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A broad-scale structural classification of vegetation for practical purposes

D. EDWARDS*

ABSTRACT

An *a priori* system is presented for the broad structural classification of vegetation. The objectives are to provide a descriptive, consistent, easily applied system, with unambiguous, straight-forward terminology, which can be used in the field and with remote sensing and air photo techniques, and which can be used in conjuction with floristic and habitat terms to convey the essential physiognomy and structure of the vegetation. The attributes used are a primary set of four growth forms, a set of four projected crown cover classes, and a set of four height classes for each growth form. In addition, shrub substratum is used to define thicket and bushland. Special growth forms, substratal, leaf and other attributes can be readily incorporated to extend the two-way table system where such detail is needed.

RÉSUMÉ

UNE CLASSIFICATION STRUCTURALE À GRANDE ÉCHELLE DE LA VÉGÉTATION À BUT UTILITAIRE

Un systéme a priori *de grande classification structurale de la végétation est présenté. Son but est de fournir un système descriptif, logique et d'application aisée, avec une terminologie directe et sans ambiguïté, pouvant être utilisé sur le terrain et avec des techniques de télé-détection et de photographies aériennes, et pouvant être utilisé conjointement avec des termes de floristique et d'habitat pour traduire la physionomie et la structure essentielles de la végétation. Les éléments utilisés sont: un ensemble de quatre formes biologiques, un ensemble de quatre classes de recouvrement (projection des cimes) et un ensemble de quatre classes de hauteur pour chaque forme biologique. En plus, la sous-strate arbustive sert à définir le fourné et la formation buissonante. Des formes biologiques spéciales, des caractères de la sous-strate, des feuilles et autres peuvent aisément être incorporés pour étendre le système du tableau à double entrée, lorsque cela se justifie.*

INTRODUCTION

Recognition of the different structural kinds of vegetation are as old as man himself and is etymologically rooted in words such as forest and thicket in languages over the world. In the purely structural sense, such different kinds of vegetation have been significant for the activities of man from the hunter and food gatherer stage to the modern technological phase. In modern botanical literature, physiognomic-structural classifications of vegetation date chiefly from the latter part of the last century (see e.g. Mueller-Dombois & Ellenberg, 1974; Dansereau, 1957; Kuchler, 1967; Beard, 1978, 1981) with a resurgence of interest since the advent of the International Biological Programme (IBP) in the late 1960's when comparison of the vegetation for different parts of the world was needed. Notable systems of classification proposed at this time were that of Fosberg (1967), which was suggested for use by the International Biological Programme and was based upon purely vegetational attributes, and that of UNESCO by Ellenberg & Mueller-Dombois (1967), which was based upon vegetational structure and physiognomy as well as broad ecological attributes. As a result of work done for the IBP, it became evident that certain difficulties were encountered in the application of the Fosberg system, and independent strikingly similar modifications were proposed in the three southern hemisphere countries of Australia (Specht, 1974; 1981), Brazil (Eiten, 1968; 1972) and South Africa (Edwards, 1976, unpublished).

This contribution is presented since it is evident that there is still a need, at least locally, for a simple, consistent, broad-scale classification of vegetation for a variety of purposes ranging from needs in natural resource inventory, vegetation description, remote sensing, air photo interpretation and mapping, to needs from other non-plant scientific disciplines. Although the structural classification proposed here is in line with similar recent classifications, it differs in certain basic concepts and in some of the terminology which at a broad scale is more uniformly applicable, but where such detail is needed can also take into account local kinds of specialized vegetation by using specialized terms. The structural classification is regarded as purely complementary to and independent of floristic and other forms of vegetation classification and may be useful on its own for certain purposes. It is restricted here to terrestrial vegetation dominated by predominant angiosperm, gymnosperm and pteridophyte plant growth form types. For purely practical reasons, of observation and description, it is limited to the above ground portions of vegetation.

1 BASIC CONSIDERATIONS

As defined by Danserau (1957), *vegetation structure* is 'the organization in space of the individuals that form a stand (and by extension a vegetation type or a plant association)' and the 'primary elements of structure are growth-form,

* Botanical Research Institute, Department of Agriculture, Private Bag X101, Pretoria 0001, South Africa.

stratification and coverage'. Although, as discussed by Mueller-Dombois & Ellenberg (1974) and Barkman (1979), there are other usages and interpretations of vegetation structure, the definition of Dansereau is used here as a working definition that includes spatial as well as morphological features of vegetation, but excludes purely floristic features. In accordance with Fosberg (1967), 'physiognomy is the appearance, especially the external appearance, of the vegetation, partly resulting from, but not to be confused with, *structure* and *function* . . . .'.

As pointed out by Fosberg (1967), a distinction should be made between classifications of vegetation based solely on the properties of the vegetation itself and those based also on various environmental factors, which are more properly termed ecological classifications and in which care must be taken to avoid circular reasoning leading to false correlation. The structural classification proposed here is based solely on vegetation characters and is independent of, but complementary to, floristic, habitat and ecological classifications of vegetation.

Since growth form, cover, height and other attributes that qualify the various structural characteristics of vegetation show continuous variation, vegetation is viewed here as a multi-dimensional continuum that may be segmented at certain arbitrarily defined points to provide a classification, which is an abstraction. Although discontinuities may exist in any particular region, elsewhere intermediates will usually be found so that the abstract class limits are essentially a matter of convenience in conformity with general usage and acceptance. For purposes of description, communication and understanding, definition and classification are necessary, bearing in mind the oft forgotten corollary that classifications are abstractions in which a certain range of internal class variation ('heterogeneity') is found dependent on the classifactory level and fineness of resolution (approximate to the concrete level) that is intended.

Although the *a priori* kind of classification is often rejected on the grounds of unreality and that knowledge is inadequate for proper definition, this is only true if the classificatory criteria are irrelevant or are such that they do not cover the range of possibilities within the purpose of the classification. For the finer resolution of the more detailed levels of classification, *a priori* classifications may well prove inadequate because of the lack of knowledge needed to adequately define these more detailed levels, but this does not preclude the validity of *a priori* classification at the broader classificatory levels where such fine information is not necessary. The intention here is to provide a definition of the broader structural classes of vegetation so that they may convey a more precise and consistent meaning to these structural kinds of vegetation.

Terminology is an important but difficult aspect of the structural classification of vegetation. Once one proceeds beyond a simple set of binomials or trinomials, terminology becomes a clumsy diagnostic description rather than a terse, usable, specific phrase. An endeavour has been made here to provide a set of simple consistent, basic terms for the broader structural classes of vegetation, as well as in the consistent appropriate use of terms for certain common parameters of vegetation, for example, cover and density. As an expression of the percentage of the ground surface that is covered by plants, cover may more realistically be referred to as closed, open or sparse rather than as dense and mid-dense. The latter usage can only serve to confuse when referring to a high or moderate density of plants, which is expressed in either the spacing or the number of plants per unit area and for which density is the standard and universally recognized term. Confusion is further enhanced by an older common use of dense canopy when this refers to the thickness or light impedance of the canopy, which at least has some merit.

2 BASES OF THE STRUCTURAL CLASSIFICATION

The proposed structural classification is hierarchical and at the levels considered here is based on a set of dominant primary growth form types, cover, height and partly on substrata. Further subdivision, on leaf character, leaf permanence, subsidiary growth form types, etc., are not considered here.

The primary attributes used in the structural classification are, therefore,

- a primary set of four growth form types,
- a primary set of four cover classes and
- a set of four height classes for each growth form type.

In addition, shrub substratum has been used to define a thicket and bushland class, which is considered necessary at this stage, and a set of desert vegetation classes below a certain total plant cover.

The basic procedure followed to determine the structural classes is to establish a matrix or two-way table as follows:

(1) Growth form × cover = structural group,
(2) Structural group × height = formation class.

The ranking terms structural group and formation class that will be used here are tentative.

2.1 *Primary growth form set*

Four types of growth form are considered as being the primary set of attributes that determine the essential spatial geometry of vegetation. These are self-supporting plant growth forms, which are grouped into four main classes, namely, woody trees and shrubs, and non-woody grasses (and graminoids) and herbs, defined as follows:

Trees are rooted, woody, self-supporting plants over 2 m high and with one or a few definite trunks normally branching above ground level;

Shrubs are rooted, woody, self-supporting plants up to 5 m high, multi-stemmed and branching at or near ground level when 2–5 m high, or either multi-stemmed or single-stemmed when less than 2 m high;

Grasses are rooted, non-woody, herbaceous plants belonging to the family Poaceae, or graminoid plants, such as Cyperaceae and

Restionaceae, resembling grasses. At lower levels of classification, Cyperaceae and Restionaceae would be referred to specifically as sedges and restioids. Although members of the Poaceae, many bamboos are best considered as trees or shrubs, or as bambusoids at lower levels of classification;

Herbs are rooted, non-woody, self-supporting, non-grass-like plants. If woodiness is evident, this is restricted to the permanent lower portions of the plant at or near ground level.

Woody lianes and herbaceous climbers are considered either as shrubs, herbs, or grasses (if grass-like or Poaceae) when growing in the absence of other supporting plants, or as subsidiary defining growth forms for lower classificatory levels.

Trees, shrubs, grasses and herbs are further subdivided on height (2.3).

2.2 *Cover classes*

Cover is defined in the accepted sense as the vertical projection of the crown or shoot area of the plant onto the ground. Unless otherwise stated, cover here refers to the projected crown cover. The cover of the upper growth form stratum is basic to the structural class definition and refers to the total canopy cover (out of 100%) of that growth form, irrespective of differences in height class (see Fig. 1). In this way, the problem of defining a 'dominant' tree or other layer is avoided when there is considerable variation in height of the primary growth form stratum.

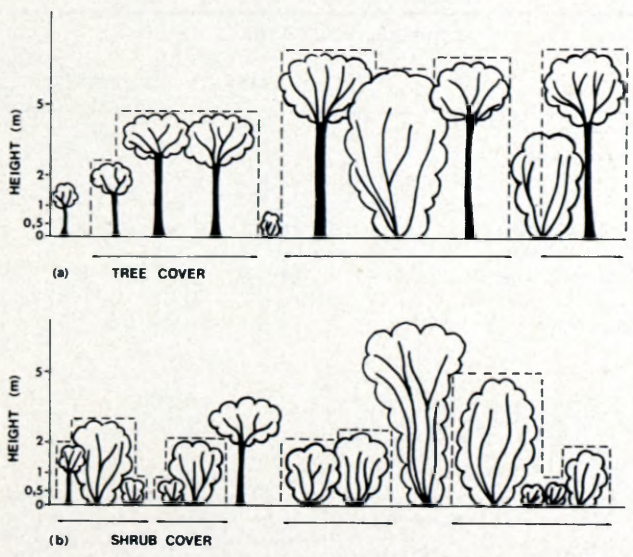

FIG. 1.—Basis of canopy cover determination illustrated (a) for trees and (b) for shrubs. Note in (a) and (b) shrub over 5 m high classed as tree and in (a) and (b) tree less than 2 m high classed as shrub.

Although normally given as a per cent of the ground reference, cover may also be expressed in other ways, such as the dimensionless crown: gap ratio, given in terms of the ratio of mean crown diameter to the mean distance, as number of crown diameters, between the crowns of the plants. Thus, with reference to a hexagonal closest packing of circular crowns before overlapping, the percentage crown cover is given by $\frac{90.7}{(n+1)^2}$ where n = the mean number of crown diameters by which the plant crowns are separated (see Fig. 2). Similarly, for a somewhat looser square packing of crowns the formula is approximately $\frac{80}{(n+1)^2}$. The method has been independently derived by Eiten (1968) and Edwards (1976), but crown:gap ratios have been used by various authors such as Ellenberg & Mueller-Dombois (1967), Boughey (1957); Fosberg (1967), Tinley (1969) and others. It is important to note that cover as estimated by the crown:gap ratio is based on a ground projection of the crown as a whole, whereas many other cover estimates are based on estimates of foliage cover (e.g. Specht, 1974), which will be lower for species with open foliage crowns. The projected crown cover is more consistently and easily estimated, especially on vertical air photos, than the projected foliage cover. It is also possible to relate by photographs or other estimates the projected crown cover to foliage cover for different species.

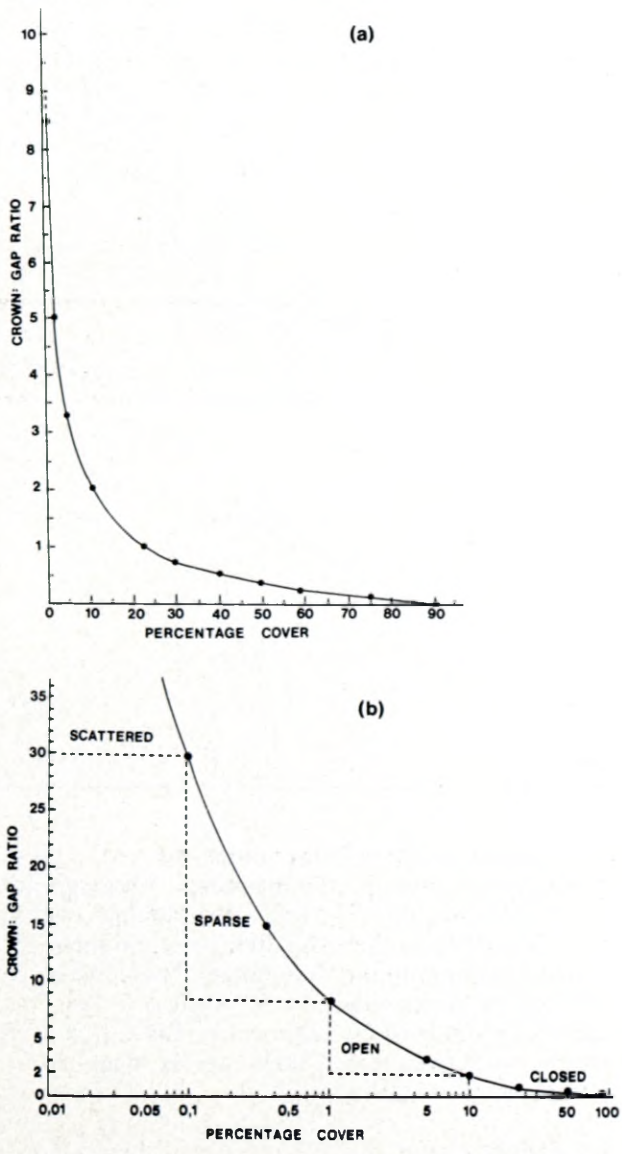

FIG. 2.—Relationship of crown:gap ratio to percentage cover (a) linear scale and (b) semi-log scale. Primary cover classes with crown:gap ratios shown in (b).

The method is useful in air photo interpretation and also shows other interesting features (Fig. 2). When the crown diameters are known, density can be quickly estimated in terms of the spacing between individuals. It is also evident that for a specific percentage cover, the smaller the crown diameter the higher the density, so that normally for a specific plant cover shrublands have higher plant densities than woodlands. Furthermore, at a cover of 25% the crown to gap ratio is 0,9, whereas at 10% the ratio is 2, showing that despite the apparently low per cent cover the spacing between individuals is closer than may be expected for these relatively low percentage cover values. Light interception even at a cover of 10% is likely to be appreciable, especially with increasing plant height and increase in latitude. As shown by Rutherford (in press) in the Northern Transvaal bushveld, root spread for *Burkea africana* may be some seven times greater than the canopy diameter, so that root competition between individuals, even at what appears as a low canopy cover of 10%, is intense and, in certain plant communities at least, is not unexpected if the spacing is taken into account. From a functional view point it therefore seems appropriate to lay greater stress on class separation at the lower end of the percentage cover scale by considering the espacements of plants as related to cover instead of the purely areal cover percentages of plants. For these reasons, preference is for a logarithmic approach to the basic cover class intervals used in the classification (Table 1).

TABLE 1.—Primary and subsidiary cover classes

Primary cover classes			Subsidiary sub-divisions		
Cover	% Cover	Crown:Gap	Cover	% Cover	Crown:Gap
			Continuous (Overlapping or nearly so)	76–100	<0.1
Closed	10–100	0–2	Sub-continuous	51–75	0.1–0.3
			Moderately closed	26–50	0.3–0.9
			Semi-open	11–25	0.9–2.0
Open	1–10	2–8,5			
Sparse	0,1–1	8,5–30			
Scattered	<0,1	>30			

As shown in Table 1, the terms attached to these cover classes have specific meanings. Although not used here, except for 75–100% overlapping cover in the case of trees, there is often a requirement for finer subdivision of the wide range of percentages in the closed cover class. It is suggested that the subsidiary subdivisions as shown in Table 1 be used which, apart from terminology, are as suggested by Campbell *et al.* (1981).

2.3 *Height classes*

Height classes used for the different primary growth form types are shown in Table 2 and, for reasons similar to those discussed for cover (2.2), are logarithmic in character. The term height class is used as distinct from stratum, since height class is essentially an arbitrary circumscription whereas stratum refers to a natural layering of the vegetation provided by one or more growth forms, or a certain height layering of a growth form. A height class 'tall tree', for example has a definite meaning in terms of metres above ground and may cut across natural height strata, whereas a 'tall' tree stratum may include several tree height classes, or may straddle two height classes.

TABLE 2.—Height classes

	Trees	Shrubs	Grasses & herbs
High	<20m	2–5m	>2m
Tall	10–20m	1–2m	1–2m
Short	5–10m	0.5–1m	0.5–1m
Low	2–5m	<0,5m	<0.5m

As shown in Table 2, for different growth forms the same terms in the same order show increasing height, the height ranges being similar for shrubs, grasses and herbs. The high tree, high grass and high herb classes as well as the low shrub, grass and herb classes are given as open-ended but could also simply be extended into extra classes, for example, 20–50 m for trees, 2–5 m for grasses and herbs, 0,2–0,5 m and 0,1–0,2 m for shrubs, grasses and herbs if required.

It must be appreciated that, based on sufficiently extensive sampling, any given set of height classes will never be universally 'natural' and will apply better in one vegetation type than in another. What is given here is, therefore, an arbitrary but meaningful height terminology for vegetation based on certain commonly but by no means universally

accepted height standards. It is suggested that where an obvious stratum straddles two height classes this be indicated by a '/' between the two height classes, bearing in mind that the actual height range will obviously be recorded in the detailed description.

When determining the dominant height class that describes the height of a structural group, it must clearly be realized as to which part of the growth form stratum the term is applied. Based on cover and height, a definition of the dominant height class that is simple and leads to the fewest anomalies is as follows:

Within a closed or open growth form stratum the dominant height class is the tallest height class whose cover is greater than, equal to, or not more than one cover class less than the cover of any lower height class. For a sparse or scattered (desert) growth form stratum the dominant height class is simply a conspicuous taller height class.

For example, for a particular growth form stratum, an open cover height class above a closed cover height class will be recognized as the dominant height class, but not a sparse cover height class above a closed cover height class when the closed height class would be recognized as the dominant height class. A sparse cover height class would be the dominant height class when above an open, sparse, or scattered lower height class.

3 THE STRUCTURAL CLASSIFICATION

As derived from combinations of the sets of growth form, cover and height attributes, with a limited use of substratum growth form to define Thicket and Bushland and of total plant cover to define desert vegetation classes, the structural classification is set out in Table 3 and is further illustrated diagrammatically in Fig. 3, which illustrates the intergrading character of cover and height of the dominant growth forms and the segmenting of this continuum.

Table 3 is self-explanatory, being essentially a multiple entry key to the nine structural groups A–I, which are Forest and Woodland, Thicket and Bushland, Shrubland, Grassland, Herbland, Desert Woodland, Desert Shrubland, Desert Grassland and Desert Herbland. Each structural group is then subdivided on the basis of the height of the dominant height class, as defined in 2.3, into 72 formation classes. The Desert structural groups are separated initially from the non-desert groups on the basis of total plant cover.

A certain measure of additional complexity has had to be introduced into Table 3, because of the need to define a Thicket and Bushland structural group in relation to Forest and Woodland on the basis of the shrub stratum, which has had further to be qualified in terms of height in relation to tree height. This is necessary to specify the continuity in height and cover of trees and shrubs that characterize Thicket and Bushland formation classes. A similar exception to the logical simplicity of Table 3 has also had to be introduced in the case of Closed Shrublands where there is present a sparse tree cover over a tall closed shrub cover. This has been considered necessary because of the closely related character of short and low trees and high and tall shrubs. In general, further attention is to be devoted to the incorporation of substratal characteristics into the classification but, in the meantime, except for Thicket, Bushland and Closed Shrubland as defined, it is suggested that where there is a high substratal cover in relation to the dominant defining growth form of the structural group the terms 'shrubby', 'grassy' and 'herby' be used.

Despite what may appear as complexity in Table 3, the classification is actually extremely simple and easily memorized. All that is needed is understanding of the simple procedures for cover and height determination, the easy memorization of the growth forms, cover and height classes, and of the three qualifications for Thicket, Bushland and Closed Shrubland. The class limits and terminology are simple, logical and consistent.

The classification proposed here is most similar to those of Specht (1974, 1981) and Eiten (1968, 1972) and to a lesser extent Fosberg (1967), but differs markedly in a number of features. The chief difference is in the use here of projected crown cover rather than of projected foliage cover. However, in the latter use, higher cover values are used to separate classes than here, so that the difference is not as marked as would appear at first sight since projected foliage cover is usually lower than projected crown cover. Use of the subsidiary cover classes given in Table 1 to subdivide the broad closed cover class used here would bring this classification more closely in line with many other classifications insofar as cover limits are concerned. To do so would be simple and straight forward without further modification to Table 3.

More overall attention is here given to cover at the lower limits than for other classifications. The distinction of sparse classes of woodland and shrubland, which in the absence here of any other substratal or co-dominant (possibly even dominant in the functional sense) recognition other than the suggested shrubby, grassy or herby at present, may well raise comment (cf White, In press). However, the general use of a sparse tree cover over a closed grass layer, for example, is often useful for certain ecological situations, such as dynamic ones, where an invasion of grassland by trees is taking place as a result of disturbance by human activity. Recognition of the class is in the structural sense demarcation of the continuum from woodland to grassland. Provision is, therefore, made for sparse formation classes of vegetation but qualification is recommended as previously indicated. For regional mapping sparse woodland, for example, would often be mapped in association with grassland.

Finally, in terms of the criteria for classification as given by Whittaker (1978), the structural classification given here appears to be: (i) highly accessible in that the community attributes used are simple and readily observable on the ground and from the air; (ii) the criteria are significant at the broad classificatory level in distinguishing the broad structures of vegetation and in covering the

TABLE 3.—Tabular key to structural groups and formation classes

Dominant height class	*Total plant cover > 0,1%*				*Total plant cover ≤0,1%*
	Total tree cover >0,1% shrub cover <10% if >1 m high **A. Forest & Woodland** *Total tree cover*				**F. Desert woodland** *Trees dominant*
	100–75% 0–0,1ø	*75–10% 0,1–2ø*	*10–1% 2–8,5ø*	*1–0,1% 8,5–30ø*	
Trees >20 m	1. High forest	5. High closed woodland	9. High open woodland	13. High sparse woodland	57 High desert woodland ?
Trees 10–20 m	2. Tall forest	6. Tall closed woodland	10. Tall open woodland	14. Tall sparse woodland	58. Tall desert woodland
Trees 5–10 m	3. Short forest	7. Short closed woodland	11. Short open woodland	15. Short sparse woodland	59. Short desert woodland
Trees 2–5 m	4. Low forest	8. Low closed woodland	12. Low open woodland	16. Low sparse woodland	60. Low desert woodland
	Total tree cover >1% shrub cover >10% & >1 m high **B. Thicket & Bushland** *Total tree cover*				
	100–10% 0–2ø		*10–1% 2–8,5ø*		
Trees 5–10 m & shrubs 2–5 m	17. Short thicket		19. Short bushland		
Trees 2–5 m & shrubs 1–5 m	18. Low thicket		20. Low bushland		
	Total tree cover <0,1% shrub cover >0,1% or tree cover up to 1% & shrub cover >10% & >1 m high (closed shrublands) **C. Shrubland** *Total shrub cover*				**G. Desert shrubland** *Shrubs dominant*
	100–10% 0–2ø	*10–1% 2–8,5ø*		*1–0,1% 8,5–30ø*	
Shrubs 2–5 m	21. High closed shrubland	25. High open shrubland		29. High sparse shrubland	61. High desert shrubland
Shrubs 1–2 m	22. Tall closed shrubland	26. Tall open shrubland		30. Tall sparse shrubland	62. Tall desert shrubland
Shrubs 0,5–1 m	23. Short closed shrubland	27. Short open shrubland		31. Short sparse shrubland	63. Short desert shrubland
Shrubs <0,5 m	24. Low closed shrubland	28. Low open shrubland		32. Low sparse shrubland	64. Low desert shrubland
	Total tree cover <0,1% shrub cover <0,1% grass cover dominant and >0,1% **D. Grassland** *Total grass cover*				**H. Desert grassland** *Grasses dominant*
	100–10% 0–2ø	*10–1% 2–8,5ø*		*1–0,1% 8,5–30ø*	
Grasses >2 m	33. High closed grassland	37. High open grassland		41. High sparse grassland	65. High desert grassland
Grasses 1–2 m	34. Tall closed grassland	38. Tall open grassland		42. Tall sparse grassland	66. Tall desert grassland
Grasses 0,5–1 m	35. Short closed grassland	39. Short open grassland		43. Short sparse grassland	67. Short desert grassland
Grasses <0,5 m	36. Low closed grassland	40. Low open grassland		44. Low sparse grassland	68. Low desert grassland
	Total tree cover <0,1% shrub cover <0,1% herb cover dominant and >0,1% **E. Herbland** *Total herb cover*				**I. Desert herbland** *Herbs dominant*
	100–10% 0–1ø	*10–1% 2–8,5ø*		*1–0,1% 8,5–30ø*	
Herbs >2 m	45. High closed herbland	49. High open herbland		53.High sparse herbland	69. High desert herbland
Herbs 1–2 m	46. Tall closed herbland	50. Tall open herbland		54. Tall sparse herbland	70. Tall desert herbland
Herbs 0,5–1 m	47. Short closed herbland	51. Short open herbland		55. Short sparse herbland	71. Short desert herbland
Herbs <0,5 m	48. Low closed herbland	52. Low open herbland		56. Low sparse herbland	72. Low desert herbland

Note: (1) % cover refers to projected crown cover as percentage
(2) ø refers to mean crown: gap ratio as mean number of crown diameters apart
(3) where straddling of height classes occurs this may be indicated by '/'
(4) where mosaics of classes are found this may be indicated by '//' e.g. High closed // open woodland
(5) where there is a high substratal cover of shrubs (excluding thicket & bushland as defined), grasses, or herbs, this may be indicated by terms such as 'shrubby', 'grassy' and 'herby'

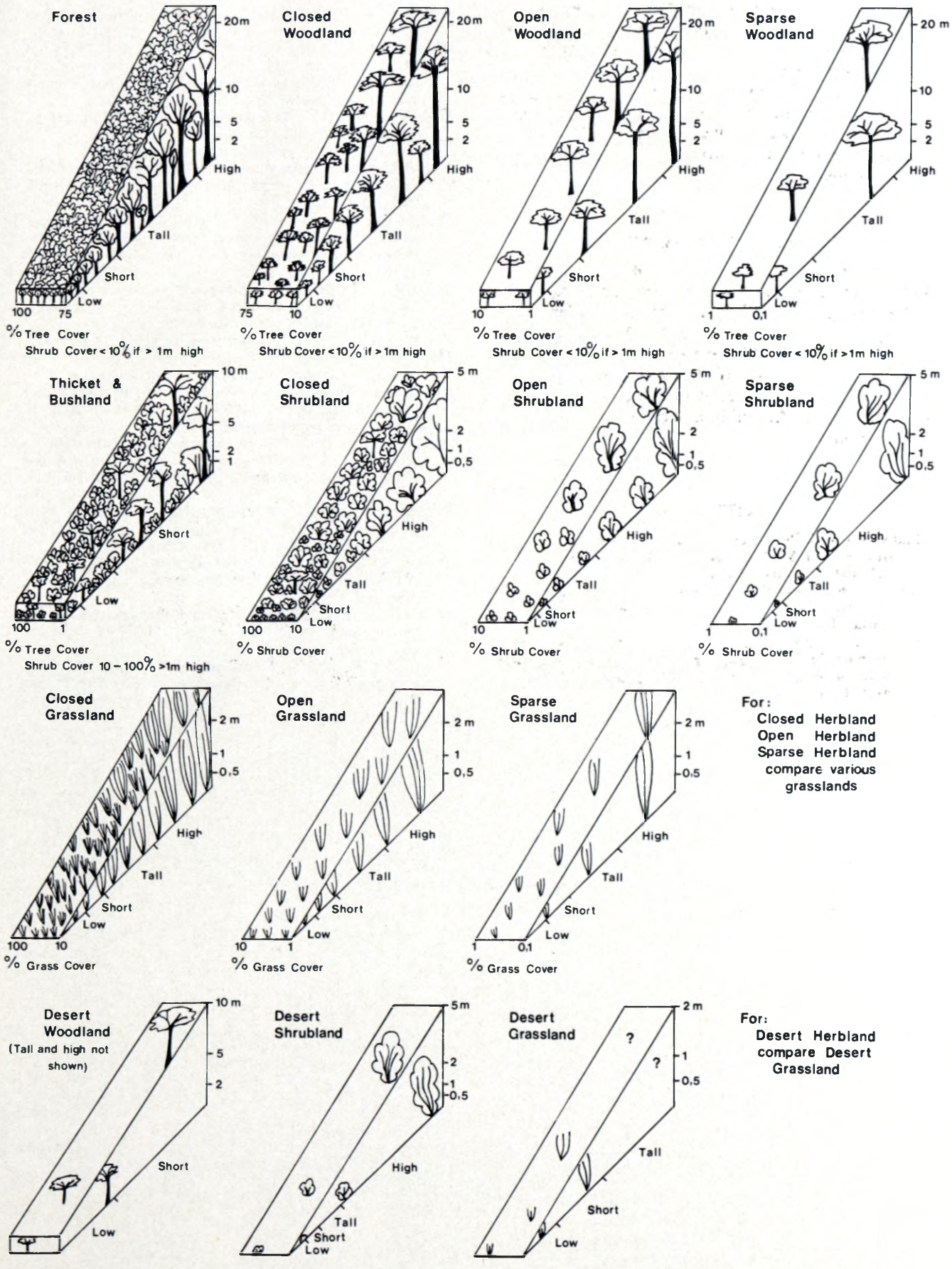

FIG. 3.—Diagrammatic representation of structural groups and formation classes. Dominant growth forms only are shown.

continuum from forest to desert in all combinations of primary growth form type, cover and height; and (iii) effective at the broad scale of resolution, but also, as field trials have shown, remarkably sensitive to structural differences in vegetation at the local scale. Assessment of effectiveness can, however, only be judged by extensive use and on the basis that no one approach to a structural classification can claim exclusive merit.

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