDITERRANEAN DWARF-SHRUBS                  TMAX     0.11
           9. XERIC CUSHION-HERBS                         MI       0.35
          10. SUCCULENT FORBS                             TMAX     0.0
          11. XERIC THALLOPHYTES                          MULT.    1.00
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                                                                 12
        LOCATION                                          LAT     LONG
     TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

374. BAHIA DOUGLAS                 CHILE                 -55.90  -67.70
      9.2   1.0  915.  115.   42.   65.  2.03                 5.
         * 1. SHORT SWARD-GRASSES                         TMAX     0.46
         * 2. TALL TUSSOCK-GRASSES                        TMIN     0.18
           3. SHORT BUNCH-GRASSES                         MI       0.53
           4. SUMMERGREEN TUNDRA DWARF-SHRUBS             TMAX     0.35
           5. MESIC EVERGREEN CUSHION-SHRUBS              TMIN     0.0
           6. TEMPERATE EVERGREEN DWARF-SHRUBS            TMAX     0.35
           7. TEMPERATE EVERGREEN FORBS                   TMIN     0.26
           8. MAT-FORMING THALLOPHYTES                    MI       0.67

390. BUENOS AIRES                  ARGENTIN              -34.60  -58.45
     23.0  10.0  962.  125.   52.   73.  1.37                25.
         * 1. SUMMERGREEN BROAD-LEAVED TREES              MI       0.35
         * 2. WARM-TEMPERATE BROAD-EVERGREEN TREES        TMIN     0.23
         * 3. TEMPERATE BROAD-RAINFOREST TREES            PMTMAX   0.18
         * 4. TEMPERATE NEEDLE-TREES                      TMAX     0.11
           5. MEDITERRANEAN BROAD-EVERGREEN TREES         PMTMAX   0.02
           6. SUB-MEDITERRANEAN NEEDLE-TREES              TMAX     0.36
           7. TROPICAL EVERGREEN MICROPHYLL-TREES         TMIN     0.13
           8. TROPICAL EVERGREEN SCLEROPHYLL TREES        TMIN     0.09
           9. TALL GRASSES                                TMAX     0.48
          10. TEMP. BROAD-EVERGREEN SMALL TREES           TMAX     0.45
          11. BROAD-SUMMERGREEN SMALL TREES               TMAX     0.37
          12. TALL CANE-GRAMINOIDS                        TMIN     0.31
          13. ARBORESCENT GRASSES                         TMIN     0.29
          14. TROPICAL BROAD-EVERGREEN SMALL TREES        TMIN     0.10
          15. TROPICAL BROAD-EVERGREEN LIANAS             TMIN     0.0
          16. SHORT SWARD-GRASSES                         TMAX     0.48
          17. SUMMERGREEN GIANT-SCRUB                     TMAX     0.48
          18. TEMPERATE BROAD-EVERGREEN SHRUBS            TMAX     0.47
          19. BROAD-SUMMERGREEN MESIC SHRUBS              TMAX     0.44
          20. DWARF-NEEDLE SMALL TREES                    TMAX     0.42
          21. MEDITERRANEAN EVERGREEN SHRUBS              TMIN     0.38
          22. TROPICAL BROAD-EVERGREEN SHRUBS             TMIN     0.17
          23. PALMIFORM TUFT-TREELETS                     TMIN     0.0
          24. TALL TUSSOCK-GRASSES                        TMAX     0.0
          25. SHORT BUNCH-GRASSES                         TMAX     0.68
          26. NEEDLE-LEAVED EVERGREEN SHRUBS              MI       0.46
          27. EVERGREEN GIANT-SCRUB                       TMIN     0.10
          28. PALMIFORM MESIC ROSETTE-SHRUBS              TMIN     0.09
          29. SUMMERGREEN FORBS                           TMAX     0.48
          30. TROPICAL EVERGREEN FORBS                    TMIN     0.29
          31. TEMPERATE EVERGREEN FORBS                   TMAX     0.28
          32. EVERGREEN FERNS                             MI       0.20
          33. SUMMERGREEN FERNS                           MI       0.20
          34. BUSH STEM-SUCCULENTS                        MI       0.10
          35. TEMPERATE EVERGREEN DWARF-SHRUBS            TMAX     0.06
          36. MARITIME HEATH DWARF-SHRUBS                 TMAX     0.0
          37. BROAD-WINTERGREEN EPIPHYTES                 TMIN     0.36
          38. MAT-FORMING THALLOPHYTES                    TMAX     0.28
          39. BROAD-SUMMERGREEN VINES                     MI       0.27
          40. BROAD-EVERGREEN VINES                       TMIN     0.23
          41. NARROW-LEAVED EPIPHYTES                     TMIN     0.20
          42. XERIC THALLOPHYTES                          MI       0.46
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Appendix B. Predicted vegetation at selected representative and well-known sites.

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
397. REYKJAVIK	ISLAND	64.15	-21.85
11.0 -1.0 870. 98. 49. 49. 1.87		5.	
1. BOREAL/MONTANE SHORT-NEEDLED TREES		TMAX	0.0
2. TALL GRASSES		TMAX	0.08
3. BROAD-SUMMERGREEN SMALL TREES		TMAX	0.0
4. SHORT SWARD-GRASSES		TMAX	0.46
5. TALL TUSSOCK-GRASSES		TMIN	0.0
6. SHORT BUNCH-GRASSES		MI	0.61
7. SUMMERGREEN TUNDRA DWARF-SHRUBS		TMAX	0.42
8. NEEDLE-LEAVED TREELINE KRUMMHOLZ		TMAX	0.33
9. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.08
10. TEMPERATE EVERGREEN DWARF-SHRUBS		TMAX	0.38
11. TEMPERATE EVERGREEN FORBS		TMIN	0.17
12. SUMMERGREEN FORBS		TMAX	0.08
13. MAT-FORMING THALLOPHYTES		MI	0.58
14. SEASONAL COLD-DESERT HERBS		TMAX	0.31
15. XERIC THALLOPHYTES		MI	0.07
416. VARBERG	SVERIGE	57.10	12.25
16.0 -1.0 571. 88. 28. 67. 1.02		7.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES		MI	0.42
* 2. TEMPERATE NEEDLE-TREES		TMAX	0.11
3. SUMMERGREEN BROAD-LEAVED TREES		TMAX	0.07
4. BOREAL SUMMERGREEN NEEDLE-TREES		TMAX	0.40
5. SUB-MEDITERRANEAN NEEDLE-TREES		TMIN	0.0
6. BOREAL BROAD-SUMMERGREEN TREES		MI	0.22
7. TALL GRASSES		MI	0.32
8. BROAD-SUMMERGREEN SMALL TREES		TMAX	0.28
9. SHORT SWARD-GRASSES		MI	0.52
10. SUMMERGREEN GIANT-SCRUB		TMAX	0.22
11. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.13
12. TEMPERATE BROAD-EVERGREEN SHRUBS		TMIN	0.05
13. TALL TUSSOCK-GRASSES		TMIN	0.0
14. SHORT BUNCH-GRASSES		TMIN	0.66
15. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.33
16. SUMMERGREEN TUNDRA DWARF-SHRUBS		TMAX	0.17
17. SHORT TUSSOCK-GRASSES		TMIN	0.0
18. SUMMERGREEN FORBS		TMAX	0.33
19. TEMPERATE EVERGREEN DWARF-SHRUBS		MI	0.32
20. TEMPERATE EVERGREEN FORBS		MI	0.12
21. MARITIME HEATH DWARF-SHRUBS		TMIN	0.0
22. MAT-FORMING THALLOPHYTES		MI	0.22
23. BROAD-SUMMERGREEN VINES		MI	0.02
24. XERIC THALLOPHYTES		MI	0.97

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
431. CAMBRIDGE	ENGLAND	52.22	0.13
17.0 4.0 551. 62. 34. 62. 0.88		14.	
* 1. TEMPERATE NEEDLE-TREES		TMAX	0.22
2. BOREAL BROAD-SUMMERGREEN TREES		MI	0.10
3. TALL GRASSES		MI	0.21
4. BROAD-SUMMERGREEN SMALL TREES		MI	0.21
5. TEMP. BROAD-EVERGREEN SMALL TREES		MI	0.15
+ 6. SHORT SWARD-GRASSES		MI	0.44
7. SUMMERGREEN GIANT-SCRUB		TMAX	0.26
8. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.19
9. TEMPERATE BROAD-EVERGREEN SHRUBS		TMAX	0.13
10. TALL TUSSOCK-GRASSES		MI	0.10
+11. SHORT BUNCH-GRASSES		TMIN	0.71
+12. SHORT TUSSOCK-GRASSES		TMAX	0.42
13. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.37
14. SUMMERGREEN FORBS		TMAX	0.37
15. TEMPERATE EVERGREEN DWARF-SHRUBS		MI	0.21
16. BUSH STEM-SUCCULENTS		TMIN	0.13
17. XERIC CUSHION-HERBS		MI	0.14
18. MAT-FORMING THALLOPHYTES		MI	0.10
19. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.07
20. XERIC THALLOPHYTES		MULT.	1.00
434. AMSTERDAM	NEDERLAN	52.35	4.87
18.0 3.0 648. 70. 33. 54. 1.03		2.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES		TMAX	0.36
* 2. TEMPERATE NEEDLE-TREES		TMAX	0.33
* 3. SUMMERGREEN BROAD-LEAVED TREES		MI	0.12
4. BOREAL SUMMERGREEN NEEDLE-TREES		TMAX	0.40
5. BOREAL BROAD-SUMMERGREEN TREES		MI	0.22
6. TALL GRASSES		MI	0.32
7. BROAD-SUMMERGREEN SMALL TREES		MI	0.32
8. TEMP. BROAD-EVERGREEN SMALL TREES		TMIN	0.08
9. SHORT SWARD-GRASSES		MI	0.52
10. SUMMERGREEN GIANT-SCRUB		TMAX	0.30
11. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.25
12. TALL TUSSOCK-GRASSES		MI	0.22
13. TEMPERATE BROAD-EVERGREEN SHRUBS		TMAX	0.20
14. DWARF-NEEDLE SMALL TREES		TMAX	0.0
15. SHORT BUNCH-GRASSES		TMIN	0.70
16. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.40
17. SHORT TUSSOCK-GRASSES		MI	0.25
18. SUMMERGREEN TUNDRA DWARF-SHRUBS		TMAX	0.0
19. SUMMERGREEN FORBS		TMAX	0.40
20. TEMPERATE EVERGREEN DWARF-SHRUBS		MI	0.32
21. TEMPERATE EVERGREEN FORBS		MI	0.12
22. BUSH STEM-SUCCULENTS		TMIN	0.10
23. MARITIME HEATH DWARF-SHRUBS		MI	0.03
24. MAT-FORMING THALLOPHYTES		MI	0.22
25. BROAD-WINTERGREEN EPIPHYTES		TMIN	0.11
26. BROAD-SUMMERGREEN VINES		MI	0.03
27. XERIC THALLOPHYTES		MI	0.96

15

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
439. STRASBOURG	FRANCE	48.58	7.75
18.8 1.0 696. 89. 34. 89. 1.10		141.	
* 1. TEMPERATE NEEDLE-TREES		TMIN	0.33
* 2. BOREAL/MONTANE SHORT-NEEDLED TREES		TMAX	0.29
* 3. SUMMERGREEN BROAD-LEAVED TREES		MI	0.18
4. BOREAL SUMMERGREEN NEEDLE-TREES		TMAX	0.32
5. SUB-MEDITERRANEAN NEEDLE-TREES		PMTMAX	0.12
6. BOREAL BROAD-SUMMERGREEN TREES		MI	0.27
7. BROAD-SUMMERGREEN SMALL TREES		MI	0.36
8. TALL GRASSES		MI	0.36
9. SHORT SWARD-GRASSES		MI	0.55
10. SUMMERGREEN GIANT-SCRUB		TMAX	0.33
11. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.30
12. TALL TUSSOCK-GRASSES		TMIN	0.18
13. TEMPERATE BROAD-EVERGREEN SHRUBS		TMIN	0.14
14. DWARF-NEEDLE SMALL TREES		TMAX	0.07
15. SHORT BUNCH-GRASSES		TMIN	0.68
16. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.42
17. SHORT TUSSOCK-GRASSES		MI	0.15
18. SUMMERGREEN FORBS		TMAX	0.42
19. TEMPERATE EVERGREEN DWARF-SHRUBS		TMAX	0.29
20. TEMPERATE EVERGREEN FORBS		MI	0.18
21. MARITIME HEATH DWARF-SHRUBS		MI	0.09
22. BUSH STEM-SUCCULENTS		TMIN	0.03
23. MAT-FORMING THALLOPHYTES		MI	0.27
24. BROAD-SUMMERGREEN VINES		MI	0.09
25. BROAD-WINTERGREEN EPIPHYTES		TMIN	0.04
26. XERIC THALLOPHYTES		MI	0.83
448. MARSEILLE	FRANCE	43.30	5.40
22.5 6.8 572. 98. 18. 18. 0.77		75.	
* 1. TEMPERATE NEEDLE-TREES		MI	0.16
2. TEMP. BROAD-EVERGREEN SMALL TREES		MI	0.03
+ 3. DWARF-NEEDLE SMALL TREES		TMAX	0.38
4. XERIC SUMMERGREEN SHRUBS		MI	0.30
5. MEDITERRANEAN EVERGREEN SHRUBS		TMIN	0.14
6. TROPICAL BROAD-EVERGREEN SHRUBS		TMIN	0.03
+ 7. SHORT BUNCH-GRASSES		TMAX	0.71
8. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.49
9. SUMMERGREEN FORBS		TMAX	0.51
10. MEDITERRANEAN DWARF-SHRUBS		TMIN	0.32
11. BUSH STEM-SUCCULENTS		TMIN	0.23
12. XERIC CUSHION-SHRUBS		MI	0.17
13. XERIC ROSETTE-SHRUBS		TMAX	0.13
14. LEAFLESS XEROMORPHIC LARGE-SCRUB		MI	0.04
15. XERIC CUSHION-HERBS		MI	0.30
16. BROAD-WINTERGREEN EPIPHYTES		MI	0.23
17. SUCCULENT FORBS		TMIN	0.07
18. XERIC DWARF-SHRUBS		MI	0.04
19. XERIC THALLOPHYTES		TMAX	0.71

16

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
456. PORTO	PORTUGAL	41.18	-8.60
20.0 9.0 1189. 150. 21. 21. 1.61		100.	
* 1. TEMPERATE NEEDLE-TREES		TMAX	0.44
* 2. TROPICAL LINEAR-LEAVED TREES		TMIN	0.20
3. TROPICAL MONTANE RAINFOREST TREES		TMIN	0.07
4. MONTANE BROAD-RAINGREEN TREES		PMTMAX	0.05
5. MEDITERRANEAN BROAD-EVERGREEN TREES		TMAX	0.0
6. SUB-MEDITERRANEAN NEEDLE-TREES		TMAX	0.43
7. TROPICAL EVERGREEN MICROPHYLL-TREES		TMIN	0.09
8. TROPICAL EVERGREEN SCLEROPHYLL TREES		TMIN	0.05
9. TEMP. BROAD-EVERGREEN SMALL TREES		TMAX	0.40
10. TALL CANE-GRAMINOIDS		TMIN	0.28
11. TROPICAL BROAD-EVERGREEN SMALL TREES		TMIN	0.05
12. ARBORESCENT GRASSES		PMTMAX	0.05
13. BROAD-SUMMERGREEN SMALL TREES		PMTMAX	0.05
14. BROAD-RAINGREEN SMALL TREES		TMIN	0.05
15. MEDITERRANEAN EVERGREEN SHRUBS		MI	0.25
16. DWARF-NEEDLE SMALL TREES		TMAX	0.17
17. TROPICAL BROAD-EVERGREEN SHRUBS		TMIN	0.13
18. BROAD-SUMMERGREEN MESIC SHRUBS		PMTMAX	0.05
19. SUMMERGREEN GIANT-SCRUB		PMTMAX	0.05
20. SHORT BUNCH-GRASSES		TMIN	0.77
21. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.24
22. PALMIFORM MESIC ROSETTE-SHRUBS		TMIN	0.05
23. EVERGREEN GIANT-SCRUB		TMAX	0.0
24. SUMMERGREEN FORBS		TMAX	0.45
25. RAINGREEN FORBS		TMIN	0.09
26. TEMPERATE EVERGREEN FORBS		PMTMAX	0.05
27. MARITIME HEATH DWARF-SHRUBS		PMTMAX	0.05
28. MAT-FORMING THALLOPHYTES		TMAX	0.45
29. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.29
30. XERIC THALLOPHYTES		MI	0.24
459. ZARAGOZA	ESPANA	41.63	-0.88
24.0 5.5 312. 46. 16. 16. 0.42		205.	
* 1. XERIC SUMMERGREEN SHRUBS		PMTMAX	0.38
+ 2. SHORT BUNCH-GRASSES		MI	0.54
+ 3. COLD-WINTER XEROMORPHIC SHRUBS		TMAX	0.47
4. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.05
5. SUMMERGREEN FORBS		TMAX	0.44
6. LEAFLESS XEROMORPHIC LARGE-SCRUB		TMAX	0.36
+ 7. XERIC CUSHION-SHRUBS		TMIN	0.35
8. MEDITERRANEAN DWARF-SHRUBS		TMIN	0.21
9. DESERT-GRASSES		MI	0.19
10. BUSH STEM-SUCCULENTS		TMIN	0.18
11. XERIC ROSETTE-SHRUBS		TMIN	0.09
12. XERIC DWARF-SHRUBS		TMAX	0.46
13. XERIC CUSHION-HERBS		TMAX	0.24
14. SUCCULENT FORBS		TMIN	0.02
15. XERIC THALLOPHYTES		TMAX	0.62

Appendix B. Predicted vegetation at selected representative and well-known sites.

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                                                                17
        LOCATION                                          LAT    LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                  ELEV

465. SEVILLA                       ESPANA                37.38   -5.98
      30.0  11.0  493.   74.    2.    6.   0.49             20.
              1. DWARF-NEEDLE SMALL TREES                TMAX    0.0
              2. MEDITERRANEAN EVERGREEN SHRUBS          TMAX    0.0
            + 3. SHORT BUNCH-GRASSES                     TMAX    0.31
            + 4. HOT-DESERT EVERGREEN SHRUBS             TMIN    0.21
              5. NEEDLE-LEAVED EVERGREEN SHRUBS          MI      0.18
              6. EVERGREEN GIANT-SCRUB                   TMIN    0.15
              7. XERIC EVERGREEN TUFT-TREELETS           TMIN    0.14
              8. LEAFLESS XEROMORPHIC LARGE-SCRUB        TMAX    0.40
              9. BUSH STEM-SUCCULENTS                    TMAX    0.33
             10. XERIC ROSETTE-SHRUBS                    TMIN    0.30
            +11. MEDITERRANEAN DWARF-SHRUBS              TMAX    0.26
             12. SUMMERGREEN FORBS                       TMAX    0.20
             13. TYPICAL STEM-SUCCULENTS                 TMIN    0.17
             14. XERIC CUSHION-SHRUBS                    TMAX    0.17
             15. DESERT-GRASSES                          MI      0.03
             16. XERIC DWARF-SHRUBS                      TMAX    0.36
             17. SUCCULENT FORBS                         TMIN    0.24
             18. EPHEMERAL DESERT HERBS                  MI      0.03
             19. XERIC CUSHION-HERBS                     TMAX    0.0
             20. XERIC THALLOPHYTES                      TMAX    0.31

470. PALMA, MALLORCA               ESPANA                39.57    2.65
      24.8  10.2  481.   63.    9.   22.   0.59             20.
            * 1. TROPICAL EVERGREEN SCLEROPHYLL TREES    TMIN    0.10
              2. BROAD-RAINGREEN SMALL TREES             TMIN    0.10
            + 3. XERIC SUMMERGREEN SHRUBS                TMAX    0.49
              4. MEDITERRANEAN EVERGREEN SHRUBS          MI      0.24
              5. DWARF-NEEDLE SMALL TREES                MI      0.24
              6. SUMMERGREEN GIANT-SCRUB                 PMTMAX  0.11
              7. RAINGREEN THORN-SCRUB                   TMIN    0.10
            + 8. SHORT BUNCH-GRASSES                     TMAX    0.57
              9. NEEDLE-LEAVED EVERGREEN SHRUBS          MI      0.33
             10. HOT-DESERT EVERGREEN SHRUBS             TMAX    0.16
             11. EVERGREEN GIANT-SCRUB                   TMIN    0.11
             12. XERIC EVERGREEN TUFT-TREELETS           TMIN    0.10
             13. ARBORESCENT STEM-SUCCULENTS             TMIN    0.10
            +14. MEDITERRANEAN DWARF-SHRUBS              TMAX    0.46
             15. SUMMERGREEN FORBS                       TMAX    0.41
             16. XERIC CUSHION-SHRUBS                    TMAX    0.38
             17. LEAFLESS XEROMORPHIC LARGE-SCRUB        MI      0.36
             18. BUSH STEM-SUCCULENTS                    TMIN    0.34
             19. XERIC ROSETTE-SHRUBS                    TMAX    0.24
             20. RAINGREEN FORBS                         TMIN    0.14
             21. TYPICAL STEM-SUCCULENTS                 MI      0.02
             22. SCLEROPHYLLOUS GRASSES                  TMIN    0.01
             23. XERIC DWARF-SHRUBS                      MI      0.36
             24. XERIC CUSHION-HERBS                     TMAX    0.21
             25. SUCCULENT FORBS                         TMIN    0.21
             26. BROAD-RAINGREEN VINES                   TMIN    0.01
             27. XERIC THALLOPHYTES                      TMAX    0.57
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                                                                18
        LOCATION                                          LAT    LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                  ELEV

478. NAPOLI                        ITALIA                40.85   14.28
      24.0   8.2  875.  120.   16.   41.   1.08            149.
            * 1. MEDITERRANEAN BROAD-EVERGREEN TREES     MI      0.26
            * 2. SUMMERGREEN BROAD-LEAVED TREES          MI      0.17
              3. MONTANE BROAD-RAINGREEN TREES           TMIN    0.01
              4. TROPICAL XERIC NEEDLE-TREES             TMIN    0.01
              5. TEMPERATE NEEDLE-TREES                  TMAX    0.0
              6. SUB-MEDITERRANEAN NEEDLE-TREES          MI      0.22
              7. TROPICAL EVERGREEN MICROPHYLL-TREES     TMIN    0.05
              8. TROPICAL EVERGREEN SCLEROPHYLL TREES    TMIN    0.01
              9. BROAD-SUMMERGREEN SMALL TREES           TMAX    0.32
             10. TEMP. BROAD-EVERGREEN SMALL TREES       MI      0.31
             11. TALL GRASSES                            PMTMAX  0.26
             12. TALL CANE-GRAMINOIDS                    TMIN    0.25
             13. ARBORESCENT GRASSES                     TMIN    0.20
             14. TROPICAL BROAD-EVERGREEN SMALL TREES    TMIN    0.01
             15. BROAD-RAINGREEN SMALL TREES             TMIN    0.01
             16. DWARF-NEEDLE SMALL TREES                TMAX    0.50
             17. SUMMERGREEN GIANT-SCRUB                 TMAX    0.48
             18. SHORT SWARD-GRASSES                     PMTMAX  0.39
             19. BROAD-SUMMERGREEN MESIC SHRUBS          MI      0.36
             20. TEMPERATE BROAD-EVERGREEN SHRUBS        PMTMAX  0.26
             21. MEDITERRANEAN EVERGREEN SHRUBS          TMIN    0.25
             22. TROPICAL BROAD-EVERGREEN SHRUBS         TMIN    0.09
             23. SHORT BUNCH-GRASSES                     TMAX    0.62
             24. NEEDLE-LEAVED EVERGREEN SHRUBS          TMAX    0.44
             25. SHORT TUSSOCK-GRASSES                   TMAX    0.04
             26. EVERGREEN GIANT-SCRUB                   TMIN    0.01
             27. PALMIFORM MESIC ROSETTE-SHRUBS          TMIN    0.01
             28. SUMMERGREEN FORBS                       TMAX    0.44
             29. BUSH STEM-SUCCULENTS                    TMIN    0.27
             30. TEMPERATE EVERGREEN FORBS               MI      0.17
             31. MEDITERRANEAN DWARF-SHRUBS              MI      0.11
             32. XERIC ROSETTE-SHRUBS                    MI      0.11
             33. RAINGREEN FORBS                         TMIN    0.05
             34. TEMPERATE EVERGREEN DWARF-SHRUBS        TMAX    0.0
             35. BROAD-WINTERGREEN EPIPHYTES             TMIN    0.29
             36. MAT-FORMING THALLOPHYTES                TMAX    0.23
             37. BROAD-EVERGREEN VINES                   TMIN    0.16
             38. SUCCULENT FORBS                         MI      0.11
             39. NARROW-LEAVED EPIPHYTES                 MI      0.08
             40. BROAD-SUMMERGREEN VINES                 PMTMAX  0.02
             41. XERIC THALLOPHYTES                      TMAX    0.62

482. SAN BERNARDINO, TICINO        SCHWEIZ               46.47    9.20
       8.0  -7.0 2595.  290.   92.  254.   6.87           2073.
            * 1. SHORT SWARD-GRASSES                     TMAX    0.38
              2. SUMMERGREEN TUNDRA DWARF-SHRUBS         TMAX    0.25
              3. TEMPERATE EVERGREEN DWARF-SHRUBS        TMAX    0.25
              4. MAT-FORMING THALLOPHYTES                MI      0.90
              5. SEASONAL COLD-DESERT HERBS              TMAX    0.88
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LOCATION							LAT	LONG
TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	ELEV	
484. ZUERICH			SCHWEIZ				47.48	8.53
17.0	-2.0	1105.	140.	52.	140.	1.94	569.	

*	1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.45
*	2. TEMPERATE NEEDLE-TREES	TMIN	0.19
*	3. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.13
	4. BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.33
	5. TALL GRASSES	TMAX	0.37
	6. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.32
	7. SHORT SWARD-GRASSES	TMAX	0.63
	8. BROAD-ERICOID EVERGREEN SHRUBS	MI	0.28
	9. SUMMERGREEN GIANT-SCRUB	TMAX	0.26
	10. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.19
	11. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.0
	12. SHORT BUNCH-GRASSES	MI	0.55
	13. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.08
	14. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.04
	15. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.39
	16. SUMMERGREEN FORBS	TMAX	0.37
	17. SUMMERGREEN FERNS	TMAX	0.37
	18. TEMPERATE EVERGREEN FORBS	TMIN	0.13
	19. MAT-FORMING THALLOPHYTES	MI	0.59
	20. BROAD-SUMMERGREEN VINES	TMAX	0.13
	21. XERIC THALLOPHYTES	MI	0.03

LOCATION							LAT	LONG
488. OBERGURGL			OESTERRE				47.00	10.76
10.8	-4.0	831.	105.	49.	91.	1.97	1927.	

	1. TALL GRASSES	TMAX	0.06
	2. SHORT SWARD-GRASSES	TMAX	0.45
	3. SHORT BUNCH-GRASSES	MI	0.53
	4. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.40
	5. NEEDLE-LEAVED TREELINE KRUMMHOLZ	TMAX	0.27
	6. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.02
	7. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.37
	8. SUMMERGREEN FERNS	TMAX	0.06
	9. SUMMERGREEN FORBS	TMAX	0.06
	10. TEMPERATE EVERGREEN FORBS	TMIN	0.04
	11. MAT-FORMING THALLOPHYTES	MI	0.60
	12. SEASONAL COLD-DESERT HERBS	TMAX	0.33
	13. XERIC THALLOPHYTES	MI	0.02

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LOCATION							LAT	LONG
TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	ELEV	
490. WIEN (HOHE WARTE)			OESTERRE				48.22	16.33
19.5	-1.0	685.	85.	40.	85.	1.10	203.	

*	1. TEMPERATE NEEDLE-TREES	TMIN	0.24
*	2. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.23
*	3. SUMMERGREEN BROAD-LEAVED TREES	MI	0.18
	4. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.25
	5. SUB-MEDITERRANEAN NEEDLE-TREES	TMIN	0.0
	6. BOREAL BROAD-SUMMERGREEN TREES	MI	0.27
	7. BROAD-SUMMERGREEN SMALL TREES	MI	0.37
	8. TALL GRASSES	MI	0.37
	9. SHORT SWARD-GRASSES	MI	0.55
	10. SUMMERGREEN GIANT-SCRUB	TMAX	0.35
	11. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.34
	12. DWARF-NEEDLE SMALL TREES	TMAX	0.13
	13. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.05
	14. SHORT BUNCH-GRASSES	TMIN	0.66
	15. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.44
	16. SUMMERGREEN FORBS	TMAX	0.44
	17. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.25
	18. TEMPERATE EVERGREEN FORBS	TMIN	0.17
	19. MAT-FORMING THALLOPHYTES	MI	0.27
	20. BROAD-SUMMERGREEN VINES	MI	0.09
	21. XERIC THALLOPHYTES	MI	0.83

LOCATION							LAT	LONG
496. KOELN			DEUTSCHL				50.93	6.98
18.0	2.5	660.	78.	41.	78.	1.03	56.	

*	1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.36
*	2. TEMPERATE NEEDLE-TREES	TMAX	0.33
*	3. SUMMERGREEN BROAD-LEAVED TREES	MI	0.13
	4. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.40
	5. SUB-MEDITERRANEAN NEEDLE-TREES	MI	0.18
	6. BOREAL BROAD-SUMMERGREEN TREES	MI	0.23
	7. TALL GRASSES	MI	0.33
	8. BROAD-SUMMERGREEN SMALL TREES	MI	0.33
	9. TEMP. BROAD-EVERGREEN SMALL TREES	TMIN	0.04
	10. SHORT SWARD-GRASSES	MI	0.52
	11. SUMMERGREEN GIANT-SCRUB	TMAX	0.30
	12. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
	13. TALL TUSSOCK-GRASSES	MI	0.23
	14. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.20
	15. DWARF-NEEDLE SMALL TREES	TMAX	0.0
	16. SHORT BUNCH-GRASSES	TMIN	0.69
	17. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.40
	18. SHORT TUSSOCK-GRASSES	MI	0.24
	19. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.0
	20. SUMMERGREEN FORBS	TMAX	0.40
	21. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.33
	22. TEMPERATE EVERGREEN FORBS	MI	0.13
	23. BUSH STEM-SUCCULENTS	TMIN	0.08
	24. MARITIME HEATH DWARF-SHRUBS	MI	0.03
	25. MAT-FORMING THALLOPHYTES	MI	0.23
	26. BROAD-WINTERGREEN EPIPHYTES	TMIN	0.09
	27. BROAD-SUMMERGREEN VINES	MI	0.03
	28. XERIC THALLOPHYTES	MI	0.94

Appendix B. Predicted vegetation at selected representative and well-known sites.

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LOCATION / TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT / ELEV	LONG
504. BERLIN	DDR	52.45	13.43
17.5 -0.5 527. 65. 30. 65. 0.87		42.	
* 1.	BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.32
* 2.	TEMPERATE NEEDLE-TREES	MI	0.26
+ 3.	BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.45
4.	BOREAL BROAD-SUMMERGREEN TREES	MI	0.09
5.	BROAD-SUMMERGREEN SMALL TREES	MI	0.20
6.	TALL GRASSES	MI	0.20
+ 7.	SHORT SWARD-GRASSES	MI	0.43
8.	SUMMERGREEN GIANT-SCRUB	TMAX	0.28
9.	BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.20
10.	XERIC SUMMERGREEN SHRUBS	MI	0.17
11.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.07
12.	TALL TUSSOCK-GRASSES	TMIN	0.05
+13.	SHORT BUNCH-GRASSES	TMIN	0.66
14.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.38
15.	SHORT TUSSOCK-GRASSES	TMIN	0.05
16.	SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.04
17.	SUMMERGREEN FORBS	TMAX	0.38
18.	TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.20
19.	XERIC CUSHION-SHRUBS	MI	0.03
20.	XERIC CUSHION-HERBS	MI	0.16
21.	MAT-FORMING THALLOPHYTES	MI	0.09
22.	XERIC THALLOPHYTES	MULT.	1.00
506. WARSZAWA	POLSKA	52.25	21.00
18.0 -3.0 545. 79. 30. 79. 0.94		121.	
* 1.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.36
* 2.	TEMPERATE NEEDLE-TREES	TMIN	0.14
3.	SUMMERGREEN BROAD-LEAVED TREES	MI	0.04
+ 4.	BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.40
5.	BOREAL BROAD-SUMMERGREEN TREES	MI	0.15
6.	TALL GRASSES	MI	0.26
7.	BROAD-SUMMERGREEN SMALL TREES	MI	0.26
+ 8.	SHORT SWARD-GRASSES	MI	0.47
9.	SUMMERGREEN GIANT-SCRUB	TMAX	0.30
10.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
11.	XERIC SUMMERGREEN SHRUBS	MI	0.08
12.	DWARF-NEEDLE SMALL TREES	TMAX	0.0
+13.	SHORT BUNCH-GRASSES	TMIN	0.63
14.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.40
15.	SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.0
16.	SUMMERGREEN FORBS	TMAX	0.40
17.	TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.26
18.	TEMPERATE EVERGREEN FORBS	MI	0.04
19.	MAT-FORMING THALLOPHYTES	MI	0.15
20.	XERIC CUSHION-HERBS	MI	0.07
21.	XERIC THALLOPHYTES	MULT.	1.00

22

LOCATION / TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT / ELEV	LONG
509. DEBRECEN-PALLAG	MAGYAROR	47.53	21.63
20.8 -2.0 583. 70. 32. 58. 0.90		135.	
* 1.	TEMPERATE NEEDLE-TREES	TMIN	0.19
* 2.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.11
3.	SUMMERGREEN BROAD-LEAVED TREES	MI	0.00
4.	BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.12
5.	BOREAL BROAD-SUMMERGREEN TREES	MI	0.11
6.	BROAD-SUMMERGREEN SMALL TREES	MI	0.22
7.	TALL GRASSES	MI	0.22
+ 8.	SHORT SWARD-GRASSES	MI	0.45
9.	SUMMERGREEN GIANT-SCRUB	TMAX	0.39
10.	BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.22
11.	DWARF-NEEDLE SMALL TREES	TMIN	0.13
12.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.0
+13.	SHORT BUNCH-GRASSES	TMIN	0.64
14.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.47
15.	SUMMERGREEN FORBS	TMAX	0.47
16.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.18
17.	TEMPERATE EVERGREEN FORBS	MI	0.00
18.	XERIC CUSHION-HERBS	MI	0.12
19.	MAT-FORMING THALLOPHYTES	MI	0.11
20.	XERIC THALLOPHYTES	TMAX	0.84
510. LJUBLJANA	JUGOSLAV	46.07	14.48
19.4 -1.8 1415. 155. 71. 134. 2.29		306.	
* 1.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.29
* 2.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.24
* 3.	TEMPERATE NEEDLE-TREES	TMIN	0.20
4.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.47
5.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.44
6.	TALL GRASSES	TMIN	0.38
7.	SHORT SWARD-GRASSES	TMIN	0.64
8.	BROAD-ERICOID EVERGREEN SHRUBS	TMIN	0.41
9.	SUMMERGREEN GIANT-SCRUB	TMAX	0.38
10.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.34
11.	DWARF-NEEDLE SMALL TREES	TMAX	0.12
12.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.01
13.	SHORT BUNCH-GRASSES	MI	0.34
14.	SUMMERGREEN FERNS	TMAX	0.48
15.	SUMMERGREEN FORBS	TMAX	0.48
16.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.26
17.	TEMPERATE EVERGREEN FORBS	TMIN	0.14
18.	MAT-FORMING THALLOPHYTES	TMAX	0.55
19.	BROAD-SUMMERGREEN VINES	TMIN	0.19

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                                                         23
      LOCATION                                   LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI          ELEV

516. IRAKLION, KRITI           HELLAS            35.33   25.15
   26.0  11.8  533.   98.   1.    1.  0.59         27.
          * 1. MEDITERRANEAN EVERGREEN SHRUBS    MI      0.25
          + 2. SHORT BUNCH-GRASSES               TMAX    0.50
            3. NEEDLE-LEAVED EVERGREEN SHRUBS    MI      0.33
            4. HOT-DESERT EVERGREEN SHRUBS       TMAX    0.22
            5. EVERGREEN GIANT-SCRUB             TMIN    0.19
            6. XERIC EVERGREEN TUFT-TREELETS     TMIN    0.17
          + 7. MEDITERRANEAN DWARF-SHRUBS        TMAX    0.47
            8. BUSH STEM-SUCCULENTS              TMIN    0.39
            9. SUMMERGREEN FORBS                 TMAX    0.36
           10. LEAFLESS XEROMORPHIC LARGE-SCRUB  MI      0.35
          +11. XERIC CUSHION-SHRUBS              TMAX    0.32
           12. TYPICAL STEM-SUCCULENTS           MI      0.01
           13. XERIC DWARF-SHRUBS                MI      0.35
           14. SUCCULENT FORBS                   TMIN    0.27
           15. XERIC CUSHION-HERBS               TMAX    0.16
           16. XERIC THALLOPHYTES                TMAX    0.50

524. SOFIJA                    BALGARIJ          42.68   23.32
   20.0  -1.0  630.   83.   28.   57.  1.02        550.
          * 1. TEMPERATE NEEDLE-TREES            TMIN    0.24
          * 2. BOREAL/MONTANE SHORT-NEEDLED TREES TMAX   0.18
          * 3. SUMMERGREEN BROAD-LEAVED TREES    MI      0.12
            4. BOREAL SUMMERGREEN NEEDLE-TREES   TMAX    0.20
            5. SUB-MEDITERRANEAN NEEDLE-TREES    TMIN    0.0
            6. BOREAL BROAD-SUMMERGREEN TREES    MI      0.22
            7. BROAD-SUMMERGREEN SMALL TREES     MI      0.32
            8. TALL GRASSES                      MI      0.32
            9. SHORT SWARD-GRASSES               MI      0.52
           10. SUMMERGREEN GIANT-SCRUB           TMAX    0.36
           11. BROAD-SUMMERGREEN MESIC SHRUBS    MI      0.32
           12. DWARF-NEEDLE SMALL TREES          TMAX    0.17
           13. TEMPERATE BROAD-EVERGREEN SHRUBS  TMIN    0.05
           14. SHORT BUNCH-GRASSES               TMIN    0.66
           15. NEEDLE-LEAVED EVERGREEN SHRUBS    TMAX    0.45
           16. SUMMERGREEN FORBS                 TMAX    0.45
           17. TEMPERATE EVERGREEN DWARF-SHRUBS  TMAX    0.22
           18. TEMPERATE EVERGREEN FORBS         MI      0.12
           19. MAT-FORMING THALLOPHYTES          MI      0.22
           20. BROAD-SUMMERGREEN VINES           MI      0.02
           21. XERIC THALLOPHYTES                TMAX    0.91

530. IZANA,TENERIFA            ISLAS CA          28.31  -16.40
   17.0   3.5  369.   75.   2.    2.  0.64        2367.
          * 1. SHORT BUNCH-GRASSES               MI      0.70
          * 2. NEEDLE-LEAVED EVERGREEN SHRUBS    TMAX    0.37
          * 3. COLD-WINTER XEROMORPHIC SHRUBS    TMAX    0.12
            4. SUMMERGREEN FORBS                 TMAX    0.37
            5. XERIC CUSHION-SHRUBS              TMIN    0.28
            6. BUSH STEM-SUCCULENTS              TMIN    0.12
            7. LEAFLESS XEROMORPHIC LARGE-SCRUB  TMAX    0.11
            8. MEDITERRANEAN DWARF-SHRUBS        TMIN    0.04
            9. XERIC CUSHION-HERBS               MI      0.56
           10. XERIC DWARF-SHRUBS                MI      0.25
           11. XERIC THALLOPHYTES                MULT.   1.00
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                                                         24
      LOCATION                                   LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI          ELEV

544. DAR-EL-BEIDA (CASABLANCA  AL-MAGHR          33.65   -7.58
   23.0  12.0  406.   77.   0.    2.  0.51         55.
          * 1. MEDITERRANEAN EVERGREEN SHRUBS    MI      0.11
          + 2. SHORT BUNCH-GRASSES               MI      0.62
            3. NEEDLE-LEAVED EVERGREEN SHRUBS    MI      0.21
            4. EVERGREEN GIANT-SCRUB             TMIN    0.20
            5. XERIC EVERGREEN TUFT-TREELETS     TMIN    0.18
            6. HOT-DESERT EVERGREEN SHRUBS       TMAX    0.06
            7. SUMMERGREEN FORBS                 TMAX    0.48
          + 8. XERIC CUSHION-SHRUBS              TMAX    0.48
            9. BUSH STEM-SUCCULENTS              TMIN    0.40
          +10. MEDITERRANEAN DWARF-SHRUBS        TMAX    0.37
           11. LEAFLESS XEROMORPHIC LARGE-SCRUB  TMAX    0.32
           12. TYPICAL STEM-SUCCULENTS           TMAX    0.15
           13. XERIC ROSETTE-SHRUBS              PMTMAX  0.05
           14. LEAF-SUCCULENT EVERGREEN SHRUBS   TMIN    0.0
           15. XERIC DWARF-SHRUBS                TMAX    0.44
           16. XERIC CUSHION-HERBS               TMAX    0.28
           17. SUCCULENT FORBS                   TMAX    0.23
           18. XERIC THALLOPHYTES                TMAX    0.68

563. TAMANRASSET               ALGERIE           22.93    5.50
   29.0  12.5   45.   14.   0.    2.  0.04        1463.
          + 1. DESERT-GRASSES                    TMAX    0.35
            2. EPHEMERAL DESERT HERBS            TMAX    0.35
            3. DRY DESERT                        TMAX    0.94
            4. XERIC THALLOPHYTES                TMAX    0.35

571. AWJILAH                   LIBIYA            29.15   21.25
   29.0  13.0   13.    6.   0.    0.  0.01         30.
            1. DRY DESERT                        TMAX    0.94
            2. XERIC THALLOPHYTES                MI      0.10

600. TOMBOUKTOU                MALI              16.77   -3.02
   34.0  22.0  285.   98.   0.   15.  0.16         250.
            1. RAINGREEN THORN-SCRUB             TMAX    0.24
          + 2. HOT-DESERT EVERGREEN SHRUBS       TMAX    0.33
          + 3. ARBORESCENT STEM-SUCCULENTS       TMAX    0.33
            4. XERIC ROSETTE-SHRUBS              TMAX    0.30
            5. TYPICAL STEM-SUCCULENTS           TMAX    0.30
          + 6. SCLEROPHYLLOUS GRASSES            TMAX    0.30
            7. LEAFLESS XEROMORPHIC LARGE-SCRUB  MULT.   0.24
            8. BUSH STEM-SUCCULENTS              TMAX    0.20
            9. DESERT-GRASSES                    TMAX    0.17
           10. XERIC CUSHION-SHRUBS              TMAX    0.03
           11. SUCCULENT FORBS                   TMAX    0.27
           12. XERIC DWARF-SHRUBS                TMAX    0.21
           13. EPHEMERAL DESERT HERBS            TMAX    0.17
           14. XERIC THALLOPHYTES                TMAX    0.17
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                                                              25
       LOCATION                                      LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI              ELEV

618. JOS                         NIGERIA             9.92    8.88
    26.0  21.0 1444.  300.    1.  103.  1.31          1047.
       * 1. MONSOON BROAD-RAINGREEN TREES            TMAX    0.25
         2. TROPICAL EVERGREEN SCLEROPHYLL TREES     TMAX    0.45
         3. PALMIFORM TUFT-TREES                     TMAX    0.42
         4. TROPICAL EVERGREEN MICROPHYLL-TREES      MULT.   0.35
         5. BROAD-RAINGREEN SMALL TREES              TMAX    0.45
         6. TROPICAL BROAD-EVERGREEN DWARF-TREES     TMAX    0.40
         7. TALL CANE-GRAMINOIDS                     TMAX    0.36
         8. PALMIFORM TUFT-TREELETS                  TMAX    0.43
         9. TROPICAL BROAD-EVERGREEN SHRUBS          TMAX    0.27
        10. EVERGREEN GIANT-SCRUB                    TMAX    0.50
        11. SHORT BUNCH-GRASSES                      TMAX    0.50
        12. RAINGREEN FORBS                          TMAX    0.36
        13. BUSH STEM-SUCCULENTS                     MI      0.14
        14. BROAD-RAINGREEN VINES                    TMAX    0.45
        15. BROAD-WINTERGREEN EPIPHYTES              TMAX    0.29
        16. BROAD-EVERGREEN VINES                    TMAX    0.27
        17. MAT-FORMING THALLOPHYTES                 TMAX    0.14
        18. XERIC THALLOPHYTES                       TMAX    0.50

637. WADI HALFA                  AS-SUDAN           21.93   31.33
    31.5  15.0    5.    2.    0.    2.  0.00           155.
         1. DRY DESERT                               MULT.   1.00

641. ADDIS-ABEBA                 YAITOPYA            9.00   38.33
    17.5  14.8 1302.  300.    6.   90.  1.80          2440.
       * 1. TROPICAL MONTANE RAINFOREST TREES        TMAX    0.28
       * 2. MONTANE BROAD-RAINGREEN TREES            TMAX    0.25
       * 3. TROPICAL LINEAR-LEAVED TREES             TMAX    0.19
         4. TROPICAL EVERGREEN MICROPHYLL-TREES      TMAX    0.15
         5. TROPICAL EVERGREEN SCLEROPHYLL TREES     TMAX    0.13
         6. PALMIFORM TUFT-TREES                     TMAX    0.08
         7. TROPICAL CLOUD-FOREST DWARF-TREES        TMAX    0.25
         8. TALL CANE-GRAMINOIDS                     TMAX    0.38
         9. TALL GRASSES                             TMAX    0.38
        10. ARBORESCENT GRASSES                      TMAX    0.38
        11. TROPICAL BROAD-EVERGREEN SMALL TREES     TMAX    0.15
        12. BROAD-RAINGREEN SMALL TREES              TMAX    0.13
        13. SHORT SWARD-GRASSES                      TMAX    0.64
        14. TROPICAL BROAD-EVERGREEN SHRUBS          TMIN    0.37
        15. PALMIFORM TUFT-TREELETS                  TMAX    0.18
        16. SHORT BUNCH-GRASSES                      MI      0.67
        17. PALMIFORM MESIC ROSETTE-SHRUBS           TMAX    0.13
        18. NEEDLE-LEAVED EVERGREEN SHRUBS           MI      0.12
        19. TROPICAL EVERGREEN FORBS                 TMIN    0.46
        20. TEMPERATE EVERGREEN DWARF-SHRUBS         TMAX    0.36
        21. RAINGREEN FORBS                          TMIN    0.34
        22. MAT-FORMING THALLOPHYTES                 MI      0.56
        23. BROAD-EVERGREEN VINES                    TMAX    0.38
        24. BROAD-RAINGREEN VINES                    TMAX    0.13
        25. BROAD-WINTERGREEN EPIPHYTES              TMAX    0.11
        26. XERIC THALLOPHYTES                       MI      0.11
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                                                              26
       LOCATION                                      LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI              ELEV

657. SUQUTRA                     SUQUTRA            12.50   54.00
    30.8  25.0  171.   91.    0.    1.  0.11            10.
       + 1. HOT-DESERT EVERGREEN SHRUBS              MI      0.27
         2. TYPICAL STEM-SUCCULENTS                  TMAX    0.46
         3. LEAFLESS XEROMORPHIC LARGE-SCRUB         TMAX    0.37
         4. BUSH STEM-SUCCULENTS                     TMAX    0.31
       + 5. DESERT-GRASSES                           TMAX    0.28
         6. XERIC CUSHION-SHRUBS                     MI      0.06
         7. SUCCULENT FORBS                          TMAX    0.42
         8. XERIC DWARF-SHRUBS                       TMAX    0.33
         9. EPHEMERAL DESERT HERBS                   TMAX    0.28
        10. XERIC THALLOPHYTES                       TMAX    0.28

658. LAMU                        KENYA              -2.27   40.90
    27.0  24.0  929.  350.    3.  128.  0.61             9.
       * 1. TROPICAL EVERGREEN SCLEROPHYLL TREES     MI      0.19
         2. XERIC RAINGREEN TREES                    TMAX    0.19
         3. BROAD-RAINGREEN SMALL TREES              TMAX    0.40
       + 4. RAINGREEN THORN-SCRUB                    TMAX    0.48
         5. SHORT SWARD-GRASSES                      MI      0.19
       + 6. SHORT BUNCH-GRASSES                      TMAX    0.45
       + 7. EVERGREEN GIANT-SCRUB                    TMAX    0.42
         8. RAINGREEN FORBS                          TMAX    0.32
         9. BROAD-RAINGREEN VINES                    TMAX    0.40
        10. BROAD-WINTERGREEN EPIPHYTES              MI      0.02
        11. XERIC THALLOPHYTES                       TMAX    0.45

671. LULUABOURG                  ZAIRE              -5.90   22.42
    25.0  24.0 1411.  280.    6.   69.  1.12           660.
       * 1. TROPICAL RAINFOREST TREES                MI      0.20
         2. MONSOON BROAD-RAINGREEN TREES            TMAX    0.17
         3. TROPICAL LINEAR-LEAVED TREES             MI      0.11
         4. TROPICAL EVERGREEN SCLEROPHYLL TREES     TMAX    0.50
         5. PALMIFORM TUFT-TREES                     TMAX    0.38
         6. TROPICAL EVERGREEN MICROPHYLL-TREES      MI      0.34
         7. BROAD-RAINGREEN SMALL TREES              TMAX    0.50
         8. TALL CANE-GRAMINOIDS                     MI      0.38
         9. TALL GRASSES                             MI      0.38
        10. TROPICAL BROAD-EVERGREEN DWARF-TREES     PMTMAX  0.27
        11. ARBORESCENT GRASSES                      TMAX    0.25
        12. TROPICAL BROAD-EVERGREEN SMALL TREES     MI      0.20
        13. TROPICAL BROAD-EVERGREEN LIANAS          MI      0.11
        14. PALMIFORM TUFT-TREELETS                  MI      0.38
        15. SHORT SWARD-GRASSES                      TMAX    0.37
        16. TROPICAL BROAD-EVERGREEN SHRUBS          TMAX    0.32
        17. SHORT BUNCH-GRASSES                      TMAX    0.56
        18. EVERGREEN GIANT-SCRUB                    TMAX    0.42
        19. PALMIFORM MESIC ROSETTE-SHRUBS           MI      0.20
        20. RAINGREEN FORBS                          TMAX    0.40
        21. BUSH STEM-SUCCULENTS                     MI      0.34
        22. TROPICAL EVERGREEN FORBS                 MI      0.20
        23. BROAD-RAINGREEN VINES                    TMAX    0.50
        24. BROAD-WINTERGREEN EPIPHYTES              TMAX    0.36
        25. BROAD-EVERGREEN VINES                    MI      0.20
        26. MAT-FORMING THALLOPHYTES                 TMAX    0.19
        27. XERIC THALLOPHYTES                       TMAX    0.56
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Appendix B. Predicted vegetation at selected representative and well-known sites.

27

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
700. LOURENCO MARQUES MOCAMBIQ	-25.97	32.58
26.0 18.0 716. 135. 12. 110. 0.68	59.	
* 1. TROPICAL EVERGREEN SCLEROPHYLL TREES	MI	0.27
2. XERIC RAINGREEN TREES	TMAX	0.13
3. BROAD-RAINGREEN SMALL TREES	TMAX	0.45
4. RAINGREEN THORN-SCRUB	TMAX	0.44
5. SHORT SWARD-GRASSES	MULT.	0.27
6. MEDITERRANEAN EVERGREEN SHRUBS	PMTMAX	0.14
7. TEMPERATE BROAD-EVERGREEN SHRUBS	MI	0.12
+ 8. EVERGREEN GIANT-SCRUB	TMAX	0.50
+ 9. SHORT BUNCH-GRASSES	TMAX	0.50
+10. XERIC EVERGREEN TUFT-TREELETS	TMIN	0.45
11. ARBORESCENT STEM-SUCCULENTS	MI	0.17
12. HOT-DESERT EVERGREEN SHRUBS	MI	0.10
13. BUSH STEM-SUCCULENTS	TMAX	0.50
14. RAINGREEN FORBS	TMAX	0.36
15. XERIC CUSHION-SHRUBS	MI	0.32
16. XERIC ROSETTE-SHRUBS	TMAX	0.30
17. LEAF-SUCCULENT EVERGREEN SHRUBS	MI	0.18
18. BROAD-RAINGREEN VINES	TMIN	0.40
19. SUCCULENT FORBS	TMAX	0.36
20. XERIC CUSHION-HERBS	TMAX	0.16
21. BROAD-WINTERGREEN EPIPHYTES	MI	0.12
22. XERIC THALLOPHYTES	TMAX	0.50
718. TABLE MOUNTAIN,CAPE PROV SOUTH AF	-33.95	18.42
17.0 9.5 1780. 280. 55. 55. 2.84	761.	
* 1. TEMPERATE RAINFOREST NEEDLE-TREES	TMAX	0.38
* 2. TROPICAL LINEAR-LEAVED TREES	TMAX	0.15
* 3. TROPICAL MONTANE RAINFOREST TREES	TMIN	0.10
4. TEMPERATE NEEDLE-TREES	MI	0.07
5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.11
6. SUB-MEDITERRANEAN NEEDLE-TREES	MI	0.08
7. TALL GRASSES	TMAX	0.41
8. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.29
9. ARBORESCENT GRASSES	TMIN	0.26
10. TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.07
11. TALL CANE-GRAMINOIDS	MI	0.07
12. SHORT SWARD-GRASSES	PMTMAX	0.55
13. TALL TUSSOCK-GRASSES	TMAX	0.35
14. BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.33
15. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.15
16. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.13
17. PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.07
18. MESIC EVERGREEN CUSHION-SHRUBS	TMAX	0.07
19. SHORT BUNCH-GRASSES	MI	0.06
20. TEMPERATE EVERGREEN FORBS	TMIN	0.63
21. MARITIME HEATH DWARF-SHRUBS	TMAX	0.45
22. SUMMERGREEN FORBS	TMAX	0.41
23. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.41
24. TROPICAL EVERGREEN FORBS	TMIN	0.27
25. EVERGREEN FERNS	PMTMAX	0.09
26. MAT-FORMING THALLOPHYTES	TMAX	0.76
27. BROAD-EVERGREEN VINES	TMIN	0.21
28. NARROW-LEAVED EPIPHYTES	TMIN	0.18
29. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.07

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
746. KERGUELEN KERGUELE	-49.25	69.17
6.8 1.0 925. 150. 40. 82. 2.10	16.	
* 1. SHORT SWARD-GRASSES	TMAX	0.26
* 2. TALL TUSSOCK-GRASSES	TMIN	0.18
3. SHORT BUNCH-GRASSES	MI	0.47
4. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.12
5. MESIC EVERGREEN CUSHION-SHRUBS	TMIN	0.0
6. TEMPERATE EVERGREEN FORBS	TMIN	0.26
7. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.12
8. MAT-FORMING THALLOPHYTES	MI	0.68
759. JEVPATORIJA,UKRAINA SSSR	45.20	33.37
25.0 0.0 349. 36. 24. 26. 0.51	6.	
* 1. XERIC SUMMERGREEN SHRUBS	TMAX	0.48
* 2. DWARF-NEEDLE SMALL TREES	MULT.	0.12
+ 3. SHORT BUNCH-GRASSES	TMAX	0.56
+ 4. COLD-WINTER XEROMORPHIC SHRUBS	TMAX	0.41
5. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.40
6. SUMMERGREEN FORBS	TMAX	0.40
7. BUSH STEM-SUCCULENTS	TMIN	0.0
8. XERIC DWARF-SHRUBS	TMIN	0.40
9. XERIC CUSHION-HERBS	TMAX	0.20
10. XERIC THALLOPHYTES	TMAX	0.56
761. LENINGRAD,ROSSIJA SSSR	59.92	30.25
17.0 -8.0 470. 65. 22. 59. 0.96	6.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.38
2. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.50
3. BOREAL BROAD-SUMMERGREEN TREES	MI	0.17
4. BROAD-SUMMERGREEN SMALL TREES	MI	0.28
5. TALL GRASSES	TMIN	0.25
6. SHORT SWARD-GRASSES	MI	0.49
7. SUMMERGREEN GIANT-SCRUB	TMAX	0.26
8. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.19
9. XERIC SUMMERGREEN SHRUBS	MI	0.05
10. SHORT BUNCH-GRASSES	TMIN	0.58
11. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.37
12. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.08
13. SUMMERGREEN FORBS	TMAX	0.37
14. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.28
15. MAT-FORMING THALLOPHYTES	MI	0.17
16. XERIC CUSHION-HERBS	MI	0.04
17. XERIC THALLOPHYTES	MULT.	1.00
764. ASTRACHAN',ROSSIJA SSSR	46.35	48.05
25.0 -7.0 156. 18. 9. 14. 0.23	-14.	
+ 1. COLD-WINTER XEROMORPHIC SHRUBS	TMAX	0.41
+ 2. DESERT-GRASSES	TMAX	0.56
3. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMIN	0.26
4. EPHEMERAL DESERT HERBS	TMIN	0.27
5. XERIC DWARF-SHRUBS	TMIN	0.26
6. XERIC CUSHION-HERBS	MI	0.12
7. XERIC THALLOPHYTES	TMAX	0.56

Appendix B. Predicted vegetation at selected representative and well-known sites.

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                                                                   29
       LOCATION                                            LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                   ELEV

797. KOLGUJEV , O. KOLGUJEV      SSSR                      69.35   49.00
   8.0 -12.5  224.  40.   3.   25.  0.73                           7.
          1. SHORT SWARD-GRASSES                           PMTMAX  0.0
        + 2. SHORT BUNCH-GRASSES                           TMIN    0.54
          3. SEASONAL COLD-DESERT HERBS                    TMAX    0.70
          4. XERIC CUSHION-HERBS                           TMAX    0.30
          5. XERIC THALLOPHYTES                            MULT.   1.00

802. BATUMI, GRUZHIJA            SSSR                      41.63   41.63
   23.0   7.0 2404.  305.  84.  204.  3.28                        3.
        * 1. SUMMERGREEN BROAD-LEAVED TREES                TMAX    0.47
        * 2. TEMPERATE BROAD-RAINFOREST TREES              TMIN    0.15
          3. WARM-TEMPERATE BROAD-EVERGREEN TREES          TMIN    0.0
          4. SWAMP SUMMERGREEN NEEDLE-TREES                TMAX    0.17
          5. TROPICAL EVERGREEN MICROPHYLL-TREES           TMIN    0.0
          6. TALL GRASSES                                  TMAX    0.52
          7. TEMP. BROAD-EVERGREEN SMALL TREES             TMIN    0.38
          8. BROAD-SUMMERGREEN SMALL TREES                 TMAX    0.37
          9. ARBORESCENT GRASSES                           TMIN    0.14
         10. SHORT SWARD-GRASSES                           TMAX    0.52
         11. SUMMERGREEN GIANT-SCRUB                       TMAX    0.48
         12. BROAD-SUMMERGREEN MESIC SHRUBS                TMAX    0.44
         13. TEMPERATE BROAD-EVERGREEN SHRUBS              TMIN    0.41
         14. BROAD-ERICOID EVERGREEN SHRUBS                TMAX    0.17
         15. TROPICAL BROAD-EVERGREEN SHRUBS               TMIN    0.04
         16. TALL TUSSOCK-GRASSES                          TMAX    0.0
         17. SUMMERGREEN FORBS                             TMAX    0.52
         18. SUMMERGREEN FERNS                             TMAX    0.35
         19. TEMPERATE EVERGREEN FORBS                     TMAX    0.30
         20. TEMPERATE EVERGREEN DWARF-SHRUBS              TMAX    0.06
         21. MARITIME HEATH DWARF-SHRUBS                   TMAX    0.0
         22. BROAD-SUMMERGREEN VINES                       TMAX    0.47
         23. MAT-FORMING THALLOPHYTES                      TMAX    0.30
         24. BROAD-WINTERGREEN EPIPHYTES                   TMIN    0.25
         25. BROAD-EVERGREEN VINES                         TMIN    0.12
         26. NARROW-LEAVED EPIPHYTES                       TMIN    0.08

804. PEREVAL KRESTOVYJ,GRUZHI  SSSR                        42.53   44.47
   11.0 -11.5 1502.  220.  65.  188.  3.97                      2380.
          1. BOREAL/MONTANE SHORT-NEEDLED TREES            TMAX    0.0
          2. TALL GRASSES                                  TMAX    0.09
          3. BROAD-SUMMERGREEN SMALL TREES                 TMAX    0.0
          4. SHORT SWARD-GRASSES                           TMIN    0.51
          5. SUMMERGREEN TUNDRA DWARF-SHRUBS               TMAX    0.45
          6. NEEDLE-LEAVED TREELINE KRUMMHOLZ              TMAX    0.33
          7. TEMPERATE EVERGREEN DWARF-SHRUBS              TMIN    0.22
          8. SUMMERGREEN FERNS                             TMAX    0.09
          9. SUMMERGREEN FORBS                             TMAX    0.09
         10. MAT-FORMING THALLOPHYTES                      MI      0.82
         11. SEASONAL COLD-DESERT HERBS                    TMAX    0.36
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                                                                   30
       LOCATION                                            LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                   ELEV

830. FRUNZE, KIRGHIZ             SSSR                      42.90   74.60
   23.0  -4.5  382.  70.  16.  27.  0.59                         750.
        * 1. XERIC SUMMERGREEN SHRUBS                      TMAX    0.43
        * 2. SUMMERGREEN GIANT-SCRUB                       PMTMAX  0.25
          3. SHORT SWARD-GRASSES                           PMTMAX  0.06
          4. DWARF-NEEDLE SMALL TREES                      TMIN    0.02
        + 5. SHORT BUNCH-GRASSES                           TMIN    0.62
        + 6. COLD-WINTER XEROMORPHIC SHRUBS                TMAX    0.47
          7. NEEDLE-LEAVED EVERGREEN SHRUBS                MI      0.33
          8. SUMMERGREEN FORBS                             TMAX    0.48
          9. LEAFLESS XEROMORPHIC LARGE-SCRUB              TMIN    0.31
         10. XERIC DWARF-SHRUBS                            TMIN    0.31
         11. XERIC CUSHION-HERBS                           TMAX    0.28
         12. XERIC THALLOPHYTES                            TMAX    0.68

833. PAMIRSKI POST, TADZHIKIS  SSSR                        37.80   73.25
   14.0 -17.0   59.  12.   1.  12.  0.15                        3640.
        + 1. DESERT-GRASSES                                TMIN    0.48
          2. SEASONAL COLD-DESERT HERBS                    TMAX    0.07
          3. EPHEMERAL DESERT HERBS                        TMIN    0.06
          4. XERIC DWARF-SHRUBS                            TMIN    0.06
          5. DRY DESERT                                    MI      0.65
          6. XERIC THALLOPHYTES                            TMIN    0.64

856. JENISEJSK, SIBIR'           SSSR                      58.45   92.17
   19.0 -22.0  426.  65.  13.  60.  0.93                          78.
        * 1. BOREAL/MONTANE SHORT-NEEDLED TREES            TMIN    0.24
        + 2. BOREAL SUMMERGREEN NEEDLE-TREES               TMAX    0.30
          3. BOREAL BROAD-SUMMERGREEN TREES                MI      0.14
          4. BROAD-SUMMERGREEN SMALL TREES                 TMIN    0.17
        + 5. SHORT SWARD-GRASSES                           TMIN    0.37
          6. BROAD-SUMMERGREEN MESIC SHRUBS                TMIN    0.17
          7. SUMMERGREEN GIANT-SCRUB                       TMIN    0.17
          8. XERIC SUMMERGREEN SHRUBS                      MI      0.09
        + 9. SHORT BUNCH-GRASSES                           TMIN    0.49
         10. NEEDLE-LEAVED EVERGREEN SHRUBS                TMIN    0.18
         11. SUMMERGREEN FORBS                             TMAX    0.43
         12. MAT-FORMING THALLOPHYTES                      MI      0.14
         13. XERIC CUSHION-HERBS                           MI      0.09
         14. XERIC THALLOPHYTES                            MULT.   1.00

897. JAKUTSK, SIBIR'             SSSR                      62.22  129.82
   19.0 -44.0  187.  40.   4.  25.  0.44                         102.
          1. BOREAL SUMMERGREEN NEEDLE-TREES               PMTMAX  0.0
        + 2. SHORT BUNCH-GRASSES                           TMIN    0.29
          3. DESERT-GRASSES                                MI      0.13
          4. SUMMERGREEN FORBS                             TMIN    0.11
          5. XERIC CUSHION-HERBS                           TMIN    0.29
          6. XERIC THALLOPHYTES                            MULT.   1.00
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Appendix B. Predicted vegetation at selected representative and well-known sites.

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
931. LEVCOSIA	KIPROS	35.18	33.35
28.4 9.8 379. 80. 1. 3. 0.39		159.	
* 1. SHORT BUNCH-GRASSES		TMAX	0.38
* 2. HOT-DESERT EVERGREEN SHRUBS		TMIN	0.16
* 3. EVERGREEN GIANT-SCRUB		TMIN	0.09
* 4. XERIC EVERGREEN TUFT-TREELETS		TMIN	0.08
5. LEAFLESS XEROMORPHIC LARGE-SCRUB		TMAX	0.46
+ 6. MEDITERRANEAN DWARF-SHRUBS		TMAX	0.35
7. BUSH STEM-SUCCULENTS		TMIN	0.33
+ 8. DESERT-GRASSES		MI	0.28
9. SUMMERGREEN FORBS		TMAX	0.26
10. XERIC ROSETTE-SHRUBS		TMIN	0.25
11. XERIC CUSHION-SHRUBS		TMAX	0.22
12. TYPICAL STEM-SUCCULENTS		TMIN	0.12
13. XERIC DWARF-SHRUBS		TMAX	0.41
14. EPHEMERAL DESERT HERBS		MI	0.28
15. SUCCULENT FORBS		TMIN	0.19
16. XERIC CUSHION-HERBS		TMAX	0.06
17. XERIC THALLOPHYTES		TMAX	0.38
941. CEDRES	AL-LUBNA	34.35	36.10
17.5 0.5 768. 190. 0. 7. 1.35		1930.	
* 1. SUB-MEDITERRANEAN NEEDLE-TREES		TMIN	0.09
2. SHORT BUNCH-GRASSES		TMIN	0.67
3. NEEDLE-LEAVED EVERGREEN SHRUBS		TMAX	0.38
4. SUMMERGREEN FORBS		TMAX	0.38
5. BUSH STEM-SUCCULENTS		TMIN	0.02
6. BROAD-WINTERGREEN EPIPHYTES		TMIN	0.02
7. XERIC THALLOPHYTES		MI	0.48
944. TEL AVIV-YAFO	YISRA'EL	32.05	34.77
25.0 13.0 476. 135. 0. 3. 0.53		3.	
* 1. MEDITERRANEAN EVERGREEN SHRUBS		MI	0.15
+ 2. SHORT BUNCH-GRASSES		TMAX	0.56
3. EVERGREEN GIANT-SCRUB		TMIN	0.25
4. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.25
5. XERIC EVERGREEN TUFT-TREELETS		TMIN	0.23
6. HOT-DESERT EVERGREEN SHRUBS		TMAX	0.17
+ 7. MEDITERRANEAN DWARF-SHRUBS		TMAX	0.47
8. BUSH STEM-SUCCULENTS		TMIN	0.43
9. SUMMERGREEN FORBS		TMAX	0.40
+10. XERIC CUSHION-SHRUBS		TMAX	0.37
11. XERIC ROSETTE-SHRUBS		PMTMAX	0.23
12. TYPICAL STEM-SUCCULENTS		MI	0.14
13. LEAF-SUCCULENT EVERGREEN SHRUBS		TMIN	0.08
14. SUCCULENT FORBS		TMAX	0.32
15. XERIC CUSHION-HERBS		TMAX	0.20
16. XERIC THALLOPHYTES		TMAX	0.56
948. ADH-DHARAN	AL-'ARAB	26.30	50.13
36.0 16.0 54. 17. 0. 0. 0.04		150.	
+ 1. DESERT-GRASSES		TMAX	0.11
2. EPHEMERAL DESERT HERBS		TMAX	0.11
3. DRY DESERT		TMAX	0.95
4. XERIC THALLOPHYTES		TMAX	0.11

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
950. SANA'A	AL-YAMAN	15.38	44.20
21.0 14.0 390. 100. 0. 2. 0.49		2360.	
* 1. MEDITERRANEAN EVERGREEN SHRUBS		MI	0.09
+ 2. SHORT BUNCH-GRASSES		MI	0.61
3. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.19
4. XERIC EVERGREEN TUFT-TREELETS		TMAX	0.18
5. EVERGREEN GIANT-SCRUB		TMAX	0.08
+ 6. XERIC CUSHION-SHRUBS		TMAX	0.61
7. SUMMERGREEN FORBS		TMAX	0.48
8. BUSH STEM-SUCCULENTS		TMIN	0.47
9. MEDITERRANEAN DWARF-SHRUBS		TMAX	0.26
10. LEAFLESS XEROMORPHIC LARGE-SCRUB		TMAX	0.26
11. LEAF-SUCCULENT EVERGREEN SHRUBS		TMIN	0.15
12. TYPICAL STEM-SUCCULENTS		TMAX	0.05
13. DESERT-GRASSES		MI	0.01
14. XERIC ROSETTE-SHRUBS		PMTMAX	0.0
15. XERIC CUSHION-HERBS		TMAX	0.39
16. XERIC DWARF-SHRUBS		TMAX	0.39
17. SUCCULENT FORBS		TMAX	0.14
18. EPHEMERAL DESERT HERBS		MI	0.01
19. XERIC THALLOPHYTES		TMAX	0.83
968. TEHERAN	IRAN	35.67	51.43
29.5 2.5 246. 50. 1. 3. 0.26		1220.	
+ 1. SHORT BUNCH-GRASSES		MI	0.25
2. COLD-WINTER XEROMORPHIC SHRUBS		TMAX	0.15
3. LEAFLESS XEROMORPHIC LARGE-SCRUB		TMAX	0.42
+ 4. DESERT-GRASSES		TMAX	0.33
5. SUMMERGREEN FORBS		TMAX	0.22
6. BUSH STEM-SUCCULENTS		TMIN	0.08
7. XERIC DWARF-SHRUBS		TMAX	0.38
8. EPHEMERAL DESERT HERBS		TMAX	0.33
9. XERIC CUSHION-HERBS		TMAX	0.02
10. XERIC THALLOPHYTES		TMAX	0.33
974. KABUL	AFGHANES	34.50	69.18
24.0 -2.0 316. 90. 2. 11. 0.44		1815.	
1. XERIC SUMMERGREEN SHRUBS		MULT.	0.06
+ 2. SHORT BUNCH-GRASSES		MI	0.56
+ 3. COLD-WINTER XEROMORPHIC SHRUBS		TMAX	0.47
4. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.10
5. SUMMERGREEN FORBS		TMAX	0.44
6. LEAFLESS XEROMORPHIC LARGE-SCRUB		TMAX	0.36
7. DESERT-GRASSES		MI	0.13
8. XERIC DWARF-SHRUBS		TMIN	0.36
9. XERIC CUSHION-HERBS		TMAX	0.24
10. EPHEMERAL DESERT HERBS		MI	0.13
11. XERIC THALLOPHYTES		TMAX	0.62

Appendix B. Predicted vegetation at selected representative and well-known sites.

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                                                                    33
       LOCATION                                           LAT    LONG
    TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

983. PUNA                       BHARAT                    18.52   73.90
    29.0  20.0  672.  160.    2.   38.  0.51               556.
          1. TROPICAL EVERGREEN SCLEROPHYLL TREES         MI      0.02
          2. XERIC RAINGREEN TREES                        TMAX    0.31
          3. BROAD-RAINGREEN SMALL TREES                  TMAX    0.30
        + 4. RAINGREEN THORN-SCRUB                        TMAX    0.44
          5. SHORT SWARD-GRASSES                          MI      0.02
        + 6. ARBORESCENT STEM-SUCCULENTS                  TMAX    0.39
        + 7. SHORT BUNCH-GRASSES                          TMAX    0.35
          8. XERIC EVERGREEN TUFT-TREELETS                TMAX    0.35
          9. EVERGREEN GIANT-SCRUB                        TMAX    0.25
         10. XERIC ROSETTE-SHRUBS                         TMAX    0.45
         11. BUSH STEM-SUCCULENTS                         TMAX    0.37
         12. RAINGREEN FORBS                              TMAX    0.24
         13. XERIC CUSHION-SHRUBS                         TMAX    0.20
         14. TYPICAL STEM-SUCCULENTS                      MI      0.19
         15. LEAF-SUCCULENT EVERGREEN SHRUBS              TMAX    0.18
         16. SUCCULENT FORBS                              TMAX    0.50
         17. BROAD-RAINGREEN VINES                        TMAX    0.30
         18. XERIC CUSHION-HERBS                          TMAX    0.04
         19. XERIC THALLOPHYTES                           TMAX    0.35

995. SIMLA                      BHARAT                    31.15   77.25
    19.8   5.0 1558.  435.    7.  144.  2.29              2200.
        * 1. SUMMERGREEN BROAD-LEAVED TREES               TMAX    0.32
          2. TALL GRASSES                                 TMAX    0.49
          3. BROAD-SUMMERGREEN SMALL TREES                TMAX    0.46
          4. TEMP. BROAD-EVERGREEN SMALL TREES            TMIN    0.23
          5. TALL CANE-GRAMINOIDS                         TMIN    0.14
          6. ARBORESCENT GRASSES                          TMIN    0.05
          7. SHORT SWARD-GRASSES                          TMIN    0.73
          8. BROAD-ERICOID EVERGREEN SHRUBS               MI      0.42
          9. SUMMERGREEN GIANT-SCRUB                      TMAX    0.39
         10. BROAD-SUMMERGREEN MESIC SHRUBS               TMAX    0.36
         11. TEMPERATE BROAD-EVERGREEN SHRUBS             TMIN    0.32
         12. SHORT BUNCH-GRASSES                          MI      0.34
         13. SUMMERGREEN FORBS                            TMAX    0.49
         14. SUMMERGREEN FERNS                            TMAX    0.49
         15. TEMPERATE EVERGREEN DWARF-SHRUBS             TMAX    0.23
         16. TROPICAL EVERGREEN FORBS                     TMIN    0.11
         17. MAT-FORMING THALLOPHYTES                     TMAX    0.52
         18. BROAD-SUMMERGREEN VINES                      TMAX    0.32
         19. BROAD-WINTERGREEN EPIPHYTES                  TMIN    0.18
         20. BROAD-EVERGREEN VINES                        TMIN    0.04
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                                                                    34
       LOCATION                                           LAT    LONG
    TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

1005. COX'S BAZAAR              BANGLADE                  21.43   91.98
    28.0  20.0 3560.  900.    4.  356.  2.57               12.
        * 1. MONSOON BROAD-RAINGREEN TREES                MI      0.21
          2. PALMIFORM TUFT-TREES                         TMIN    0.47
          3. TROPICAL EVERGREEN MICROPHYLL-TREES          TMAX    0.24
          4. BROAD-RAINGREEN SMALL TREES                  TMAX    0.35
          5. TALL CANE-GRAMINOIDS                         MI      0.19
          6. TROPICAL BROAD-EVERGREEN LIANAS              TMAX    0.17
          7. PALMIFORM TUFT-TREELETS                      TMAX    0.33
          8. SHORT SWARD-GRASSES                          TMAX    0.25
          9. TROPICAL BROAD-EVERGREEN SHRUBS              TMAX    0.18
         10. TEMPERATE BROAD-EVERGREEN SHRUBS             TMAX    0.13
         11. SHORT BUNCH-GRASSES                          MI      0.18
         12. RAINGREEN FORBS                              TMAX    0.28
         13. BROAD-RAINGREEN VINES                        TMAX    0.35
         14. BROAD-EVERGREEN VINES                        TMAX    0.18
         15. BROAD-WINTERGREEN EPIPHYTES                  TMAX    0.14
         16. MAT-FORMING THALLOPHYTES                     TMAX    0.07

1007. GALLE                     SRI LANK                   6.03   80.22
    28.0  25.0 2737.  300.   78.  300.  1.83              100.
        * 1. TROPICAL RAINFOREST TPEES                    TMAX    0.20
          2. HELIOPHILIC LONG-NEEDLED TREES               TMAX    0.38
          3. TROPICAL LINEAR-LEAVED TREES                 TMAX    0.0
          4. PALMIFORM TUFT-TREES                         TMAX    0.50
          5. TROPICAL EVERGREEN SCLEROPHYLL TREES         TMAX    0.35
          6. TROPICAL EVERGREEN MICROPHYLL-TREES          TMAX    0.24
          7. TALL GRASSES                                 TMAX    0.28
          8. TALL CANE-GRAMINOIDS                         TMAX    0.28
          9. TROPICAL BROAD-EVERGREEN SMALL TREES         TMAX    0.24
         10. TROPICAL BROAD-EVERGREEN LIANAS              TMAX    0.17
         11. ARBORESCENT GRASSES                          TMAX    0.10
         12. PALMIFORM TUFT-TREELETS                      TMAX    0.33
         13. SHORT SWARD-GRASSES                          TMAX    0.23
         14. TROPICAL BROAD-EVERGREEN SHRUBS              TMAX    0.18
         15. SHORT BUNCH-GRASSES                          TMAX    0.40
         16. PALMIFORM MESIC ROSETTE-SHRUBS               TMAX    0.35
         17. EVERGREEN GIANT-SCRUB                        MI      0.10
         18. TROPICAL EVERGREEN FORBS                     TMAX    0.23
         19. EVERGREEN FERNS                              TMAX    0.10
         20. BROAD-EVERGREEN VINES                        TMAX    0.18
         21. NARROW-LEAVED EPIPHYTES                      TMAX    0.17
         22. BROAD-WINTERGREEN EPIPHYTES                  TMAX    0.14
         23. TROPICAL BROAD-EVERGREEN EPIPHYTES           TMAX    0.11
         24. MAT-FORMING THALLOPHYTES                     TMAX    0.07
         25. XERIC THALLOPHYTES                           MI      0.09
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Appendix B. Predicted vegetation at selected representative and well-known sites.

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
1013. DALANDZADGAD MONGOL A	43.58	104.50
21.5 -16.0 119. 30. 1. 11. 0.22	1466.	
1. COLD-WINTER XEROMORPHIC SHRUBS	TMIN	0.15
2. SHORT BUNCH-GRASSES	MI	0.08
+ 3. DESERT-GRASSES	TMIN	0.52
4. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMIN	0.08
5. SUMMERGREEN FORBS	MI	0.08
6. EPHEMERAL DESERT HERBS	TMIN	0.08
7. XERIC DWARF-SHRUBS	TMIN	0.08
8. XERIC CUSHION-HERBS	MI	0.08
9. XERIC THALLOPHYTES	TMAX	0.79
1041. NANNING, GUANGXI ZHUANG ZHONGGUO	22.80	108.33
29.0 15.0 1382. 240. 30. 210. 1.17	120.	
* 1. HELIOPHILIC LONG-NEEDLED TREES	MI	0.15
* 2. WARM-TEMPERATE BROAD-EVERGREEN TREES	TMAX	0.10
3. MONSOON BROAD-RAINGREEN TREES	TMIN	0.07
4. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.07
5. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.30
6. PALMIFORM TUFT-TREES	TMIN	0.21
7. TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.18
8. BROAD-RAINGREEN SMALL TREES	TMAX	0.30
9. TALL CANE-GRAMINOIDS	TMAX	0.24
10. TALL GRASSES	TMAX	0.24
11. TROPICAL BROAD-EVERGREEN SMALL TREES	TMAX	0.18
12. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.15
13. TROPICAL BROAD-EVERGREEN LIANAS	TMAX	0.08
14. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.05
15. ARBORESCENT GRASSES	TMAX	0.05
16. TROPICAL BROAD-EVERGREEN DWARF-TREES	TMIN	0.0
17. SUMMERGREEN GIANT-SCRUB	TMAX	0.26
18. PALMIFORM TUFT-TREELETS	TMIN	0.25
19. SHORT SWARD-GRASSES	TMAX	0.20
20. TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.14
21. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.07
22. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.06
23. SHORT BUNCH-GRASSES	TMAX	0.35
24. EVERGREEN GIANT-SCRUB	TMAX	0.25
25. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.24
26. PALMIFORM MESIC ROSETTE-SHRUBS	MI	0.24
27. BUSH STEM-SUCCULENTS	MI	0.28
28. RAINGREEN FORBS	TMAX	0.24
29. SUMMERGREEN FORBS	TMAX	0.24
30. TROPICAL EVERGREEN FORBS	TMAX	0.19
31. EVERGREEN FERNS	TMAX	0.05
32. TEMPERATE EVERGREEN FORBS	TMAX	0.04
33. BROAD-RAINGREEN VINES	TMIN	0.25
34. BROAD-EVERGREEN VINES	TMAX	0.14
35. NARROW-LEAVED EPIPHYTES	TMAX	0.13
36. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.07
37. MAT-FORMING THALLOPHYTES	TMAX	0.03
38. XERIC THALLOPHYTES	TMAX	0.35

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
1047. SHANGHAI, SHANGHAI SHI ZHONGGUO	31.22	121.47
27.0 4.0 1120. 200. 34. 102. 1.37	12.	
* 1. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.20
* 2. HELIOPHILIC LONG-NEEDLED TREES	TMIN	0.09
3. SWAMP SUMMERGREEN NEEDLE-TREES	PMTMAX	0.02
4. TALL GRASSES	TMAX	0.32
5. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.16
6. TEMP. BROAD-EVERGREEN SMALL TREES	TMIN	0.15
7. TALL CANE-GRAMINOIDS	TMIN	0.10
8. ARBORESCENT GRASSES	TMIN	0.0
9. SUMMERGREEN GIANT-SCRUB	TMAX	0.35
10. SHORT SWARD-GRASSES	TMAX	0.28
11. DWARF-NEEDLE SMALL TREES	TMAX	0.25
12. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.20
13. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.19
14. SHORT BUNCH-GRASSES	TMAX	0.45
15. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.32
16. SUMMERGREEN FORBS	TMAX	0.32
17. SUMMERGREEN FERNS	TMAX	0.15
18. TEMPERATE EVERGREEN FORBS	TMAX	0.12
19. BUSH STEM-SUCCULENTS	MI	0.09
20. BROAD-SUMMERGREEN VINES	TMAX	0.20
21. BROAD-WINTERGREEN EPIPHYTES	TMIN	0.14
22. MAT-FORMING THALLOPHYTES	TMAX	0.10
23. BROAD-EVERGREEN VINES	TMIN	0.0
24. XERIC THALLOPHYTES	TMAX	0.45
1064. KAGOSHIMA, KYUSHU NIHON	31.60	130.55
26.0 7.5 2244. 435. 88. 207. 2.74	5.	
* 1. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.27
* 2. TEMPERATE BROAD-RAINFOREST TREES	TMAX	0.13
3. WARM-TEMPERATE BROAD-EVERGREEN TREES	TMIN	0.04
4. SWAMP SUMMERGREEN NEEDLE-TREES	TMIN	0.26
5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.02
6. TALL GRASSES	TMAX	0.36
7. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.30
8. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.21
9. ARBORESCENT GRASSES	TMIN	0.17
10. TALL CANE-GRAMINOIDS	MI	0.11
11. SUMMERGREEN GIANT-SCRUB	TMAX	0.39
12. SHORT SWARD-GRASSES	TMAX	0.35
13. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.27
14. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
15. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.06
16. SHORT BUNCH-GRASSES	MI	0.10
17. SUMMERGREEN FORBS	TMAX	0.36
18. SUMMERGREEN FERNS	TMAX	0.20
19. TEMPERATE EVERGREEN FORBS	TMAX	0.16
20. BROAD-WINTERGREEN EPIPHYTES	TMIN	0.27
21. BROAD-SUMMERGREEN VINES	TMAX	0.27
22. MAT-FORMING THALLOPHYTES	TMAX	0.15
23. BROAD-EVERGREEN VINES	TMIN	0.13

Appendix B. Predicted vegetation at selected representative and well-known sites.

LOCATION: TMAX TMIN PRCP PMAX PMIN PMTMAX MI — LAT LONG ELEV — 37

1069. TAEGU — CHOSON — 35.88 128.58 — 52.

26.0 -1.0 980. 235. 19. 132. 1.37

* 1.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.27
2.	TALL GRASSES	TMAX	0.36
3.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.21
4.	SUMMERGREEN GIANT-SCRUB	TMAX	0.39
5.	SHORT SWARD-GRASSES	TMAX	0.32
6.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
7.	DWARF-NEEDLE SMALL TREES	TMIN	0.17
8.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.05
9.	SHORT BUNCH-GRASSES	TMAX	0.50
10.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.36
11.	SUMMERGREEN FORBS	TMAX	0.36
12.	SUMMERGREEN FERNS	MI	0.20
13.	TEMPERATE EVERGREEN FORBS	TMAX	0.16
14.	BROAD-SUMMERGREEN VINES	TMIN	0.24
15.	MAT-FORMING THALLOPHYTES	TMAX	0.14
16.	XERIC THALLOPHYTES	MI	0.47

1070. T'AINAN — T'AI-WAN — 23.00 120.18 — 14.

28.0 17.0 1679. 410. 15. 310. 1.42

* 1.	MONSOON BROAD-RAINGREEN TREES	TMIN	0.21
* 2.	WARM-TEMPERATE BROAD-EVERGREEN TREES	TMAX	0.20
* 3.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.13
4.	TROPICAL LINEAR-LEAVED TREES	TMAX	0.0
5.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.35
6.	PALMIFORM TUFT-TREES	TMIN	0.32
7.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.24
8.	BROAD-RAINGREEN SMALL TREES	TMAX	0.35
9.	TALL GRASSES	TMAX	0.28
10.	TALL CANE-GRAMINOIDS	TMAX	0.28
11.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMAX	0.24
12.	TROPICAL BROAD-EVERGREEN LIANAS	TMAX	0.17
13.	TROPICAL BROAD-EVERGREEN DWARF-TREES	TMIN	0.13
14.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.11
15.	ARBORESCENT GRASSES	TMAX	0.10
16.	PALMIFORM TUFT-TREELETS	TMAX	0.33
17.	SUMMERGREEN GIANT-SCRUB	TMAX	0.30
18.	SHORT SWARD-GRASSES	TMAX	0.23
19.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.18
20.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.13
21.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.13
22.	SHORT BUNCH-GRASSES	TMAX	0.40
23.	PALMIFORM MESIC ROSETTE-SHRUBS	TMAX	0.35
24.	EVERGREEN GIANT-SCRUB	TMAX	0.33
25.	RAINGREEN FORBS	TMAX	0.28
26.	TROPICAL EVERGREEN FORBS	TMAX	0.23
27.	TEMPERATE EVERGREEN FORBS	TMAX	0.08
28.	BROAD-RAINGREEN VINES	TMAX	0.35
29.	BROAD-EVERGREEN VINES	MULT.	0.18
30.	NARROW-LEAVED EPIPHYTES	TMAX	0.17
31.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
32.	TROPICAL BROAD-EVERGREEN EPIPHYTES	TMAX	0.11
33.	MAT-FORMING THALLOPHYTES	TMAX	0.07
34.	XERIC THALLOPHYTES	TMAX	0.40

LOCATION: TMAX TMIN PRCP PMAX PMIN PMTMAX MI — LAT LONG ELEV — 3

1075. RANGOON — MYANMA — 16.78 96.17 — 5.

30.0 25.0 2633. 600. 6. 173. 1.58

1.	TROPICAL RAINFOREST TREES	TMAX	0.0
2.	MONSOON BROAD-RAINGREEN TREES	TMAX	0.42
3.	PALMIFORM TUFT-TREES	TMAX	0.42
4.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.25
5.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.12
6.	TROPICAL BROAD-EVERGREEN DWARF-TREES	TMAX	0.33
7.	BROAD-RAINGREEN SMALL TREES	TMAX	0.25
8.	TALL GRASSES	TMAX	0.20
9.	TALL CANE-GRAMINOIDS	TMAX	0.20
10.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMAX	0.12
11.	ARBORESCENT GRASSES	TMAX	0.0
12.	TROPICAL BROAD-EVERGREEN LIANAS	TMAX	0.0
13.	PALMIFORM TUFT-TREELETS	TMAX	0.24
14.	SHORT SWARD-GRASSES	TMAX	0.17
15.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.09
16.	SHORT BUNCH-GRASSES	TMAX	0.31
17.	PALMIFORM MESIC ROSETTE-SHRUBS	TMAX	0.25
18.	EVERGREEN GIANT-SCRUB	TMAX	0.17
19.	RAINGREEN FORBS	TMAX	0.20
20.	TROPICAL EVERGREEN FORBS	TMAX	0.16
21.	BROAD-RAINGREEN VINES	TMAX	0.25
22.	BROAD-EVERGREEN VINES	TMAX	0.09
23.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.0
24.	MAT-FORMING THALLOPHYTES	TMAX	0.0
25.	XERIC THALLOPHYTES	MI	0.27

1087. SAIGON — VIET-NAM — 10.75 106.67 — 8.

28.0 25.0 1985. 340. 4. 108. 1.21

* 1.	MONSOON BROAD-RAINGREEN TREES	MI	0.26
2.	PALMIFORM TUFT-TREES	MI	0.42
3.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.35
4.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.24
5.	BROAD-RAINGREEN SMALL TREES	TMAX	0.35
6.	TROPICAL BROAD-EVERGREEN DWARF-TREES	MI	0.34
7.	TALL CANE-GRAMINOIDS	TMAX	0.28
8.	TROPICAL BROAD-EVERGREEN LIANAS	TMAX	0.17
9.	PALMIFORM TUFT-TREELETS	TMAX	0.33
10.	SHORT SWARD-GRASSES	TMAX	0.23
11.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.18
12.	SHORT BUNCH-GRASSES	TMAX	0.40
13.	EVERGREEN GIANT-SCRUB	TMAX	0.33
14.	RAINGREEN FORBS	TMAX	0.28
15.	BROAD-RAINGREEN VINES	TMAX	0.35
16.	BROAD-EVERGREEN VINES	TMAX	0.18
17.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
18.	MAT-FORMING THALLOPHYTES	TMAX	0.07
19.	XERIC THALLOPHYTES	TMAX	0.40

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                                                              39
     LOCATION                                        LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI              ELEV

1093. MANILA, LUZON              PILIPINA            14.58  120.98
      28.0  25.0 2068.  420.   11.  171.  1.28           19.
          * 1. TROPICAL RAINFOREST TREES             TMAX     0.20
            2. MONSOON BROAD-RAINGREEN TREES         MI       0.30
            3. TROPICAL LINEAR-LEAVED TREES          TMAX     0.0
            4. PALMIFORM TUFT-TREES                  MI       0.46
            5. TROPICAL EVERGREEN SCLEROPHYLL TREES  TMAX     0.35
            6. TROPICAL EVERGREEN MICROPHYLL-TREES   TMAX     0.24
            7. TROPICAL BROAD-EVERGREEN DWARF-TREES  MI       0.40
            8. BROAD-RAINGREEN SMALL TREES           TMAX     0.35
            9. TALL GRASSES                          TMAX     0.28
           10. TALL CANE-GRAMINOIDS                  TMAX     0.28
           11. TROPICAL BROAD-EVERGREEN SMALL TREES  TMAX     0.24
           12. TROPICAL BROAD-EVERGREEN LIANAS       TMAX     0.17
           13. ARBORESCENT GRASSES                   TMAX     0.10
           14. PALMIFORM TUFT-TREELETS               TMAX     0.33
           15. SHORT SWARD-GRASSES                   TMAX     0.23
           16. TROPICAL BROAD-EVERGREEN SHRUBS       TMAX     0.18
           17. SHORT BUNCH-GRASSES                   TMAX     0.40
           18. EVERGREEN GIANT-SCRUB                 TMAX     0.33
           19. PALMIFORM MESIC ROSETTE-SHRUBS        MI       0.30
           20. RAINGREEN FORBS                       TMAX     0.28
           21. TROPICAL EVERGREEN FORBS              TMAX     0.23
           22. BROAD-RAINGREEN VINES                 TMAX     0.35
           23. BROAD-EVERGREEN VINES                 TMAX     0.18
           24. NARROW-LEAVED EPIPHYTES               TMAX     0.17
           25. BROAD-WINTERGREEN EPIPHYTES           TMAX     0.14
           26. TROPICAL BROAD-EVERGREEN EPIPHYTES    TMAX     0.11
           27. MAT-FORMING THALLOPHYTES              TMAX     0.07
           28. XERIC THALLOPHYTES                    TMAX     0.40

1100. DJAKARTA, DJAWA            INDONESI            -6.17  106.80
      26.5  25.5 1793.  290.   42.  101.  1.16            8.
          * 1. TROPICAL RAINFOREST TREES             MI       0.23
            2. TROPICAL EVERGREEN SCLEROPHYLL TREES  TMAX     0.42
            3. PALMIFORM TUFT-TREES                  MI       0.40
            4. TROPICAL EVERGREEN MICROPHYLL-TREES   TMAX     0.32
            5. TALL CANE-GRAMINOIDS                  TMAX     0.34
            6. TALL GRASSES                          TMAX     0.34
            7. TROPICAL BROAD-EVERGREEN SMALL TREES  MI       0.23
            8. TROPICAL BROAD-EVERGREEN LIANAS       MI       0.14
            9. PALMIFORM TUFT-TREELETS               MI       0.40
           10. TROPICAL BROAD-EVERGREEN SHRUBS       TMAX     0.25
           11. SHORT BUNCH-GRASSES                   TMAX     0.47
           12. EVERGREEN GIANT-SCRUB                 TMAX     0.46
           13. PALMIFORM MESIC ROSETTE-SHRUBS        MI       0.23
           14. RAINGREEN FORBS                       TMAX     0.34
           15. BUSH STEM-SUCCULENTS                  MI       0.29
           16. TROPICAL EVERGREEN FORBS              MI       0.23
           17. EVERGREEN FERNS                       MI       0.05
           18. BROAD-WINTERGREEN EPIPHYTES           TMAX     0.25
           19. BROAD-EVERGREEN VINES                 MI       0.23
           20. NARROW-LEAVED EPIPHYTES               MI       0.14
           21. MAT-FORMING THALLOPHYTES              TMAX     0.12
           22. TROPICAL BROAD-EVERGREEN EPIPHYTES    MI       0.05
           23. XERIC THALLOPHYTES                    TMAX     0.47
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     LOCATION                                                LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                      ELEV

1127. CHARLOTTE WATERS,N.TERRI  AUSTRALI                   -26.00  134.83
      25.5  11.0  236.   28.   12.   18.  0.32                 166.
          * 1. HOT-DESERT EVERGREEN SHRUBS                 TMAX     0.19
          * 2. EVERGREEN GIANT-SCRUB                       TMIN     0.15
          * 3. ARBORESCENT STEM-SUCCULENTS                 TMIN     0.14
          + 4. DESERT-GRASSES                              TMAX     0.53
            5. LEAFLESS XEROMORPHIC LARGE-SCRUB            TMAX     0.42
            6. BUSH STEM-SUCCULENTS                        TMIN     0.37
          + 7. XERIC CUSHION-SHRUBS                        TMAX     0.35
            8. XERIC ROSETTE-SHRUBS                        TMAX     0.27
            9. TYPICAL STEM-SUCCULENTS                     TMIN     0.17
           10. SCLEROPHYLLOUS GRASSES                      TMIN     0.05
           11. EPHEMERAL DESERT HERBS                      TMAX     0.53
           12. XERIC DWARF-SHRUBS                          TMAX     0.49
           13. SUCCULENT FORBS                             TMIN     0.24
           14. XERIC CUSHION-HERBS                         TMAX     0.18
           15. XERIC THALLOPHYTES                          TMAX     0.53

1152. GAYNDAH, QUEENSLAND       AUSTRALI                   -25.62  151.60
      25.5  14.5  775.  125.   31.  112.  0.85                 112.
          * 1. TROPICAL XERIC NEEDLE-TREES                 TMAX     0.30
          * 2. WARM-TEMPERATE BROAD-EVERGREEN TREES        MI       0.12
            3. TROPICAL EVERGREEN SCLEROPHYLL TREES        TMIN     0.30
            4. PALMIFORM TUFT-TREES                        MI       0.18
            5. TROPICAL EVERGREEN MICROPHYLL-TREES         MI       0.12
            6. TALL CANE-GRAMINOIDS                        MI       0.18
            7. TALL GRASSES                                MI       0.18
            8. BROAD-SUMMERGREEN SMALL TREES               MI       0.18
            9. TEMP. BROAD-EVERGREEN SMALL TREES           MI       0.12
           10. ARBORESCENT GRASSES                         MI       0.06
           11. SUMMERGREEN GIANT-SCRUB                     TMAX     0.41
          +12. DWARF-NEEDLE SMALL TREES                    TMAX     0.38
          +13. SHORT SWARD-GRASSES                         TMAX     0.35
           14. TEMPERATE BROAD-EVERGREEN SHRUBS            MI       0.30
           15. BROAD-SUMMERGREEN MESIC SHRUBS              MI       0.18
           16. PALMIFORM TUFT-TREELETS                     MI       0.18
           17. TROPICAL BROAD-EVERGREEN SHRUBS             MI       0.18
           18. MEDITERRANEAN EVERGREEN SHRUBS              PMTMAX   0.12
          +19. SHORT BUNCH-GRASSES                         TMAX     0.53
           20. NEEDLE-LEAVED EVERGREEN SHRUBS              TMAX     0.38
           21. EVERGREEN GIANT-SCRUB                       TMIN     0.32
           22. XERIC EVERGREEN TUFT-TREELETS               MI       0.20
           23. BUSH STEM-SUCCULENTS                        TMIN     0.48
           24. SUMMERGREEN FORBS                           TMAX     0.38
           25. RAINGREEN FORBS                             TMIN     0.33
           26. XERIC ROSETTE-SHRUBS                        TMAX     0.27
           27. SUCCULENT FORBS                             TMAX     0.34
           28. BROAD-WINTERGREEN EPIPHYTES                 MI       0.30
           29. XERIC CUSHION-HERBS                         TMAX     0.18
           30. MAT-FORMING THALLOPHYTES                    MI       0.06
           31. XERIC THALLOPHYTES                          TMAX     0.53
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Appendix B. Predicted vegetation at selected representative and well-known sites.

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT LONG ELEV	
1162. COWRA, NEW SOUTH WALES AUSTRALI	-33.83	148.68
24.0 8.0 591. 63. 39. 51. 0.83	320.	
1. MEDITERRANEAN BROAD-EVERGREEN TREES	MI	0.04
2. TEMPERATE NEEDLE-TREES	TMAX	0.0
3. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.0
4. BROAD-SUMMERGREEN SMALL TREES	MI	0.16
5. TALL GRASSES	MI	0.16
6. TEMP. BROAD-EVERGREEN SMALL TREES	MI	0.10
7. SUMMERGREEN GIANT-SCRUB	TMAX	0.48
+ 8. DWARF-NEEDLE SMALL TREES	MI	0.46
+ 9. SHORT SWARD-GRASSES	MI	0.40
10. TEMPERATE BROAD-EVERGREEN SHRUBS	MI	0.28
11. MEDITERRANEAN EVERGREEN SHRUBS	TMIN	0.23
12. BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.16
+13. SHORT BUNCH-GRASSES	TMAX	0.62
14. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.44
15. SHORT TUSSOCK-GRASSES	TMAX	0.04
16. XERIC EVERGREEN TUFT-TREELETS	TMIN	0.0
17. EVERGREEN GIANT-SCRUB	TMIN	0.0
18. SUMMERGREEN FORBS	TMAX	0.44
19. BUSH STEM-SUCCULENTS	TMIN	0.27
20. XERIC ROSETTE-SHRUBS	TMIN	0.19
21. RAINGREEN FORBS	TMIN	0.04
22. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.0
23. BROAD-WINTERGREEN EPIPHYTES	MI	0.28
24. XERIC CUSHION-HERBS	MI	0.21
25. SUCCULENT FORBS	TMIN	0.12
26. MAT-FORMING THALLOPHYTES	MI	0.04
27. XERIC THALLOPHYTES	TMAX	0.62
1170. MIENA,TASMANIA AUSTRALI	-42.40	146.50
12.0 1.5 832. 89. 48. 48. 1.82	1087.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.09
2. TEMPERATE RAINFOREST NEEDLE-TREES	TMAX	0.0
3. TALL GRASSES	TMAX	0.14
4. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.07
5. SHORT SWARD-GRASSES	PMTMAX	0.48
6. TALL TUSSOCK-GRASSES	TMIN	0.23
7. SUMMERGREEN GIANT-SCRUB	TMAX	0.0
8. SHORT BUNCH-GRASSES	MI	0.65
9. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.50
10. NEEDLE-LEAVED TREELINE KRUMMHOLZ	TMAX	0.33
11. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.11
12. MESIC EVERGREEN CUSHION-SHRUBS	TMIN	0.06
13. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.43
14. TEMPERATE EVERGREEN FORBS	TMIN	0.28
15. SUMMERGREEN FORBS	TMAX	0.14
16. MARITIME HEATH DWARF-SHRUBS	TMAX	0.0
17. MAT-FORMING THALLOPHYTES	MI	0.56
18. XERIC THALLOPHYTES	MI	0.10

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT LONG ELEV	
1179. GLENBERVIE, NORTH ISLAND NEW ZEAL	-35.72	174.38
17.0 9.0 1680. 210. 93. 98. 2.63	250.	
* 1. TEMPERATE RAINFOREST NEEDLE-TREES	TMAX	0.38
* 2. TEMPERATE BROAD-RAINFOREST TREES	TMAX	0.27
* 3. TEMPERATE NEEDLE-TREES	MI	0.16
* 4. TROPICAL LINEAR-LEAVED TREES	TMAX	0.15
* 5. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.13
6. TROPICAL MONTANE RAINFOREST TREES	TMIN	0.07
7. TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.09
8. SUB-MEDITERRANEAN NEEDLE-TREES	PMTMAX	0.02
9. TALL GRASSES	TMAX	0.41
10. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.35
11. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.29
12. ARBORESCENT GRASSES	TMIN	0.24
13. TALL CANE-GRAMINOIDS	MI	0.16
14. TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.05
15. SHORT SWARD-GRASSES	TMAX	0.71
16. TALL TUSSOCK-GRASSES	TMAX	0.35
17. BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.33
18. SUMMERGREEN GIANT-SCRUB	TMAX	0.29
19. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.19
20. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.13
21. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.13
22. SHORT BUNCH-GRASSES	MI	0.15
23. MESIC EVERGREEN CUSHION-SHRUBS	TMAX	0.07
24. PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.05
25. TEMPERATE EVERGREEN FORBS	TMIN	0.61
26. MARITIME HEATH DWARF-SHRUBS	TMAX	0.45
27. SUMMERGREEN FORBS	TMAX	0.41
28. SUMMERGREEN FERNS	TMAX	0.41
29. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.41
30. TROPICAL EVERGREEN FORBS	TMIN	0.25
31. EVERGREEN FERNS	TMIN	0.17
32. MAT-FORMING THALLOPHYTES	MI	0.75
33. BROAD-EVERGREEN VINES	TMIN	0.19
34. NARROW-LEAVED EPIPHYTES	TMIN	0.16
35. BROAD-SUMMERGREEN VINES	TMAX	0.13
36. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.07

Appendix B. Predicted vegetation at selected representative and well-known sites.

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG 43
1185. NORFOLK ISLAND NORFOLK		-29.03	167.95
22.5 16.2 1357. 150. 70. 85. 1.61		15.	
* 1.	TROPICAL LINEAR-LEAVED TREES	MI	0.38
* 2.	TEMPERATE BROAD-RAINFOREST TREES	PMTMAX	0.29
* 3.	TROPICAL MONTANE RAINFOREST TREES	TMAX	0.17
* 4.	HELIOPHILIC LONG-NEEDLED TREES	PMTMAX	0.12
5.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.40
6.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.37
7.	PALMIFORM TUFT-TREES	TMAX	0.27
8.	TALL GRASSES	TMAX	0.51
9.	TALL CANE-GRAMINOIDS	TMAX	0.51
10.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.41
11.	ARBORESCENT GRASSES	TMAX	0.38
12.	TROPICAL BROAD-EVERGREEN LIANAS	TMIN	0.31
13.	SHORT SWARD-GRASSES	TMAX	0.51
14.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.50
15.	TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.42
16.	PALMIFORM TUFT-TREELETS	TMIN	0.31
17.	MEDITERRANEAN EVERGREEN SHRUBS	MI	0.25
18.	SHORT BUNCH-GRASSES	TMAX	0.71
19.	PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.37
20.	EVERGREEN GIANT-SCRUB	TMAX	0.21
21.	TROPICAL EVERGREEN FORBS	MI	0.44
22.	EVERGREEN FERNS	MI	0.32
23.	TEMPERATE EVERGREEN FORBS	TMAX	0.31
24.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.08
25.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.46
26.	BROAD-EVERGREEN VINES	TMAX	0.43
27.	NARROW-LEAVED EPIPHYTES	MI	0.38
28.	TROPICAL BROAD-EVERGREEN EPIPHYTES	TMIN	0.31
29.	MAT-FORMING THALLOPHYTES	TMAX	0.31
30.	XERIC THALLOPHYTES	MI	0.24
1187. SUVA FIJI		-18.13	178.42
26.3 23.0 2926. 365. 130. 323. 2.18		6.	
* 1.	TROPICAL RAINFOREST TREES	TMAX	0.37
2.	TROPICAL LINEAR-LEAVED TREES	TMAX	0.13
3.	PALMIFORM TUFT-TREES	TMAX	0.43
4.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.34
5.	TALL GRASSES	TMAX	0.35
6.	TALL CANE-GRAMINOIDS	TMAX	0.35
7.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMAX	0.34
8.	TROPICAL BROAD-EVERGREEN LIANAS	TMAX	0.31
9.	ARBORESCENT GRASSES	TMAX	0.19
10.	PALMIFORM TUFT-TREELETS	TMAX	0.41
11.	SHORT SWARD-GRASSES	TMAX	0.33
12.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.26
13.	PALMIFORM MESIC ROSETTE-SHRUBS	TMAX	0.44
14.	SHORT BUNCH-GRASSES	MI	0.41
15.	TROPICAL EVERGREEN FORBS	TMAX	0.33
16.	EVERGREEN FERNS	TMAX	0.19
17.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.26
18.	BROAD-EVERGREEN VINES	TMAX	0.26
19.	NARROW-LEAVED EPIPHYTES	TMAX	0.24
20.	TROPICAL BROAD-EVERGREEN EPIPHYTES	TMAX	0.21
21.	MAT-FORMING THALLOPHYTES	TMAX	0.14

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG 44
1197. PAPEETE,TAHITI POLYNESI		-17.53	-149.57
27.5 25.0 1889. 335. 47. 212. 1.21		90.	
* 1.	TROPICAL RAINFOREST TREES	TMAX	0.25
2.	HELIOPHILIC LONG-NEEDLED TREES	MI	0.17
3.	TROPICAL LINEAR-LEAVED TREES	TMAX	0.04
4.	PALMIFORM TUFT-TREES	MI	0.42
5.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMAX	0.38
6.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.26
7.	TALL CANE-GRAMINOIDS	TMAX	0.30
8.	TALL GRASSES	TMAX	0.30
9.	TROPICAL BROAD-EVERGREEN SMALL TREES	MI	0.26
10.	TROPICAL BROAD-EVERGREEN LIANAS	MI	0.17
11.	ARBORESCENT GRASSES	TMAX	0.13
12.	PALMIFORM TUFT-TREELETS	TMAX	0.36
13.	SHORT SWARD-GRASSES	TMAX	0.25
14.	TROPICAL BROAD-EVERGREEN SHRUBS	TMAX	0.20
15.	SHORT BUNCH-GRASSES	TMAX	0.42
16.	EVERGREEN GIANT-SCRUB	TMAX	0.38
17.	PALMIFORM MESIC ROSETTE-SHRUBS	MI	0.26
18.	RAINGREEN FORBS	TMAX	0.30
19.	TROPICAL EVERGREEN FORBS	TMAX	0.25
20.	EVERGREEN FERNS	MI	0.09
21.	BROAD-EVERGREEN VINES	TMAX	0.20
22.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.18
23.	NARROW-LEAVED EPIPHYTES	MI	0.17
24.	TROPICAL BROAD-EVERGREEN EPIPHYTES	MI	0.09
25.	MAT-FORMING THALLOPHYTES	TMAX	0.08
26.	XERIC THALLOPHYTES	TMAX	0.42
1204. HONOLULU,OAHO HAWAIIAN		21.32	-157.87
25.0 21.0 703. 100. 21. 45. 0.61		17.	
* 1.	TROPICAL EVERGREEN SCLEROPHYLL TREES	MI	0.18
2.	XERIC RAINGREEN TREES	TMAX	0.06
+ 3.	BROAD-RAINGREEN SMALL TREES	TMAX	0.50
4.	SHORT SWARD-GRASSES	MI	0.18
+ 5.	SHORT BUNCH-GRASSES	TMAX	0.56
+ 6.	EVERGREEN GIANT-SCRUB	TMAX	0.42
7.	XERIC EVERGREEN TUFT-TREELETS	TMAX	0.41
8.	BUSH STEM-SUCCULENTS	TMAX	0.56
9.	RAINGREEN FORBS	TMAX	0.40
10.	XERIC CUSHION-SHRUBS	TMAX	0.37
11.	LEAF-SUCCULENT EVERGREEN SHRUBS	MI	0.32
12.	XERIC ROSETTE-SHRUBS	TMAX	0.25
13.	SCLEROPHYLLOUS GRASSES	TMAX	0.25
14.	BROAD-RAINGREEN VINES	TMAX	0.50
15.	SUCCULENT FORBS	TMAX	0.32
16.	XERIC DWARF-SHRUBS	MI	0.32
17.	XERIC CUSHION-HERBS	TMAX	0.20
18.	BROAD-WINTERGREEN EPIPHYTES	MI	0.02
19.	XERIC THALLOPHYTES	TMAX	0.56

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                 LOCATION                              LAT    LONG
      TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI             ELEV

1208. VOLCANO OBSERVATORY,HAWA  HAWAIIAN              19.43 -155.23
        17.5  14.5 2626.  300.  135.  181.  3.61        1200.
            * 1. TROPICAL MONTANE RAINFOREST TREES    TMAX    0.28
            * 2. TROPICAL LINEAR-LEAVED TREES         TMAX    0.19
              3. TROPICAL EVERGREEN MICROPHYLL-TREES  TMAX    0.15
              4. PALMIFORM TUFT-TREES                 TMAX    0.09
              5. TROPICAL CLOUD-FOREST DWARF-TREES    TMAX    0.25
              6. TALL GRASSES                         TMAX    0.43
              7. ARBORESCENT GRASSES                  TMAX    0.43
              8. TROPICAL BROAD-EVERGREEN SMALL TREES MULT.   0.15
              9. SHORT SWARD-GRASSES                  TMAX    0.71
             10. TREE FERNS                           TMAX    0.38
             11. TROPICAL BROAD-EVERGREEN SHRUBS      TMIN    0.35
             12. PALMIFORM TUFT-TREELETS              TMAX    0.20
             13. PALMIFORM MESIC ROSETTE-SHRUBS       TMAX    0.14
             14. TROPICAL EVERGREEN FORBS             TMIN    0.45
             15. EVERGREEN FERNS                      TMIN    0.41
             16. TEMPERATE EVERGREEN DWARF-SHRUBS     TMAX    0.37
             17. MAT-FORMING THALLOPHYTES             TMAX    0.71
             18. BROAD-EVERGREEN VINES                TMIN    0.40
             19. NARROW-LEAVED EPIPHYTES              TMIN    0.38
             20. TROPICAL BROAD-EVERGREEN EPIPHYTES   TMIN    0.22
             21. BROAD-WINTERGREEN EPIPHYTES          TMAX    0.11

1211. CAMPBELL ISLAND           CAMPBELL             -52.50  169.00
        9.0   4.5 1382.  150.   65.   65.  2.71           23.
            * 1. TALL TUSSOCK-GRASSES                 TMAX    0.44
            * 2. SHORT SWARD-GRASSES                  TMAX    0.44
              3. MESIC EVERGREEN CUSHION-SHRUBS       PMTMAX  0.38
              4. SHORT BUNCH-GRASSES                  MI      0.11
              5. TEMPERATE EVERGREEN DWARF-SHRUBS     TMAX    0.33
              6. TROPICAL EVERGREEN FORBS             TMIN    0.09
              7. MAT-FORMING THALLOPHYTES             MI      0.76
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                 LOCATION                              LAT    LONG
      TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI             ELEV

1212. CUMBERLAND BAY              S.GEORGI           -54.25  -36.75
        5.3  -2.0 1313.  145.   68.  121.  4.22            2.
              1. SHORT SWARD-GRASSES                  TMAX    0.01
              2. TEMPERATE EVERGREEN FORBS            TMAX    0.01
              3. SEASONAL COLD-DESERT HERBS           TMAX    0.35
              4. MAT-FORMING THALLOPHYTES             TMAX    0.18
              5. ICE DESERT                           TMAX    0.00

1215. DECEPTION ISLAND, PENIN.  ANTARCTI             -62.95  -60.63
        1.0  -8.5  563.  100.    7.   43. 15.03            8.
              1. SEASONAL COLD-DESERT HERBS           TMAX    0.07
              2. MAT-FORMING THALLOPHYTES             TMAX    0.03
              3. ICE DESERT                           TMAX    0.00

1225. SOUTH POLE                ANTARCTI             -90.00    0.0
      -28.1 -59.2   70.   15.    2.   6.700.00          2800.
              1. ICE DESERT                           TMAX    0.03
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APPENDIX C

Predicted vegetation at the validation sites

The macroclimatic data and predicted vegetation at each of the 74 validation sites are presented below in computer-generated form. The listing contains all the information provided on the primary ECOSIEVE printout but has been reformatted by ECOSIEVE in order to fit a narrower page. Station name, country (truncated after eight characters), and geographic coordinates are listed on the first line for each site, with climatic data and elevation on the second line in the format suggested by the heading on each page. Temperatures are in °C, precipitation amounts in millimeters, and elevations in meters. The two columns after the predicted forms represent closest environmental limits and the respective distances to them, expressed as standardized fractions of the largest applicable range (see section 5.E). The annual moisture index MI (last climatic value in line two) is understood as an estimate of total vegetation cover in percent (100% when MI $>$ 1.0). Asterisks indicate potentially dominant forms in the highest dominance level present, especially in closed formations (MI $>$ 0.9). Potential dominants in drier, more open formations (MI $<$ 0.9) are indicated by plus signs, with asterisks retained to indicate potentially larger but widely spaced forms (e.g. trees in a savanna). Asterisks and plusses are deleted when the corresponding forms are near environmental limits. For interpretation of the predicted results see sections 5.F and 6.A in the main text.

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                                                              1
   LOCATION                                         LAT    LONG
 TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

1. FAIRBANKS/ALASKA            USA                 64.85 -147.72
   15.4 -23.0  303.    56.    9.    46.  0.72          134.
         * 1. BOREAL/MONTANE SHORT-NEEDLED TREES   MI      0.17
         + 2. BOREAL SUMMERGREEN NEEDLE-TREES      TMAX    0.34
           3. BROAD-SUMMERGREEN SMALL TREES        MI      0.03
         + 4. SHORT SWARD-GRASSES                  MI      0.31
           5. SUMMERGREEN GIANT-SCRUB              TMIN    0.15
           6. XERIC SUMMERGREEN SHRUBS             TMAX    0.08
           7. BROAD-SUMMERGREEN MESIC SHRUBS       MI      0.03
         + 8. SHORT BUNCH-GRASSES                  TMIN    0.48
           9. NEEDLE-LEAVED EVERGREEN SHRUBS       TMIN    0.16
          10. SUMMERGREEN FORBS                    TMAX    0.31
          11. XERIC CUSHION-HERBS                  MI      0.39
          12. XERIC THALLOPHYTES                   MULT.   1.00

2. VANCOUVER(PMO)/BRIT.COLU   CANADA               49.27 -123.12
   18.0    3.0 1438.  235.    34.    34.  2.25          39.
         * 1. BOREAL/MONTANE SHORT-NEEDLED TREES   TMAX    0.36
         * 2. TEMPERATE NEEDLE-TREES               TMAX    0.33
         * 3. TEMPERATE RAINFOREST NEEDLE-TREES    PMTMAX  0.27
         * 4. SUMMERGREEN BROAD-LEAVED TREES       PMTMAX  0.12
           5. BOREAL SUMMERGREEN NEEDLE-TREES      PMTMAX  0.27
           6. SUB-MEDITERRANEAN NEEDLE-TREES       TMIN    0.25
           7. BOREAL BROAD-SUMMERGREEN TREES       PMTMAX  0.12
           8. BROAD-SUMMERGREEN SMALL TREES        TMAX    0.39
           9. TALL GRASSES                         PMTMAX  0.12
          10. TEMP. BROAD-EVERGREEN SMALL TREES    TMIN    0.08
          11. TALL CANE-GRAMINOIDS                 TMIN    0.07
          12. SUMMERGREEN GIANT-SCRUB              TMAX    0.33
          13. SHORT SWARD-GRASSES                  PMTMAX  0.27
          14. BROAD-SUMMERGREEN MESIC SHRUBS       TMAX    0.25
          15. TEMPERATE BROAD-EVERGREEN SHRUBS     PMTMAX  0.12
          16. TALL TUSSOCK-GRASSES                 PMTMAX  0.12
          17. BROAD-ERICOID EVERGREEN SHRUBS       PMTMAX  0.12
          18. DWARF-NEEDLE SMALL TREES             TMAX    0.0
          19. SHORT BUNCH-GRASSES                  MI      0.36
          20. SUMMERGREEN TUNDRA DWARF-SHRUBS      TMAX    0.0
          21. SUMMERGREEN FORBS                    TMAX    0.44
          22. MARITIME HEATH DWARF-SHRUBS          TMIN    0.36
          23. TEMPERATE EVERGREEN FORBS            TMIN    0.35
          24. TEMPERATE EVERGREEN DWARF-SHRUBS     PMTMAX  0.27
          25. MAT-FORMING THALLOPHYTES             TMAX    0.67
          26. BROAD-WINTERGREEN EPIPHYTES          TMIN    0.11
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                                                              2
   LOCATION                                         LAT    LONG
 TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI               ELEV

3. BANFF/ALBERTA               CANADA              51.17 -115.57
   14.5 -10.0  454.    64.   26.    40.  0.98         1397.
         * 1. BOREAL/MONTANE SHORT-NEEDLED TREES   TMAX    0.32
           2. BOREAL SUMMERGREEN NEEDLE-TREES      TMAX    0.25
           3. BOREAL BROAD-SUMMERGREEN TREES       TMAX    0.13
           4. BROAD-SUMMERGREEN SMALL TREES        TMAX    0.21
           5. TALL GRASSES                         TMIN    0.21
           6. SHORT SWARD-GRASSES                  PMTMAX  0.38
           7. SUMMERGREEN GIANT-SCRUB              TMAX    0.15
           8. BROAD-SUMMERGREEN MESIC SHRUBS       TMAX    0.03
           9. XERIC SUMMERGREEN SHRUBS             MI      0.03
          10. SHORT BUNCH-GRASSES                  TMIN    0.56
          11. SUMMERGREEN TUNDRA DWARF-SHRUBS      MI      0.29
          12. NEEDLE-LEAVED EVERGREEN SHRUBS       TMAX    0.27
          13. SUMMERGREEN FORBS                    TMAX    0.27
          14. TEMPERATE EVERGREEN DWARF-SHRUBS     TMIN    0.26
          15. MAT-FORMING THALLOPHYTES             MI      0.19
          16. SEASONAL COLD-DESERT HERBS           TMAX    0.03
          17. XERIC CUSHION-HERBS                  MI      0.03
          18. XERIC THALLOPHYTES                   MULT.   1.00

4. SASKATOON/SASKATCHEWAN      CANADA              52.12 -106.63
   18.9 -17.0  358.    68.   14.    58.  0.70          501.
         * 1. BOREAL/MONTANE SHORT-NEEDLED TREES   MI      0.15
         + 2. BOREAL SUMMERGREEN NEEDLE-TREES      TMAX    0.31
           3. BROAD-SUMMERGREEN SMALL TREES        MI      0.00
           4. TALL GRASSES                         MI      0.00
         + 5. SHORT SWARD-GRASSES                  MI      0.29
           6. SUMMERGREEN GIANT-SCRUB              TMIN    0.28
           7. XERIC SUMMERGREEN SHRUBS             TMAX    0.23
           8. BROAD-SUMMERGREEN MESIC SHRUBS       MI      0.00
         + 9. SHORT BUNCH-GRASSES                  TMIN    0.52
          10. NEEDLE-LEAVED EVERGREEN SHRUBS       TMIN    0.29
          11. COLD-WINTER XEROMORPHIC SHRUBS       PMTMAX  0.03
          12. SUMMERGREEN FORBS                    TMAX    0.43
          13. LEAFLESS XEROMORPHIC LARGE-SCRUB     TMIN    0.06
          14. TEMPERATE EVERGREEN DWARF-SHRUBS     MI      0.00
          15. XERIC CUSHION-HERBS                  MI      0.43
          16. XERIC DWARF-SHRUBS                   TMIN    0.06
          17. XERIC THALLOPHYTES                   MULT.   1.00
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Appendix C. Predicted vegetation at the validation sites.

3

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
5. SWIFT CURRENT/SASKATCHEW CANADA	50.28	-107.83
19.0 -12.0 377. 74. 15. 52. 0.71	744.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.15
+ 2. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.30
3. BROAD-SUMMERGREEN SMALL TREES	MI	0.01
4. TALL GRASSES	MI	0.01
5. SUMMERGREEN GIANT-SCRUB	TMAX	0.33
+ 6. SHORT SWARD-GRASSES	MI	0.30
7. XERIC SUMMERGREEN SHRUBS	TMAX	0.24
8. BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.01
+ 9. SHORT BUNCH-GRASSES	TMIN	0.55
10. NEEDLE-LEAVED EVERGREEN SHRUBS	TMIN	0.40
11. COLD-WINTER XEROMORPHIC SHRUBS	PMTMAX	0.15
12. SUMMERGREEN FORBS	TMAX	0.43
13. LEAFLESS XEROMORPHIC LARGE-SCRUB	MI	0.13
14. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.01
15. XERIC CUSHION-HERBS	MI	0.42
16. XERIC DWARF-SHRUBS	MI	0.13
17. XERIC THALLOPHYTES	MULT.	1.00
6. SIOUX LOOKOUT/ONTARIO CANADA	50.10	-91.92
18.0 -18.0 694. 95. 32. 81. 1.44	373.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.36
2. SUMMERGREEN BROAD-LEAVED TREES	TMIN	0.05
3. BOREAL SUMMERGREEN NEEDLE-TREES	MULT.	0.40
4. BOREAL BROAD-SUMMERGREEN TREES	TMIN	0.34
5. BROAD-SUMMERGREEN SMALL TREES	TMIN	0.26
6. TALL GRASSES	TMIN	0.04
7. SHORT SWARD-GRASSES	TMIN	0.43
8. SUMMERGREEN GIANT-SCRUB	TMIN	0.26
9. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
10. SHORT BUNCH-GRASSES	TMIN	0.51
11. NEEDLE-LEAVED EVERGREEN SHRUBS	TMIN	0.27
12. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.0
13. SUMMERGREEN FORBS	TMAX	0.40
14. SUMMERGREEN FERNS	TMIN	0.06
15. TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.05
16. MAT-FORMING THALLOPHYTES	MI	0.45
17. XERIC THALLOPHYTES	MI	0.39

4

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
7. ALBANEL (LAC)/QUEBEC CANADA	51.15	-73.00
17.5 -17.2 775. 100. 32. 97. 1.60	127.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMIN	0.39
2. SUMMERGREEN BROAD-LEAVED TREES	TMIN	0.08
3. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.45
4. BOREAL BROAD-SUMMERGREEN TREES	TMIN	0.37
5. BROAD-SUMMERGREEN SMALL TREES	TMIN	0.27
6. TALL GRASSES	TMIN	0.06
7. SHORT SWARD-GRASSES	TMIN	0.44
8. SUMMERGREEN GIANT-SCRUB	TMIN	0.27
9. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.22
10. SHORT BUNCH-GRASSES	TMIN	0.52
11. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.25
12. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.04
13. SUMMERGREEN FORBS	TMAX	0.38
14. SUMMERGREEN FERNS	TMIN	0.09
15. TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.07
16. MAT-FORMING THALLOPHYTES	MI	0.50
17. XERIC THALLOPHYTES	MI	0.25
8. OLYMPIA/WASHINGTON USA	47.05	-122.88
17.9 4.0 1301. 215. 15. 16. 2.05	21.	
* 1. TEMPERATE NEEDLE-TREES	TMAX	0.32
2. SUB-MEDITERRANEAN NEEDLE-TREES	TMAX	0.28
3. TEMP. BROAD-EVERGREEN SMALL TREES	TMIN	0.15
4. TALL CANE-GRAMINOIDS	TMIN	0.10
5. SHORT BUNCH-GRASSES	MI	0.51
6. SUMMERGREEN FORBS	TMAX	0.44
7. MAT-FORMING THALLOPHYTES	TMAX	0.68
8. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.14
9. DAVIS/CALIFORNIA USA	38.55	-121.73
24.6 7.8 410. 91. 0. 1. 0.49	16.	
* 1. MEDITERRANEAN EVERGREEN SHRUBS	MI	0.09
+ 2. SHORT BUNCH-GRASSES	TMAX	0.58
3. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.19
4. HOT-DESERT EVERGREEN SHRUBS	TMIN	0.07
5. SUMMERGREEN FORBS	TMAX	0.42
+ 6. MEDITERRANEAN DWARF-SHRUBS	TMIN	0.40
+ 7. XERIC CUSHION-SHRUBS	TMAX	0.39
8. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.38
9. BUSH STEM-SUCCULENTS	TMIN	0.26
10. TYPICAL STEM-SUCCULENTS	TMIN	0.03
11. DESERT-GRASSES	MI	0.01
12. XERIC DWARF-SHRUBS	TMAX	0.47
13. XERIC CUSHION-HERBS	TMAX	0.22
14. SUCCULENT FORBS	TMIN	0.11
15. EPHEMERAL DESERT HERBS	MI	0.01
16. XERIC THALLOPHYTES	TMAX	0.58

5

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
10. TANBARK FLAT/CALIFORNIA U.S.A.	34.20	-117.77
23.0 8.6 642. 140. 0. 6. 0.92	853.	
* 1. MEDITERRANEAN BROAD-EVERGREEN TREES	MI	0.13
2. SUB-MEDITERRANEAN NEEDLE-TREES	MI	0.07
3. TALL CANE-GRAMINOIDS	MI	0.24
4. MEDITERRANEAN EVERGREEN SHRUBS	TMIN	0.28
5. DWARF-NEEDLE SMALL TREES	PMTMAX	0.18
6. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.11
+ 7. SHORT BUNCH-GRASSES	TMAX	0.68
8. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.48
9. EVERGREEN GIANT-SCRUB	TMIN	0.03
10. XERIC EVERGREEN TUFT-TREELETS	TMIN	0.03
11. SUMMERGREEN FORBS	TMAX	0.48
12. MEDITERRANEAN DWARF-SHRUBS	MI	0.31
13. BUSH STEM-SUCCULENTS	TMIN	0.29
14. XERIC ROSETTE-SHRUBS	TMAX	0.15
15. BROAD-WINTERGREEN EPIPHYTES	TMIN	0.31
16. SUCCULENT FORBS	TMIN	0.14
17. XERIC CUSHION-HERBS	MI	0.10
18. XERIC THALLOPHYTES	TMAX	0.68
11. WEST YELLOWSTONE/MONTANA USA	44.50	-111.08
15.2 -11.5 570. 72. 25. 39. 1.29	2035.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.38
2. SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.01
3. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.32
4. BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.18
5. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.24
6. TALL GRASSES	TMIN	0.18
7. SHORT SWARD-GRASSES	PMTMAX	0.35
8. SUMMERGREEN GIANT-SCRUB	TMAX	0.19
9. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.07
10. SHORT BUNCH-GRASSES	TMIN	0.55
11. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.30
12. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.23
13. SUMMERGREEN FORBS	TMAX	0.30
14. TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.22
15. MAT-FORMING THALLOPHYTES	MI	0.38
16. XERIC THALLOPHYTES	MI	0.56
12. LOGAN/UTAH U.S.A.	41.73	-111.82
22.8 -4.4 418. 50. 13. 14. 0.67	1455.	
1. TEMPERATE NEEDLE-TREES	MI	0.03
2. XERIC SUMMERGREEN SHRUBS	PMTMAX	0.26
3. DWARF-NEEDLE SMALL TREES	TMIN	0.03
+ 4. SHORT BUNCH-GRASSES	TMIN	0.62
5. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.41
+ 6. COLD-WINTER XEROMORPHIC SHRUBS	MI	0.34
7. SUMMERGREEN FORBS	TMAX	0.49
8. LEAFLESS XEROMORPHIC LARGE-SCRUB	MI	0.19
9. XERIC CUSHION-HERBS	TMAX	0.29
10. XERIC DWARF-SHRUBS	MI	0.19
11. XERIC THALLOPHYTES	TMAX	0.69

6

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
13. CODY/WYOMING U.S.A.	44.53	-109.07
20.8 -4.5 235. 39. 9. 21. 0.44	1519.	
* 1. XERIC SUMMERGREEN SHRUBS	TMAX	0.32
+ 2. SHORT BUNCH-GRASSES	MI	0.56
+ 3. COLD-WINTER XEROMORPHIC SHRUBS	TMAX	0.34
4. SUMMERGREEN FORBS	TMAX	0.47
5. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.25
6. DESERT-GRASSES	MI	0.14
7. XERIC CUSHION-HERBS	TMAX	0.40
8. XERIC DWARF-SHRUBS	TMIN	0.31
9. EPHEMERAL DESERT HERBS	MI	0.14
10. XERIC THALLOPHYTES	TMAX	0.84
14. FLAGSTAFF/ARIZONA USA	35.20	-111.65
18.0 -2.0 554. 80. 10. 70. 1.04	2070.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.36
* 2. TEMPERATE NEEDLE-TREES	TMIN	0.19
* 3. SUMMERGREEN BROAD-LEAVED TREES	MI	0.13
4. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.40
5. BOREAL BROAD-SUMMERGREEN TREES	MI	0.23
6. TALL GRASSES	MI	0.33
7. BROAD-SUMMERGREEN SMALL TREES	MI	0.33
8. SHORT SWARD-GRASSES	MI	0.52
9. SUMMERGREEN GIANT-SCRUB	TMAX	0.30
10. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.25
11. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.0
12. DWARF-NEEDLE SMALL TREES	TMAX	0.0
13. SHORT BUNCH-GRASSES	TMIN	0.64
14. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.40
15. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.0
16. SUMMERGREEN FORBS	TMAX	0.40
17. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.33
18. TEMPERATE EVERGREEN FORBS	TMIN	0.13
19. MAT-FORMING THALLOPHYTES	MI	0.23
20. BROAD-SUMMERGREEN VINES	MI	0.04
21. XERIC THALLOPHYTES	MI	0.93
15. PHOENIX(AIRPORT)/ARIZONA USA	33.50	-112.00
31.8 9.8 197. 27. 1. 27. 0.18	339.	
1. HOT-DESERT EVERGREEN SHRUBS	TMIN	0.16
2. ARBORESCENT STEM-SUCCULENTS	TMIN	0.08
3. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.33
4. BUSH STEM-SUCCULENTS	TMAX	0.27
5. XERIC ROSETTE-SHRUBS	TMIN	0.25
+ 6. DESERT-GRASSES	TMAX	0.24
7. TYPICAL STEM-SUCCULENTS	TMIN	0.12
8. XERIC DWARF-SHRUBS	TMAX	0.29
9. EPHEMERAL DESERT HERBS	TMAX	0.24
10. SUCCULENT FORBS	TMIN	0.19
11. XERIC THALLOPHYTES	TMAX	0.24

Appendix C. Predicted vegetation at the validation sites.

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
16. TUCSON/ARIZONA USA	32.22	-110.97
30.0 10.0 293. 62. 5. 42. 0.29	739.	
1. XERIC SUMMERGREEN SHRUBS	MI	0.14
2. RAINGREEN THORN-SCRUB	TMIN	0.09
+ 3. SHORT BUNCH-GRASSES	TMAX	0.31
4. HOT-DESERT EVERGREEN SHRUBS	TMIN	0.17
5. EVERGREEN GIANT-SCRUB	TMIN	0.10
6. XERIC EVERGREEN TUFT-TREELETS	TMIN	0.09
7. ARBORESCENT STEM-SUCCULENTS	TMIN	0.09
8. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.40
9. BUSH STEM-SUCCULENTS	TMAX	0.33
+10. DESERT-GRASSES	TMAX	0.31
11. XERIC ROSETTE-SHRUBS	TMIN	0.26
12. SUMMERGREEN FORBS	TMAX	0.20
13. MEDITERRANEAN DWARF-SHRUBS	MULT.	0.18
14. XERIC CUSHION-SHRUBS	TMAX	0.17
15. TYPICAL STEM-SUCCULENTS	TMIN	0.13
16. RAINGREEN FORBS	TMIN	0.13
17. SCLEROPHYLLOUS GRASSES	TMIN	0.0
18. XERIC DWARF-SHRUBS	TMAX	0.36
19. EPHEMERAL DESERT HERBS	TMAX	0.31
20. SUCCULENT FORBS	TMIN	0.20
21. BROAD-RAINGREEN VINES	TMIN	0.0
22. XERIC CUSHION-HERBS	TMAX	0.0
23. XERIC THALLOPHYTES	TMAX	0.31
17. SANTA FE/NEW MEXICO USA	35.70	-106.95
20.0 -5.0 365. 63. 18. 56. 0.60	1929.	
* 1. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.20
2. SUMMERGREEN GIANT-SCRUB	MI	0.34
3. XERIC SUMMERGREEN SHRUBS	TMAX	0.29
4. SHORT SWARD-GRASSES	MI	0.17
5. DWARF-NEEDLE SMALL TREES	TMIN	0.0
+ 6. SHORT BUNCH-GRASSES	TMIN	0.61
7. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.34
8. COLD-WINTER XEROMORPHIC SHRUBS	PMTMAX	0.07
9. SUMMERGREEN FORBS	TMAX	0.45
10. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.23
11. XERIC CUSHION-HERBS	TMAX	0.45
12. XERIC DWARF-SHRUBS	TMIN	0.30
13. XERIC THALLOPHYTES	TMAX	0.91

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
18. COLORADO SPRINGS/COLORAD USA	38.83	-104.82
20.0 -1.0 363. 70. 6. 57. 0.64	1855.	
1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.06
2. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.20
3. SUMMERGREEN GIANT-SCRUB	TMAX	0.36
4. XERIC SUMMERGREEN SHRUBS	TMAX	0.29
5. SHORT SWARD-GRASSES	MI	0.22
6. DWARF-NEEDLE SMALL TREES	TMAX	0.17
7. TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.05
+ 8. SHORT BUNCH-GRASSES	TMIN	0.66
9. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.38
10. COLD-WINTER XEROMORPHIC SHRUBS	PMTMAX	0.06
11. SUMMERGREEN FORBS	TMAX	0.45
12. LEAFLESS XEROMORPHIC LARGE-SCRUB	TMAX	0.23
13. XERIC CUSHION-HERBS	TMAX	0.45
14. XERIC DWARF-SHRUBS	MI	0.26
15. XERIC THALLOPHYTES	TMAX	0.91
19. CUSTER/SOUTH DAKOTA U.S.A.	43.77	-103.60
17.9 -6.1 455. 79. 9. 69. 0.94	1622.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	MI	0.36
+ 2. BOREAL SUMMERGREEN NEEDLE-TREES	TMAX	0.41
3. TALL GRASSES	MI	0.25
4. BROAD-SUMMERGREEN SMALL TREES	MI	0.25
+ 5. SHORT SWARD-GRASSES	MI	0.47
6. SUMMERGREEN GIANT-SCRUB	TMAX	0.30
7. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.24
8. XERIC SUMMERGREEN SHRUBS	MI	0.09
+ 9. SHORT BUNCH-GRASSES	TMIN	0.60
10. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.40
11. SUMMERGREEN FORBS	TMAX	0.40
12. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.25
13. MAT-FORMING THALLOPHYTES	MI	0.15
14. XERIC CUSHION-HERBS	MI	0.08
15. XERIC THALLOPHYTES	MULT.	1.00
20. OELRICHS/SOUTH DAKOTA U.S.A.	43.18	-103.23
23.3 -5.5 454. 80. 14. 64. 0.74	1017.	
1. TEMPERATE NEEDLE-TREES	TMIN	0.02
2. TALL GRASSES	MI	0.05
3. BROAD-SUMMERGREEN SMALL TREES	MI	0.05
4. SUMMERGREEN GIANT-SCRUB	MI	0.46
+ 5. XERIC SUMMERGREEN SHRUBS	MI	0.36
+ 6. SHORT SWARD-GRASSES	MI	0.33
7. BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.05
+ 8. SHORT BUNCH-GRASSES	TMIN	0.61
9. NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.46
10. SUMMERGREEN FORBS	TMAX	0.47
11. LEAFLESS XEROMORPHIC LARGE-SCRUB	MI	0.08
12. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.04
13. XERIC CUSHION-HERBS	TMAX	0.27
14. XERIC DWARF-SHRUBS	MI	0.08
15. XERIC THALLOPHYTES	TMAX	0.66

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                                                        9
    LOCATION                                  LAT    LONG
TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI         ELEV

21. OKLAHOMA CITY/OKLAHOMA      USA           35.47  -97.53
 27.3   2.6  802.  125.   27.    74.  0.93      383.
         1. SUMMERGREEN BROAD-LEAVED TREES    MI     0.03
         2. SUB-MEDITERRANEAN NEEDLE-TREES    TMAX   0.05
       + 3. TALL GRASSES                      MI     0.25
         4. BROAD-SUMMERGREEN SMALL TREES     TMAX   0.14
         5. TALL CANE-GRAMINOIDS              TMIN   0.06
         6. TEMP. BROAD-EVERGREEN SMALL TREES TMIN   0.05
         7. SUMMERGREEN GIANT-SCRUB           TMAX   0.33
       + 8. SHORT SWARD-GRASSES               TMAX   0.26
         9. DWARF-NEEDLE SMALL TREES          TMAX   0.23
        10. TEMPERATE BROAD-EVERGREEN SHRUBS  TMAX   0.18
        11. BROAD-SUMMERGREEN MESIC SHRUBS    TMAX   0.17
       +12. SHORT BUNCH-GRASSES               TMAX   0.43
        13. NEEDLE-LEAVED EVERGREEN SHRUBS    TMAX   0.31
        14. SUMMERGREEN FORBS                 TMAX   0.31
        15. BUSH STEM-SUCCULENTS              TMIN   0.09
        16. TEMPERATE EVERGREEN FORBS         MI     0.03
        17. BROAD-WINTERGREEN EPIPHYTES       TMIN   0.09
        18. MAT-FORMING THALLOPHYTES          TMAX   0.09
        19. XERIC CUSHION-HERBS               MI     0.09
        20. XERIC THALLOPHYTES                TMAX   0.43

22. BARTLESVILLE/OKLAHOMA      U.S.A.         36.75  -96.00
 27.8   2.2  921.  127.   39.    75.  1.08      218.
       * 1. SUMMERGREEN BROAD-LEAVED TREES    TMAX   0.15
         2. TALL GRASSES                      TMAX   0.29
         3. BROAD-SUMMERGREEN SMALL TREES     TMAX   0.12
         4. TALL CANE-GRAMINOIDS              TMIN   0.04
         5. SUMMERGREEN GIANT-SCRUB           TMAX   0.31
         6. SHORT SWARD-GRASSES               TMAX   0.24
         7. DWARF-NEEDLE SMALL TREES          TMAX   0.18
         8. TEMPERATE BROAD-EVERGREEN SHRUBS  TMAX   0.15
         9. BROAD-SUMMERGREEN MESIC SHRUBS    TMAX   0.14
        10. SHORT BUNCH-GRASSES               TMAX   0.41
        11. NEEDLE-LEAVED EVERGREEN SHRUBS    TMAX   0.29
        12. SUMMERGREEN FORBS                 TMAX   0.29
        13. TEMPERATE EVERGREEN FORBS         TMAX   0.09
        14. BUSH STEM-SUCCULENTS              TMIN   0.07
        15. BROAD-WINTERGREEN EPIPHYTES       TMIN   0.08
        16. MAT-FORMING THALLOPHYTES          TMAX   0.07
        17. BROAD-SUMMERGREEN VINES           MI     0.07
        18. XERIC THALLOPHYTES                TMAX   0.41
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                                                        10
    LOCATION                                  LAT    LONG
TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI         ELEV

23. SOUTH BEND/INDIANA          USA           41.68  -86.25
 23.0  -3.5  904.   99.   40.    78.  1.42      221.
       * 1. SUMMERGREEN BROAD-LEAVED TREES    MI     0.37
       * 2. TEMPERATE NEEDLE-TREES            TMAX   0.11
         3. BOREAL BROAD-SUMMERGREEN TREES    TMAX   0.17
         4. BROAD-SUMMERGREEN SMALL TREES     TMAX   0.37
         5. TALL GRASSES                      TMIN   0.34
         6. SHORT SWARD-GRASSES               TMAX   0.48
         7. SUMMERGREEN GIANT-SCRUB           TMAX   0.48
         8. BROAD-SUMMERGREEN MESIC SHRUBS    TMAX   0.44
         9. DWARF-NEEDLE SMALL TREES          TMIN   0.07
        10. BROAD-ERICOID EVERGREEN SHRUBS    MI     0.01
        11. SHORT BUNCH-GRASSES               TMIN   0.63
        12. NEEDLE-LEAVED EVERGREEN SHRUBS    MI     0.41
        13. SUMMERGREEN FORBS                 TMAX   0.48
        14. SUMMERGREEN FERNS                 MI     0.23
        15. TEMPERATE EVERGREEN FORBS         TMIN   0.07
        16. TEMPERATE EVERGREEN DWARF-SHRUBS  TMAX   0.06
        17. MAT-FORMING THALLOPHYTES          TMAX   0.28
        18. BROAD-SUMMERGREEN VINES           TMIN   0.09
        19. XERIC THALLOPHYTES                MI     0.41

24. COLUMBUS/OHIO               USA           39.95  -83.00
 23.0  -1.5  963.  102.   57.    95.  1.43      243.
       * 1. SUMMERGREEN BROAD-LEAVED TREES    MI     0.37
       * 2. TEMPERATE NEEDLE-TREES            TMAX   0.11
         3. BOREAL BROAD-SUMMERGREEN TREES    TMAX   0.17
         4. TALL GRASSES                      TMIN   0.39
         5. BROAD-SUMMERGREEN SMALL TREES     TMAX   0.37
         6. SHORT SWARD-GRASSES               TMAX   0.48
         7. SUMMERGREEN GIANT-SCRUB           TMAX   0.48
         8. BROAD-SUMMERGREEN MESIC SHRUBS    TMAX   0.44
         9. DWARF-NEEDLE SMALL TREES          TMIN   0.15
        10. TEMPERATE BROAD-EVERGREEN SHRUBS  TMIN   0.02
        11. BROAD-ERICOID EVERGREEN SHRUBS    MI     0.02
        12. SHORT BUNCH-GRASSES               TMIN   0.65
        13. NEEDLE-LEAVED EVERGREEN SHRUBS    MI     0.40
        14. SUMMERGREEN FORBS                 TMAX   0.48
        15. SUMMERGREEN FERNS                 MI     0.23
        16. TEMPERATE EVERGREEN FORBS         TMIN   0.15
        17. TEMPERATE EVERGREEN DWARF-SHRUBS  TMAX   0.06
        18. MAT-FORMING THALLOPHYTES          TMAX   0.28
        19. BROAD-SUMMERGREEN VINES           TMIN   0.21
        20. XERIC THALLOPHYTES                MI     0.40
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Appendix C. Predicted vegetation at the validation sites.

11

LOCATION	TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	LAT	LONG	ELEV
25. BAR HARBOR/MAINE U.S.A.	19.2	-5.0	1219.	125.	82.	84.	2.20	44.38	-68.20	9.

* 1.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.28
* 2.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.25
3.	TEMPERATE NEEDLE-TREES	TMIN	0.05
4.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.48
5.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.43
6.	TALL GRASSES	TMIN	0.31
7.	SHORT SWARD-GRASSES	TMIN	0.60
8.	SUMMERGREEN GIANT-SCRUB	TMAX	0.37
9.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.32
10.	BROAD-ERICOID EVERGREEN SHRUBS	TMIN	0.25
11.	DWARF-NEEDLE SMALL TREES	TMIN	0.0
12.	SHORT BUNCH-GRASSES	MI	0.40
13.	SUMMERGREEN FORBS	TMAX	0.48
14.	SUMMERGREEN FERNS	PMTMAX	0.40
15.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.27
16.	TEMPERATE EVERGREEN FORBS	TMIN	0.0
17.	MAT-FORMING THALLOPHYTES	TMAX	0.56
18.	BROAD-SUMMERGREEN VINES	TMIN	0.0

LOCATION	TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	LAT	LONG	ELEV
26. TRENTON/NEW JERSEY USA	24.0	0.0	1013.	110.	68.	107.	1.46	40.22	-74.75	17.

* 1.	SUMMERGREEN BROAD-LEAVED TREES	MI	0.39
2.	TEMPERATE NEEDLE-TREES	TMAX	0.0
3.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.08
4.	TALL GRASSES	TMIN	0.42
5.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.32
6.	SUMMERGREEN GIANT-SCRUB	TMAX	0.48
7.	SHORT SWARD-GRASSES	TMAX	0.42
8.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.38
9.	DWARF-NEEDLE SMALL TREES	TMIN	0.22
10.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMIN	0.09
11.	BROAD-ERICOID EVERGREEN SHRUBS	MI	0.04
12.	SHORT BUNCH-GRASSES	TMAX	0.62
13.	NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.37
14.	SUMMERGREEN FORBS	TMAX	0.44
15.	SUMMERGREEN FERNS	MI	0.25
16.	TEMPERATE EVERGREEN FORBS	TMIN	0.22
17.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.0
18.	BUSH STEM-SUCCULENTS	TMIN	0.0
19.	BROAD-SUMMERGREEN VINES	TMIN	0.29
20.	MAT-FORMING THALLOPHYTES	TMAX	0.23
21.	BROAD-WINTERGREEN EPIPHYTES	TMIN	0.0
22.	XERIC THALLOPHYTES	MI	0.37

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LOCATION	TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	LAT	LONG	ELEV
27. MT.MITCHELL (2 SSW)/N.CA U.S.A.	15.2	-4.0	1736.	173.	92.	156.	3.56	35.73	-82.28	1989.

* 1.	BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.38
2.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.01
3.	BOREAL BROAD-SUMMERGREEN TREES	TMAX	0.18
4.	TALL GRASSES	TMIN	0.33
5.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.28
6.	SHORT SWARD-GRASSES	TMIN	0.61
7.	SUMMERGREEN GIANT-SCRUB	TMAX	0.21
8.	BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.18
9.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.08
10.	SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.23
11.	TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.42
12.	SUMMERGREEN FERNS	TMAX	0.34
13.	SUMMERGREEN FORBS	TMAX	0.34
14.	TEMPERATE EVERGREEN FORBS	TMIN	0.04
15.	MAT-FORMING THALLOPHYTES	MI	0.82
16.	BROAD-SUMMERGREEN VINES	TMAX	0.01

LOCATION	TMAX	TMIN	PRCP	PMAX	PMIN	PMTMAX	MI	LAT	LONG	ELEV
28. CHARLESTON/SOUTH CAROLIN USA	27.5	10.6	1168.	200.	51.	200.	1.20	32.80	-79.95	3.

* 1.	WARM-TEMPERATE BROAD-EVERGREEN TREES	TMAX	0.25
* 2.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.17
* 3.	HELIOPHILIC LONG-NEEDLED TREES	MI	0.17
4.	TEMPERATE BROAD-RAINFOREST TREES	TMAX	0.03
5.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.16
6.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.12
7.	SWAMP SUMMERGREEN NEEDLE-TREES	TMAX	0.08
8.	TALL GRASSES	TMAX	0.30
9.	TALL CANE-GRAMINOIDS	TMAX	0.30
10.	TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.22
11.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.13
12.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.13
13.	ARBORESCENT GRASSES	TMAX	0.13
14.	SUMMERGREEN GIANT-SCRUB	TMAX	0.33
15.	SHORT SWARD-GRASSES	TMAX	0.25
16.	TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.19
17.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.17
18.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.16
19.	PALMIFORM TUFT-TREELETS	TMIN	0.03
20.	DWARF-NEEDLE SMALL TREES	PMTMAX	0.0
21.	SHORT BUNCH-GRASSES	TMAX	0.42
22.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.30
23.	EVERGREEN GIANT-SCRUB	TMIN	0.13
24.	PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.12
25.	SUMMERGREEN FORBS	TMAX	0.30
26.	BUSH STEM-SUCCULENTS	MI	0.25
27.	TEMPERATE EVERGREEN FORBS	TMAX	0.10
28.	SUMMERGREEN FERNS	MI	0.08
29.	BROAD-EVERGREEN VINES	TMAX	0.20
30.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.18
31.	NARROW-LEAVED EPIPHYTES	MI	0.17
32.	BROAD-SUMMERGREEN VINES	MI	0.17
33.	MAT-FORMING THALLOPHYTES	TMAX	0.08
34.	XERIC THALLOPHYTES	TMAX	0.42

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LOCATION / TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
29. SAVANNAH/GEORGIA USA		32.07	-81.08
27.5 10.4 1162. 180. 40. 180. 1.20		15.	
* 1.	WARM-TEMPERATE BROAD-EVERGREEN TREES	TMAX	0.25
* 2.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.17
* 3.	HELIOPHILIC LONG-NEEDLED TREES	MI	0.17
4.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.15
5.	TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.11
6.	SWAMP SUMMERGREEN NEEDLE-TREES	TMAX	0.08
7.	TALL GRASSES	TMAX	0.30
8.	TALL CANE-GRAMINOIDS	TMAX	0.30
9.	TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.22
10.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.13
11.	ARBORESCENT GRASSES	TMAX	0.13
12.	TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.12
13.	SUMMERGREEN GIANT-SCRUB	TMAX	0.33
14.	SHORT SWARD-GRASSES	TMAX	0.25
15.	TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.18
16.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.17
17.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.16
18.	DWARF-NEEDLE SMALL TREES	PMTMAX	0.11
19.	PALMIFORM TUFT-TREELETS	TMIN	0.02
20.	SHORT BUNCH-GRASSES	TMAX	0.42
21.	NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.30
22.	EVERGREEN GIANT-SCRUB	TMIN	0.12
23.	PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.11
24.	SUMMERGREEN FORBS	TMAX	0.30
25.	BUSH STEM-SUCCULENTS	MI	0.25
26.	RAINGREEN FORBS	TMIN	0.15
27.	TEMPERATE EVERGREEN FORBS	TMAX	0.10
28.	SUMMERGREEN FERNS	MI	0.08
29.	XERIC ROSETTE-SHRUBS	MI	0.00
30.	BROAD-EVERGREEN VINES	TMAX	0.20
31.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.18
32.	NARROW-LEAVED EPIPHYTES	MI	0.17
33.	BROAD-SUMMERGREEN VINES	MI	0.17
34.	MAT-FORMING THALLOPHYTES	TMAX	0.08
35.	SUCCULENT FORBS	MI	0.00
36.	XERIC THALLOPHYTES	TMAX	0.42

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LOCATION / TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
30. BIRMINGHAM/ALABAMA USA		33.52	-86.82
26.5 7.5 1353. 155. 69. 145. 1.57		182.	
* 1.	HELIOPHILIC LONG-NEEDLED TREES	TMIN	0.24
* 2.	SUMMERGREEN BROAD-LEAVED TREES	TMAX	0.23
* 3.	TEMPERATE BROAD-RAINFOREST TREES	TMAX	0.10
4.	WARM-TEMPERATE BROAD-EVERGREEN TREES	TMIN	0.04
5.	SWAMP SUMMERGREEN NEEDLE-TREES	TMAX	0.25
6.	TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.02
7.	TALL GRASSES	TMAX	0.34
8.	TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.27
9.	TALL CANE-GRAMINOIDS	TMIN	0.22
10.	BROAD-SUMMERGREEN SMALL TREES	TMAX	0.18
11.	ARBORESCENT GRASSES	TMIN	0.17
12.	SUMMERGREEN GIANT-SCRUB	TMAX	0.37
13.	SHORT SWARD-GRASSES	TMAX	0.30
14.	DWARF-NEEDLE SMALL TREES	TMAX	0.29
15.	TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.23
16.	BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.22
17.	TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.06
18.	SHORT BUNCH-GRASSES	TMAX	0.47
19.	NEEDLE-LEAVED EVERGREEN SHRUBS	MI	0.27
20.	SUMMERGREEN FORBS	TMAX	0.34
21.	SUMMERGREEN FERNS	TMAX	0.17
22.	TEMPERATE EVERGREEN FORBS	TMAX	0.14
23.	BROAD-WINTERGREEN EPIPHYTES	TMAX	0.25
24.	BROAD-SUMMERGREEN VINES	TMAX	0.23
25.	BROAD-EVERGREEN VINES	TMIN	0.13
26.	MAT-FORMING THALLOPHYTES	TMAX	0.12
27.	XERIC THALLOPHYTES	MI	0.27

Appendix C. Predicted vegetation at the validation sites.

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                                                         15
      LOCATION                                     LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

31. XILITLA                MEXICO                 21.33  -98.57
    24.0  15.3 2537.  760.   38.  218.  2.58        1035.
          * 1. WARM-TEMPERATE BROAD-EVERGREEN TREES  TMAX    0.40
          * 2. SUMMERGREEN BROAD-LEAVED TREES        TMAX    0.40
          * 3. TROPICAL LINEAR-LEAVED TREES          TMAX    0.31
            4. TROPICAL MONTANE RAINFOREST TREES     TMAX    0.0
            5. TROPICAL EVERGREEN MICROPHYLL-TREES   TMIN    0.36
            6. SWAMP SUMMERGREEN NEEDLE-TREES        TMAX    0.33
            7. PALMIFORM TUFT-TREES                  TMIN    0.23
            8. TALL GRASSES                          TMAX    0.46
            9. TROPICAL BROAD-EVERGREEN SMALL TREES  TMIN    0.36
           10. BROAD-SUMMERGREEN SMALL TREES         TMAX    0.32
           11. ARBORESCENT GRASSES                   TMAX    0.30
           12. TROPICAL BROAD-EVERGREEN LIANAS       TMIN    0.26
           13. TALL CANE-GRAMINOIDS                  MI      0.18
           14. SUMMERGREEN GIANT-SCRUB               TMAX    0.48
           15. SHORT SWARD-GRASSES                   TMAX    0.46
           16. TEMPERATE BROAD-EVERGREEN SHRUBS      TMAX    0.40
           17. BROAD-SUMMERGREEN MESIC SHRUBS        TMAX    0.38
           18. TROPICAL BROAD-EVERGREEN SHRUBS       TMAX    0.36
           19. PALMIFORM TUFT-TREELETS               TMIN    0.26
           20. PALMIFORM MESIC ROSETTE-SHRUBS        TMIN    0.33
           21. SHORT BUNCH-GRASSES                   MI      0.18
           22. TROPICAL EVERGREEN FORBS              TMAX    0.46
           23. RAINGREEN FORBS                       TMIN    0.36
           24. EVERGREEN FERNS                       TMAX    0.30
           25. TEMPERATE EVERGREEN FORBS             TMAX    0.25
           26. TEMPERATE EVERGREEN DWARF-SHRUBS      TMAX    0.0
           27. BROAD-WINTERGREEN EPIPHYTES           TMAX    0.43
           28. BROAD-EVERGREEN VINES                 TMAX    0.36
           29. NARROW-LEAVED EPIPHYTES               TMAX    0.33
           30. TROPICAL BROAD-EVERGREEN EPIPHYTES    TMIN    0.26
           31. MAT-FORMING THALLOPHYTES              TMAX    0.25

32. MAZATLAN               MEXICO                 23.22 -106.42
    27.5  19.8  850.  270.    0.  141.  0.70          78.
          * 1. TROPICAL EVERGREEN SCLEROPHYLL TREES  MI      0.29
            2. XERIC RAINGREEN TREES                 TMAX    0.22
            3. BROAD-RAINGREEN SMALL TREES           TMAX    0.38
          + 4. RAINGREEN THORN-SCRUB                 MI      0.44
          + 5. XERIC EVERGREEN TUFT-TREELETS         MI      0.44
          + 6. SHORT BUNCH-GRASSES                   TMAX    0.42
            7. EVERGREEN GIANT-SCRUB                 TMAX    0.38
            8. BUSH STEM-SUCCULENTS                  TMAX    0.42
            9. RAINGREEN FORBS                       TMAX    0.30
           10. LEAF-SUCCULENT EVERGREEN SHRUBS       MI      0.16
           11. BROAD-RAINGREEN VINES                 TMAX    0.38
           12. BROAD-WINTERGREEN EPIPHYTES           MI      0.14
           13. XERIC CUSHION-HERBS                   TMAX    0.10
           14. XERIC THALLOPHYTES                    TMAX    0.42
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                                                         16
      LOCATION                                     LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

33. QUIBDO                COLOMBIA                 5.70  -76.67
    27.5  27.010545. 1115.  540.  950.  6.10          43.
          * 1. TROPICAL RAINFOREST TREES             TMAX    0.25
            2. PALMIFORM TUFT-TREES                  TMAX    0.48
            3. TROPICAL EVERGREEN MICROPHYLL-TREES   TMAX    0.26
            4. TROPICAL BROAD-EVERGREEN SMALL TREES  TMAX    0.26
            5. TROPICAL BROAD-EVERGREEN LIANAS       TMAX    0.21
            6. PALMIFORM TUFT-TREELETS               TMAX    0.36
            7. TROPICAL BROAD-EVERGREEN SHRUBS       TMAX    0.20
            8. PALMIFORM MESIC ROSETTE-SHRUBS        TMAX    0.38
            9. TROPICAL EVERGREEN FORBS              TMAX    0.27
           10. EVERGREEN FERNS                       TMAX    0.13
           11. BROAD-EVERGREEN VINES                 TMAX    0.20
           12. NARROW-LEAVED EPIPHYTES               TMAX    0.19
           13. BROAD-WINTERGREEN EPIPHYTES           TMAX    0.18
           14. TROPICAL BROAD-EVERGREEN EPIPHYTES    TMAX    0.14
           15. MAT-FORMING THALLOPHYTES              TMAX    0.09

34. BARINAS               VENEZUEL                 8.63  -70.20
    27.0  26.0 1863.  350.   11.  305.  1.14         180.
          * 1. TROPICAL RAINFOREST TREES             MI      0.21
            2. MONSOON BROAD-RAINGREEN TREES         MI      0.21
            3. TROPICAL EVERGREEN SCLEROPHYLL TREES  TMAX    0.40
            4. PALMIFORM TUFT-TREES                  MI      0.39
            5. TROPICAL EVERGREEN MICROPHYLL-TREES   TMAX    0.29
            6. BROAD-RAINGREEN SMALL TREES           TMAX    0.40
            7. TALL GRASSES                          TMAX    0.32
            8. TALL CANE-GRAMINOIDS                  TMAX    0.32
            9. TROPICAL BROAD-EVERGREEN DWARF-TREES  MI      0.30
           10. TROPICAL BROAD-EVERGREEN SMALL TREES  MI      0.21
           11. TROPICAL BROAD-EVERGREEN LIANAS       MI      0.13
           12. PALMIFORM TUFT-TREELETS               TMAX    0.38
           13. TROPICAL BROAD-EVERGREEN SHRUBS       TMAX    0.23
           14. SHORT BUNCH-GRASSES                   TMAX    0.45
           15. EVERGREEN GIANT-SCRUB                 TMAX    0.42
           16. PALMIFORM MESIC ROSETTE-SHRUBS        MI      0.21
           17. RAINGREEN FORBS                       TMAX    0.32
           18. TROPICAL EVERGREEN FORBS              MI      0.21
           19. BROAD-RAINGREEN VINES                 TMAX    0.40
           20. BROAD-EVERGREEN VINES                 MI      0.21
           21. BROAD-WINTERGREEN EPIPHYTES           TMAX    0.21
           22. NARROW-LEAVED EPIPHYTES               MI      0.13
           23. MAT-FORMING THALLOPHYTES              TMAX    0.10
           24. TROPICAL BROAD-EVERGREEN EPIPHYTES    MI      0.04
           25. XERIC THALLOPHYTES                    TMAX    0.45
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Appendix C. Predicted vegetation at the validation sites.

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT LONG ELEV	
35. OBIDOS	BRASIL	-1.92	-55.52
27.0 25.7 1680. 315. 20. 60. 1.12		24.	
* 1. TROPICAL RAINFOREST TREES		MI	0.20
2. MONSOON BROAD-RAINGREEN TREES		MI	0.20
3. TROPICAL EVERGREEN SCLEROPHYLL TREES		TMAX	0.40
4. PALMIFORM TUFT-TREES		MI	0.38
5. TROPICAL EVERGREEN MICROPHYLL-TREES		TMAX	0.29
6. BROAD-RAINGREEN SMALL TREES		TMAX	0.40
7. TALL GRASSES		TMAX	0.32
8. TALL CANE-GRAMINOIDS		TMAX	0.32
9. TROPICAL BROAD-EVERGREEN SMALL TREES		MI	0.20
10. TROPICAL BROAD-EVERGREEN DWARF-TREES		PMTMAX	0.17
11. TROPICAL BROAD-EVERGREEN LIANAS		MI	0.11
12. PALMIFORM TUFT-TREELETS		MI	0.38
13. TROPICAL BROAD-EVERGREEN SHRUBS		TMAX	0.23
14. SHORT BUNCH-GRASSES		TMAX	0.45
15. EVERGREEN GIANT-SCRUB		TMAX	0.42
16. PALMIFORM MESIC ROSETTE-SHRUBS		MI	0.20
17. RAINGREEN FORBS		TMAX	0.32
18. TROPICAL EVERGREEN FORBS		MI	0.20
19. BROAD-RAINGREEN VINES		TMAX	0.40
20. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.21
21. BROAD-EVERGREEN VINES		MI	0.20
22. NARROW-LEAVED EPIPHYTES		MI	0.11
23. MAT-FORMING THALLOPHYTES		TMAX	0.10
24. TROPICAL BROAD-EVERGREEN EPIPHYTES		MI	0.02
25. XERIC THALLOPHYTES		TMAX	0.45
36. QUIXERAMOBIM	BRASIL	-5.20	-39.28
28.7 27.0 747. 192. 0. 70. 0.43		199.	
* 1. XERIC RAINGREEN TREES		MI	0.19
2. BROAD-RAINGREEN SMALL TREES		TMAX	0.32
+ 3. RAINGREEN THORN-SCRUB		TMAX	0.45
+ 4. ARBORESCENT STEM-SUCCULENTS		TMAX	0.37
+ 5. XERIC EVERGREEN TUFT-TREELETS		TMAX	0.37
6. SHORT BUNCH-GRASSES		TMAX	0.37
7. EVERGREEN GIANT-SCRUB		TMAX	0.28
8. XERIC ROSETTE-SHRUBS		TMAX	0.43
9. TYPICAL STEM-SUCCULENTS		MI	0.41
10. BUSH STEM-SUCCULENTS		TMAX	0.38
11. RAINGREEN FORBS		TMAX	0.25
12. DESERT-GRASSES		MI	0.17
13. SUCCULENT FORBS		TMAX	0.49
14. BROAD-RAINGREEN VINES		TMAX	0.32
15. XERIC THALLOPHYTES		TMAX	0.37

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT LONG ELEV	
37. BELO HORIZONTE	BRASIL	-19.92	-43.93
22.4 16.0 1534. 330. 9. 303. 1.72		857.	
* 1. TROPICAL LINEAR-LEAVED TREES		MI	0.42
* 2. MONTANE BROAD-RAINGREEN TREES		TMAX	0.26
* 3. TROPICAL MONTANE RAINFOREST TREES		TMAX	0.18
4. TROPICAL EVERGREEN MICROPHYLL-TREES		TMIN	0.39
5. TROPICAL EVERGREEN SCLEROPHYLL TREES		TMIN	0.36
6. PALMIFORM TUFT-TREES		TMIN	0.26
7. TALL CANE-GRAMINOIDS		TMAX	0.51
8. TALL GRASSES		TMAX	0.51
9. TROPICAL BROAD-EVERGREEN SMALL TREES		TMIN	0.40
10. ARBORESCENT GRASSES		TMAX	0.38
11. BROAD-RAINGREEN SMALL TREES		TMIN	0.36
12. TROPICAL BROAD-EVERGREEN LIANAS		TMIN	0.30
13. TROPICAL BROAD-EVERGREEN DWARF-TREES		TMIN	0.07
14. SHORT SWARD-GRASSES		TMAX	0.52
15. TEMPERATE BROAD-EVERGREEN SHRUBS		TMAX	0.49
16. TROPICAL BROAD-EVERGREEN SHRUBS		TMIN	0.42
17. PALMIFORM TUFT-TREELETS		TMIN	0.30
18. SHORT BUNCH-GRASSES		TMAX	0.72
19. PALMIFORM MESIC ROSETTE-SHRUBS		TMIN	0.36
20. EVERGREEN GIANT-SCRUB		MI	0.16
21. TROPICAL EVERGREEN FORBS		MI	0.48
22. RAINGREEN FORBS		TMIN	0.39
23. TEMPERATE EVERGREEN DWARF-SHRUBS		TMAX	0.09
24. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.46
25. BROAD-EVERGREEN VINES		TMAX	0.44
26. MAT-FORMING THALLOPHYTES		TMAX	0.31
27. BROAD-RAINGREEN VINES		TMIN	0.30
28. XERIC THALLOPHYTES		MI	0.16

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
38. SAO PAOLO	BRASIL	-23.53	-46.62
21.0 14.0 1270. 228. 20. 186. 1.63		740.	
* 1. MONTANE BROAD-RAINGREEN TREES		TMAX	0.40
* 2. TROPICAL LINEAR-LEAVED TREES		MI	0.39
* 3. TROPICAL MONTANE RAINFOREST TREES		TMAX	0.33
* 4. TEMPERATE NEEDLE-TREES		TMAX	0.33
* 5. TEMPERATE RAINFOREST NEEDLE-TREES		MI	0.14
* 6. WARM-TEMPERATE BROAD-EVERGREEN TREES		TMAX	0.10
7. HELIOPHILIC LONG-NEEDLED TREES		TMAX	0.08
8. TROPICAL EVERGREEN MICROPHYLL-TREES		TMIN	0.30
9. TROPICAL EVERGREEN SCLEROPHYLL TREES		TMIN	0.27
10. PALMIFORM TUFT-TREES		TMIN	0.16
11. TALL GRASSES		TMAX	0.48
12. TEMP. BROAD-EVERGREEN SMALL TREES		TMAX	0.45
13. ARBORESCENT GRASSES		TMAX	0.45
14. TALL CANE-GRAMINOIDS		TMIN	0.45
15. TROPICAL BROAD-EVERGREEN SMALL TREES		TMIN	0.30
16. BROAD-RAINGREEN SMALL TREES		TMIN	0.27
17. TROPICAL BROAD-EVERGREEN LIANAS		TMIN	0.20
18. SHORT SWARD-GRASSES		TMAX	0.61
19. TEMPERATE BROAD-EVERGREEN SHRUBS		TMAX	0.40
20. TROPICAL BROAD-EVERGREEN SHRUBS		TMIN	0.33
21. PALMIFORM TUFT-TREELETS		TMIN	0.20
22. SHORT BUNCH-GRASSES		TMIN	0.82
23. PALMIFORM MESIC ROSETTE-SHRUBS		TMIN	0.27
24. NEEDLE-LEAVED EVERGREEN SHRUBS		MI	0.23
25. EVERGREEN GIANT-SCRUB		TMAX	0.08
26. SUMMERGREEN FORBS		TMAX	0.48
27. TROPICAL EVERGREEN FORBS		TMIN	0.43
28. TEMPERATE EVERGREEN FORBS		TMAX	0.39
29. RAINGREEN FORBS		TMIN	0.30
30. TEMPERATE EVERGREEN DWARF-SHRUBS		TMAX	0.17
31. MAT-FORMING THALLOPHYTES		TMAX	0.39
32. BROAD-EVERGREEN VINES		TMIN	0.38
33. NARROW-LEAVED EPIPHYTES		TMIN	0.36
34. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.36
35. BROAD-RAINGREEN VINES		TMIN	0.20
36. TROPICAL BROAD-EVERGREEN EPIPHYTES		TMIN	0.20
37. XERIC THALLOPHYTES		MI	0.23

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LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI		LAT ELEV	LONG
39. VILLA NOUGUES/TUCUMAN	ARGENTIN	-27.00	-65.70
18.7 9.2 1437. 250. 22. 250. 2.22		1388.	
* 1. TEMPERATE RAINFOREST NEEDLE-TREES		MI	0.41
* 2. SUMMERGREEN BROAD-LEAVED TREES		TMAX	0.25
* 3. TROPICAL LINEAR-LEAVED TREES		TMIN	0.21
* 4. TEMPERATE NEEDLE-TREES		PMTMAX	0.20
* 5. MONTANE BROAD-RAINGREEN TREES		TMIN	0.09
* 6. TROPICAL MONTANE RAINFOREST TREES		TMIN	0.08
7. TROPICAL EVERGREEN MICROPHYLL-TREES		TMIN	0.10
8. TROPICAL EVERGREEN SCLEROPHYLL TREES		TMIN	0.05
9. TALL GRASSES		TMAX	0.47
10. BROAD-SUMMERGREEN SMALL TREES		TMAX	0.41
11. TEMP. BROAD-EVERGREEN SMALL TREES		TMAX	0.36
12. TALL CANE-GRAMINOIDS		TMIN	0.28
13. ARBORESCENT GRASSES		TMIN	0.25
14. TROPICAL BROAD-EVERGREEN SMALL TREES		TMIN	0.06
15. BROAD-RAINGREEN SMALL TREES		TMIN	0.05
16. SHORT SWARD-GRASSES		TMAX	0.73
17. BROAD-ERICOID EVERGREEN SHRUBS		MI	0.41
18. SUMMERGREEN GIANT-SCRUB		TMAX	0.36
19. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.29
20. TEMPERATE BROAD-EVERGREEN SHRUBS		TMAX	0.25
21. TROPICAL BROAD-EVERGREEN SHRUBS		TMIN	0.13
22. SHORT BUNCH-GRASSES		MI	0.39
23. PALMIFORM MESIC ROSETTE-SHRUBS		TMIN	0.05
24. TEMPERATE EVERGREEN FORBS		TMAX	0.60
25. SUMMERGREEN FORBS		TMAX	0.47
26. SUMMERGREEN FERNS		TMAX	0.47
27. MARITIME HEATH DWARF-SHRUBS		TMAX	0.39
28. TEMPERATE EVERGREEN DWARF-SHRUBS		TMAX	0.29
29. TROPICAL EVERGREEN FORBS		TMIN	0.26
30. RAINGREEN FORBS		TMIN	0.10
31. MAT-FORMING THALLOPHYTES		TMAX	0.60
32. BROAD-SUMMERGREEN VINES		TMAX	0.25
33. BROAD-EVERGREEN VINES		TMIN	0.20
34. BROAD-WINTERGREEN EPIPHYTES		TMAX	0.19
35. NARROW-LEAVED EPIPHYTES		TMIN	0.17
40. ISLA VICTORIA/LAGO NAHUE	ARGENTIN	-41.00	-71.58
14.7 3.4 1644. 265. 35. 35. 3.22		900.	
* 1. TEMPERATE RAINFOREST NEEDLE-TREES		TMAX	0.21
2. BOREAL BROAD-SUMMERGREEN TREES		TMAX	0.14
3. BROAD-SUMMERGREEN SMALL TREES		TMAX	0.25
4. TALL GRASSES		PMTMAX	0.14
5. TEMP. BROAD-EVERGREEN SMALL TREES		TMIN	0.11
6. SHORT SWARD-GRASSES		PMTMAX	0.29
7. SUMMERGREEN GIANT-SCRUB		TMAX	0.18
8. TALL TUSSOCK-GRASSES		PMTMAX	0.14
9. BROAD-ERICOID EVERGREEN SHRUBS		TMAX	0.14
10. BROAD-SUMMERGREEN MESIC SHRUBS		TMAX	0.05
11. TEMPERATE EVERGREEN FORBS		TMIN	0.37
12. SUMMERGREEN FORBS		TMAX	0.32
13. TEMPERATE EVERGREEN DWARF-SHRUBS		PMTMAX	0.29
14. MARITIME HEATH DWARF-SHRUBS		TMAX	0.25
15. MAT-FORMING THALLOPHYTES		MI	0.80

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
41. BARILOCHE, SAN CARLOS DE ARGENTIN	-41.13	-71.25
14.9 3.0 1081. 181. 27. 27. 2.16	825.	
* 1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.35
2. TEMPERATE RAINFOREST NEEDLE-TREES	PMTMAX	0.07
3. SUB-MEDITERRANEAN NEEDLE-TREES	TMAX	0.06
4. BROAD-SUMMERGREEN SMALL TREES	PMTMAX	0.26
5. TEMP. BROAD-EVERGREEN SMALL TREES	TMIN	0.08
6. TALL CANE-GRAMINOIDS	TMIN	0.07
7. SUMMERGREEN GIANT-SCRUB	TMAX	0.19
8. SHORT SWARD-GRASSES	PMTMAX	0.07
9. BROAD-SUMMERGREEN MESIC SHRUBS	TMAX	0.06
10. SHORT BUNCH-GRASSES	MI	0.43
11. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.26
12. SUMMERGREEN FORBS	TMAX	0.33
13. TEMPERATE EVERGREEN FORBS	PMTMAX	0.26
14. MARITIME HEATH DWARF-SHRUBS	PMTMAX	0.26
15. TEMPERATE EVERGREEN DWARF-SHRUBS	PMTMAX	0.07
16. MAT-FORMING THALLOPHYTES	MI	0.69
17. RAINGREEN COLD-DESERT HERBS	TMAX	0.01
42. VALDIVIA CHILE	-39.80	-73.23
15.5 8.2 2489. 420. 62. 66. 4.18	5.	
* 1. TEMPERATE RAINFOREST NEEDLE-TREES	TMAX	0.27
* 2. TEMPERATE BROAD-RAINFOREST TREES	PMTMAX	0.10
3. TROPICAL LINEAR-LEAVED TREES	TMAX	0.04
4. TROPICAL MONTANE RAINFOREST TREES	TMIN	0.01
5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.03
6. TALL GRASSES	TMAX	0.35
7. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.23
8. ARBORESCENT GRASSES	TMIN	0.20
9. TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.01
10. SHORT SWARD-GRASSES	PMTMAX	0.62
11. TALL TUSSOCK-GRASSES	TMAX	0.48
12. BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.21
13. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.09
14. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.03
15. MESIC EVERGREEN CUSHION-SHRUBS	TMAX	0.17
16. PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.01
17. TEMPERATE EVERGREEN FORBS	TMIN	0.57
18. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.55
19. SUMMERGREEN FORBS	TMAX	0.35
20. MARITIME HEATH DWARF-SHRUBS	TMAX	0.32
21. TROPICAL EVERGREEN FORBS	TMIN	0.22
22. EVERGREEN FERNS	TMIN	0.14
23. MAT-FORMING THALLOPHYTES	MI	0.85
24. BROAD-EVERGREEN VINES	TMIN	0.16
25. NARROW-LEAVED EPIPHYTES	TMIN	0.13

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
43. USHUAIA CHILE	-54.78	-68.33
10.0 1.6 556. 65. 40. 42. 1.23	34.	
1. TALL GRASSES	TMAX	0.0
2. SHORT SWARD-GRASSES	PMTMAX	0.41
3. TALL TUSSOCK-GRASSES	TMIN	0.24
4. SHORT BUNCH-GRASSES	TMAX	0.67
5. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.33
6. NEEDLE-LEAVED TREELINE KRUMMHOLZ	TMAX	0.0
7. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.0
8. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.33
9. TEMPERATE EVERGREEN FORBS	MI	0.27
10. BUSH STEM-SUCCULENTS	TMAX	0.0
11. SUMMERGREEN FORBS	TMAX	0.0
12. MAT-FORMING THALLOPHYTES	MI	0.35
13. XERIC THALLOPHYTES	MI	0.63
44. THINGVELLIR ISLAND	64.25	-21.12
11.5 -2.4 1340. 162. 71. 84. 2.97	103.	
1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.05
2. TALL GRASSES	TMAX	0.13
3. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.04
4. SHORT SWARD-GRASSES	TMAX	0.57
5. NEEDLE-LEAVED TREELINE KRUMMHOLZ	TMAX	0.50
6. SUMMERGREEN TUNDRA DWARF-SHRUBS	TMAX	0.48
7. SHORT BUNCH-GRASSES	MI	0.01
8. TEMPERATE EVERGREEN DWARF-SHRUBS	TMIN	0.46
9. SUMMERGREEN FERNS	TMAX	0.13
10. SUMMERGREEN FORBS	TMAX	0.13
11. TEMPERATE EVERGREEN FORBS	TMIN	0.11
12. MAT-FORMING THALLOPHYTES	MI	0.76
13. SEASONAL COLD-DESERT HERBS	TMAX	0.30
45. ABISKO SVERIGE	68.33	18.85
11.0 -11.0 267. 42. 11. 42. 0.74	388.	
1. BOREAL/MONTANE SHORT-NEEDLED TREES	TMAX	0.0
2. BROAD-SUMMERGREEN SMALL TREES	TMAX	0.0
+ 3. SHORT SWARD-GRASSES	MI	0.32
+ 4. SHORT BUNCH-GRASSES	TMIN	0.55
5. NEEDLE-LEAVED TREELINE KRUMMHOLZ	MI	0.19
6. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.08
7. SUMMERGREEN TUNDRA DWARF-SHRUBS	MI	0.05
8. SUMMERGREEN FORBS	TMAX	0.08
9. TEMPERATE EVERGREEN DWARF-SHRUBS	MI	0.05
10. XERIC CUSHION-HERBS	MI	0.36
11. SEASONAL COLD-DESERT HERBS	TMAX	0.31
12. XERIC THALLOPHYTES	MULT.	1.00

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                                                                 23
        LOCATION                                           LAT    LONG
    TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                 ELEV

46. LUND(DALBY SOEDERSKOG)/S   SVERIGE                    55.70   13.18
    16.0  -0.7  616.   75.   32.   67.  1.12                 65.
           * 1. BOREAL/MONTANE SHORT-NEEDLED TREES        TMAX    0.45
           * 2. TEMPERATE NEEDLE-TREES                    TMAX    0.11
             3. SUMMERGREEN BROAD-LEAVED TREES            TMAX    0.07
             4. BOREAL SUMMERGREEN NEEDLE-TREES           TMAX    0.40
             5. SUB-MEDITERRANEAN NEEDLE-TREES            TMIN    0.02
             6. BOREAL BROAD-SUMMERGREEN TREES            TMAX    0.25
             7. TALL GRASSES                              TMAX    0.33
             8. BROAD-SUMMERGREEN SMALL TREES             TMAX    0.28
             9. SHORT SWARD-GRASSES                       MI      0.56
            10. SUMMERGREEN GIANT-SCRUB                   TMAX    0.22
            11. BROAD-SUMMERGREEN MESIC SHRUBS            TMAX    0.13
            12. TEMPERATE BROAD-EVERGREEN SHRUBS          TMIN    0.06
            13. TALL TUSSOCK-GRASSES                      TMIN    0.03
            14. SHORT BUNCH-GRASSES                       TMIN    0.66
            15. NEEDLE-LEAVED EVERGREEN SHRUBS            TMAX    0.33
            16. SUMMERGREEN TUNDRA DWARF-SHRUBS           TMAX    0.17
            17. SHORT TUSSOCK-GRASSES                     TMIN    0.03
            18. TEMPERATE EVERGREEN DWARF-SHRUBS          MI      0.38
            19. SUMMERGREEN FORBS                         TMAX    0.33
            20. TEMPERATE EVERGREEN FORBS                 TMIN    0.19
            21. MARITIME HEATH DWARF-SHRUBS               TMIN    0.03
            22. SUMMERGREEN FERNS                         MI      0.02
            23. MAT-FORMING THALLOPHYTES                  MI      0.29
            24. BROAD-SUMMERGREEN VINES                   TMAX    0.07
            25. XERIC THALLOPHYTES                        MI      0.79

47. MIKULOV/WEINVIERTEL       OESTERRE                    0.0     0.0
    20.5  -1.0  511.   80.   19.   53.  0.95                236.
           * 1. TEMPERATE NEEDLE-TREES                    TMIN    0.24
           * 2. BOREAL/MONTANE SHORT-NEEDLED TREES        TMAX    0.14
             3. SUMMERGREEN BROAD-LEAVED TREES            MI      0.06
             4. BOREAL SUMMERGREEN NEEDLE-TREES           TMAX    0.15
             5. SUB-MEDITERRANEAN NEEDLE-TREES            TMIN    0.0
             6. BOREAL BROAD-SUMMERGREEN TREES            MI      0.16
             7. BROAD-SUMMERGREEN SMALL TREES             MI      0.27
             8. TALL GRASSES                              MI      0.27
             9. SHORT SWARD-GRASSES                       MI      0.48
            10. SUMMERGREEN GIANT-SCRUB                   TMAX    0.38
            11. BROAD-SUMMERGREEN MESIC SHRUBS            MI      0.27
            12. DWARF-NEEDLE SMALL TREES                  TMIN    0.17
            13. XERIC SUMMERGREEN SHRUBS                  MI      0.06
            14. TEMPERATE BROAD-EVERGREEN SHRUBS          TMIN    0.05
            15. SHORT BUNCH-GRASSES                       TMIN    0.66
            16. NEEDLE-LEAVED EVERGREEN SHRUBS            TMAX    0.47
            17. SUMMERGREEN FORBS                         TMAX    0.47
            18. TEMPERATE EVERGREEN DWARF-SHRUBS          TMAX    0.19
            19. TEMPERATE EVERGREEN FORBS                 MI      0.06
            20. MAT-FORMING THALLOPHYTES                  MI      0.16
            21. XERIC CUSHION-HERBS                       MI      0.06
            22. XERIC THALLOPHYTES                        TMAX    0.87

                                                                 24
        LOCATION                                           LAT    LONG
    TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                 ELEV

48. AIN-DRAHAM                 TUNISIE                    36.78    8.70
    25.0   6.7 1534.  190.    4.   58.  2.01                739.
           * 1. SUMMERGREEN BROAD-LEAVED TREES            TMAX    0.33
           * 2. MEDITERRANEAN BROAD-EVERGREEN TREES       TMIN    0.17
             3. SUB-MEDITERRANEAN NEEDLE-TREES            TMAX    0.21
             4. BROAD-SUMMERGREEN SMALL TREES             TMAX    0.26
             5. TALL CANE-GRAMINOIDS                      TMIN    0.20
             6. SUMMERGREEN GIANT-SCRUB                   TMAX    0.43
             7. DWARF-NEEDLE SMALL TREES                  TMAX    0.42
             8. SHORT SWARD-GRASSES                       TMAX    0.40
             9. TEMPERATE BROAD-EVERGREEN SHRUBS          TMAX    0.33
            10. BROAD-SUMMERGREEN MESIC SHRUBS            TMAX    0.31
            11. TROPICAL BROAD-EVERGREEN SHRUBS           TMIN    0.03
            12. BROAD-ERICOID EVERGREEN SHRUBS            TMAX    0.0
            13. SHORT BUNCH-GRASSES                       MI      0.55
            14. SUMMERGREEN FORBS                         TMAX    0.40
            15. SUMMERGREEN FERNS                         PMTMAX  0.13
            16. BROAD-SUMMERGREEN VINES                   PMTMAX  0.31
            17. BROAD-WINTERGREEN EPIPHYTES               TMIN    0.24
            18. MAT-FORMING THALLOPHYTES                  TMAX    0.20
            19. BROAD-EVERGREEN VINES                     TMIN    0.10

49. AZROU                      AL-MAGHR                   33.45   -5.23
    26.0   7.0  837.  110.    7.   16.  1.11               1250.
           * 1. MEDITERRANEAN BROAD-EVERGREEN TREES       TMIN    0.20
             2. SUB-MEDITERRANEAN NEEDLE-TREES            TMAX    0.14
             3. TROPICAL EVERGREEN MICROPHYLL-TREES       TMIN    0.0
             4. TEMP. BROAD-EVERGREEN SMALL TREES         TMAX    0.30
             5. TALL CANE-GRAMINOIDS                      TMIN    0.21
             6. DWARF-NEEDLE SMALL TREES                  TMAX    0.33
             7. MEDITERRANEAN EVERGREEN SHRUBS            TMIN    0.15
             8. TROPICAL BROAD-EVERGREEN SHRUBS           TMIN    0.04
             9. SHORT BUNCH-GRASSES                       TMAX    0.50
            10. NEEDLE-LEAVED EVERGREEN SHRUBS            TMAX    0.36
            11. SUMMERGREEN FORBS                         TMAX    0.36
            12. BUSH STEM-SUCCULENTS                      TMIN    0.23
            13. MEDITERRANEAN DWARF-SHRUBS                MI      0.08
            14. XERIC ROSETTE-SHRUBS                      MI      0.08
            15. RAINGREEN FORBS                           TMIN    0.0
            16. BROAD-WINTERGREEN EPIPHYTES               TMIN    0.25
            17. MAT-FORMING THALLOPHYTES                  TMAX    0.14
            18. SUCCULENT FORBS                           MI      0.08
            19. XERIC THALLOPHYTES                        TMAX    0.50

50. KSAR-ES-SOUQ               AL-MAGHR                   31.93    4.43
    31.8   9.1  134.   24.    3.    3.  0.13               1060.
             1. HOT-DESERT EVERGREEN SHRUBS               TMIN    0.13
             2. LEAFLESS XEROMORPHIC LARGE-SCRUB          TMAX    0.33
             3. BUSH STEM-SUCCULENTS                      TMAX    0.27
           + 4. DESERT-GRASSES                            TMAX    0.24
             5. XERIC ROSETTE-SHRUBS                      TMIN    0.23
             6. TYPICAL STEM-SUCCULENTS                   TMIN    0.09
             7. XERIC DWARF-SHRUBS                        TMAX    0.29
             8. EPHEMERAL DESERT HERBS                    TMAX    0.24
             9. SUCCULENT FORBS                           TMIN    0.16
            10. DRY DESERT                                MI      0.89
            11. XERIC THALLOPHYTES                        TMAX    0.24
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                                                                  25
        LOCATION                                           LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                    ELEV

51. DEMANHUR                          MISRA                0.0      0.0
    26.2  12.7    90.    23.     0.     3.  0.09               20.
              1. HOT-DESERT EVERGREEN SHRUBS              MI       0.14
            + 2. DESERT-GRASSES                           TMAX     0.49
              3. LEAFLESS XEROMORPHIC LARGE-SCRUB         TMAX     0.45
              4. BUSH STEM-SUCCULENTS                     TMIN     0.42
              5. TYPICAL STEM-SUCCULENTS                  TMIN     0.25
              6. EPHEMERAL DESERT HERBS                   TMAX     0.49
              7. XERIC DWARF-SHRUBS                       MI       0.46
              8. SUCCULENT FORBS                          TMIN     0.31
              9. DRY DESERT                               TMAX     0.93
             10. XERIC THALLOPHYTES                       TMAX     0.49

52. MAHADDAY-WEYNE                    SOMALIYA             3.00    45.53
    29.0  25.0  477.   105.      2.   105.  0.28              115.
              1. BROAD-RAINGREEN SMALL TREES              MI       0.12
            + 2. RAINGREEN THORN-SCRUB                    TMAX     0.44
            + 3. ARBORESCENT STEM-SUCCULENTS              TMAX     0.39
              4. SHORT BUNCH-GRASSES                      MI       0.30
              5. XERIC EVERGREEN TUFT-TREELETS            MI       0.12
              6. EVERGREEN GIANT-SCRUB                    MI       0.12
              7. TYPICAL STEM-SUCCULENTS                  TMAX     0.45
              8. XERIC ROSETTE-SHRUBS                     TMAX     0.45
              9. BUSH STEM-SUCCULENTS                     TMAX     0.37
            +10. DESERT-GRASSES                           TMAX     0.35
             11. RAINGREEN FORBS                          TMAX     0.24
             12. XERIC CUSHION-SHRUBS                     TMAX     0.20
             13. LEAF-SUCCULENT EVERGREEN SHRUBS          TMAX     0.18
             14. SUCCULENT FORBS                          TMAX     0.50
             15. EPHEMERAL DESERT HERBS                   TMAX     0.35
             16. BROAD-RAINGREEN VINES                    MI       0.12
             17. XERIC CUSHION-HERBS                      TMAX     0.04
             18. XERIC THALLOPHYTES                       TMAX     0.35

53. ASMERA/ERITREA                    YAITOPYA            15.33    38.92
    19.7  15.8  469.   138.      0.    47.  0.59              2372.
            * 1. TROPICAL EVERGREEN SCLEROPHYLL TREES     MI       0.16
              2. BROAD-RAINGREEN SMALL TREES              TMAX     0.23
              3. RAINGREEN THORN-SCRUB                    TMAX     0.22
            + 4. SHORT BUNCH-GRASSES                      MI       0.67
              5. XERIC EVERGREEN TUFT-TREELETS            TMAX     0.10
            + 6. XERIC CUSHION-SHRUBS                     MI       0.53
              7. BUSH STEM-SUCCULENTS                     TMAX     0.45
              8. RAINGREEN FORBS                          TMIN     0.38
              9. LEAF-SUCCULENT EVERGREEN SHRUBS          TMAX     0.28
             10. XERIC CUSHION-HERBS                      TMAX     0.47
             11. BROAD-RAINGREEN VINES                    TMAX     0.23
             12. SUCCULENT FORBS                          TMAX     0.08
             13. XERIC THALLOPHYTES                       TMAX     0.94
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                                                                  26
        LOCATION                                           LAT     LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                    ELEV

54. KERICHO                           KENYA               -0.37    35.28
    18.8  17.0 1816.   190.     68.   151.  2.31              2042.
            * 1. TROPICAL MONTANE RAINFOREST TREES        TMAX     0.42
            * 2. TROPICAL LINEAR-LEAVED TREES             TMAX     0.29
              3. TROPICAL EVERGREEN MICROPHYLL-TREES      TMAX     0.22
              4. PALMIFORM TUFT-TREES                     TMAX     0.15
              5. TROPICAL EVERGREEN SCLEROPHYLL TREES     MI       0.09
              6. TROPICAL CLOUD-FOREST DWARF-TREES        TMAX     0.12
              7. ARBORESCENT GRASSES                      TMAX     0.47
              8. TALL GRASSES                             TMAX     0.47
              9. TALL CANE-GRAMINOIDS                     MI       0.33
             10. TROPICAL BROAD-EVERGREEN SMALL TREES     TMAX     0.22
             11. TROPICAL BROAD-EVERGREEN LIANAS          TMAX     0.07
             12. SHORT SWARD-GRASSES                      TMAX     0.73
             13. TROPICAL BROAD-EVERGREEN SHRUBS          TMIN     0.46
             14. TREE FERNS                               TMAX     0.27
             15. PALMIFORM TUFT-TREELETS                  TMAX     0.26
             16. SHORT BUNCH-GRASSES                      MI       0.33
             17. PALMIFORM MESIC ROSETTE-SHRUBS           TMAX     0.20
             18. TROPICAL EVERGREEN FORBS                 TMIN     0.54
             19. EVERGREEN FERNS                          TMAX     0.47
             20. TEMPERATE EVERGREEN DWARF-SHRUBS         TMAX     0.29
             21. MAT-FORMING THALLOPHYTES                 TMAX     0.60
             22. NARROW-LEAVED EPIPHYTES                  TMIN     0.48
             23. BROAD-EVERGREEN VINES                    TMAX     0.47
             24. TROPICAL BROAD-EVERGREEN EPIPHYTES       TMIN     0.35
             25. BROAD-WINTERGREEN EPIPHYTES              TMAX     0.20

55. NANYUKI                           KENYA                0.02    37.07
    17.8  15.8  679.   100.     11.    69.  0.93              1947.
            * 1. TROPICAL XERIC NEEDLE-TREES              TMAX     0.19
            * 2. MONTANE BROAD-RAINGREEN TREES            MI       0.14
              3. TROPICAL EVERGREEN MICROPHYLL-TREES      TMAX     0.16
              4. TROPICAL EVERGREEN SCLEROPHYLL TREES     TMAX     0.14
              5. PALMIFORM TUFT-TREES                     TMAX     0.09
              6. TALL CANE-GRAMINOIDS                     MI       0.25
              7. TALL GRASSES                             MI       0.25
              8. BROAD-RAINGREEN SMALL TREES              TMAX     0.14
              9. ARBORESCENT GRASSES                      MI       0.14
            +10. SHORT SWARD-GRASSES                      MI       0.47
             11. TROPICAL BROAD-EVERGREEN SHRUBS          MI       0.25
             12. PALMIFORM TUFT-TREELETS                  TMAX     0.19
             13. RAINGREEN THORN-SCRUB                    MI       0.08
            +14. SHORT BUNCH-GRASSES                      MI       0.79
             15. PALMIFORM MESIC ROSETTE-SHRUBS           MI       0.03
             16. BUSH STEM-SUCCULENTS                     TMAX     0.39
             17. RAINGREEN FORBS                          TMIN     0.38
             18. TEMPERATE EVERGREEN DWARF-SHRUBS         MI       0.25
             19. TROPICAL EVERGREEN FORBS                 MI       0.03
             20. BROAD-RAINGREEN VINES                    TMAX     0.14
             21. MAT-FORMING THALLOPHYTES                 MI       0.14
             22. BROAD-WINTERGREEN EPIPHYTES              TMAX     0.13
             23. XERIC CUSHION-HERBS                      MI       0.09
             24. BROAD-EVERGREEN VINES                    MI       0.03
             25. XERIC THALLOPHYTES                       MULT.    1.00
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Appendix C. Predicted vegetation at the validation sites.

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                                                            27
      LOCATION                                      LAT    LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

56. MAKURDI                  NIGERIA                7.75     8.53
   30.0  25.0 1377.  175.    0.   109.  0.83           111.
                1. TROPICAL XERIC NEEDLE-TREES      TMAX     0.0
                2. TROPICAL EVERGREEN SCLEROPHYLL TREES  TMAX     0.25
                3. PALMIFORM TUFT-TREES             MI       0.16
                4. TROPICAL EVERGREEN MICROPHYLL-TREES   MI       0.09
              + 5. XERIC RAINGREEN TREES            MI       0.27
              + 6. BROAD-RAINGREEN SMALL TREES      TMAX     0.25
                7. TALL CANE-GRAMINOIDS             MI       0.16
                8. RAINGREEN THORN-SCRUB            MI       0.21
                9. PALMIFORM TUFT-TREELETS          MI       0.16
               10. TROPICAL BROAD-EVERGREEN SHRUBS  TMAX     0.09
              +11. SHORT BUNCH-GRASSES              TMAX     0.31
               12. XERIC EVERGREEN TUFT-TREELETS    MI       0.23
               13. EVERGREEN GIANT-SCRUB            TMAX     0.17
               14. XERIC ROSETTE-SHRUBS             MI       0.46
               15. BUSH STEM-SUCCULENTS             TMAX     0.33
               16. RAINGREEN FORBS                  TMAX     0.20
               17. SUCCULENT FORBS                  TMAX     0.45
               18. BROAD-RAINGREEN VINES            TMAX     0.25
               19. BROAD-WINTERGREEN EPIPHYTES      TMAX     0.0
               20. XERIC THALLOPHYTES               TMAX     0.31

57. LUSAKA                   ZAMBIA                -15.42   28.28
   25.0  16.0  835.  165.    0.    62.  0.89          1278.
              * 1. TROPICAL XERIC NEEDLE-TREES      TMAX     0.33
                2. MONTANE BROAD-RAINGREEN TREES    TMAX     0.0
                3. TROPICAL EVERGREEN SCLEROPHYLL TREES  TMIN     0.36
                4. PALMIFORM TUFT-TREES             MI       0.22
                5. TROPICAL EVERGREEN MICROPHYLL-TREES   MI       0.16
                6. XERIC RAINGREEN TREES            TMAX     0.06
              + 7. BROAD-RAINGREEN SMALL TREES      TMIN     0.36
                8. TALL CANE-GRAMINOIDS             MI       0.22
                9. MEDITERRANEAN EVERGREEN SHRUBS   TMAX     0.36
               10. TROPICAL BROAD-EVERGREEN SHRUBS  MI       0.22
               11. PALMIFORM TUFT-TREELETS          MI       0.22
               12. RAINGREEN THORN-SCRUB            MI       0.12
              +13. SHORT BUNCH-GRASSES              TMAX     0.56
              +14. EVERGREEN GIANT-SCRUB            TMIN     0.40
               15. XERIC EVERGREEN TUFT-TREELETS    MI       0.14
               16. BUSH STEM-SUCCULENTS             TMIN     0.53
               17. RAINGREEN FORBS                  TMIN     0.39
               18. XERIC ROSETTE-SHRUBS             TMAX     0.25
               19. XERIC CUSHION-SHRUBS             MI       0.01
               20. BROAD-WINTERGREEN EPIPHYTES      MI       0.33
               21. SUCCULENT FORBS                  TMAX     0.32
               22. BROAD-RAINGREEN VINES            TMIN     0.30
               23. XERIC CUSHION-HERBS              MI       0.13
               24. XERIC THALLOPHYTES               TMAX     0.56
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                                                            28
      LOCATION                                      LAT    LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

58. MAUN                     BOTSWANA             -20.00    23.42
   26.5  15.0  457.  100.    0.    26.  0.43           942.
              * 1. XERIC RAINGREEN TREES            TMAX     0.16
                2. BROAD-RAINGREEN SMALL TREES      TMIN     0.32
                3. RAINGREEN THORN-SCRUB            TMIN     0.32
              + 4. SHORT BUNCH-GRASSES              TMAX     0.47
              + 5. EVERGREEN GIANT-SCRUB            TMIN     0.35
                6. XERIC EVERGREEN TUFT-TREELETS    TMIN     0.32
                7. HOT-DESERT EVERGREEN SHRUBS      TMAX     0.25
                8. ARBORESCENT STEM-SUCCULENTS      TMAX     0.25
                9. NEEDLE-LEAVED EVERGREEN SHRUBS   MI       0.08
               10. BUSH STEM-SUCCULENTS             TMAX     0.47
               11. LEAFLESS XEROMORPHIC LARGE-SCRUB TMAX     0.46
              +12. MEDITERRANEAN DWARF-SHRUBS       TMAX     0.45
               13. RAINGREEN FORBS                  TMAX     0.34
               14. SUMMERGREEN FORBS                TMAX     0.34
               15. XERIC ROSETTE-SHRUBS             TMAX     0.32
               16. TYPICAL STEM-SUCCULENTS          TMAX     0.32
               17. XERIC CUSHION-SHRUBS             TMAX     0.30
               18. SCLEROPHYLLOUS GRASSES           TMIN     0.25
               19. LEAF-SUCCULENT EVERGREEN SHRUBS  TMIN     0.23
               20. DESERT-GRASSES                   MI       0.16
               21. XERIC DWARF-SHRUBS               TMAX     0.48
               22. SUCCULENT FORBS                  TMAX     0.39
               23. BROAD-RAINGREEN VINES            TMIN     0.25
               24. EPHEMERAL DESERT HERBS           MI       0.16
               25. XERIC CUSHION-HERBS              TMAX     0.14
               26. XERIC THALLOPHYTES               TMAX     0.47
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29

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
59. KROONSTAD/ORANJE FRYSTAA SOUTH AF	-27.77	27.20
22.5 8.5 606. 95. 8. 64. 0.84	1348.	
* 1. TEMPERATE NEEDLE-TREES	TMAX	0.17
2. MEDITERRANEAN BROAD-EVERGREEN TREES	MI	0.05
3. MONTANE BROAD-RAINGREEN TREES	TMIN	0.04
4. TROPICAL XERIC NEEDLE-TREES	TMIN	0.02
5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMIN	0.07
6. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.02
7. BROAD-SUMMERGREEN SMALL TREES	MI	0.17
8. TALL GRASSES	MI	0.17
9. TEMP. BROAD-EVERGREEN SMALL TREES	MI	0.11
10. ARBORESCENT GRASSES	MI	0.05
11. BROAD-RAINGREEN SMALL TREES	TMIN	0.02
12. SUMMERGREEN GIANT-SCRUB	TMAX	0.46
+13. SHORT SWARD-GRASSES	MI	0.41
+14. DWARF-NEEDLE SMALL TREES	TMAX	0.38
15. TEMPERATE BROAD-EVERGREEN SHRUBS	MI	0.29
16. MEDITERRANEAN EVERGREEN SHRUBS	TMIN	0.27
17. XERIC SUMMERGREEN SHRUBS	MI	0.21
18. BROAD-SUMMERGREEN MESIC SHRUBS	MI	0.17
19. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.10
20. RAINGREEN THORN-SCRUB	TMIN	0.02
+21. SHORT BUNCH-GRASSES	TMAX	0.71
22. NEEDLE-LEAVED EVERGREEN SHRUBS	TMAX	0.51
23. EVERGREEN GIANT-SCRUB	TMIN	0.02
24. XERIC EVERGREEN TUFT-TREELETS	TMIN	0.02
25. SUMMERGREEN FORBS	TMAX	0.51
26. BUSH STEM-SUCCULENTS	TMIN	0.28
27. XERIC ROSETTE-SHRUBS	TMAX	0.13
28. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.08
29. XERIC CUSHION-SHRUBS	MI	0.08
30. RAINGREEN FORBS	TMIN	0.07
31. BROAD-WINTERGREEN EPIPHYTES	MI	0.29
32. XERIC CUSHION-HERBS	MI	0.20
33. SUCCULENT FORBS	TMIN	0.14
34. MAT-FORMING THALLOPHYTES	MI	0.05
35. XERIC THALLOPHYTES	TMAX	0.71

30

LOCATION TMAX TMIN PRCP PMAX PMIN PMTMAX MI	LAT ELEV	LONG
60. CATHEDRAL PEAK(LITTLE BE SOUTH AF	-28.98	29.23
17.0 10.0 1418. 289. 12. 197. 2.21	1860.	
* 1. TEMPERATE NEEDLE-TREES	TMAX	0.22
* 2. TROPICAL LINEAR-LEAVED TREES	TMAX	0.15
* 3. MONTANE BROAD-RAINGREEN TREES	TMIN	0.14
* 4. TROPICAL MONTANE RAINFOREST TREES	TMIN	0.13
5. TROPICAL EVERGREEN MICROPHYLL-TREES	TMAX	0.12
6. TROPICAL EVERGREEN SCLEROPHYLL TREES	TMIN	0.09
7. TALL GRASSES	TMAX	0.41
8. TALL CANE-GRAMINOIDS	TMIN	0.31
9. TEMP. BROAD-EVERGREEN SMALL TREES	TMAX	0.29
10. ARBORESCENT GRASSES	TMIN	0.29
11. TROPICAL BROAD-EVERGREEN SMALL TREES	TMIN	0.10
12. BROAD-RAINGREEN SMALL TREES	TMIN	0.09
13. SHORT SWARD-GRASSES	TMAX	0.71
14. BROAD-ERICOID EVERGREEN SHRUBS	TMAX	0.33
15. TROPICAL BROAD-EVERGREEN SHRUBS	TMIN	0.17
16. TEMPERATE BROAD-EVERGREEN SHRUBS	TMAX	0.13
17. PALMIFORM TUFT-TREELETS	TMIN	0.0
18. SHORT BUNCH-GRASSES	MI	0.39
19. PALMIFORM MESIC ROSETTE-SHRUBS	TMIN	0.09
20. MESIC EVERGREEN CUSHION-SHRUBS	TMAX	0.07
21. TEMPERATE EVERGREEN FORBS	MI	0.65
22. SUMMERGREEN FORBS	TMAX	0.41
23. TEMPERATE EVERGREEN DWARF-SHRUBS	TMAX	0.41
24. TROPICAL EVERGREEN FORBS	TMIN	0.29
25. RAINGREEN FORBS	TMIN	0.13
26. MAT-FORMING THALLOPHYTES	MI	0.70
27. BROAD-EVERGREEN VINES	TMIN	0.23
28. NARROW-LEAVED EPIPHYTES	TMIN	0.20
29. BROAD-WINTERGREEN EPIPHYTES	TMAX	0.07
30. BROAD-RAINGREEN VINES	TMIN	0.0
31. TROPICAL BROAD-EVERGREEN EPIPHYTES	TMIN	0.0

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                                                              31
     LOCATION                                          LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                ELEV

61. HELL-BOURG               REUNION                 -21.10  55.60
    19.7  14.0 2444.  500.   20.  150.  3.31             935.
        * 1. MONTANE BROAD-RAINGREEN TREES            TMIN    0.43
        * 2. TEMPERATE RAINFOREST NEEDLE-TREES        TMAX    0.41
        * 3. TROPICAL MONTANE RAINFOREST TREES        TMIN    0.40
        * 4. TROPICAL LINEAR-LEAVED TREES             TMAX    0.36
          5. TROPICAL EVERGREEN MICROPHYLL-TREES      TMAX    0.28
          6. PALMIFORM TUFT-TREES                     TMIN    0.16
          7. TROPICAL CLOUD-FOREST DWARF-TREES        TMAX    0.03
          8. TALL GRASSES                             TMAX    0.49
          9. ARBORESCENT GRASSES                      TMIN    0.48
         10. TEMP. BROAD-EVERGREEN SMALL TREES        TMAX    0.39
         11. TROPICAL BROAD-EVERGREEN SMALL TREES     TMAX    0.28
         12. BROAD-RAINGREEN SMALL TREES              TMAX    0.24
         13. TROPICAL BROAD-EVERGREEN LIANAS          TMAX    0.14
         14. SHORT SWARD-GRASSES                      TMAX    0.75
         15. TROPICAL BROAD-EVERGREEN SHRUBS          TMIN    0.33
         16. TEMPERATE BROAD-EVERGREEN SHRUBS         TMAX    0.31
         17. PALMIFORM TUFT-TREELETS                  TMIN    0.20
         18. PALMIFORM MESIC ROSETTE-SHRUBS           TMAX    0.24
         19. TEMPERATE EVERGREEN FORBS                TMAX    0.52
         20. TROPICAL EVERGREEN FORBS                 TMIN    0.43
         21. RAINGREEN FORBS                          TMIN    0.30
         22. TEMPERATE EVERGREEN DWARF-SHRUBS         TMAX    0.24
         23. MAT-FORMING THALLOPHYTES                 TMAX    0.52
         24. BROAD-EVERGREEN VINES                    TMIN    0.38
         25. NARROW-LEAVED EPIPHYTES                  TMIN    0.36
         26. BROAD-WINTERGREEN EPIPHYTES              TMAX    0.26
         27. BROAD-RAINGREEN VINES                    TMIN    0.20
         28. TROPICAL BROAD-EVERGREEN EPIPHYTES       TMIN    0.20

62. BORISOVKA/ROSSIJA         SSSR                    50.63  35.97
    19.7  -9.0  537.   74.   28.   64.  0.94             200.
        * 1. BOREAL/MONTANE SHORT-NEEDLED TREES       TMAX    0.21
          2. SUMMERGREEN BROAD-LEAVED TREES           MI      0.05
          3. BOREAL SUMMERGREEN NEEDLE-TREES          TMAX    0.23
          4. BOREAL BROAD-SUMMERGREEN TREES           MI      0.15
          5. BROAD-SUMMERGREEN SMALL TREES            MI      0.26
          6. TALL GRASSES                             TMIN    0.23
        + 7. SHORT SWARD-GRASSES                      MI      0.48
          8. SUMMERGREEN GIANT-SCRUB                  TMAX    0.35
          9. BROAD-SUMMERGREEN MESIC SHRUBS           MI      0.26
         10. XERIC SUMMERGREEN SHRUBS                 MI      0.07
        +11. SHORT BUNCH-GRASSES                      TMIN    0.57
         12. NEEDLE-LEAVED EVERGREEN SHRUBS           TMAX    0.45
         13. SUMMERGREEN FORBS                        TMAX    0.45
         14. TEMPERATE EVERGREEN DWARF-SHRUBS         TMAX    0.24
         15. MAT-FORMING THALLOPHYTES                 MI      0.15
         16. XERIC CUSHION-HERBS                      MI      0.07
         17. XERIC THALLOPHYTES                       TMAX    0.94
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                                                              32
     LOCATION                                          LAT    LONG
  TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                ELEV

63. KERKI/TURKMENISTAN        SSSR                    37.83  65.20
    29.5   2.0  161.   34.    0.    2.  0.17             242.
          1. COLD-WINTER XEROMORPHIC SHRUBS           TMAX    0.15
          2. LEAFLESS XEROMORPHIC LARGE-SCRUB         TMAX    0.42
        + 3. DESERT-GRASSES                           TMAX    0.33
          4. BUSH STEM-SUCCULENTS                     TMIN    0.07
          5. XERIC DWARF-SHRUBS                       TMAX    0.38
          6. EPHEMERAL DESERT HERBS                   TMAX    0.33
          7. XERIC THALLOPHYTES                       TMAX    0.33

64. CHATKAL MTNS./KIRGHIZ     SSSR                    41.60  70.70
    20.6  -3.4  995.  203.    0.    1.  1.63            1433.
        * 1. SHORT BUNCH-GRASSES                      TMIN    0.63
        * 2. NEEDLE-LEAVED EVERGREEN SHRUBS           MI      0.23
          3. SUMMERGREEN FORBS                        TMAX    0.47
          4. XERIC THALLOPHYTES                       MI      0.23

65. NAJAF                     AL-'IRAQ                31.95  44.30
    38.0  10.0   83.   18.    0.    0.  0.06              40.
          1. TYPICAL STEM-SUCCULENTS                  TMAX    0.10
          2. LEAFLESS XEROMORPHIC LARGE-SCRUB         TMAX    0.08
          3. BUSH STEM-SUCCULENTS                     TMAX    0.07
          4. DESERT-GRASSES                           TMAX    0.05
          5. SUCCULENT FORBS                          TMAX    0.09
          6. XERIC DWARF-SHRUBS                       TMAX    0.07
          7. EPHEMERAL DESERT HERBS                   TMAX    0.05
          8. DRY DESERT                               TMAX    0.95
          9. XERIC THALLOPHYTES                       TMAX    0.05

66. MAIMANA                   AFGHANES                35.92  64.63
    23.5   3.0  400.   90.    0.   11.  0.55             615.
        * 1. DWARF-NEEDLE SMALL TREES                 MI      0.18
        + 2. SHORT BUNCH-GRASSES                      MI      0.65
        + 3. COLD-WINTER XEROMORPHIC SHRUBS           TMAX    0.50
          4. NEEDLE-LEAVED EVERGREEN SHRUBS           MI      0.27
          5. SUMMERGREEN FORBS                        TMAX    0.46
          6. LEAFLESS XEROMORPHIC LARGE-SCRUB         TMAX    0.34
          7. BUSH STEM-SUCCULENTS                     TMIN    0.10
          8. XERIC ROSETTE-SHRUBS                     TMIN    0.0
          9. MEDITERRANEAN DWARF-SHRUBS               TMIN    0.0
         10. XERIC DWARF-SHRUBS                       TMAX    0.45
         11. XERIC CUSHION-HERBS                      TMAX    0.26
         12. XERIC THALLOPHYTES                       TMAX    0.65

67. KOTGAI                    AFGHANES                33.95  69.90
    19.0  -5.0  519.  105.    7.   18.  0.94            2450.
        * 1. BOREAL/MONTANE SHORT-NEEDLED TREES       TMAX    0.27
          2. TEMPERATE NEEDLE-TREES                   TMIN    0.05
          3. DWARF-NEEDLE SMALL TREES                 TMIN    0.0
        + 4. SHORT BUNCH-GRASSES                      TMIN    0.61
          5. NEEDLE-LEAVED EVERGREEN SHRUBS           TMAX    0.43
          6. SUMMERGREEN FORBS                        TMAX    0.43
          7. MAT-FORMING THALLOPHYTES                 MI      0.15
          8. XERIC CUSHION-HERBS                      MI      0.08
          9. XERIC THALLOPHYTES                       MULT.   1.00
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Appendix C. Predicted vegetation at the validation sites.

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                                                             33
        LOCATION                                    LAT     LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

68. MUSSOORIE                  BHARAT               30.45   78.25
     20.2    6.4 2368.  785.    7.     8.   3.32     1500.
             1. TROPICAL BROAD-EVERGREEN SHRUBS     TMIN     0.02
             2. SUMMERGREEN FORBS                   TMAX     0.50
             3. MAT-FORMING THALLOPHYTES            TMAX     0.49
             4. BROAD-WINTERGREEN EPIPHYTES         TMIN     0.23

69. YUELIN/ORDOS               ZHONGGUO              0.0     0.0
     23.0   -8.8  405.  120.    4.    83.   0.72     1121.
             1. BROAD-SUMMERGREEN SMALL TREES       MI       0.03
             2. SUMMERGREEN GIANT-SCRUB             TMIN     0.45
           + 3. SHORT SWARD-GRASSES                 MI       0.31
             4. BROAD-SUMMERGREEN MESIC SHRUBS      MI       0.03
           + 5. SHORT BUNCH-GRASSES                 TMIN     0.57
             6. NEEDLE-LEAVED EVERGREEN SHRUBS      MI       0.45
             7. SUMMERGREEN FORBS                   TMAX     0.48
             8. XERIC CUSHION-HERBS                 TMAX     0.28
             9. XERIC THALLOPHYTES                  TMAX     0.68

70. MITCHELL PLATEAU CAMP/W.  AUSTRALI             -14.82  125.83
     28.8   19.5 1611.  369.    0.    90.   1.15      268.
           * 1. MONSCON BROAD-RAINGREEN TREES       MI       0.22
             2. PALMIFORM TUFT-TREES                MI       0.40
             3. TROPICAL EVERGREEN SCLEROPHYLL TREES TMAX    0.31
             4. TROPICAL EVERGREEN MICROPHYLL-TREES TMAX     0.19
             5. BROAD-RAINGREEN SMALL TREES         TMAX     0.31
             6. TALL CANE-GRAMINOIDS                TMAX     0.25
             7. PALMIFORM TUFT-TREELETS             TMAX     0.30
             8. TROPICAL BROAD-EVERGREEN SHRUBS     TMAX     0.15
             9. SHORT BUNCH-GRASSES                 TMAX     0.36
            10. EVERGREEN GIANT-SCRUB               TMAX     0.27
            11. RAINGREEN FORBS                     TMAX     0.25
            12. BROAD-RAINGREEN VINES               TMAX     0.31
            13. BROAD-WINTERGREEN EPIPHYTES         TMAX     0.09
            14. XERIC THALLOPHYTES                  TMAX     0.36

71. WILUNA/W.AUSTRALIA         AUSTRALI            -26.60  120.22
     30.0   12.0  247.   34.    5.    33.   0.25      556.
             1. RAINGREEN THORN-SCRUB               TMIN     0.18
           + 2. HOT-DESERT EVERGREEN SHRUBS         TMIN     0.25
             3. SHORT BUNCH-GRASSES                 MI       0.19
             4. ARBORESCENT STEM-SUCCULENTS         TMIN     0.18
             5. LEAFLESS XEROMORPHIC LARGE-SCRUB    TMAX     0.40
             6. XERIC ROSETTE-SHRUBS                TMIN     0.33
             7. BUSH STEM-SUCCULENTS                TMAX     0.33
           + 8. DESERT-GRASSES                      TMAX     0.31
             9. TYPICAL STEM-SUCCULENTS             TMIN     0.22
            10. RAINGREEN FORBS                     MI       0.19
            11. SUMMERGREEN FORBS                   MI       0.19
            12. XERIC CUSHION-SHRUBS                TMAX     0.17
            13. SCLEROPHYLLOUS GRASSES              TMIN     0.10
            14. LEAF-SUCCULENT EVERGREEN SHRUBS     TMIN     0.0
            15. XERIC DWARF-SHRUBS                  TMAX     0.36
            16. EPHEMERAL DESERT HERBS              TMAX     0.31
            17. SUCCULENT FORBS                     TMIN     0.28
            18. XERIC CUSHION-HERBS                 TMAX     0.0
            19. XERIC THALLOPHYTES                  TMAX     0.31
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                                                             34
        LOCATION                                    LAT     LONG
   TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI            ELEV

72. PERTH/WESTERN AUSTRALIA   AUSTRALI             -31.93  115.83
     24.0   13.0  883.  150.    8.    19.   1.14       65.
           * 1. MEDITERRANEAN BROAD-EVERGREEN TREES MI       0.30
           * 2. TROPICAL LINEAR-LEAVED TREES        MI       0.12
             3. TEMPERATE NEEDLE-TREES              TMAX     0.0
             4. TROPICAL MONTANE RAINFOREST TREES   TMAX     0.0
             5. TROPICAL EVERGREEN MICROPHYLL-TREES TMIN     0.26
             6. SUB-MEDITERRANEAN NEEDLE-TREES      MI       0.25
             7. TROPICAL EVERGREEN SCLEROPHYLL TREES TMIN    0.23
             8. PALMIFORM TUFT-TREES                TMIN     0.11
             9. TALL CANE-GRAMINOIDS                MI       0.39
            10. TEMP. BROAD-EVERGREEN SMALL TREES   MI       0.34
            11. BROAD-RAINGREEN SMALL TREES         TMIN     0.23
            12. TROPICAL BROAD-EVERGREEN SMALL TREES MI      0.21
            13. DWARF-NEEDLE SMALL TREES            TMAX     0.50
            14. MEDITERRANEAN EVERGREEN SHRUBS      TMAX     0.43
            15. TROPICAL BROAD-EVERGREEN SHRUBS     TMIN     0.29
            16. PALMIFORM TUFT-TREELETS             TMIN     0.15
            17. SHORT BUNCH-GRASSES                 TMAX     0.62
            18. NEEDLE-LEAVED EVERGREEN SHRUBS      TMAX     0.44
            19. EVERGREEN GIANT-SCRUB               TMIN     0.25
            20. SUMMERGREEN FORBS                   TMAX     0.44
            21. BUSH STEM-SUCCULENTS                MI       0.32
            22. RAINGREEN FORBS                     TMIN     0.26
            23. MEDITERRANEAN DWARF-SHRUBS          MI       0.06
            24. XERIC ROSETTE-SHRUBS                MI       0.06
            25. SCLEROPHYLLOUS GRASSES              MI       0.06
            26. BROAD-WINTERGREEN EPIPHYTES         TMAX     0.43
            27. MAT-FORMING THALLOPHYTES            TMAX     0.23
            28. BROAD-RAINGREEN VINES               TMIN     0.15
            29. SUCCULENT FORBS                     MI       0.06
            30. XERIC THALLOPHYTES                  TMAX     0.62
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Appendix C. Predicted vegetation at the validation sites.

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                                                                35
   LOCATION                                            LAT     LONG
 TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                 ELEV

73. KIETH(DARK ISLAND)/S.AUS   AUSTRALI             -36.10  140.52
    22.0   9.1  457.   60.   20.   20.  0.68                 0.
           1. TEMPERATE NEEDLE-TREES                 MI      0.05
           2. TROPICAL EVERGREEN SCLEROPHYLL TREES   TMIN    0.05
           3. BROAD-RAINGREEN SMALL TREES            TMIN    0.05
         + 4. XERIC SUMMERGREEN SHRUBS               TMAX    0.38
           5. DWARF-NEEDLE SMALL TREES               TMAX    0.33
           6. MEDITERRANEAN EVERGREEN SHRUBS         TMIN    0.32
           7. RAINGREEN THORN-SCRUB                  TMIN    0.05
           8. SUMMERGREEN GIANT-SCRUB                PMTMAX  0.0
         + 9. SHORT BUNCH-GRASSES                    MI      0.72
          10. NEEDLE-LEAVED EVERGREEN SHRUBS         MI      0.42
          11. EVERGREEN GIANT-SCRUB                  TMIN    0.05
          12. XERIC EVERGREEN TUFT-TREELETS          TMIN    0.05
          13. ARBORESCENT STEM-SUCCULENTS            TMAX    0.0
          14. HOT-DESERT EVERGREEN SHRUBS            TMAX    0.0
          15. SUMMERGREEN FORBS                      TMAX    0.50
          16. XERIC CUSHION-SHRUBS                   MI      0.32
          17. MEDITERRANEAN DWARF-SHRUBS             TMAX    0.32
          18. BUSH STEM-SUCCULENTS                   TMIN    0.30
          19. LEAFLESS XEROMORPHIC LARGE-SCRUB       MI      0.17
          20. XERIC ROSETTE-SHRUBS                   TMAX    0.10
          21. RAINGREEN FORBS                        TMIN    0.09
          22. XERIC CUSHION-HERBS                    TMAX    0.33
          23. XERIC DWARF-SHRUBS                     MI      0.17
          24. SUCCULENT FORBS                        TMIN    0.16
          25. BROAD-WINTERGREEN EPIPHYTES            MI      0.13
          26. XERIC THALLOPHYTES                     TMAX    0.75
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                                                                36
   LOCATION                                            LAT     LONG
 TMAX  TMIN  PRCP  PMAX  PMIN  PMTMAX  MI                 ELEV

74. ALEXANDRA/CTAGO              NEW ZEAL           -45.33  169.38
    16.6   2.8  330.   49.   15.   33.  0.63               158.
           1. BOREAL/MONTANE SHORT-NEEDLED TREES     MI      0.04
           2. SUMMERGREEN GIANT-SCRUB                TMAX    0.25
           3. SHORT SWARD-GRASSES                    MI      0.20
           4. XERIC SUMMERGREEN SHRUBS               TMAX    0.14
           5. TEMPERATE BROAD-EVERGREEN SHRUBS       MI      0.04
         + 6. SHORT BUNCH-GRASSES                    MI      0.69
           7. NEEDLE-LEAVED EVERGREEN SHRUBS         TMAX    0.35
           8. SHORT TUSSOCK-GRASSES                  MI      0.20
           9. COLD-WINTER XEROMORPHIC SHRUBS         TMAX    0.09
          10. SUMMERGREEN FORBS                      TMAX    0.35
          11. XERIC CUSHION-SHRUBS                   TMIN    0.26
          12. BUSH STEM-SUCCULENTS                   TMIN    0.09
          13. LEAFLESS XEROMORPHIC LARGE-SCRUB       TMAX    0.09
          14. XERIC CUSHION-HERBS                    MI      0.61
          15. XERIC DWARF-SHRUBS                     TMAX    0.25
          16. XERIC THALLOPHYTES                     MULT.   1.00
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APPENDIX D

Actual vegetation at the validation sites

Descriptions of the actual vegetation at the validation sites include a formation name and lists of the most important taxa in each structural class present. In presenting this information a number of abbreviations are necessary, as shown below. The vegetation descriptions and species lists were constructed from various sources, as indicated for each site. Dominant taxa are denoted by asterisks. (Note that, through the author's oversight, taxonomic names in this appendix are not italicized, since type-setting was done from a computer-printed original.)

Abbreviations

Growth forms/life forms:

B - large bushes	RS - rosette-shrubs
Ch - chamaephytes	RT - rosette-trees
DS - dwarf-shrubs	S - shrubs
DT - dwarf trees	SS - stem-succulents
E - epiphytes	ST - small trees
Eph - ephemerals	T - trees
F - forbs	TG - tussock-grasses
Fn - ferns	Th - therophytes
G - graminoids	UB - underbrush
Gp - geophytes	US - understorey
H - herbs	UT - understorey trees
Hc - hemi-cryptophytes	V - vines and lianas
OB - overgrown bushes	

Seasonal habits:

EG - evergreen	E - ephemeral
SG - summergreen	Sf - suffrutescent
RG - raingreen	

Leaf sizes and shapes:

mic - microphyllous	n - narrow
nan - nanophyllous	b - broad
lep - leptophyllous	

Others:

a - arborescent	s - sward-forming (grass)
d - dwarf	w - white-pubescent
b - bunch (grass)	

This appendix was largely completed in 1978 and thus omits some more recent studies. No systematic attempt has been made to resolve synonyms, check the accuracy of the original sources, or obtain complete species lists for lower synusiae, since such information is often available only locally and seeking it would greatly delay publication. The author invites readers with (better) local vegetation descriptions (including species lists) and applicable climatic data to send them for comparison with predicted vegetation profiles.

1. FAIRBANKS/ALASKA U.S.A.

Continental, closed Boreal Spruce-Hardwood Forest, with scattered bogs and with lower, open forests on north slopes:

T: *Picea glauca, Larix alaskana, Betula resinifera (= B. alaskana, B. neoalaskana), B. papyrifera, Populus balsamifera, et al.

S: Arctostaphylos rubra, A. uva-ursi, Empetrum nigrum, Ledum decumbens, Ribes triste, Rosa acicularis, Salix alaxensis, S. arbusculoides, S. bebbiana et al., Vaccinium vitis-idaea, V. uliginosum et al., Viburnum edule, Amelanchier alnifolia, et al.

H: Microthermal tundra and meadow herbs (e.g. Carex, Scirpus, Eriophorum, Ranunculus, Oxytropis, Epilobium, Castilleja pallida, Artemisia frigida).

References: Jordal 1951; Knapp 1965; Viereck & Little 1972.

2. VANCOUVER (PMO)/BRIT. COLUMBIA CANADA

Tall, dense Douglas Fir Forest, with Hemlock and Red Cedar:

T: *Pseudotsuga menziesii var. menziesii, Tsuga heterophylla, Thuja plicata, Pinus monticola, P. contorta, Abies grandis.

UT: Alnus rubra, Acer spp., Prunus emarginata, Populus balsamifera ssp. trichocarpa, Arbutus menziesii (EG), Corylus cornuta var. californica, Berberis nervosa (EG), et al.

S: Rhododendron californicum, Vaccinium spp., Arctostaphylos uva-ursi, Rubus spectabilis, et al.

H: Gaultheria shallon, Chimaphila umbellata var. occidentalis, Trientalis europa var. latifolia, Viola sempervirens, Goodyera decipiens, Pyrola spp., Pteridium aquilinum, et al.

References: Rowe 1959; Knapp 1965; Krajina 1969.

3. BANFF/ALBERTA CANADA

Boreal-Montane Transitional Needle Forest:

T: *Picea engelmannii, *Abies lasiocarpa, *Pinus contorta var. latifolia, P. banksiana, Picea glauca var. albertiana, P. mariana, Thuja occidentalis, Larix laricina, L. lyallii, Betula papyrifera, Populus tremuloides, P. balsamifera.

US: Vaccinium ssp., with tundra herbs and dwarf-shrubs.

References: Rowe 1959; Knapp 1965; Shelford 1963.

4. SASKATOON/SASKATCHEWAN CANADA

Northern Grove Belt (Fescue Prairie):

T: Populus tremuloides

S: Rosa arkansasa (Sf)

G: *Festuca scabrella (b), Koeleria cristata, Danthonia spp., Agropyron spp., Stipa spp., Carex spp., with Bromus pumpellianus, Calamagrostis montanensis, Muhlenbergia spp., and many others.

F: prairie forbs, e.g. Solidago, Aster, Achillea, Artemisia, Potentilla, Astragalus, Antennaria, and many others.

References: Coupland & Brayshaw 1953; Weaver & Albertson 1956; Knapp 1965.

5. SWIFT CURRENT/SASKATCHEWAN CANADA

Northern Short and Mixed-Grass Prairie (northern limit):

G: *Bouteloua gracilis et al., *Stipa comata et al., Buchloë dactyloides, Sporobolus cryptandrus, Agropyron smithii et al., Aristida spp., Koeleria cristata, Sitanion hystrix, Carex spp., and many others.

S: Eurotia lanata, Atriplex nuttallii, Artemisia cana.

SS: Opuntia polyacantha.

F: prairie forbs, e.g. Artemisia frigida, Phlox hoodii, Asclepias spp., Astragalus mollissimus, Castilleja sessilifolia, Oenothera spp., Oxytropis lamberti, Plantago purshii, and many others.

References: Weaver & Albertson 1956; Küchler 1964; Knapp 1965.

6. SIOUX LOOKOUT/ONTARIO CANADA

Central Boreal Forest:

T: *Picea glauca, *Abies balsamea, Picea mariana, Betula papyrifera, Populus tremuloides, with Larix laricina, Pinus banksiana, Thuja occidentalis, Betula lutea, Populus grandidentata, et al.

US: Vaccinium spp., Lycopodium spp., Trientalis borealis, Cornus canadensis, Gaultheria procumbens, Pyrola spp., et al.

References: Rowe 1959; Knapp 1965; Shelford 1963.

7. LAC ALBANEL/QUEBEC CANADA

Eastern Boreal Forest:

T: *Picea mariana, P. glauca, Abies balsamea, with Larix laricina, Pinus banksiana, Picea rubens, Thuja occidentalis, et al. and with groves of Betula papyrifera, Populus tremuloides, P. balsamifera, et al.

US: Vaccinium spp., Lycopodium spp., Trientalis borealis, Cornus canadensis, Gaultheria procumbens, Pyrola spp., et al.

References: Rowe 1959; Shelford 1963; Knapp 1965.

8. OLYMPIA/WASHINGTON U.S.A.

Tall, dense Douglas Fir Forest with Red Cedar and Hemlock:

T: *Pseudotsuga menziesii var. viridis, *Tsuga heterophylla, *Thuja plicata, Pinus monticola, Abies grandis.

UT: Acer spp., Alnus rubra, Berberis nervosa, Corylus cornuta var. californica, Prunus virginiana demissa, et al.

S: Rhododendron californicum, Vaccinium spp., Rubus spectabilis, Arctostaphylos uva-ursi, et al.

H: Gaultheria shallon, Chimaphila umbellata var. occidentalis, Trientalis europea var. latifolia, Viola sempervirens, Goodyera decipiens, Pyrola spp., Pteridium aquilinum, et al.

References: Andrews & Cowlin 1937; Küchler 1964; Knapp 1965; Franklin & Dyrness 1973; personal observation.

9. DAVIS/CALIFORNIA U.S.A.

California Bunch-Grass Prairie with many forbs:

G: *Stipa pulchra, *S. cernua, S. lepida, Aristida divaricata, Koeleria cristata, Poa scabrella, Elymus spp., Festuca spp., Hordeum brachyantherum, et al., plus ruderals.

F: spring ephemerals (e.g. Brodiaea, Calochortus, Allium) and prairie forbs (e.g. Lupinus spp., Trifolium spp., Eschscholtzia californica, Gilia spp. (= Ipomopsis)), et al.

DS: white-pubescent dwarf-shrubs, e.g. Salvia, Eriogonum, Artemisia californica.

SS: scattered Opuntia, especially where overgrazed.

References: Knapp 1965; Shelford 1963; Küchler 1964, 1977.

10. TANBARK FLAT/CALIFORNIA U.S.A.

Chamise Chaparral:

S: *Adenostoma fasciculatum, Arctostaphylos spp., Ceanothus spp., Rhamnus spp., Heteromeles arbutifolia, Quercus dumosa, Cercocarpus betuloides, Garrya veatchii, Prunus ilicifolia, Rhus spp., et al.

DS: Eriogonum fasciculatum (Sf), Salvia spp. (Sf. w), et al.

H: various grasses and forbs.

References: Mooney & Parsons 1973; Küchler 1964.

11. WEST YELLOWSTONE/MONTANA U.S.A.

Montane Spruce-Fir Forest with Douglas Fir and Pine:

T: *Picea engelmannii, *Abies lasiocarpa, Pseudotsuga menziesii, Pinus contorta var. latifolia s. str., with Larix spp., Populus tremuloides et al., Alnus tenuifolia, Salix spp., et al.

S: Vaccinium spp., Cornus spp., Spiraea spp., et al.

F: Gaultheria humifusa, Ranunculus spp., Aquilegia spp., Viola spp., Castilleja spp., Trifolium pratense, Gentiana spp., et al.

G: Carex spp., et al.

References: Küchler 1964; Knapp 1965; Shaw 1974; Shelford 1963.

12. LOGAN/UTAH U.S.A.

Summergreen and Semi-Deciduous Scrub ('Deciduous Chaparral'):

S: *Cercocarpus ledifolius (EG), *Quercus gambelii, Qu. utahensis et al., Arctostaphylos spp., Ceanothus velutinus (EG), Purshia tridentata, Cowania stansburiana, Amelanchier utahensis, Acer grandidentatum, Pachystima myrsinites, Physocarpus malvacens, Rhus trilobata, Symphoricarpos spp., Peraphyllum ramosissimum, et al.

H: various grasses and forbs.

References: Küchler 1964; Welsh & Moore 1973; personal observation.

13. CODY/WYOMING U.S.A.

Sagebrush-Short Grass Steppe:

S: *Artemisia tridentata, et al.

G: *Agropyron spicatum et al., Festuca idahoensis, Stipa spp., Poa spp., et al.

F: scattered Phlox spp., Purshia tridentata, Lithospermum ruderale, Lupinus sericens, Atriplex spp., et al.

SS: Opuntia spp.

References: Weaver & Albertson 1956; Küchler 1964; personal observation.

14. FLAGSTAFF/ARIZONA U.S.A.

Southern Rocky Mountain Yellow-Pine Forest:

T: *Pinus ponderosa var. scopulorum, other Pinus spp., Populus tremuloides, et al.

S: Ceanothus fendleri, Quercus spp., Holodiscus dumosus, et al.

G: *Muhlenbergia spp., Festuca spp., Aristida spp., et al.

F: Antennaria spp., Lupinus spp., et al.

References: Küchler 1964; Knapp 1965; Shelford 1963.

15. PHOENIX/ARIZONA U.S.A.

Colorado Valley Larrea-Franseria (90–95%) semi-desert:

S: *Larrea tridentata (EG), *Franseria dumosa (SG), et al.

G: desert grasses, e.g. Bouteloua, Aristida.

SS: occasional Opuntia, Echinocactus, et al.

F: Encelia, et al.

Eph: abundant summer and winter ephemerals.

Small, mostly deciduous trees and bushes (e.g. Prosopis juliflora, Torreyana, Cercidium ssp., Olneya tesota, Dalea) may be found on upper bajadas and in drainage-ways.

References: Shreve & Wiggins 1964; Knapp 1965; Küchler 1964; Shelford 1963; personal observation.

16. TUCSON/ARIZONA U.S.A.

Upland Larrea-Cercidium-Opuntia Scrub, with tall cacti:

T: *Cercidium microphyllum (RG) et al., Prosopis juliflora (RG), Olneya tesota (SG), et al.

S: *Larrea tridentata, *Franseria dumosa (SG), Fouquiera splendens (RG), Ephedra, et al.

SS: Carnegiea gigantea (a), Opuntia spp., Echinocereus, et al.

G: desert-grasses, e.g. Bouteloua, Aristida (locally abundant),

F: Encelia farinosa, et al.

Eph: abundant summer and fewer winter ephemerals.

References: Shreve & Wiggins 1964; Walter 1973; Küchler 1964; Knapp 1965; Shelford 1963; personal observation.

17. SANTA FE/NEW MEXICO U.S.A.

Open Juniper-Pinyon Woodland, with grasses but few forbs:

DT: *Juniperus monosperma, *J. scopulorum, J. osteosperma (= J. utahensis), *Pinus edulis, P. monophylla.

S: Cercocarpus spp., Ceanothus spp., Quercus spp., Arenaria filiorum, Chrysothamnus spp., Artemisia tridentata, et al.

H: turf and bunch grasses (Agropyron smithii, Bouteloua gracilis, Buchloe dactyloides, Sporobolus).

References: Weaver & Albertson 1965; Knapp 1965; Küchler 1964; personal observation.

18. COLORADO SPRINGS/COLORADO U.S.A.

Southern Short and Mixed-Grass Prairie:

G: *Bouteloua gracilis, B. hirsuta, Muhlenbergia gracillima, Aristida longiseta; with Stipa comata et al., Andropogon scoparius, Schedonnardus paniculatus, Koeleria cristata, Sitanion elymoides, Sporobolus cryptandrus, Hilaria jamesii, Bouteloua curtipendula, and other grasses.

DT: scattered Juniperus spp.

RS: Yucca glauca.

SS: occasional Opuntia spp.

F: steppe forbs, e.g. Plantago, Senecio, Haplopappus,

References: Weaver & Albertson 1956; Daubenmire 1943; Shantz 1906; Küchler 1964; Knapp 1965.

19. CUSTER/SOUTH DAKOTA U.S.A.

Black Hills Pine Forest:

T: *Pinus ponderosa.

UT: Prunus virginiana, et al.

S: Arctostaphylos uva-ursi, Juniperus communis, Symphoricarpus spp., Artemisia tridentata, Cercocarpus parviflorus, Physocarpus intermedia, Rhus trilobata, et al.

G: Elymus spp., Poa pratense, Agropyron spp., Koeleria cristata, Bouteloua gracilis(s), Stipa comata, Buchloë dactyloides(s), et al., plus Carex spp.

F: Chrysothamnus graveolens, Gutierrezia sarothrae, et al.

References: Hayward 1928; Weaver & Albertson 1956; Van Bruggen 1976; Küchler 1964; personal observation.

20. OELRICHS/SOUTH DAKOTA U.S.A.

Short Bunch-Grass (Agropyron-Stipa) Steppe:

G(mid-height): *Koeleria cristata, *Agropyron smithii, A. spicatum, *Stipa comata, et al.

G(short): *Buchloë dactyloides(s), *Bouteloua gracilis, other Agropyron and Stipa spp., et al.

F: many steppe forbs, e.g. Liatris, Aster, Penstemon, Mertensia, Solidago, Artemisia frigida(w).

References: Hayward 1928; Weaver & Albertson 1956; Küchler 1964; personal observation.

21. OKLAHOMA CITY/OKLAHOMA U.S.A.

Southern Tall-Grass Prairie (red-clay Stipa-Koeleria association):

T: occasional Quercus stellata, Qu. marilandica, Carya texana.

G: *Andropogon scoparius et al., *Bouteloua racemosa, *Agropyron smithii, *Sporobolus asper, with other tall and mid-height grasses.

F: numerous prairie forbs, e.g. Claytonia virginica, Houstonia minima, Bursa, Draba, Anemone caroliniana, Baptisia spp., Allium spp., Achillea spp., Asclepias, Croton, Psoralea, Solidago, Helianthus, Veronica, and many more.

S: numerous steppe semi-shrubs, e.g. Rhus, Amorpha, Clematis.

References: Knapp 1965; Bruner 1931; Küchler 1964; personal observation.

22. BARTLESVILLE/OKLAHOMA U.S.A.

Oak Woodland-Tall (subclimax) Grassland Mosaic, with cove-like closed oak forests:

T: *Quercus marilandica, *Qu. stellata, other Quercus spp., Carya texana, et al.

UT: Cercis canadensis, Celtis spp., Prunus serotina, et al.

G: *Andropogon scoparius, *A. gerardi, Bouteloua spp., Elymus canadensis, Panicum virgatum, Stipa leucotricha, Sporobolus spp., Eragrostis spp., Sorghastrum nutans, et al.

F: numerous steppe forbs, especially Compositae (e.g. Solidago, Aster, Erigeron, Helianthus, Liatris) and legumes (e.g. Baptisia, Amorpha, Psoralea).

Soil: fine-textured (shale) soils, favoring grasses over trees.

References: Bruner 1931; Ray 1959; Küchler 1964; personal observation.

23. SOUTH BEND/INDIANA U.S.A.

Summergreen Oak-Hickory Forest (western limit):

T: *Quercus macrocarpa, *Qu. velutina, *Qu. alba, *Qu. rubra, *Carya ovata, *C. tomentosa, other Quercus and Carya spp., Acer rubrum, Fraxinus americana, Juglans nigra, Tilia americana, Ulmus americana, et al.

UT: Prunus serotina, Cercis canadensis, Sassafras albidum, Hamamelis virginiana, Malus spp., et al.

H: many grasses and mesic-submesic forbs.

References: Braun 1950; Knapp 1965; Küchler 1964.

24. COLUMBUS/OHIO U.S.A.

Summergreen Beech-Maple Forest:

T: *Fagus grandifolia, *Acer saccharum, Fraxinus americana, Quercus rubra, Qu. alba, Carya spp., Ulmus spp., Betula lutea, Carpinus caroliniana, Liriodendron tulipfera, Juglans cinerea, Tilia americana, et al.

UT: Prunus serotina, Ostrya virginiana, Aesculus spp., Cercis canadensis, et al.

UB: Lonicera canadensis, et al.

F: Hepatica americana, Hydrophyllum macrophyllum, and many others.

References: Braun 1950; Knapp 1965; Küchler 1964.

25. BAR HARBOR/MAINE U.S.A.

Spruce-Northern Hardwood Forest and open Woodlands with bogs:

T: *Picea rubra, *P. canadensis, Abies balsamea, Pinus strobus, Thuja occidentalis, Tsuga canadensis, Betula papyrifera, B. populifolia, B. lutea, Populus tremuloides, P. grandidentata, Acer rubrum, Quercus rubra, Fagus grandifolia, et al.

S: Vaccinium spp., Alnus spp., Viburnum cassinoides, Gaylussacia baccata, Kalmia angustifolia, Acer spp., Rubus spp., et al.

H: Agrostis spp., Festuca spp., Carex spp., et al.

Soil: glacial till, with sand and areas of bare rock.

References: Moore & Taylor 1927; Küchler 1964; Davis 1966; Damman 1977; personal observation.

26. TRENTON/NEW JERSEY U.S.A.

Appalachian Summergreen Oak-Chestnut Forest:

T: *Quercus rubra, Qu, alba, *Castanea dentata (destroyed by Chestnut Blight), Quercus coccinea et al., Liriodendron tulipfera, Acer saccharum, A. rubrum, Fagus grandifolia, Liquidambar styraciflua, Carya spp., Nyssa sylvatica, Pinus rigida, P. strobus, Fraxinus americana, Betula lenta, Carpinus caroliniana, Tsuga canadensis, et al.

UT: Cornus florida, Cercis canadensis, Prunus spp., et al.

S: Vaccinium spp., Kalmia spp., et al.

H: many summergreen mesic forbs.

References: Braun 1950; Knapp 1965; Küchler 1964.

27. MT. MITCHELL/N. CAROLINA U.S.A.

Appalachian Fir-Spruce Forest:

T: *Abies fraseri, Picea rubens.

UT: Sorbus americana, Prunus pennsylvanica, Betula lutea, Acer spicatum, et al.

S: Rhododendron catawbiense, R. maximum, Rubus spp., Vaccinium erythrocarpum, Viburnum alnifolium, Menziesia pilosa, et al.

H: Houstonia serpyllifolia, Oxalis acetosella, Clintonia borealis, Aster acuminatus, Saxifraga michauxii, Chelone lyonii, Carex debilis, Cinna latifolia, et al.

References: Whittaker 1956; Davis 1930; Radford 1976; personal observation.

28. CHARLESTON/SOUTH CAROLINA U.S.A.

Southern Bottomland Mixed Forest (with local swamps):

T: Quercus virginiana, Qu. laurifolia, Qu. alba (SG), Qu. stellata (SG), Qu. phellos (SG), Magnolia grandiflora, M. virginiana, Liquidambar styraciflua (SG), Carya spp. (SG), Pinus taeda, P. echinata, Nyssa sylvatica (SG), et al., with Taxodium distichum (SG, Conif.) in swamps.

UT: Ilex vomitoria, Persea borbonia, Cornus florida (SG), et al.

RS: Sabal palmetto.

S: Vaccinium, Bumelia, Baccharis, Myrica cerifera, et al.

G: Arundinaria gigantea, et al.

Also: Tillandsia usneoides (Ep), with many vines.

References: Braun 1950; Küchler 1964; Radford, Ahles & Bell 1968; personal observation.

29. SAVANNAH/GEORGIA U.S.A.

Coastal Plain Pine-Hardwood Forest (with more pines and with local swamps):

T: Quercus virginiana, Qu. phellos (SG), Pinus taeda, P. flexilis, P. palustris, Liquidambar styraciflua (SG), Nyssa sylvatica (SG), Magnolia grandiflora, et al., with Taxodium distichum (SG, Conif.) in swamps.

UT: Persea borbonia, Ilex vomitoria, Cornus florida (SG), et al.

RS: Sabal palmetto.

S: Vaccinium spp., Baccharis spp., Myrica cerifera, et al.

G: Arundinaria gigantea, Panicum amarum, et al., with Spartina and Juncus prairies (brackish).

Also: Tillandsia usneoides (Ep), with many vines.

References: Braun 1950; Küchler 1964; Shelford 1963; personal observation.

30. BIRMINGHAM/ALABAMA U.S.A.

Southern Pine-Summergreen Oak Forest:

T: *Quercus stellata, *Qu. alba, *Pinus taeda, *P. echinata, P. australis, P. palustris, P. caribaea, Quercus margaretta, Qu. marilandica, Qu. velutina, Carya spp., Nyssa sylvatica, Oxydendron arboreum, et al.

UT: Cornus florida, Cercis canadensis.

S: Vaccinium spp., Chrysobalanus, Eriogonum, Gaylussacia, Croton, Leiophyllum, et al.

G: Aristida stricta, Panicum, Sporobolus, Andropogon, et al.

Also: many vines and spring forbs.

References: Braun 1950; Knapp 1965; Küchler 1963; personal observation.

31. XILITLA MEXICO

Tropical Montane Rainforest with Holarctic Species (lower altitudinal limit):

T: Quercus candolleana, Qu. excelsa, Qu. trinitatis, Qu. xalapensis et al., Carpinus caroliniana, Carya mexicana, Clethra spp., Cornus spp., Liquidambar styraciflua, Pinus patula, Podocarpus spp., et al.

US: Turpinia spp., Vaccinium spp., Leucothoe mexicana, Eugenia, Garrya laurifolia, Ilex spp., et al.

V: Rhus radicans, Parthenocissus quinquefolia, et al.

H: Gaultheria spp., Asplenium spp., et al.

References: Miranda & Sharp 1950; Knapp 1965.

32. MAZATLAN MEXICO

Lowland Dry Raingreen Thorn Forest:

T: *Ipomoea arborescens, *Acacia cymbispina, *Zizyphus sonorensis (EG), Bauhinia longiflora, Crescentia alata, Bunchosia palmeri, Acacia farnesiana, A. pennatula, Bursera, Piscidia piscipula, Alvaradoa amorphoides, Ceiba, Haematoxylon brasiletto, Pedilanthus macrocarpus, Lysiloma, Prosopis juliflora, Pithecellobium sonorae, Lonchocarpus, Caesalpinia, Guaiacum (Zygophyll.), Jatropha cinerea, Ficus petiolaris, Cordia, Mimosa, et al.

S: Croton alamosanus, Fouquiera macdougalii, Cassia spp., et al.

SS: Cereus thurberi, Pachycereus (both arborescent).

H: Bouteloua curtipendula, B. rothrockii, Hilaria semplei, Cathestecum spp., et al.

References: Leopold 1950; Shreve 1934; Pesman 1962; Mata et al. 1972; Miranda & Hernandez 1963; Knapp 1965.

33. QUIBDO COLOMBIA

Tropical coastal-lowland Rainforest (tall, multistoreyed, with numerous lianas and epiphytes, and with palm forests in swamps):

T: Cespedetia apathulata, Brosimum utile, Terminalia amazonica, Ficus, Dialyanthera, Hura crepitans, Aniba perutilis, Hevea, Nectandra, Cedrela, Tabebuia, Castilla, Cariniana, Prioria, Myroxylon, Ochroma, Cecropia, Schizolobium, and many others.

UT: numerous palms (e.g. Jessenia polycarpa, Welfia regia, Phytelephas spp.), and many other trees.

Also: many shrubs, lianas, epiphytes, and ferns.

References: Verdoorn 1945; Hueck 1966; West 1958.

34. BARINAS VENEZUELA

Tradewind Raingreen (Monsoon) Forest:

T: Spondias mombin, Pterocarpus vernalis et al., Bombacopsis sepium, Sapium, Hura crepitans, Astronium graveolens, Brosimum, Tabebuia spp., Cochlospermum vitifolium, Cordia spp., Pouteria, Terminalia, Cedrela mexicana, Swietenia macrophylla, Samanea saman, et al.

US: palms (e.g. Attalea, Orbignya, Oenocarpus, Syagrus, Oreodoxa), et al.

S: Psychotria, Miconia, Urera, Croton, et al.

H: many grasses and forbs, including Scitaminaceae.

E: Ficus spp., Coussapoa (Morac.) spp., Phoradendron spp.

References: Hueck 1966; Veillon 1955.

35. OBIDOS BRAZIL

Dry Tropical Rainforest with Campos Cobertos (islands of drier open forest):

T: Curatella americana, Anacardium occidentale, Bowdichia, Aeschynomene, Qualea, Vochysia, Byrsonima, et al., with Cassia, Calliandra, Crotalaria, Eugenia, et al.

H: tall and short tropical grasses and many other species.

Soil: terra roxa

References: Hueck 1966; Ule 1915.

36. QUIXERAMOBIM BRAZIL

True Caatinga (Raingreen Thorn-Woodland with palms and arborescent stem-succulents):

T: Zizyphus joazeiro (EG), Mimosa, Cassia, Caesalpinia, Acacia, Piptadenia (Leg.), Amburana, Cavanillesia arborea (Bombac.), Chorisia ventricosa (Bombac.), Melanoxylon, Aspidosperma, Platymiscium, Machaerium, Spondias, Pithecolobium, et al.

RT: Cocos schizophylla, Copernicia cerifera, et al.

RS: Ground-bromeliads, e.g. Aechmoa, Ananas, Billbergia, Dyckia, Pitcairnia, Neoglaziovia.

SS: Cereus jamacaru, C. squamosus, Opuntia, Pilocereus gounellei, Melanocactus (most arborescent).

S: Capparis yco (EG), Euphorbia, Croton, Caesalpinia, Jatropha, Anonaceae, Coccoloba, Cnidoscolus, et al.

H: short grasses but few forbs.

References: Hueck 1966; Corrêa 1926; Hueck & Seibert 1972.

37. BELO HORIZONTE BRAZIL

Campos Cerrados (dwarf evergreen woodland of 2–4 m, with thick grass cover; near transition to mixed forests):

T: Kielmeyera, Byrsonima, Dimorphandra, Machaerium (EG Leg.), Stryphnodendron, Dalbergia (EG Leg.), Copaifera (EG Leg.), Caryocar, Aspidosperma tomentosum (RG) et al., Bombax, Curatella americana, Quassia versicolor, Luehea paniculata, Caryocar brasilense, Palicourea rigida, Terminalia argentea, Shinus, Lithraea, Astronium, et al.

RS: dwarf-palms, e.g. Attalea exigua, Cocos petraea, C. acaulis, Asterocaryum avenarium, Diplothemium campestre, Acrocomia sclerocarpa.

S: Erythroxylon, Byrsonima, Cassia, et al.

H: many tall and mid-height grasses, with numerous forbs.

References: Hueck 1966; Ferri 1969; Hueck & Seibert 1972.

38. SAO PAOLO BRAZIL

Subtropical Species-Rich Semi-Evergreen Forest:

T: Cedrela fissilis, C. glaziovii, Balfourodendron riedelianum, Hymenaea stilbocarpa, Inga edulis, Centrolobium robustum, Myroxylon peruiferum, Dalbergia nigra, Aspidosperma polyneutron, Myrocarpus frondosus, Machaerium spp., Piptadenia spp., Holocalyx glariovii, Luehea divaricata, Gallesia guararema, Cabralea cangarena, Phoebe porosa, Tabebuia spp., Cariniana estrellensis, Melanoxylon brauna, Plathymenia foliosa, Ficus spp., Vochysia spp., et al.

UT: palms, e.g. Arecastrum romanzoffianum, Acrocomia totai.

UB: thick brush, with Euphorbiaceae, lianas, epiphytes.

Current use: fields and plantations, especially coffee.

References: Hueck 1956, 1966; Hueck & Seibert 1972.

39. VILLA NOUGUES/TUCUMAN ARGENTINA

Southern Andes Subalpine Alder Belt (near lower limit):

T: *Alnus jorullensis (SG), with species from the montane belt, e.g. Juglans australis (SG), Podocarpus parlatorei (EG), Prunus spp.

US: Sambucus, Ilex, Berberis, et al.

F: Geum, Ranunculus, Anemone, Vicia, Urtica, Lathyrus, Thalictrum, Geranium, Stachys, Salvia, Veronica, Cerastium, et al.

References: Hueck 1954, 1966; Hieronymus 1945.

40. ISLA VICTORIA/LAGO NAHUEL HUAPI ARGENTINA

Patagonian Lower-Montane Nothofagus Rainforest (30–40 m):

T: *Nothofagus dombeyi, with N. betuloides, Eucryphia cordifolia.

UT: Drimys winteri, Nothofagus pumilio (SG), scattered Libocedrus tetragona (= Pilgerodendron uviferum), Podocarpus (e.g. P. andinus, P. poepp. ex Endl., P. nubigenus Lindl.), Saxegothea, et al.

UB: Weinmannia trichosperma, Caldcluvia paniculata, Laurelia serrata, Myrtaceae, et al;

Also: many ferns, epiphytes, and often bamboo.

Reference: Hueck 1966.

41. BARILOCHE, SAN CARLOS DE ARGENTINA

Patagonian Lower-Montane Libocedrus Forest (20–25 m)

T: *Libocedrus chilensis (up to 90%), with Lomatia hirsuta, Diostea juncea, Schinus crenatus, Maytenus boaria, and isolated Araucaria araucana.

S: Berberis buxifolia, B. darwinii, Azara microphylla, Fabiana imbricata, Pernettya poeppigii.

Also: Patagonian steppe-grasses and dwarf-shrubs.

References: Hueck 1966; Schmithüsen 1960.

42. VALDIVIA CHILE

Temperate Species-Rich Broad-Macrophyll Rainforest (40–50 m) (near transition to summergreen mesophytic forest):

T: Aextoxicon punctatum, Eucryphia cordifolia, Laurelia aromatica, L. serrata, Drimys winteri, et al. (all with large, lauraceous EG leaves); Myrceugenella apiculata, et al. (with small, myricaceous EG leaves); plus Flotovia diacanthoides, Guerina avellana, Lomatia ferruginea, L. hirsuta, Maytenus boaria, Nothofagus obliqua (SG), N. procera (SG), scattered Fitzroya patagonica (Coniferae), et al.

S: Weinmannia trichosperma, Caldcluvia paniculata, Rhaphithamnus cyanocarpus, Ugni molinae, Coriaria ruscifolia, et al.

Also: many lianas (e.g. Boquila trifoliata, Mitraria coccinea, Griselinia ruscifolia, Dioscorea brachybotrya), epiphytes, climbing and rigid bamboo-grasses, and a thick ground cover of forbs and mosses.

References: Hueck 1966; Veblen & Ashton 1978; Schmithüsen 1956, 1960.

43. USHUAIA CHILE

Subantarctic Summergreen Microphyllous Forest (10–20 m), near southern limit:

T: *Nothofagus pumilio, with N. antarctica and scattered N. betuloides (EG) and N. dombeyi (EG).

S(few): Ribes magellanicum, R. cucullatum, Berberis spp., Pernettya mucronata, Escallonia spp.

G: Carex, Festuca, Trisetum, Elymus, plus the bamboo Chusquea.

F: Viola, Rubus, Ranunculus, Senecio, Sisyrinchium, Anemone, Vicia, et al.

Reference: Hueck 1966.

44. THINGVELLIR ICELAND

Icelandic Maritime 'Mo' Tundra (herbs, dwarf-shrubs, and mosses):

G: *Festuca rubra et al., *Carex spp., Agrostis canina, Luzula spicata, Juncus trifidus, Deschampsia flexuosa, Poa, Trisetum, et al.

DS: Salix herbacea, Empetrum nigrum, Calluna vulgaris, Arctostaphylos uva-ursi, et al.

F: Polygonum viviparum, Galium spp., Selaginella selaginoides, Equisetum spp., et al.

Also: many mosses and lichens (locally dominant).

References: Hansen 1930; Jonsson 1905; Ostenfeld & Grontved 1934; personal observation.

45. ABISKO SWEDEN

Summergreen Fell-Birch Forest-Tundra:

T: *Betula tortuosa (= B. pubescens ssp. tortuosa), B. callosa, Populus tremula, with Pinus silvestris on moors and on serpentine soils.

S: Betula nana, Empetrum hermaphroditum, Vaccinium myrtillus, with Arctostaphylos alpina, A. uva-ursi, Loiseleuria procumbens, et al.

Also: Carex ssp., grasses, mosses, lichens (Cladonia, Nephroma).

References: Blüthgen 1960; Acta Phytogeogr. Suecica 1965; personal observation.

46. DALBY SÖDERSKOG (LUND)/SKÅNE SWEDEN

Summergreen Elm-Oak Forest, with low-tree and shrub layers (undisturbed since 1916):

T: *Ulmus glabra, *Quercus robur, Fagus sylvatica, Fraxinus excelsior

UT: mainly Ulmus saplings, Corylus avellana, Crataegus laevigata, Acer platanoides, Euonymus europaeus

S: Prunus padus, Crataegus, saplings

H: Anemone nemorosa, Ranunculus ficaria, et al., Oxalis acetosella, Corydalis, Gagea, Geum, Veronica, Carex, Poa, Viola, Campanula, Equisetum, etc.

V: Lonicera xylosetum.

Reference: Malmer et al. 1978.

47. MIKULOV/WEINVIERTEL AUSTRIA

Summergreen Woodland and Scrub with dry grassland mosaic:

T: *Quercus pubescens, Carpinus, Pinus sylvestris, P. nigra, Robinia pseudoacacia, Betula, Corylus

UB: *Quercus, Carpinus, Corylus, Betula

G: *Festuca (Festucetalia valesiacae), Agropyron repens, A. intermedium, Poa angustifolia, P. compressa, Bromus inermis, Stipa, Danthonia, et al.

V: Convolvulus arvensis

F: Cardaria draba, Equisetum arvense, Kochia prostrata, and many others

Reference: Eijsink et al. 1978.

48. AIN-DRAHAM TUNISIA

Semi-Evergreen Mesic Oak Forest (10–20 m):

T: *Quercus faginea ssp. baetica (SG), Qu. suber (EG), Sorbus torminalis, Prunus avium, Acer campestre, Ilex aquifolium.

S: Crataegus ssp., Erica arborea, Cytisus triflorus, et al.

V: Rubus discolor, Tamus communis, Hedera helix s.l., et al.

F: Cyclamen africanum, Geranium spp., Scilla aristidis, Moehringia pentandra, Asperula laevigata, and many others.

G: Festuca drymeja var. grandis, Melica minuta, Carex, et al.

References: Knapp 1973; UNESCO 1969.

49. AZROU MOROCCO

Mediterranean Montane Oak Forest:

T: *Quercus ilex (EG).

US: Sarothamnus baeticus, Cytisus triflorus, Crataegus monogyna, Cistus salvifolius, Jasminum fruticans, Thymus zygis, Viburnum tinus, Rosa spp., and individually Buxus sempervirens, Phillyrea spp., Pistacia spp., et al.

V: Lonicera, Smilax, Clematis, Rubia, Tamus.

Ch: Ononis arborescens, Psoralea bituminosa, Ruta montana, Ajuga pseudo-Iva, Cephalaria leucantha, Artemisia sp., Ilex aquifolium, Daphne laureola, Rhamnus, et al.

Hc: Festuca, Carex, Rumex, Ranunculus, Eryngium, Haynaldia hordacea, Salvia, Geum, et al.

References: Knapp 1973; Walter 1968, 1977b; UNESCO 1969; Braun-Blanquet & Maine 1924; Emberger 1938; personal observation.

50. KSAR-ES-SOUQ MOROCCO

Sub-Saharan High-Plateau Shrub-Bunch Grass Steppe:

G: *Stipa tenacissima(b), Aristida pungens, A. plumosa, Panicum turgidum, et al.

S: Artemisia herba-alba, A. campestris, Ephedra alata, Anabasis spp., Balanites aegyptiaca, Salvadora persica, Zizyphus lotus, Boscia senegalensis, Calotropis procera, Genista raetum, Lygeum spartum, et al.

F: yellow-flowered Compositae, et al.

References: Shantz & Marbut 1923; Zohary 1973; UNESCO 1969; Emberger 1938; personal observation.

51. DAMANHUR AREA EGYPT

(west, along Cairo-Alexandria road)

Sparse Artemisia-Thymelaea Desert Scrub (10% cover):

S: *Artemisia monosperma, Zygophyllum coccineum, *Thymelaea hirsuta, Anabasis articulata, Salsola, Lithospermum callosum

G: Aristida plumosa, A. pungens, Panicum turgidum et al.

F: Allium, Muscari, Plantago albicans, Asphodelus, Helianthemum lippii

Eph: Mesembryanthemum forskalei, Trigonella, Ifloga, Erodium, Matthiola, Salvia lanigera, Malva, Chrysanthemum coronarium, et al.

V: Convolvulus lanatus

References: Ayyad & El-Ghonemy 1976; Walter 1973.

52. MAKURDI NIGERIA

Raingreen Wooded Savanna (Wet-Savanna Zone):

T: *Daniellia oliveri (Caesalp.), *Lophira alata, *L. lanceolata, *Parinari polyandra, Terminalia spp., Afzelia africana, Bridelia ferruginea, Butyrospermum parkii, Cussonia barteri, Hymenocardia acida, Vitex doniana, Annona, Detarium senegalense, Gardenia, Lannea, Prosopis africana, et al.

G: *Hyparrhenia spp., *Andropogon spp., *Pennisetum spp., Panicum, Schizachyrium, Tephrosia, Eriosema, et al.

F: Eulophia spp., Indigofera, Curculigo pilosa, Amorphophallus spp., Kaempferia, Costus spectabilis.

References: Knapp 1973; Keay 1949.

53. MAHADDAY-WEYNE SOMALIA

Dry Raingreen (Commiphora) Thorn-Scrub:

T/B: *Commiphora spp., *Acacia spp., Capparidaceae (e.g. Boscia, Cadaba, Maerua, Capparis, Courbonia), Grewia spp., Delonix elata, Sterculia, Heeria (Anacard.), Lannea (Anacard.), Sesamothamnus (Pedaliac.), Salvadora persica, et al.

G: Chrysopogon aucheri, Aristida stipoides, Cenchrus ciliaris, Sporobolus variegatus, Schoenfeldia gracilis, et al. (all short), with tall Beckeropsis and Hyparrhenia in wide river valleys.

References: Knapp 1973; Keay 1959.

54. ASMERA/ERITREA ETHIOPIA

Region of Dry Thorn-Scrub, Dwarf-Shrub, and Montane (short) Grassland Mosaic:

T: *Acacia spp., Juniperus procera, Olea africana, Balanites aegyptica, Sanseveria longiflora, Barbeya oleoides (Ulmac.), Celtis africana, Sideroxylon oxyacantha, Tarchonanthus camphoratus.

S: *Acokanthera schimperi, *Buxus hildebrandtii, et al.

SS: Euphorbia spp.

RT: Dracaena.

G: *Festuca abyssinica, *Pentaschistis mannii, *Agrostis isopholis, et al.

References: Knapp 1973; Keay 1959; Shantz & Marbut 1923.

55. KERICHO KENYA

Region of Equatorial Montane (Evergreen) Rainforest:

T_2: *Ocotea usambarensis, *Podocarpus spp., with Aningeria, Casearia, Chrysophyllum, Ekebergia, Entandrophrgama, Ficus, Macaranga, Polyscias, Pygeum, Strombosia, Schefflera, Vitex, and many others.

T_1: Afrocrania, Allophylus, Canthium, Cassine, Cassipourea, Croton, Cyclicomorpha, Conopharyngia, Cola, Dracaena, Enneastemon, Ficalhoa, Galiniera, Grumelia, Lasianthus, Oxyanthus, Peddiea, Premna, Trichilia, Trichocladus, Uvariodendron, Xymalos, et al.

References: Knapp 1973; Lind & Morrison 1974.

56. NANYUKI KENYA

Region of potential Dry Montane Conifer Forest (open-forest mosaic with thorn-scrub and wooded steppe):

T: *Juniperus procera, *Olea africana, *O. hochstetteri, Podocarpus spp., Croton megalocarpus, Cussonia spicata, Tarchonanthus camphoratus, et al.

UB: *Acacia spp., *Commiphora spp., Acanthus emiens, et al.

G: Chrysopogon, Aristida, et al.

References: Knapp 1973; Keay 1959; Lind & Morrison 1974.

57. LUSAKA ZAMBIA

Miombo Forest (somewhat open raingreen forest dominated by legumes with mid-size, compound leaves):

T: *Brachystegia (Caesalp.) spp., Julbernardia (Leg.), Isoberlinia (Leg.), Berlinia (Caesalp.), Guibourtia (Caesalp.), Marquesia (Caesalp.), Afrormosia (Leg.), Parinari (Ros.), Pterocarpus (Leg.) et al.

UT: Uapaca (Euphorb.) spp., Diospyros spp., Monotes (Dipterocarp.) spp., Pseudolachnostylis (Euphorb.), Faurea (Proteac.), et al.

S: Hexalobus, Hymnocardia, Maprounea, Allophylus, et al.

H: many grasses and forbs, especially active during the dry season.

References: Knapp 1973; Keay 1959; Shantz & Marbut 1923.

58. MAUN BOTSWANA

Mopane Dry Forest (open raingreen forest with sparse undergrowth):

T: *Colophospermum mopane (Caesalp.: entire mesophylls), with Acacia nigrescens, Kirkia acuminata (Simaroub.), Terminalia prunioides, et al.

S: Grewia, Combretum, Capparidaceae (e.g. Courbonia), Ximenia, Boscia, et al.

H: relatively few grasses and forbs.

References: Knapp 1973; Keay 1959.

59. KROONSTAD/ORANJE FRYSTAAT SOUTH AFRICA

Region of Tall, Forb-Poor Themeda Grassland (High Veld):

G: *Themeda triandra, Heteropogon contortus et al., Setaria flabellata, Elyonurus argenteus, Eragrostis, Cymbopogon, Microchloa caffra, Tristachya spp., Helichrysum rugulosum, Vernonia kraussii, Andropogon spp., Hyparrhenia hirta, et al.

F: Elephantorrhiza burchellii, Hypoxis costata, Aster serrulatus, Clerodendron triphyllum, Indigofera hedyantha, et al.

References: Shantz & Marbut 1923; Knapp 1973; Acocks 1953; Zinderen Bakker 1973.

60. CATHEDRAL PEAK (LITTLE BERG)/DRAKENSBERG SOUTH AFRICA

Montane Evergreen Heathland (Fynbos):

S: *Passerina filiformis, *Philippia evansii, *Widdringtonia nodiflora (n, Coniferae), Passerina montana, Protea, Erica, Myrica, Cliffortia, Macowania, Buchenroedera, Anthospermum, Rhus discolor, R. dentata, Buddleja, Syncolostemon, Calpurnia, Melianthus, Asparagus, Senecio, with Stoebe, Euphorbia, Myrsine, Artemisia, Psoralea, Polygala and many more.

RT: Encephalartos ghellinekii (cycad)

V: Riocreuxia torulosa var. tomentosa, Dioscorea sylvatica, Clematis brachiata.

H: Restio spp., Polystichum, Cymbopogon validus, Berkheya macrocephala, Festuca costata, Helichrysum spp., Indigofera, and many others.

Reference: Killick 1979.

61. HELL-BOURG REUNION

Region of Montane Evergreen Rainforest:

T: Cassine (= Elaeodendron), Diospyros, Dodonaea,Doratoxylon, Evodia, Linociera, Mimusops, Nuxia, Ocotea, Olea, Psiloxylon, Sideroxylon, Tabernaemontana, Terminalia, Weinmannia, Xylopia, Danais, et al.

References: Knapp 1973; Cadet 1974.

62. BORISOVKA/RUSSIA U.S.S.R.

Summergreen Oak-Basswood Forest:

T: *Quercus robur, *Tilia cordata, Acer platanoides, A. campestre, Ulmus montana, Malus sylvestris, Crataegus curvipendula, et al.

S: Euonymus europea, E. verrucosa, et al.

F: spring geophytes, e.g. Scilla sibirica,Corydalis halleri, Anemone ranunculoides, Gagea lutea, Ficaria verna; summer forbs, e.g. Aegopodium podagraria, Galium (Asperula) odorata, Stellaria holostea, Glechoma hirsuta, Pulmonaria obscura, Polygonatum multiflorum, Geum urbanum, Viola suavis, Asarum europaeum.

G: Carex pilosa, Poa nemoralis, Festuca gigantea, et al.

Reference: Walter 1976a.

63. KERKI/TURKMENISTAN U.S.S.R.

Kara-Kum Semi-Desert (with leafless and nanophyllous trees):

T: *Ammodendron conollyi (Leg.), *Haloxylon aphyllum (= ammodendron) (Chenopod.).

S: *Haloxylon persicum, Calligonum spp. (Polygon.), Salsola richteri, S. arbuscula, Astragalus paucijugus, Aellenia subaphylla, Ephedra strobilacea.

S(Sf): Smirnovia turkestana (Leg.), Artemisia spp., Astragalus spp., Salsola spp.

H: Carex physodes, C. subphysodes, C. pachystylis, Poa bulbosa, Tournefortia sogdiana, Heliotropium arguzioides, Aristida karelinii, Allium spp., Gagea spp., Tulipa sogdiana, Iris spp., Rhinopetalum arianum, Eremurus inderiensis (Lil.), Eminium lehmannii (Arac.), Rheum turkestanicum, Dorema sabulosa, et al.; and many annual herbs.

References: Walter 1976a; Walter & Box, in press.

64. CHATKAL MOUNTAINS/KIRGHIZ U.S.S.R.

Montane Summergreen Walnut Belt:

T: *Juglans fallax (= J. regia ssp. fallax), Prunus divaricata, Acer spp., Malus spp., Crataegus spp., et al.

G: Melica altissima, Festuca gigantea, Agropyron caninum, Poa nemoralis, Bromus spp., Carex polyphylla, et al.

F: Impatiens parviflora, Aegopodium podagraria, Lamium album, Cerastium, Senecio, Allium, Polygonatum, Arum, et al.

Also: Lonicera spp., Rosa spp., Galanthus, Brachypodium, et al.

Reference: Walter 1974.

65. NAJAF DEPRESSION IRAQ

Salsola-Zygophyllum Shrub Steppe (5–15% cover) with saline marshes:

S: *Salsola crassa, *Zygophyllum coccineum, Nitraria retusa, Seidlitzia rosmarinus, Halocnemum strobilaceum

H: Limonium carnosum, Cleome arabica, Bienertia cycloptera, Frankenia pulverulenta, Schangenia aegyptiaca, Atriplex leucoclada, Aeluropus logopoides

Reference: Abul-Fatih 1975.

66. MAIMANA AFGHANISTAN

Open Summergreen Pistacia Woodland (5–40% cover, 2–5 m., with shrubs, grasses, and forbs):

T: *Pistacia vera, Amygdalus (Prunus) spp., Cercis griffithii.

S: Amygdalus spinosissima, Cerasus (Prunus) bifrons, Colutea gracilis, Ephedra spp., Rosa spp.

DS: Artemisia tenuiseta, Acantholimon sp.

Hc: Cousinia spp., Phlomis bucharia, Chrysanthemum umbelliferum, Helichrysum plicatum, Delphinium zalil, Poa bulbosa, Chaetolimon sogdianum, Salvia pterocalyx, Solenanthus turkestanicus, et al.

Gp: Carex stenophylla, Eremurus olgae, Ungernia trisphaera, Bellevalia atroviolacea, Bongardia chrysogonum, Eranthis longistipata, Anemone sp., et al.

Th: Aegilops crassa et al., Bromus spp., Taeniantherum crinitum, Astragalus severtzowii, and many others.

References: Walter 1974; Freitag 1971; Kitamura 1960.

67. KOTGAI AFGHANISTAN

Montane Cedrus deodara Forest:

T: *Cedrus deodara, Juniperus seravschanica, Pinus gerardiana (dominates belt immediately lower), P. wallachiana, Quercus semecarpifolia, Qu. baloot (EG).

S: Sophora griffithii, Rosa ecae, Cotoneaster sp., Berberis sp., Lonicera quinquelocularis, et al.

H: Salvia nubicola, Phlomis cashmeriana, Ph. spectabilis, Nepeta pinetorum, Astragalus (Myobroma) erythrosemius, Carex cardiolepis, Poa sp., Oryzopsis gracilis, Isatis koelzii, Fragaria nubicola, Saussurea amplifolia, Taraxacum stenolepum, Thlaspi griffithianum, et al.

References: Freitag 1971; Breckle 1975.

68. MUSSOORIE INDIA

Montane Evergreen Quercus incana Forest, with Rhododendron, Lyonia, Viburnum and Berberis:

T: *Quercus incana, with Cedrela serrata (locally) and Cedrus deodara and Pinus roxburghii on dry exposures.

UT: Rhododendron arboreum, Lyonia ovalifolia, Euonymus tingens, Populus ciliata, Lonicera, Cornus macrophylla, Persea odoratissima, Rhus cotinus, Ilex dipyrena, Pyrus pashia

S: Rhododendron, Leptodermis lanceolata, Rhamnus virgatus, Viburnum cylindricum, Berberis, Indigofera

V: Hedera nepalensis, Smilax aspera, Rubus, Parthenocissus

G: Arundinaria, Cympogon, Themeda, Chrysopogon

F: Bergenia ciliata, Myriactis wallichii, Impatiens, Rubus, Desmodium, Plectranthus, Artemisia roxburghiana, Sarcococca saligna, Commelina oblique, Polygonum

Fn: Polystichum aculeatum, Dryopteris, Pteris

Reference: Saxena & Srivastava 1973.

69. YÜJLIN/ORDOS REGION CHINA

Cold-Winter Xeric Shrub Steppe (15–40% cover) on aeolian sand:

OB: Caragana korshinskii (only on mobile dunes)

S: *Artemisia ordosica, Caragana microphylla, C. stenophylla

G: Carex duriuscula, Stipa glareosa et al.

F: Artemisia frigida, Allium mongolicum, Pycnostelma lateriflorum, Peganum nigellastrum

References: Walter 1968, 1974; Walter & Box, in press.

70. WILUNA/W. AUSTRALIA AUSTRALIA

Mulga Scrub (large, evergreen shrubs with polymorphic phyllodes):

S: *Acacia aneura, with other Acacia spp., Eremophila (Myorpor.), Cassia (Caesalp.), Hakea (Proteac.), smaller Eucalyptus spp., et al.

G: patches of Triodia (sclerophyllous hummock-grasses), et al.

H: ephemeral carpets of Weitzia aurea and Helipterum spp. (both Compositae), et al.

Also: Chenopodiaceae on saline sites.

References: Walter 1973, 1977b; Beard 1965; Milton Moore 1970.

71. KEITH (DARK ISLAND)/S. AUSTRALIA AUSTRALIA

Open Dry Evergreen Heath (1–2 m.) with scattered mallee:

T: Eucalyptus spp.

S: *Banksia ornata (b, mic), *Casuarina pusilla (n), *Leptospermum myrsinoides (b, lep), B.marginata (b, nan), Phyllota (n), Adenanthos terminalis (n), Spyridium subochreatum var. laxiusculum (n)

RS: *Xanthorrhoea australis

DS: Hibbertia spp. (n), Leucopogon spp. (b, lep), Baeckea ericaea (n), Calytrix alpestris (n), Boronia caerulescens (n)

G: Hypolaena fastigiata (n), Lepidosperma spp., Schoenus, Lepidobolus, Amphipogon, Lomandra juncea, Danthonia, Stipa, Triodia.

F: Thysanotus and other Liliaceae, Orchidaceae, Proteaceae, Epacridaceae, Asteraceae, and various others.

Reference: Specht 1979.

72. MITCHELL PLATEAU CAMP/W. AUSTRALIA AUSTRALIA

Open Eucalyptus Woodland (to 18 m) on the plateau, with patches of Savanna Woodland and Monsoon Forest on laterite rubble below plateau level.

Plateau woodland:

T: *Eucalyptus tetrodonta, *Eu. miniata, Eu. nesophila
RT: Livistona eastonii (3–5 m)
ST: Erythrophloeum chlorostachys, Terminalia circumalata
S: Cochlospermum heteroneurum, Grevillea spp., Petalostigma quadriloculare, Persoonia falcata
G: *Heteropogon contortus (?), Sorghum plumosum, Themeda australis, Chrysopogon latifolius, Plectrachne pungens (rare)
F: Gomphrena canescens

In open grassy glades:

ST: Eucalyptus latifolia
S: Calytrix achaeta, C. exstipulata, Grevillea heliosperma
G: *Eriachne (?)

Monsoon forest patches (1–25 ha thickets with scattered emergent trees):

T: *Zizyphus quadrilocularis, *Albizia lebbek, *Atalaya variifolia, *Cochlospermum fraseri, *Pouteria sericea, *Wrightia pubescens plus Aglaia sp., Bauhinia cunninghamii, Mimusops elengi, Terminalia platyphylla, et al.
ST/S: Litsea, Randia, Cassia, Acacia, Murraya, Cassine, Euphorbia (all rather site-specific), plus a common but unidentified 'prickly shrub'
V: various climbers
H: various forbs, grasses, some ferns (mostly unidentified)

Savanna woodland matrix:

T: *Eucalyptus tectifica, *Eu. grandifolia, *Erythrophloeum chlorostachys, Terminalia circumalata, Melaleuca viridiflora, Adansonia gregorii
ST: Acacia pachyphloea, Hakea arborescens
RT: Cycas basaltica
G: Sorghum et al.

Reference: Beard 1976b.

73. PERTH/W. AUSTRALIA AUSTRALIA

Evergreen Jarrah (Eucalyptus marginata) Forest:

T: *Eucalyptus marginata, with scattered other Euc. spp.
US: Casuarina priesii, Banksia (Proteac.), et al.
RS: the 'grass-trees' Kingia australia and Xanthorrhoea priesii (both Liliaceae).
S: many Proteaceae, Myrtaceae, Leguminosae, Epacridaceae, et al.
H: Goodeniaceae, et al., with scattered orchids and insectivorous Drosera.

References: Walter 1968; Beard 1965; Milton Moore 1970.

74. ALEXANDRA/SOUTH ISLAND NEW ZEALAND

Low-Tussock Grassland (valley site):

TG(short): *Festuca novae-zelandiae, *Poa caespitosa, P. intermedia, Agropyron scabrum, et al.
S: Discaria toumatoa (Rhamn.), Carmichaelia (Leg.), Aciphylla (yucca-like Umbellif.), with Raoulia spp. on highly degraded sites.
DS: Leucopogon (Epacrid.).
G: Carex spp., Danthonia spp., Poa, Agrostis, et al.
F: Luzula, Chrysobactron (Lilac.), Muehlenbeckia (Polygonac.), Scleranthus (Caryoph.), Ranunculus, Acaena (Ros.), Oxalis, Gnaphalium, Epilobium (Onagrac.), Plantago, et al.
Also: numerous ruderal European grasses and weeds, e.g. Agrostis tenuis, Anthoxanthum odoratum, Holcus lanatus, Rumex acetosella, Hypochoeris radicata, et al.

References: Walter 1968; Cockayne 1958.

APPENDIX E

The macroclimatic data-base

The data-base for generating the world climatic and vegetation distributions consists of 1225 meteorological stations for which basic temperature and precipitation data are available. The data were read from climate diagrams in the *Climate-Diagram World Atlas* (Walter & Lieth 1960–67) and, to a much lesser extent, from other sources as needed especially in the polar areas. The climate-diagram atlas contains data for about 8000 stations, more than four times as many as in any other known compilation available at the time the data-gathering began (1973). Various compendia of digital monthly data were available (e.g. the *World Weather Records* compiled by the Environmental Sciences Services Administration, 1966), but these cover too few stations and could be used only for individual stations not available in the climate-diagram atlas. A computerized file of monthly data for about 2000 sites (Spangler & Jenne 1979) has recently been acquired and is being adapted for use with all future world models.

The data-base consisted initially of 988 sites used by Box, Lieth, & Wolaver (1971). These sites were spread evenly over the earth such that there was at least one and were generally three of four sites in each 10° by 10° quadrat on the land areas. This data-set contained geographic coordinates which were accurate to only 1°, as well as mean annual temperature and average annual precipitation only. The accuracy of the geographic coordinates was increased to two decimal digits, and other climatic data were added over the period 1973–1974. In 1975–76 the data were scrutinized for errors and another 237 data-sites were added, primarily in regions of high topographic complexity and in poorly represented regions such as polar areas and Central Asia.

The data items in the primary data-base (CLIM177, 177 = January 1977) are shown below. Because of the large number of values to be gathered, it was necessary to reduce the number of values actually read. Thus, only the annual values and necessary local maxima and minima of the temperature and precipitation curves were read from hard data. The other monthly values were interpolated by the routine CLIMFIT (see Appendix F). The hard data for each data-site require from two to five punchcards, depending on the complexity of the annual temperature and precipitation curves. The number of data items gathered for each site varies from a minimum of 17 to a maximum of over 40.

Data-sites are arranged by political or physiographic unit beginning with northern North America (Greenland) and proceeding south through the Americas, through Europe, Africa, the Soviet Union, Asia, Australia, and Oceania, and ending in Antarctica. In order to avoid problems of translation, both station names and names of appropriate political or physiographic units are rendered in the most appropriate local language or in a romanization of that language based on the International Phonetic Alphabet, which corresponds closely to English consonants and Latin vowels. In most cases the spellings are those of the Rand-McNally *International Atlas* (Rand-McNally and Co. 1969), from which the geographic coordinates were also obtained.

CLIM177 contains the climatic data necessary for estimating annual curves for mean temperature and average precipitation. Each CLIM177 record consists of two card-images in a standard format plus one to three additional card-images containing additional extrema of mean temperature (first card) or average precipitation (second and third cards). The records have the following format.

Card 1. Basic site and climatic data
column 1: level of data provided.
0 = two card-images with monthly data only for the two extreme months (temperature and precipitation);
1 = basic data (level 0) plus additional extrema.
columns 2–9: data source, assumed to be the climate-diagram atlas unless otherwise indicated. Abbreviations include the author, year, and page or table number.
columns 10–15: site latitude, coded with two decimal digits. Northern latitudes are coded as positive numbers, southern latitudes as negative numbers.
columns 16–22: site longitude, coded with two decimal digits. Eastern longitudes are coded as positive numbers, western longitudes as negative numbers.
columns 23–28: site elevation, in meters.
columns 29–33: mean annual temperature, in °C.
columns 34–38: highest monthly mean temperature, in °C.
columns 39–43: lowest monthly mean temperature, in °C.
columns 44–49: average annual precipitation, in mm.
columns 50–55: highest average monthly precipitation, in mm.
columns 56–61: lowest average monthly precipitation, in mm.
columns 62–65: month of highest monthly precipitation.
columns 66–69: month of lowest monthly precipitation.
columns 70–73: month of highest mean monthly temperature.
(The last three items are cloded with one decimal digit. Integer values represent monthly mid-points.)
columns 77–80: site sequence number.

Card 2. Site description and other data
columns 1–32: name of data-site (additional data as desired).
columns 33–48: name of appropriate political or physiographic unit (e.g. U.S.A., England, but Hawaiian Islands).
columns 63–34: number of temperature extrema per year.
columns 67–68: number of precipitation extrema per year.
columns 77–80: site sequence number.

Card 3. Additional temperature reference values
Card 3 is included only if the number of annual extrema exceeds two. Values are coded as above; integers represent monthly mid-points. Extrema must be coded in annual sequence.
columns 3–6: month of lowest mean monthly temperature.
columns 9–12, 21–24, 33–36, etc.: months of additional extrema in the annual curve of mean temperature.
columns 15–18, 27–30, 39–42, etc.: corresponding extrema of mean temperature.
columns 77–80: site sequence number.

Cards 4 and 5. Additional precipitation reference values
Cards 4 and 5 are included only if the number of annual extrema exceeds two. (Card 5 only if needed for overflow from card 4). Extrema must be coded in annual sequence.
columns 3–6, 15–18, 27–30, etc.: months of additional extrema in the annual curve of average precipitation.
columns 9–12, 21–24, 33–36, etc.: corresponding extrema of average precipitation.
columns 77–80: site sequence number.

APPENDIX F

The processing and mapping programs

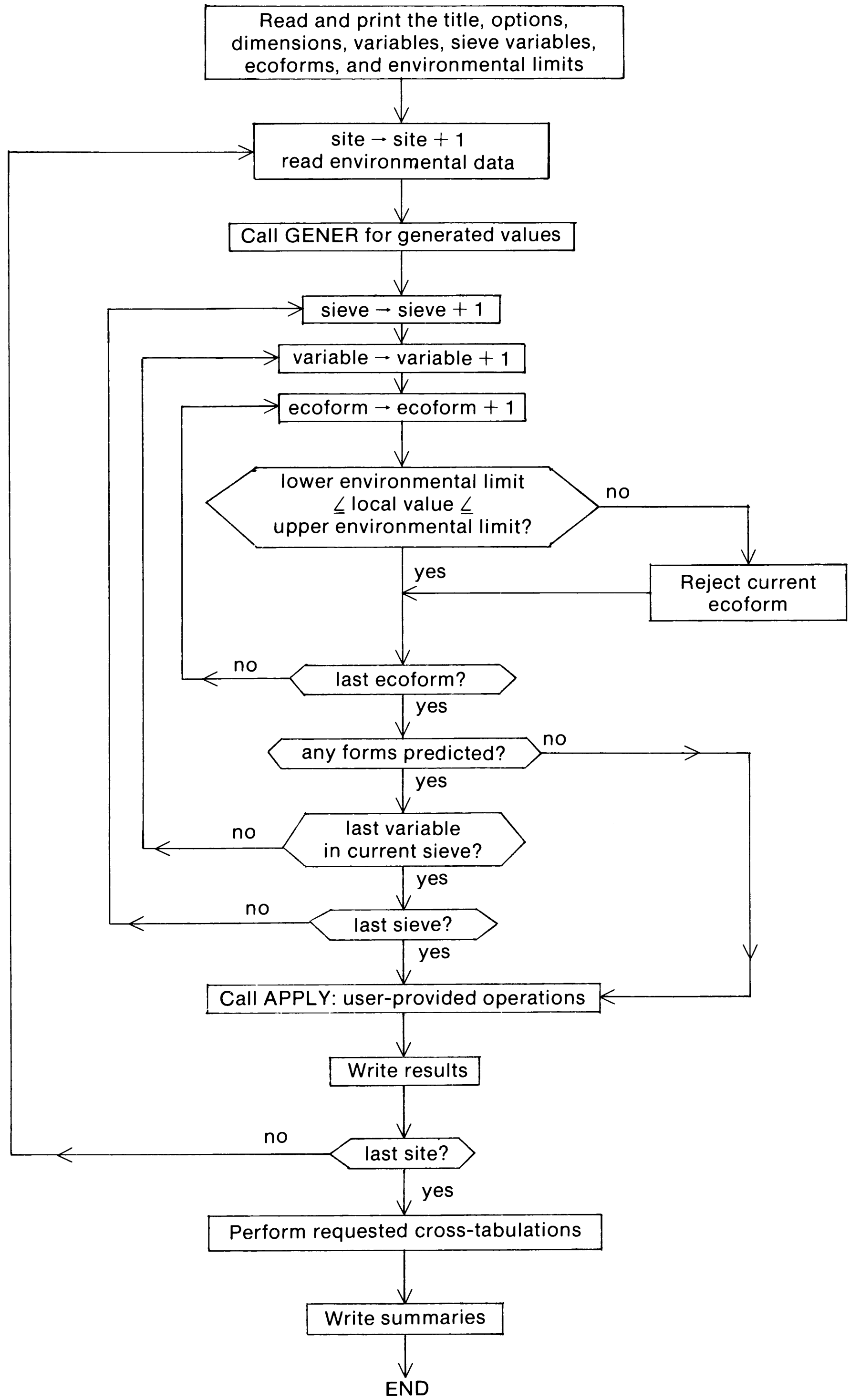
Development of the vegetation model and its application to large data-sets, with output as computer maps, required the development of a number of computer programs and modular subprograms. Most of these are described generally or at least mentioned in the main text. Except for the mapping program SYMAP (Harvard University), all programming components were developed entirely by the author. Most have been revised and improved several times, as indicated by version numbers attached to the programs. SYMAP has been described in section 6.B and is documented by Dougenik and Sheehan (1975). Some SYMAP adjunct routines and the use of SYMAP to make world maps are described by Box (1979a). The other programs are described below. All are in FORTRAN.

ECOSIEVE (Version 2.6)

ECOSIEVE is the main processing program for applying the vegetation model (or other models based on environmental limitation) to particular environmental situations, which can represent either actual data sites or hypothetical situations. This is accomplished by series of screening operations based on the environmental limits of the objects to be predicted. Predictions generated by ECOSIEVE can be useful both during the development of ecological hypotheses and models and to check model accuracy by geographic simulation and extrapolation.

The structure of ECOSIEVE is illustrated by the flow-chart in this section. ECOSIEVE consists of a main program, a subroutine SIEVE which performs the screening operations, and three user-programmed subroutines for definition of generated secondary variables (subroutine GENER), expression of non-constant environmental limits (subroutine FUNCTN), and application of additional operations (subroutine APPLY) to be performed after the basic screening. The main program provides for definition of the screening structure, which consists of a set of environmental variables defining an environmental hyperspace, a set of objects to be predicted (called ecoforms), and sets of upper and lower environmental limits which partition the hyperspace into environmental envelopes for the individual ecoforms. Variables and ecoforms are identified by names. Values for variables may be read from an external source or generated (in GENER) from other variables. ECOSIEVE currently permits up to 24 variables and 100 ecoforms. The main program also provides for user-specifiable formats and headings, access to the screening and adjunct subroutines, and various processing and input/output options. These options may involve additional printed or written output, processing of only selected sites and/or ecoforms, cross-tabulation of results, and/or identification of rejecting variables or closest environmental limits.

Processing consists of set-up and execution phases. After reading all instructions and constructing the screening structure, ECOSIEVE applies it to the data sites in the order in which they are presented. Each site is independent and is completed before the next is begun. For each site,


Read and print the title, options, dimensions, variables, sieve variables, ecoforms, and environmental limits
site → site + 1
read environmental data
Call GENER for generated values
sieve → sieve + 1
variable → variable + 1
ecoform → ecoform + 1
lower environmental limit ≦ local value ≦ upper environmental limit?
no
Reject current ecoform
yes
no
last ecoform?
yes
any forms predicted?
no
yes
no
last variable in current sieve?
yes
no
last sieve?
yes
Call APPLY: user-provided operations
Write results
no
last site?
yes
Perform requested cross-tabulations
Write summaries
END

every ecoform is considered by comparing its environmental limits with the corresponding local values. Ecoforms are rejected immediately whenever the following relation does not hold:

$$L \leq v \leq U$$

where L and U are corresponding lower and upper environmental limits respectively, and v is the corresponding local value. Limits may be constant-valued (resulting in rectangular envelopes) or functional, in order to express factor interactions (resulting in curved boundaries). Factor interactions may also be expressed, however, through integrative predictive variables, which may greatly simplify the mathematical form of the envelopes. Envelopes may overlap, be contiguous, or be disjunct, and are entirely independent of each other. (A utility program to check for 'holes' in a predictive design is being developed).

When all screening operations have been performed, the successful ecoforms are available for adjunct operations (e.g. dominance considerations) provided through the user-programmed subroutine APPLY. After these operations the successful ecoforms are listed on the primary printout (see Appendix B or C), written on auxiliary files if requested, and tabulated for the final summary. The summary includes prediction frequencies for all ecoforms and optional, cross-tabulated listings of successful sites for each ecoform.

The ECOSIEVE configuration for the world vegetation model presented herein also involves the computation of secondary variables through GENER and a dominance-based general successional algorithm CLIMAX, which is called through APPLY. CLIMAX eliminates all ecoforms from lower dominance levels (see Table 9) according to user-specifiable criteria. APPLY interprets these results and assigns actual dominance (+ or * on the listings in Appendices B and C), depending also on potential total vegetation cover and on proximity of forms to environmental limits, as described in sections 5.C–5.F. The computation of the Thornthwaite estimate of annual potential evapotranspiration is performed in a module PETCWT which is called from GENER. GENER divides this value into annual precipitation to produce the annual moisture index (MI) and computes annual temperature range (DTY), precipitation of the warmest month (PMTMAX), and various other climatic values not used in the final model.

ECOSIEVE was originally written in 1973 at the Nuclear Research Center in Jülich, Germany. In addition to its use in this book, it has also been used to generate world vegetation distributions used as the basis for world terrestrial maps of estimated average annual photosynthetic energy fixation (Box 1976) and photosynthetic efficiency (Box 1977). ECOSIEVE is not limited to vegetation models but can be used to predict any object for which environmental limits are appropriate (e.g. species, ecosystem types, management options). The structure of the program is particularly suited to overlay approaches. Version 2.0 of ECOSIEVE was documented by Box (1979a). A user's manual for the current version 2.6 is available (Box, 1981b).

CLIMFIT (Version 2.0)

CLIMFIT is a program which converts the minimal sets of hard climatic data of Appendix E into sequences of interpolated monthly values, based on the assumption of at least piecewise sinusoidal temporal patterns. Climatic phenomena which appear to meet the sinusoidal criterion include long-term averages of mean temperature, precipitation, and most other important macroclimatic factors. CLIMFIT is used herein to estimate the precipitation of the warmest month (PMTMAX), when it is not a measured extremum, and to estimate the annual curve of mean temperature used as the basis for estimating potential evapotranspiration.

Required input data for each curve to be estimated are all local maxima and minima during the year, the yeartimes at which they occur, and the annual total (e.g. precipitation) or mean value (e.g. temperature), whichever is appropriate. The annual curve is generated by interpolation of half-cycle cosine curve segments between adjacent extrema, coupled with an iterative correction procedure based on the annual total or mean. The correction is equivalent to deforming each curve segment after initial fitting toward one extremum or the other (i.e. up or down) until the corresponding annual total or mean matches that provided in the hard data. Mathematical details of the procedure and its validation are given in Box (1978a). The method is an interpolation, not a curve-fitting procedure, so the estimated curve is constrained to pass through each reference-point (extremum) provided. CLIMFIT estimates only the values between the measured extrema.

There are a number of sources of potential error in the CLIMFIT procedure, especially in certain, fairly well-defined cases in which CLIMFIT assumptions are violated. In order to test the accuracy of CLIMFIT results, annual curves of mean temperature and average precipitation estimated by CLIMFIT were compared with monthly values obtained from the *World Weather Records* (Environmental Sciences Services Administration 1966). The comparisons were made for 38 sites which were selected from a larger set of 113 geographically representative climate-diagram sites by the availability of the corresponding digital data in the *World Weather Records*. Since different data sources may provide different values based on different periods of measurement and/or different sets of records, the comparisons were standardized by basing the CLIMFIT estimates on the data in the *World Weather Records* rather than on the data in the computerized data-base (Appendix E). The comparisons were made by a program called FITCHECK, with results summarized in Box (1978a).

The only model variables which can be affected by CLIMFIT errors are the annual moisture index (MI) and the precipitation of the warmest month (PMTMAX). These effects are minimized since only values for intermediate months are estimated by CLIMFIT. Systematic (i.e. unbalanced) errors in the temperature curves causing possible shifts in evaporation estimates could not be seen. Errors significantly affecting PMTMAX may occur in a very few cases where PMTMAX is very low but not the yearly minimum. Such errors usually permit ecoforms to occur rather than to be precluded erroneously, and the effects of such errors are minimized by consideration of proximity to environmental limits.

CLIMFIT estimates appear to be acceptable for most applications in which the focus is on annual levels and extremes rather than on all monthly values. Although discrepancies may be significant in a few cases, the interannual variation in actual values is also large, and the discrepancies are certainly within the year-to-year variation. Most significant discrepancies occur in situations where they are not of utmost ecological importance (e.g. during the middle part of a monsoonal upswing in the precipitation curve). The recent provision of a computerized world climatic data-base (with monthly values for individual years) by Spangler & Jenne (1979) will make CLIMFIT unnecesary for those sites in their data-base. CLIMFIT remains useful for reconstructing interesting but insufficiently described sites. It also contains a routine for more drastic reconstruction by triangulation using adjacent sites. A computer-printable user's manual is available.

FLEXVEG (Version 3.3)

FLEXVEG is the routine for converting ECOSIEVE-generated model predictions into a form which can be used to produce SYMAP maps. FLEXVEG is built into SYMAP through the latter's subroutine FLEXIN (FLEXible INput) and provides general mechanisms for:

1. Specifying which plant types are to appear on which maps.
2. Grouping similar plant forms into single mapping units.
3. Applying the dominance hierarchy.
4. Identifying basic physiognomic classes and the life forms belonging to each.
5. Producing maps of life-form occurrence, importance and dominance.
6. Producing maps of life-form ecotones.
7. Producing maps of life-form diversity, both total and within specifiable sub-groupings (e.g. synusiae).
8. Producing complementary partial maps for subsequent overlaying.

The operations to be performed, as well as necessary parameters, are communicated to FLEXVEG by instruction cards placed in the SYMAP instruction packages. FLEXVEG also includes logic for converting site geographic coordinates to SYMAP coordinates at execution-time, based on the coordinate-conversion routine FLEXPROJ (see section 6.B or Box 1979a).

FLEXVEG is mainly an interface routine and performs mostly identification, grouping and input/output operations. Where it does involve cover, importance or dominance considerations its logic follows that of the ECOSIEVE system. An earlier version of FLEXVEG was described in Box (1978a). Documentation for the current expanded version is in preparation.

Other programs

A variety of other programs were involved peripherally in the project. MAPCOUNT (Box 1979a) was used to check the areal accuracy of the mapping basis (Box 1975) but has been used more in studies involving world and regional budgets for plant productivity and other functional processes (e.g. Box 1978b). MAPCOUNT could be used to quantify predicted vegetation areas on computer maps (e.g. under hypothetical past or future world climate), but site density and consequent confidence in predicted boundaries should first be increased. MAPMERGE (Box 1979a) was used during model development to overprint complementary partial maps to produce more complex world maps corresponding to the Rübel (1930) and Holdridge (1947) models. SOLWAT (Box, 1981a), began as an improved programming of the Thornthwaite-Mather (1957) soil water budgeting procedure and was then generalized to be applicable also to a variety of more natural situations (e.g. saturated soil, permafrost). SOLWAT was not used directly in the final model but has been used for a variety of other applications, including model development (see section IV.B), estimates of actual evapotranspiration used as the basis for world models of phytomass accumulation (Box, in preparation), litter production and decomposition (Meentemeyer et al., in preparation), and soil chemistry (Folkoff, in preparation).

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