STRUCTURAL CLASSIFICATION OF VEGETATION

Brian Tunstall

2008

Key Words: Vegetation, Structural Classification, Vegetation Function, Vegetation Development

Abstract

Structural vegetation classifications were developed to identify relationships between vegetation and the environment. They have increased in importance with global warming as vegetation structure is significant for levels of carbon sequestration and potential rates of CO2 fixation. Anomalies in the scheme most used to classify Australian vegetation are identified and the scheme developed to increase applicability and remove anomalies without increasing complexity.

Introduction

Aspects of the form and structure of vegetation have always been used to identify and describe vegetation, as with deserts and rainforest. Within these groups floristics have generally been used to increase the differentiation between different forms of vegetation. The identifiers are often genera, as with eucalypt and acacia woodlands. However, the identifiers can also be other forms of species assemblages, such as softwood and hardwood forest.

Scientific vegetation survey has usually focused on floristics because the large number of species provides a high level of discrimination between different forms of vegetation. The vegetation is readily classified into any number of classes and, given the large number of plant species, the number of classes is effectively only limited by the number of survey sites. However, the relationship between the classes is usually obscure because the functional significance of the classification is unknown. The significance of difference species for the functioning of the plant communities may be known for a few dominant species but not for the great bulk of the many species used to provide the discrimination.

The main consequence of the lack of knowledge of the functional similarities between different species is that floristic classifications are poor at identifying similarities between different forms of vegetation. Moreover, where they are used to identify similarities the significance of the similarities is unknown. The use of species in vegetation classifications typically increases discrimination but reduces comprehension and hence understanding.

Vegetation structure is directly related to the functioning of plant communities. Rainforests are typically luxuriant due to the abundant supply of water and nutrients. Deserts have sparse vegetation due to a lack of water. Grasslands and grassy woodlands have moderate rainfalls and a moderate to good nutrient supply and hence provide good grazing for large herbivores such as livestock. When cleared they are good for farming. The structure of vegetation has always been used as an indicator of the potential of the land for human use. This application is reliable because of the functional significance of vegetation structure.

In the recent past most vegetation classification has addressed floristics because of the apparent high level of information provided by the large number of species, and because of the focus on species conservation. As the significance of individual species is unknown progress in understanding the functional aspects of vegetation has stalled. However, the focus is now turning to the structure due to its significance for global warming. To a very great extent the structure rather than floristics determines functional aspects such as transpiration, CO_2 fixation and carbon sequestration.

The relationship between the structure of vegetation and the environment is increasingly being expressed using explicit relationships, as in models of energy exchange and carbon fixation, but it has traditionally been addressed by way of physiological and physiognomic relations. Different structural characteristics have been interpreted as adaptations to particular environments, and hence are used to investigate factors that control the development of vegetation.

Explicit physical models employ coarse generalisations of vegetation structure to examine broad relationships between existing vegetation and the environment. They provide coarse approximations of the physical changes arising from existing forms of vegetation but give no indication of how the form of vegetation arises, or how it will change either naturally or through land use impacts. They provide summary descriptions of the functioning of what exists but more detailed information on vegetation structure is needed to examine the constraints on vegetation development. Knowing what the existing vegetation is doing is a good start but it has little application without knowledge of how it will change.

Structural classification has always been used in practical application in Australia. Structural classification also has a long history in scientific studies. However, the classification systems have evolved without a clear focus as to the requirement being addressed. The prime objective with some structural classifications appears to have been to provide a simple system for describing vegetation that can be used without the need for a botanist having detailed knowledge of floristics. Another objective has been to attempt to make floristic classifications comprehensible and improve their practical application. A critically important function of structural classifications, that of developing understanding of the development and functioning of plant communities, has not been well addressed.

Details on the relationship between the structure of vegetation and the environment provide considerable background on structural classification of vegetation but the paper does not present a simple classification scheme (Tunstall 1987). This paper presents a simple scheme suitable for practical application. The approach taken is to build on what exists by modifying an existing structural classification scheme to remove anomalies and increase its applicability to understanding vegetation development. The focus is on the formal classification scheme as that has greatest application. However, the classification scheme is an artifact constructed to facilitate communication. Greatest value lies in the approach to describing and analysing vegetation.

Existing Approaches to Structural Vegetation Classification

The main dichotomy in approaches to structural vegetation classification is illustrated by the schemes given by Walker & Hopkins (McDonald et al. 1984). The scheme given for rainforest is generally described as being physiognomic and is based on complexity, floristics, indicator growth form, structural formation, and leaf size. The scheme given for the remainder of the terrestrial vegetation, in Australia commonly referred to as sclerophyll vegetation, is based on the height and cover of the foliage of the tallest plant life form (tallest stratum).

Both approaches have a long history. There are therefore many variants and intergrades, particularly since systems are commonly modified to suite the circumstances and whims of individual practitioners. However, the schemes given by Walker and Hopkins illustrate the basics of the main approaches.

The physiognomic approach mirrors that for floristic classifications with genera being replaced by structural attributes typical of genera or higher level groupings of plant species. For example, instead of describing a stand of vegetation as containing palms it is described as containing large dissected leaves. As the functional significance of a large dissected leaf compared to other forms of leaf is unknown this change in terminology serves no useful purpose. The same issue arises with complexity and structural formation as their significance for community function is not at all clear. Indeed, it is not even clear what they are.

By combining complexity, floristics, indicator growth form, structural formation and leaf size as discriminators in the classification the approach taken is to use as many criteria as possible to increase the discrimination of perceived different forms of rainforest. The approach is identical to that incorporated in floristic classifications, hence the limitations are identical. The detail provides a façade of precision but no one can synthesise the information to draw useful conclusions or improve understanding of the system.

The amount of leaf is undoubtedly highly significant for vegetation function as it captures solar radiation, and is the exit point for most water. It addresses two factors that exercise strong control on vegetation development, namely light and water. With most models used to simulate the functioning of native vegetation the species composition is of no consequence due to the dominant effect of the amount of leaf and uncertainties arising from other factors that determine the model outcomes.

The second most important structural attribute is the vertical arrangement of leaf. In models this primarily arises through patterns of light interception. However, depending on the form and density of vegetation the vertical arrangement of the leaf need not be significant. Some systems can effectively be structurally represented as a single layer with the leaf thickness of the leaf area index. That is, as a single horizontal layer that is one, two or three leaves thick depending on the amount of leaf.

The conclusion that the vertical arrangement of leaves need not be important derives from work on monocultures but with vegetation the vertical stratification is invariably associated with differences in plant life forms such as tree, shrub and grasses. As these differ considerably in their functional relationships there is always a need for vertical stratification in a structural classification of vegetation, even if results from models indicate otherwise.

The information contained in estimates of the amount and vertical stratification of leaf is normally greater than can be gainfully used. That is, there is generally no need for further stratification given current levels of knowledge. However, leaf size, leaf form and other such criteria are commonly used to increase the number of classes, and thereby the discrimination in theory at least. This potential third level of stratification in a structural vegetation classification is addressed by way of the functional significance of leaf characteristics.

Functional Significance of Leaf Characteristics

Leaf size categories such as microphyll and mesophyll form a primary categorisation in some classifications that have been applied to all forms of vegetation. While leaf size has some significance for photosynthesis (Parkhurst and Loucks, 1972) it is small compared to the abundance of leaf and the arrangement of leaves on plants and within the community. The amount of leaf and the seasonality of conditions are much more important than leaf size for rainforests but they are seldom addressed because of the difficulty of providing reliable measures.

The main physiognomic difference between rainforest and sclerophyll vegetation relates to nutrient recycling. Nutrient recycling is typically strongly internal with sclerophyll plants wherein the nutrient withdrawal from dehisced woody leaves slows litter breakdown and promotes fires. Nutrient recycling is strongly external with rainforest plants and the rapid breakdown of leaf litter helps suppress fires as well as enhance the nutrient relations of the vegetation. Differences in chemical composition of leaf litter by way of lignin and suberin promote this difference in fire response.

While the difference in the mode of nutrient recycling between sclerophyll and rainforests is pronounced the same difference arises with other forms of vegetation. Indeed, northern hemisphere softwood forests can rely on external nutrient recycling at least as much as rainforests. Moreover, all forms of vegetation incorporate both external and internal nutrient recycling so the difference is a matter of degree rather than type.

The relative magnitude of internal to external nutrient recycling is significant in the functioning of plant communities as it reflects the availability of nutrients. Where nutrients are scarce the energetic cost of developing roots to extract nutrients from the soil is high hence the benefits of retaining nutrients through internal recycling are high. However, where nutrients are readily available the energetic cost associated with the root growth needed to obtain nutrients from the soil is comparatively low.

This energetic control of patterns nutrient recycling within vegetation produces an interaction between the suitability of conditions for leaf function, typically by way of water availability or temperature, and soil nutrient availability. A deciduous growth form is most beneficial in a strongly seasonal climate on fertile soils but the benefits decrease as soil fertility decreases. The benefits of a deciduous life form depend on the interaction between seasonality and fertility. The third most significant criterion for a structural classification of vegetation is likely leaf longevity through its being determined by the interaction between fertility and seasonality.

Leaf Abundance

The ideal measure of leaf abundance is generally considered to be leaf area index, which is the ratio of the area of leaf to the area of ground in an area. This has always been difficult to measure and remains so despite advances in technology.

The surrogate measure of leaf abundance most commonly used is the projected foliage cover, which is the percentage ground covered by the vertical projection of leaves. This must be less than one whereas the leaf area index can be as high as 6. The discrepancies arise due to vertical overlap of leaf, and leaf angles departing from the horizontal. For a given amount of leaf the projected foliage cover depends strongly on the leaf angle whereas the leaf area index does not.

Projected foliage cover remains the most practical measure of leaf abundance despite its limitations.

Vertical Stratification

The vertical stratification of vegetation is given by height classes with different height classes for different plant life forms. The boundaries between the height classes are always somewhat arbitrary but through experience have been found to provide the level of discrimination useful for practical application.

The issue of height classes is irrelevant for vegetation characterisation as the actual heights are measured. Indeed, for maximum resolution the upper and lower heights of the foliage of each component should be measured. The assignment to height classes is made following the measurements rather than attempting to directly allocate vegetation to a class without or before obtaining measurements.

Plant Life Form

The main 'biological' deviation from a straight physical/physiological characterisation of the vegetation arises through the use of plant life form. The main life forms are trees, shrubs and grasses and these are the main components in most forms of vegetation. However, there are many other life forms that have arisen through evolutionary development such as palms, ferns, mosses and lichens.

The evolutionary development of life forms is significant as it produces differences in physiology and hence the relationships between the life forms and the environment. Moreover, the more recently evolved life forms have evolved in the presence of earlier ones and hence can have developed symbiotic associations. The functional significance of life forms is not well known but sufficient is known to justify retaining them as a basic stratification in structural vegetation classifications.

Plant life form usually provides additional vertical stratification to the use of specific height classes. The heights of species with a particular life form can vary considerably, as arises with trees, but the relative heights within plant communities show a high degree of consistency. For example, trees are usually the tallest life form where they occur.

Horizontal Stratification

A structural description of a stand of vegetation effectively represents a point observation. The horizontal stratification is therefore given by the sampling strategy rather than the classification scheme.

While descriptions of a stand of vegetation nominally provide a point observation vegetation can only be characterised for a finite area. This creates the issue of how to identify an appropriate area to characterise. The location and size of the area considered appropriate can vary depending on the application and priorities.

When addressing vegetation development the horizontal stratification should relate to communities, with communities being defined by the interaction between components. All the plant components in the described area should be sufficiently close to allow for a high level of interaction. The description should therefore apply to a small homogeneous patch[1]. Where parts of a stand differ they should be separately characterised rather than attempting to directly obtain an average for the stand.

[1] A basic requirement with any classification is that the variability within classes is less than the differences between.

This need to characterise the variability rather than obtain an overall average arises because the functional relationships in communities arise through interactions. The development and functioning of communities are therefore non-linear and hence cannot be simply averaged. A linear overall average for a large heterogeneous stand of vegetation has no functional significance and provides no information on the development of the system.

Despite this constraint coarse averages of vegetation structure are used in models addressing global warming: a 1km cell is considered fine resolution. Linear averages of highly diverse mixtures of vegetation are used to obtain a value for the 1km grid cells when the relationships between the forms are typically highly non linear. While the resolution achieved with such an inappropriate approximation may be considered adequate in addressing the interaction between the existing vegetation and climate it cannot address feedbacks that produce changes in vegetation. In this regard models addressing global warming are nonsense and at best provide coarse approximations to an existing situation.

The usual approach to site selection is to select representative stands. The stratification is then based on a preconception as to what should exist. Indeed, with a classic Australian study on rainforests the authors later acknowledged that the statistical significance of their stratification arose because the sites characterised had been selected to reflect the perceived different forms of vegetation. The apparently rigorous statistical analysis served only to support personal bias.

Situations arise where the characterisation of representative sites is appropriate. However, such prior judgment as to the form of vegetation expected serves no purpose other than to reinforce existing beliefs. Sampling all sites that appear to be different is the only effective means of avoiding such bias. Random sampling is invariably inefficient and usually will not provide essential information[2].

Transects have been popular in ecology when given their limitations it is hard to understand why. The serial correlation along transects limits application of most statistical analyses while the lack of interaction between plants at either end of transects prevents their use in characterising communities. At best they are highly inefficient, and at worst the interpretation of derived information is misleading.

What about rainforests?

The criteria identified here as being appropriate for a structural classifications provide more discrimination that can currently be usefully employed in categorising vegetation and developing understanding of system function. However, those working on rainforests would generally consider they provide insufficient discrimination between the forms of rainforest they consider significant. In the scheme given here, which is based on an abbreviated representation of the amount and vertical stratification of foliage, most rainforests would be encompassed by few classes.

This representation of rainforests is arguably appropriate relative to the occurrence of rainforests in Australia and throughout the world. The discrimination is no better or worse than for other forms of vegetation. The issue of discrimination largely arises because of perceptions of the significance of rainforests. It is an artifact.

---

[2] Random sampling creates an issue of how to aggregate the samples that cannot be usefully resolved by reference to the collected data alone. A basic issue is that linear averaging, as is usual when calculating averages or means, is inappropriate, and the appropriate form of averaging is unknown.

The structural criteria identified here would provide a very high level of discrimination between forms of rainforest if they were fully applied. The issue is that considerable effort and rigour are required to obtain reasonable estimates of the attributes in rainforests. If there is an issue with application of the scheme to rainforests it relates to the practicality of application rather than applicability or the level of discrimination.

The most compelling reason for not having a separate scheme for rainforests is that a structural classification must be applicable to all forms of vegetation to be useful in developing understanding of system function. The issue of identifying boxes into which forms of vegetation can be allocated is trivial compared to the provision of an approach and method that can be used to develop understanding.

Structural Classification Scheme

The scheme given by Walker & Hopkins that derives from Specht (1970, 1981) and others is used as reference as that is most widely used in Australia. The initial vegetation stratification is given by way of Structural Formation Classes (Table 1) where the classes essentially represent plant life forms. While identified as 'understory classes' the smaller life forms can be the tallest and/or dominant life form, and this is common with grasses.

Table 1 Walker & Hopkins Structural Formation Classes

Woody Plant Classes	**Understory Classes**
Tree	Tussock grass
Tree mallee	Hummock grass
Shrub	Sod grass
Mallee shrub	Sedge
Heath Shrub	Rush
Chenopod shrub	Forb
	Fern
	Moss
	Vine

Structural characteristics of the Structural Formation Classes are largely implicit rather than explicit through being given by the plant life form. Moreover, some categories relate to physiology more than structure, such as chenopod shrub.

Subdivisions within each of the Structural Formation Classes are based on plant height, and the projected canopy cover for woody vegetation and the projected foliage cover for 'understory' classes. The projected crown cover is the proportion of ground covered by the vertical projection of canopies assuming they are solid. The projected foliage cover is the proportion of ground covered by the vertical projection of foliage. The projected foliage cover of the stand can be measured directly or by determining the crown cover and the projected foliage cover within canopies.

The use of canopy cover rather than foliage cover avoids discrepancies arising from trees being deciduous and changes in foliage cover due to drought and fire. However, the use of both canopy and foliage covers in the Walker and Hopkins scheme introduces a major anomaly because of the boundaries they assign to classes. Taking a constant foliage cover for canopies, the cover categories for canopy and foliage classes should be equivalent when they are not.

Taking realistic estimates of the projected foliage cover of woody plant canopies, the relationship between cover classes for the vegetation estimated using projected canopy cover and projected foliage cover with the Walker and Hopkins scheme depends markedly on the abundance of vegetation (Table 2).

The understory/overstory ratio in Table 2 compares the levels of projected leaf cover for the overstory and understory vegetation for the cover classes used in the classification. For the categorisations of woody and non woody vegetation to be directly comparable this ratio should be one but it varies from 1.4 for dense vegetation, through one for mid dense vegetation, to 10 for sparse vegetation. The relationship between the cover classes for woody and non woody vegetation is highly anomalous and defeats the main purpose of a structural classification.

Vastly different significance is assigned to the leaf of trees compared to other forms of vegetation with this anomaly, and the significance differs with the amount of vegetation. This anomaly also arises with woody vegetation when comparing vegetation descriptions based on canopy and foliage covers.

Table 2. Canopy and foliage cover classes for woody and understory Structural Formation Classes of Walker & Hopkins. The Understory/Overstory ratio compares projected foliage covers for woody and understory classes where woody values were calculated from canopy cover using nominal but realistic projected foliage covers for canopies.

WOODY CLASSES	**Closed**	**Dense**	**Mid-dense**	**Open**	**Sparse**	**Scattered**
Canopy Cover (%)	>80	50 - 80	20 - 50	0.2 - 20	>0.2	>0.2
Foliage Cover (%) *	>50	~50 - 35	~15 - 35	~0.1 - 15	<0.1	<0.1
* Calculated from canopy covers assuming projected foliage cover of canopies given below (%)						
	0.66	0.66	0.66	0.5	0.5	0.5
UNDERSTORY CLASSES						
Foliage Cover (%)	>70	30 - 70	10 – 30	1 - 10	<1	<1
Ratio Understory/Overstory	1.4	1.2	1.0	1.5	10	10

Other issues that arise with the categorisation used by Walker and Hopkins include:

- Most field observations occur within a few categories.
  - this limits discrimination.
- Many categories do not occur (are not observed in the field).
  - this partly arises because of the use of subcategories of plant life forms to increase the discrimination (e.g. different forms of grasses, shrubs and mallee)
- The basis for discriminating the Structural Formation Classes varies.
  - most categories relate to plant life form but some relate to the environment where plants are found
  - height is used to discriminate some Structural Formation Classes, such as tree and shrub mallee, when height is discriminator in its own right
- There is considerable ambiguity with some categories.
  - e.g. herbs are not listed and are effectively included with forbs

The height categories used for different forms of vegetation by Walker & Hopkins are given in Table 3.

Table 3. Walker & Hopkins height categories for Structural Formation Classes.

Height (m)	Trees, Vines, Palms	Shrubs, mallee, cycads	Hummock & tussock grass, forbs, sedges, rushes, ferns	Sod grasses, Moss, lichen, liverwort
>35	Extremely tall	na	na	na
20 - 35	Very-tall	na	na	na
12 - 20	Tall	na	na	na
6 - 12	Mid-tall	Extremely tall	na	na
3 - 6	Low	Very-tall	Extremely tall	na
1 - 3	Dwarf	Tall	Very-tall	na
0.5 - 1	na	Mid-tall	Tall	Extremely tall
0.25 - 5	na	Low	Mid-tall	Tall
<0.25	na	Dwarf	Low	Low

Revised Structural Classification Scheme

The scheme given by Walker & Hopkins has been revised to increase applicability and remove anomalies without increasing complexity. Addressing the requirement by increasing the complexity is not a viable or useful option as classifications are used to simplify a complex situation.

Basic design criteria

Attempts to increase the resolution by increasing the discrimination of a particular variable (e.g. cover) usually decrease the reliability. This arises because of the limits to resolution of measurement and the inherent variability in the variable. However, the resolution, reliability and usefulness in application can be improved by employing multiple criteria. Combining information on the understory with the overstory can provide many more distinct categories that have with functional significance compared with basing the discrimination on the overstory alone.

Most resolution is achieved by stratifying plants according to life form. The life forms should be distinct and relate to plant physical & physiological characteristics. Ideally there should be a minimum number of classes to provide good discrimination of all circumstances, no ambiguity, and no redundant categories (i.e. no class with zero occurrence). As life forms are qualified by height and abundance, neither height nor abundance should be used in defining the life form classes.

Opinions differ as to whether the classification should be based on the tallest (largest) or the dominant (most abundant) life form. The largest life form is used here, as with Walker and Hopkins, because dominance can be difficult to determine. It is seldom clear what constitutes dominance. For example, while grasses are shaded by trees many situations arise where the impact of grasses on trees is greater than the impact of the trees on the grasses.

Basic classification structure

The vegetation is initially categorised according to the life form of the dominant plants and then according to the height and cover for each life form. The Structural Formation Classes of Walker and Hopkins are replaced by life form classes (Table 4), grouped into dominant and subdominant rather than woody and understory. Apart from the revised grouping, the key difference is simplification. Variants such as different forms of grasses and mallee have been eliminated.

Further discrimination could notionally be provided by subdividing categories, obvious ones being separating palms from cycads and sedges from rushes. However, the realised increase in discrimination would be negligible. The categories listed are considered to be the minimum needed to give a realistic representation of the functionality of the vegetation.

The cover descriptions used by Walker and Hopkins have been retained despite the differentiation between forests and woodlands being arbitrary (Table 5). The terminology is too engrained to be readily changed. However, the cover categories have been changed to take account of the practicalities of mapping and the requirement for interaction between plants when addressing ecology. Woody vegetation has a lower threshold of 2% canopy cover rather than the 0.2% with Walker and Hopkins. A 5% lower threshold may be more appropriate.

The foliage and canopy cover classes in Table 5 have been made equivalent. The result therefore does not depend on whether canopy or foliage covers are used, and the categorisations are equivalent for the different life forms.

The height categories of Walker and Hopkins have also been largely retained. The main change is the increase in the minimum height of trees to 2.5m to better address height distributions. The change in terminology from extremely tall to peak is a practicality relating to ease of tabular presentation, although it is also more explicit.

The main change to the Walker and Hopkins scheme is the addition of understory categories for woody vegetation (Table 7). These categories prefix the woody categories. For categories such as grassy woodland and shrub woodland this reflects current practice when describing vegetation. While some categories do not exist, such as a grassy closed forest, there are few redundant categories.

The subcategories of bare, grassy, shrub and swamp represent well defined conditions that reflect large differences in the functioning of the vegetation. However, as with life forms, the boundaries can sometimes be indistinct. A swamp forest can become a bare forest when dry.

All subcategories except swamp are applicable to mallee. The subcategories could also be applied to other categories, such as shrubs, but with large redundancy (many zero representations).

The potential redundancy of categories was examined by tabulating likely occurrence (Table 8). Of the dominant life form classes, tree, shrub, grass and rush categories have complete representation as examples can be found for each category. However, very dense mallee does not occur, and dense stands of succulents may be restricted to exotic species.

Few classes in the subdominant categories occur as dominants, with palms being the notable exception. The subdominant life form categories serve mainly to describe the understory vegetation but some can have transient dominance depending on seasonal conditions.

The occurrence of some categories is strongly influenced by land use. Many natural grasslands have been invaded by woody vegetation, mainly native but also exotic species. Some cleared lands have been invaded by exotic annuals/biennials such as thistles and Patterson's curse. Also, forbs have been strongly suppressed by grazing. Mosses and ground lichens are absent under agriculture but can be abundant in woodlands where livestock have been excluded.

Table 4. Plant life form categories providing the primary subdivision of the structural classification stratified according to their occurrence as dominants in Australian vegetation.

Dominant	
Classes are sequenced so prior definitions exclude occurrence in lower categories (e.g. rushes cannot be grasses).	
Tree	Upright perennial >2.5m high with a single woody stem (trunk)
Mallee	Eucalypt with multiple stems from a lignotuber
Shrub	Multi woody-stemmed perennial, non-succulent. Also, single woody stemmed perennials <2.5m high
Grass	All grasses (graminoids), annual and perennial
Rush	Rhizomateous non-woody perennial, erect foliage (includes Cyperaceae, Restionaceae, Typhaceae)
Succulent	Fleshy stemmed and fleshy leaf with woody stem
Subdominant	
These life forms are common in Australian vegetation but seldom form the upper stratum	
Vine	Climbing or rambling
Grass tree	Xanthoreaceae
Palm	Palmaceae and most cycads (Zamaceae, Cycadaceae)
Herb	Non-grassy (herbaceous) annual
Forb	Herbaceous perennial
Fern	Pteridophytes
Moss	Mosses, Liverworts
Lichen	Lichens

Table 5. Canopy and foliage cover categories for the structural classification. The categories for canopy and foliage cover are equivalent for most forms of vegetation.

Trees	Closed forest	Dense forest	Open forest	Woodland	Open woodland	Sparse woodland
Others	Closed	Dense	Mid-dense	Open	Sparse	Scattered
Vegetation Cover %						
Canopy*	100	80 - 100	60 – 80	40 – 60	20 - 40	2 - 20
Foliage**	>70	50 - 70	35 – 50	20 - 35	10 - 20	1 - 10
* Assumes that the crowns of trees are solid						
** Assumes that the crowns of trees have levels of foliage cover given below						
% foliage cover of canopies for the canopy and foliage cover categories to be equivalent						
	66	66	60	55	50	50

Table 6. Height categories for plant life forms for the structural vegetation classification.

Height (m)	Trees	Vines, palms	Shrubs, mallee	Grass, herb, forb, sedge, fern	Moss, lichen, liverwort
>35	Peak				
20 - 35	Very-tall	Peak			
12 - 20	Tall	Very-tall			
6 - 12	Mid-tall	Tall	Very-tall		
2.5 - 6	Low	Mid-tall	Tall	Very-tall	
1 – 2.5		Low	Mid-tall	Tall	
0.3 - 1		Dwarf	Low	Mid-tall	Tall
<0.3		Dwarf	Dwarf	Low	Low

Table 7. Subcategories for tree vegetation based on the nature of the ground layer. The potential occurrence is identified for each category.

	Tree Cover Category					
Understory	Closed forest	Dense forest	Open forest	Woodland	Open woodland	Sparse woodland
Bare	✓	✓	✓	✓	✓	✓
Grassy	✗		✓	✓	✓	✓
Shrub	✗		✓	✓	✓	✓
Swamp	✓	✓	✓	✓	✓	✓
✓	Common or likely					
Blank	unlikely					
✗	Does not exist					

Application Issues

A key point made by Walker and Hopkins is that classification follows description. The initial requirement is to record what is there. The classification of a stand of vegetation is based on that record rather than a personal perception of what the vegetation is.

Sampling

The result obtained primarily depends on the area selected for description. As vegetation varies with scale, and is rarely uniform even locally, results can differ between observers simply because of the selection of sample sites.

The variability arising from site selection is usually of greater consequence than differences in the consistency of description. Usefulness is therefore often determined more by the number of observations than the accuracy of individual observations. The method used for description must be consistent but it should also be rapid and highly practical. Estimates of foliage cover, the most difficult variable to measure, are addressed in Annex A.

Table 8. Potential occurrences of the plant life form categories as dominants in Australian vegetation.

Height	Closed	Dense	Mid-dense	Open	Sparse	Scattered
Tree			**Canopy or Foliage Cover**			
Mallee	×		✓	✓	✓	✓
Shrub	✓	✓	✓	✓	✓	✓
Grass	✓	✓	✓	✓	✓	✓
Rush	✓	✓	✓	✓	✓	✓
Succulent	×		✓	✓	✓	✓
Vine	⊙	⊙				
Grasstree	×	×				
Palm	✓	✓			×	×
Herb	⊙	⊙	⊙	⊙	⊙	⊙
Forb						
Fern						
Moss						
Lichen						
✓	Common or likely					
Blank	unlikely					
×	Does not exist					
⊙	Dominance is usually land use and/or seasonally dependent. Often invasive exotic species.					

Many modellers expect measures of leaf area index from vegetation surveys. However, given the high levels of spatial and seasonal variability it is not possible to provide the required information using ground survey. Their requirements can only be addressed by measurements that provide high spatial resolution at reasonable temporal frequency, at least several times each year.

As structural classifications address system function the sampling should characterise a community in which all of the component plants interact. The size of the sample area should therefore be adjusted to achieve the necessary interaction between components. Long linear transects for estimating crown separation ratio, as advocated by Walker & Hopkins, are inapplicable. Similarly, categories such as isolated tree and isolated clumps of trees having crown covers of 0.2% cannot constitute a plant community. The immediate site of an isolated trees is a separate entity to the area around it.

Forests v woodlands

Forests and woodlands are differentiated on the cover of tree canopies alone. This separation of woodlands from forests solely on the foliage cover of the trees is not a natural division, and in many regions the division arises where there is a maximal occurrence of vegetation. This creates ambiguity.

Australian woodlands were often identified by the occurrence of a grassy understory in treed vegetation as the occurrence of grass is significant for agriculture. While situations arise where shrubs and grasses have equal representation under trees they are uncommon. The form of understory vegetation represents a natural division between forests and woodlands that has functional significance. Discriminating forests from woodlands based on the understory vegetation would provide less ambiguity than basing the discrimination on the cover of trees alone.

An alternate characterisation is that all treed vegetation could be termed forest. The labels for cover categories for trees would then be the same as for all other plant life forms. There are justifiable alternatives to the current convention. However, the current convention is retained as:

- It accords with general perceptions.
- Understory qualifiers (shrubby, grassy, swampy, bare) can be used to increase the resolution of the classification.
- Entities generally recognised as shrub woodlands are common in semi-arid Australia.
- Conversion of grassy woodlands to shrub woodlands commonly arises with grazing.
- The use of understory qualifiers greatly decreases the significance of the arbitrary cover distinction between woodlands and forests.

Defining the grass or shrub dominance in treed vegetation has practical and theoretical benefits as:

- It increases the resolution and reliability of the classification.
- The relative dominance of shrubs and grasses under trees reflects an interaction between soils and rainfall and hence has high functional significance.

Discussion

The advocated approach to structural classification of vegetation has been successfully applied to obtain new information on the development of vegetation (Tunstall & Torssell, 2004 a, b). This was a necessary precursor to the advance of identifying the role of positive feedback in the development of plant communities (Tunstall 2008). The information provided by the approach is useful for advancing understanding on the development and functioning of plant communities.

The classification scheme simplifies and existing system that has proven practical application, and does so without reducing the resolution. Also, it removes errors and ambiguities. It represents an advance that should facilitate application.

ANNEX A: ESTIMATING FOLIAGE AND CANOPY COVER

Structural vegetation classification is largely based on the projected canopy or foliage cover. Projected foliage cover is termed projective foliage cover by Specht. The crown ratios used by Walker & Hopkins provide a method for estimating canopy cover.

The projected foliage cover is the % ground covered by the vertical projection of the foliage. The projected canopy cover is the vertical projection of plant crowns assuming that crowns are solid. Multiplying the canopy cover by the projected foliage cover of crowns gives the projected foliage cover of vegetation.

The projected foliage cover of the crowns of Australian plants varies with species and seasonal conditions but for woody plants is generally around 50%. Photographic examples that can be used for reference are given by Walker & Hopkins (1984) ex Walker & Tunstall (1981).

Estimating Canopy Cover

For woody vegetation the canopy cover is most readily estimated using crown ratios. Crown ratio is the width of crowns relative to the distance between crowns (average crown size / average separation of crowns). Crown ratio is most readily visually determined for patches rather than transects as a patch allows for lateral viewing whereas transects require vertical viewing.

The procedure for estimating crown rations given by Walker & Hopkins is impractical because of the need for vertical viewing. It is also ecologically unsound as a long transect means that all plants contributing to the estimate do not form a community. A community is identified by the interaction between the components and the trees on either end of transects do not interact.

Crown ratios are most readily visually estimated by viewing laterally in all directions about a point. The relative size of each tree canopy to the gap to the next canopy is visually estimated, where this provides at least two estimates for each tree. The estimate of crown ratio is the average for all tress in the patch being assessed. As ratios are dimensionless the viewing can be conducted from any distance. Scaling errors are only significant with large diameter canopies viewed at close distances. In such situations the viewing position must be changed to obtain a reliable estimate of the diameter of crowns.

The benefits of using crown or canopy cover rather than foliage cover are the lack of seasonal variations and the ability to determine it through lateral observations. The measurement is practical with all sizes of shrubs as well as trees, and with grasses that form distinct clumps. However, the measurement of crown cover is only feasible where plant crowns are distinct and regular. It is therefore inapplicable to ground layer vegetation where the plants do not form distinct canopies.

Table 9. Crown ratio to canopy cover conversions.

Ratio	0.00	.05	.10	.15	.20	.25	.30	.40	.50
Cover %	81	73	67	60	56	52	48	41	34
Ratio	.60	.75	1.00	1.25	1.50	2.00	3.00	8.00	10.00
Cover %	31	26	20	16	13	9	5	1	0.6

Crown ratios are effective with most forms of woody vegetation but the assumption of a regular crown may limit its application in Northern Australia. Some regard tree basal diameter as a preferred measure of tree abundance, but this is difficult to equate to other plant life forms. Also, it is a much poorer indicator of amount of foliage than even the coarsest estimate of projected foliage cover.

Foliage Cover

While the projected foliage cover of canopies varies between species it also varies with seasonal conditions, fire and other factors that impact on the vegetation. The apparent improvement in the estimate of foliage gained by adjusting the canopy covers for the density of the foliage can therefore be illusory. The precision of the estimate of foliage is improved but not necessarily the accuracy. For applications involving general vegetation classification the adjustment of canopy cover to obtain estimates of foliage cover then serves little if any purpose. It is simpler and more reliable to base general classification on estimates of canopy cover rather than foliage cover.

Two situations arise where estimates of foliage cover are essential through crown cover being inapplicable. The obvious one is where a species of plant life form does not form a distinct regular canopy, as with many grasses. The other is where comparisons between different life forms are of interest. All estimates have then to be presented in a directly comparable form, which is foliage cover.

Projected foliage cover can be difficult to measure, particularly since many Australian plants have vertical foliage. The need for vertical viewing limits practical application to trees and low grass. Also, very little of a vertical leaf is visible when viewed vertically. Even slight winds can hinder measurement, and reflection and refraction limit the accuracy of optical methods. Photographic and other such methods contain considerable error due to uncertainty as the location of leaf edges, and considerable leaf need not be recorded because of reflection of direct beam solar radiation by the leaf. Existing instruments are not suited to routine application in surveys where observations must be simple, inexpensive, quick and reliable under the full range of conditions experienced in the field.

Visual estimates currently provide the most convenient means of determining the foliage cover of the full spectrum of plant forms under the range of conditions encountered in the field. They also provide sufficient resolution, at least with our current limited ability to use the information they can provide. That is, the current limitation is the ability to use the information rather than the accuracy or reliability of visual estimates.

Reliability with visual estimates is achieved using comparative estimates to constrain the magnitude of error, as is done with crown ratios. Estimates of projected foliage cover are made comparative by separately estimating the cover of the foliage and the gaps. The initial observation overestimates the attribute being visualised (focused upon), say the foliage. Switching the visual focus to the gap then provides an estimate of the gap. The initial observations invariably overestimate both the gap and foliage. Successive observations of the foliage and gap are then alternately and iteratively obtained until they coincide. The method involves iterative approximation.

The gap that is viewed can be the ground or sky, or any other background, hence the method is applicable to all forms of vegetation.

Accuracy of estimates

For the report of Walker and Tunstall (1981) estimates of projected foliage cover obtained using different methods were evaluated with a traversing light sensor that provided an accurate measure of the proportion of direct bean solar radiation penetrating through trees. The measurement system used two silicon cell radiometers and a stepping motor to provide integrated readings along a 2m track. One radiometer incorporated an occulting disc, thus the difference between the radiometers provided a measure of direct beam solar radiation. Measurements were obtained at multiple locations within different communities around noon in December on the Tropic of Capricorn where this provided near vertical illumination.

The general conclusions from comparing the instrument results with those from survey methods involving viewing, distance measurement and/or photography were that:

- All fixed plot sampling methods gave poor results.
- Photographic methods were adversely affected by the reflection of light from leaves and poor discrimination of leaf edges in film processing. The only reliable photographic estimates were obtained under completely overcast conditions using a narrow angle lens and 70mm film.
- The best and equivalent estimates of projected foliage cover of the trees were given by:
  - Crown ratios adjusted for the estimated foliage cover of crowns.
  - Visual estimates of the foliage cover obtained using the comparative procedure described above.

References

McDonald, R.C., Isbell, R. F., Speight, J.G., Walker, J. and Hopkins, M.S. (1984). Australian soil and land survey. Field handbook. Inkata, Melbourne. pp 165

Parkhurst, D.F. and Loucks, O.L. (1972). Optimal leaf size in relation to environment. J. Ecol. 60, 507-37.

Specht, R.L. (1970) Vegetation. In The Australian Environment 4th edn. (Leeper, G.W. ed.) CSIRO & Melbourne University Press, Melbourne.

Specht, R.L. (1981) Major vegetation formations in Australia. In Ecological Biogeography of Australia. (Keast, A. ed.) Junk, The Netherlands.

Tunstall, B.R (1987) On the Relationship Between Vegetation Classification and Environmental Association. On www.eric.com.au 16pp

Tunstall, BR (2008). Controls on the Development of Vegetation. On www.eric.com.au 6pp

Tunstall, B. R and Torssell, B.W.R (2004a). Component Replacement of Trees, Shrubs and Grass in a Poplar Box Woodland interpreted from the Spatial Variability. On www.eric.com.au 13pp

Tunstall, B.R. & Torssell, B.W.R. (2004b). Component Replacement of Trees, Shrubs and Grass in a Poplar Box Woodland interpreted from the Spatial Variability. On www.eric.com.au 13pp

Walker, J. and Tunstall, B.R. (1981). Field estimation of foliage cover in Australian woody vegetation. CSIRO Aust. Div. Land Use Res. Tech. Memo. 81/19.