

# Classifying Eucalyptus forest vegetation data: a comparison of techniques

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## Summary

This paper reviews a number of vegetation classification techniques and illustrates their use with *Eucalyptus* forest data. The techniques include structural classifications (Specht, Johnston and Lacey, and Braun-Blanquet methods), an automated software tool (TWINSPAN), a statistical method (association analysis) and two classifications specifically designed for forests (the FAO/UNEP and Baur's Forest Type methods). The classification techniques are assessed using a set of criteria for Eucalyptus forestry-based classifications. A matrix method for comparing the classifications is suggested as a useful tool in determining the best method for a particular project.

## Introduction

In forestry, vegetation classification and mapping are critical steps in short and long term resource planning, including assessment of both timber production and conservation values.

Units of vegetation are difficult to define and map as the vegetation of the world constantly varies in response to changing environments (Specht 1972). While vegetation is commonly classified in discrete units for ease of definition, mapping and analysis, this leads to a loss of information (Skidmore 1989) due to the composition of artificial boundaries. The choice of continuous or classified data means that a compromise must be made between specificity and ease of data management and analysis.

Classification is an exercise in which entities (e.g. species) are distinguished, and grouped together so that the groups share a common relationship (Specht 1972). Classification therefore provides an appreciation of vegetation pattern in a logical, easily comprehensive and communicable form. Managers and planners commonly deal with vegetation classified into distinct units for regional and local operations.

Plant communities are complex associations which can be classified on the basis of the morphology, growth form or structural arrangement. Classification can be based on leaf size and shape, phenology and layering (Johnston and Lacey 1984); structure; floristic composition; ecology (i.e. interaction with the physical environment); and statistical relationships defining the occurrence of species.

Certain reports assert that most vegetation classifications in Australia are inadequate (Gillison 1981, Hopkins 1981, Johnston and Lacey 1984, Bureau of Rural Resources 1990), citing non-representative coverage of part of the vegetation and the use of vague environmental attributes. A further disadvantage is the lack of a comprehensive framework within which inter-relationships can be detected in local, regional or special purpose classifications (Johnston and Lacey 1984).

Choice of a classification technique is difficult. There is no single correct method, however the purpose of classification and the format of the data may indicate a preferable method. The land use activity (e.g. agriculture, forestry, wilderness conservation and recreation) could also suggest an appropriate classification method (Brown *et al.* 1989). Schema designed for forestry planning and management will have different requirements from those for urban planning or horticulture. Other important factors which will influence choice include the area covered, scale of the mapping, and the intensity of vegetation sampling (Johnston and Lacey 1984).

This paper presents a matrix, or tabular, approach to determining an appropriate vegetation classification technique for forestry. Some traditional and more recent classification techniques for forest resources are reviewed. These include structural classifications (proposed by Specht, Johnston and Lacey and Braun-Blanquet), a software program, TWINSPAN (Two-way Indicator Species Analysis), a statistical method based on association analysis, and classifications designed specifically for forestry (e.g. the management driven FAO/UNEP and Baur's Forest Typing).

## Essential qualities of a forestry classification scheme

Essential qualities of a forest classification scheme may be considered in one of two categories: those required for vegetation and those applicable to forest resources. The broad objective of forest resource classification is to assist decision making in the conservation and utilisation of forested lands, by identifying and describing the structural and floristic elements of forest communities.

The ideal (or optimum) classification will:

**C1. Be client and user driven**, meeting the needs of putative client users. The classification scheme must be acceptable to the decision maker, the planner and the workers involved in the implementation (Bureau of Rural Resources 1990);

**C2. Be able to be used pragmatically** by staff with different skill levels, in the field or the office, within workable time and cost constraints (Bureau of Rural Resources 1990);

**C3. Be based upon structural and floristic information.** Both of these factors are intrinsic to assessing similarity amongst species. This should be a reflection of the complexity of the vegetation. Management decisions are increasingly being based upon both structural and floristic components (Westbrooke *et al.* 1995);

**C4. Form a basis for integrating present and future forest attribute data.** This will ensure findings of forestry research, vegetation succession changes, and any additional survey data can be incorporated in the classification (C4). In turn it should be able to help answer questions relating to current and potential yields of forestry products (C4a), and the condition, character and current designated tenure of forest (Bureau of Rural Resources 1990);

**C5. Support potential extension of its use** to include complementary natural resource studies, such as identifying and assessing the abundance of fauna, or lower plant species, and their habitat; establishing locations of important cultural relics (such as Aboriginal sites); and assessing local wilderness value (Bureau of Rural Resources 1990);

**C6. Recognise that there is a range of scales of resolution,** and a hierarchy of requirements from national to regional and local level (Bureau of Rural Resources 1990);

**C7. Be able to relate classified data to a meaningful continuum,** ideally an ecological continuum which may be viewed spatially;

**C8. Be able to use pre-classified data** (such as aerial photography interpretation results);

**C9. Be able to take advantage of technological advances** in areas such as Geographical Information Systems (GIS), remote sensing and ecological modelling. This is increasingly important as these techniques evolve into useful tools for communication between the production area and management (Skidmore and Turner 1995);

**C10. Be accompanied by a characteristic nomenclature** for taxonomic classes (Bureau of Rural Resources 1990); and

**C11. Be repeatable/reproducible.** A range of persons, specialised or otherwise, should be able to determine the same classification or reach the same conclusion (Bureau of Rural Resources 1990).

The best classification scheme will be the one which satisfies as many of the above points as possible.

**Comparing classification techniques**

The data used to compare classification techniques are drawn from Delaney (1996). Each classification method is discussed and an example given using a subset of the Delaney data. The data were collected using 50 by 20 metre plots located in a stratified (by geology) random manner on Nullica State Forest, New South Wales. Information collected included dominant height, strata cover, species, number of individuals (by species) in 10 metre height categories and notes on understorey vegetation. Example data are shown in Table 1.

**Table 1.** Example data

Plot	Dominant height(m)	Strata cover (%)	Species <sup>1</sup>	Number of individuals in each height (m) category					
				0-10	10-20	20-30	30-40	40-50	>50
A	30	50	<i>E.muel</i>	0	2	50	0	0	0
			<i>E.cons</i>	0	50	50	0	0	0
Understorey: many <i>acacia</i>									
B	50	30	<i>E.obli</i>	0	0	0	0	0	2
			<i>E.muel</i>	0	0	0	0	0	30
			<i>E.smit</i>	0	0	0	0	1	0
Understorey: thick ferns									

<sup>1</sup> *E.muel* = *E.muellerana*, *E. cons* = *E.consideniana*, *E.obli* = *E.obliqua*, *E.smit* = *E.smithii*

Each classification technique is assessed in terms of its ability to meet the criteria listed above. The criteria which are satisfied by the technique are addressed initially, followed by those which could be met with slight changes, those which could be met after more extensive modifications, and finally the criteria unable to be satisfied by each classification scheme. The coded numbers in the text relate to the list of criteria, for example (C1) refers to the suggestion the classification should be client and user driven. These data are tabulated towards the end of the paper (Table 6) for a cross-classification comparison.

**Specht's classification**

The Specht system, originally defined by Specht in *The Australian Environment* (Specht 1970), has been refined by Specht. An example is given in *The Vegetation of South Australia* (Specht 1972) and *Vegetation Classification in Australia* (Gillison 1981). The original form is rarely used, but modified forms of Specht's scheme have been used by agencies Australia-wide (see Bureau of Rural Resources, 1990 for a list). Specht's classification has been the most popular system used by Australian botanists as it suits the taxonomic classification of vegetation (Johnston and Lacey 1984).

Specht states that a plant community can primarily be described by the structure of the upper stratum, which contains the bulk of the biomass, and is the centre of most photosynthetic processes. These processes can be characterised through various foliage leaf measures and the contribution of different species as identified through biomass/area measures. In a secondary phase, the floristic composition, or the abundance of the distinctive plant species, can be used to further subdivide the structural formation.

Specht (1972) recognises the following subdivisions within each structural formation:

- A society groups together climax ecosystems which have (1) the same structural characteristics, (2) the same dominant species (which have the greatest foliage cover in the upper stratum) and (3) the same species prominent in lower strata;
- An association groups together climax ecosystems which have (1) the same structural characteristics and (2) the same

dominant species but (3) different lower strata floristic composition;

- An alliance groups together climax ecosystems which have (1) the same structural characteristics, (2) related dominant upper strata species and (3) the same, or related, understorey species; and
- A structural formation groups together climax ecosystems which have similar structural characteristics but different floristic composition in all strata.

More detailed information on the definition of structural formations is given in Specht (1981).

An application of the Specht method to the Nullica State Forest plots (Table 1) suggests that Plot A represents open forest (eM3) and Plot B is woodland (eT2).

The abbreviation 'e' is used for *Eucalyptus* forest. The distinction between open forest and woodland is based on foliage projection cover. The 'M' indicates that the life form of the tallest stratum is 10-30 m and the 'T' indicates the life form of the tallest stratum is >30 m. The numbers '2' and '3' are a classification of the foliage projection cover of the tallest stratum. Further sub-formations can be recognised using the understorey information. For example, Plot A may be called shrubby open forest.

The main advantages of the Specht method are its simplicity and adaptability (C1). Only two measures are necessary: foliage projection cover and height of the tallest stratum. These data may be easily organised into classes and understood by workers, planners and decision-makers (C2). It is user-driven, practical and able to be adapted to a number of scales (national, regional and local) (C6).

Most of the remaining criteria listed for a successful forest classification could be satisfied with only slight modification to the Specht method. The first of these is the ability to integrate studies (C4). Although future studies can be integrated, the result would be a revision of the classification and not an enhancement. New data from a different season or life-stage of the forest could result in a new classification.

Specht's classification scheme can be adapted to support other research (C5), such as fauna distribution. For example, if it is known that a glider inhabits tall open-forest, that association may be linked to likelihood of fauna habitat sites for this glider. Remotely sensed imagery (C8) could be incorporated, using a classified image to discern canopy cover. Moreover, Specht's classification can be incorporated into a GIS (C9) for ease of mapping.

The nomenclature (C10) given by Specht is appropriate to the classes suggested. However, terms like forest, open forest and woodland to denote both formations and sub-formations may be confusing.

Specht's scheme is partially subjective (C11) and may not return the same classification for different users. Rules for distinguishing a dominant layer of vegetation and making measurements such as projection foliage could be made more objective.

Two criteria listed for a successful forest classification could be satisfied through a large modification to the Specht method. The

first concerns the balance of structural and floristic data (C3). Floristic complexity is not indicated by Specht's method. In a closed forest the complexity could be high (as in a rainforest) or low (as in a mangrove swamp). The situation may be confused by equating closed forest with rainforest. Many closed communities are not rainforests and vice versa (Johnston and Lacey 1984). An element of floristics can be included by adding a genus abbreviation, such as the 'e' in eM3. A further useful extrapolation of this may allow definition of the main species, such as *E.cons/E.mue*/M3 for Plot A.

The second large modification concerns calculation of potential yield and other forestry measures, which require a species level classification (C4). Tall open forest may consist of good quality timber or poor quality timber.

Specht's method does not attempt to represent a continuum of vegetation without further input of expert knowledge or field data (C7).

As a general vegetation classification tool Specht's method works well. However, in more specialised areas, such as forestry, greater effort needs to be made to identify and understand species relationships, as well as to appreciate the way structural parameters relate to the commercial viability of a forest for different product mixes and harvesting methods.

### Johnston and Lacey's classification

The Johnston and Lacey method was proposed in 1984. It is useful for relating information intrinsic to the classification with the vegetation, and for relating vegetation to environmental factors, such as disturbance (Johnston and Lacey 1984).

This classification, based on the structural attributes of vegetation, was developed for tree-dominated stands. The basis for the classification is primarily physiognomic and secondarily floristic and spatial (based on tree height and density).

Compared with the Specht scheme, the Johnston and Lacey method is more involved (Bureau of Rural Resources 1990). The basic variables are structural, with more complex class definitions relying upon floristic attributes. Recent growing conditions and the history of disturbance are summarised in the spatial attributes and used to describe the space occupied by the stand (Johnston and Lacey 1984).

The three types of attributes used are:

- Physiognomic. These include elements of morphology, growth form or structural arrangement characterising the community. Examples are foliage type, leaf size and shape, phenology (ranging from deciduous to evergreen) and layering (stand complexity);
- Floristic. These are formal or informal taxonomic groups, such as species, genus or family; and
- Spatial. Tree height and density are given as expressions of disturbance and environmental conditions.

These attributes generally relate to the dominant layer, although physiognomic attributes are also related to the subordinate layer and floristic attributes can be used with subordinate species to further define communities. The dominant layer of growth form and foliage type (i.e. physiognomic attributes) define formation classes and formations respectively. Further sub-formations are

defined by subordinate layer growth form. Floristic attributes determine generic classes, alliances and associations. Spatial attributes are independent dimensions.

The application of the Johnston and Lacey classification to the Nullica Sate Forest vegetation data is illustrated in Table 2. Both plots (Plots A and B from Table 1) are described as ‘tall – very tall eucalyptus forest’ but are differentiated in terms of understorey and tree spacing.

The list of criteria for a successful forest classification includes the ability to be useful at a range of scales or resolution (C6). This method can be used at various levels of spatial scale or

fauna, for example, to be investigated or used in modelling procedures.

The Johnston and Lacey classification can make use of technology, such as GIS, although this is largely limited to cartographic display (C9).

Reproducibility is also achievable with the quantification of subjective decisions, as with the Specht scheme (C11).

The criteria listed for a forest vegetation classification which could be achieved with a higher level of modification are discussed below.

**Table 2.** Johnston and Lacey plot classification

Attribute	Plot A	Plot B
Dominant form	Forest	Forest
Foliage type	Amphisophyll forest	Amphisophyll forest
Subordinate form	Amphisophyll shrub forest	Amphisophyll fern forest
Leaf size	Microamphisophyll shrub forest	Microamphisophyll fern forest
Phenology	Evergreen microamphisophyll shrub forest	Evergreen microamphisophyll fern forest
Complexity	Simple evergreen microamphisophyll shrub forest	Simple evergreen microamphisophyll fern forest
Genus	<i>Eucalyptus</i> forest	<i>Eucalyptus</i> forest
Group	Stringybark/Ash forest	Stringybark forest
Species	<i>E.muel/E.cons</i> association	<i>E.muel</i> association
Height	Tall stringybark/ash forest	Very tall stringybark forest
Spacing	Medium dense tall stringybark/ash forest	Open very tall stringybark forest

clustering. Associations can be implied at the genus, group or species level. Classes created can normally accommodate any Australian vegetation community at a number of levels of the classification.

There are a number of criteria listed for a successful forest classification that can be satisfied by only minor alteration to the Johnston and Lacey method. The need for a floristic and structural balance (C3) is partially addressed. The need to assume a community is in a climax state, as in the Specht method, is avoided hence a conflict with underlying assumptions is minimised.

Much like the Specht scheme, integrating new data would result in a new classification, rather than a refinement as the classification is a snapshot in time (C4).

With slight modification this classification method can be adapted to accommodate complementary studies (C5). The knowledge of the form and types of vegetation assembled in Table 2 would allow known associations between the flora and

In order to be user driven by a range of users this classification would require a great deal of simplification (C1). The complexity of the classification requires that the user has an understanding of a number of botanical terms such as ‘microamphisophyll’. The amount and quality of information required for the classification of any one site also affect its practicality (C2). For example, leaf size information may be of minimal influence in assessing final values, such as logging potential. In forestry practice it may be more advantageous to invest time in a larger number of data plots with limited understorey and structural information. Nevertheless, understorey information allows the sites to be distinguished from one another when the dominant layers are similar. This may be of use in locating habitats of rare and endangered subordinate species (or fauna species) allowing the forester to practice improved conservation measures.

Information about the species present as well as the complexity, height and spacing of trees, allows managers to investigate potential yield and estimate expected economic returns (C4a).

It is difficult to see how classified remotely sensed imagery (C8) could aid classification based on features such as leaf size, as this would require very high-resolution imagery (not presently available). Commonly available classified imagery, however, could be used to help in, for example, determination of dominant form and spacing.

The full nomenclature tag (C10) may be long and awkward, reflecting the need to know the complexity of the vegetation, the phenology, leaf size, subordinate and dominate form and foliage type. However, structural stereotypes such as ‘tall open forest’ and environmental stereotypes such as ‘alpine woodland’ are avoided. For ease of use, an abbreviated form of reference would be recommended.

Like Specht’s method, the Johnston and Lacey classification does not easily translate into a representation of a continuum of vegetation change (C7).

**Braun-Blanquet’s classification**

Braun-Blanquet published a vegetation classification method in the early 1920s. It has been accepted worldwide as a simple, non-superficial classification (Mueller-Dombois and Ellenberg 1974), particularly in Europe (Gauch 1986). The method is polythetic (using a number of different characteristics), divisive (the initial data set is divided sequentially into smaller groups) and hierarchical, characterised by ordered tables (Cain and de Oliveira Castro 1959).

The objective of the Braun-Blanquet method is to encapsulate a detailed knowledge of vegetation into a formal classification

based upon the relationships between species (Whittaker 1975). It operates on three assumptions:

- Community classification is based on floristic composition. Plant communities are therefore identifiable by their floristic composition, independent of environmental information;
- Some species, termed 'diagnostic' species, are more sensitive expressions of a competitive or environmental gradient. Diagnostic species are emphasised in the Braun-Blanquet method as indicators of inter-species and environmental relationships; and
- Diagnostic species can be used to organise communities into a hierarchy similar to a taxonomic hierarchy. The basic unit of this hierarchy is the association (Gauch 1986). The Braun-Blanquet association is a unit of vegetation derived from a number of surveyed plots which have a certain number of their total species in common (Mueller-Dombois and Ellenberg 1974).

This method has been compared with numerical classification methods (Stanek 1973; Hakes 1994) and contributes to the theoretical basis of computer-based classification tools, such as TWINSpan.

There are three phases in the Braun-Blanquet method: the analytic, the synthetic and the syntaxonomic. These are explained briefly below and in detail by Whittaker (1975), Gauch (1986) and Mueller-Dombois and Ellenberg (1974).

The analytic phase involves determining the species' importance. Normally the measure of cover is used, although percentage representation has also been used (Delaney 1996). The importance is assessed using a relative importance value indicator. For example: *r* indicates a solitary occurrence; *+* indicates a few occurrences, say < 5 trees or < 1% of plot cover; and 1, 2, 3, 4 and 5 indicate <5%, 5-24%, 25-49%, 50-74% and 75-100% of plot cover, respectively. The constancy of a species is then calculated. This is the number of plots with the species divided by the total number of plots.

The synthetic phase involves arranging samples and species to show the inherent structure of the data in tabular format. Initially, data are organised with species as rows and plots as columns. Paying particular attention to species which are neither present in all plots, nor very rare, the table may be rearranged to group together species which are alike in distribution in the plot data, and plots which are alike in their species composition. Species are ordered from the most common (highest constancy) to least common (lowest constancy). The rearranged, or differentiated, table will have a characteristic diagonal appearance.

Diagnostic species are then identified. There are two types of diagnostic species. Character species define the floristic classification or association. Character species are present in samples of one community type but absent, or less important, in others. Differential species are subjectively chosen species which divide associations into sub-associations. These are present in samples of one community type but absent, or almost absent, from others. Only species of intermediate constancy (10 to 60% constancy) are considered possible differential species. High constancy species tend to be typical of all plots and low constancy species can be considered accidental.

The data table is then organised so that species of a differential group are located together. Species within each group are listed in order of decreasing constancy and groups are ordered in increasing numbers of differential species. A new numbering scheme, 'running numbers', is applied to the rearranged plots. The plot with the highest number of differential species becomes plot one and the plot with the lowest becomes *n*, where *n* is the number of plots. Finally, species from the initial data not in the table (0 to 10% and 60 to 100% constancy) are added in order from high to low constancy values.

The syntaxonomic phase involves assigning plots to associations, constructing a classification hierarchy and deriving a formal, standardised nomenclature, based upon the main species.

Use of the Braun-Blanquet classification is illustrated with a sub-set of the Delaney (1996) data containing 15 plots (Table 3). There were no high constancy species in these plots, suggesting a complex forest. The cell entries in the table refer to the relative importance value indicators of the analytic phase of the classification. The arrangement of the data in a tabular format from highest to lowest constancy gives Table 3 the characteristic diagonal appearance associated with the synthetic phase. In the syntaxonomic phase the main species (*E.sieberi*, *E.muellerana*, *E.cypellocarpa*, *E.obliqua* and *E.viminalis*) were used to construct the classification hierarchy and develop the nomenclature titles for the community groups (base of Table 3). The nomenclature and the appearance of the differential table can be used to describe the complexity of the vegetation, for example in Table 3, Group C is more complex than Group A.

The Braun-Blanquet classification allows the rarer Eucalyptus species to form the distinction between levels (as shown in Table 3), which may constitute unnecessary complexity for the forest planner, or may be fundamentally important in isolating areas in which rare and endangered species are growing.

For comparison with previous examples, Plot A (described in Table 1) is a *Eucalyptus consideriana* variant of the *E.muellerana* unit (IIa) and Plot B (described in Table 1) is an *E.smithii* variant of the *E.muellerana* unit (IIa).

A strength of the Braun-Blanquet method is that it has both a floristic (e.g. separating species into groups which tend to grow together) and structural (e.g. the cover parameter) basis (C3). The number of levels in the nomenclature enables the classification to be used at many different scales (C6). In a local study variants can be used, whereas on a national scale associations, alliances or orders may be employed.

With slight modification, the classification scheme may be used to incorporate other studies (C5), such as fauna investigations. However, Whittaker (1975) states that although a similar classification of fauna is possible, the results of a fauna and vegetation study of the same region may show no correlation. This is true of the previous classification techniques discussed above.

Classified remotely sensed data (C8) may also be incorporated into the classification method, for example, in the derivation of canopy cover variables. GIS could also be used with this scheme to map the final product. It is difficult to program the method into a software program (and then perhaps create a link to a GIS) due to the need for subjective input and a need to capture the

**Table 3.** Braun-Blanquet differentiated table

Plot	121	124	130	123	125	133	127	128	132 <sup>1</sup>	135	126	134 <sup>2</sup>	129	122	131
Running No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<b>Group differential species</b>															
<b>I of the <i>E.sieberi</i> unit</b>															
<i>E.sieb</i>	5	2	5	5	4	r									
<b>Group differential species of</b>															
<b>IIa the <i>E.muellerana</i> unit</b>															
<i>E.muell</i>			2	3		5		3		4	5	3	3		
<b>Group differential species of</b>															
<b>IIb the <i>E.cypellocarpa</i> unit</b>															
<i>E.cype</i>						+		r	3			+	+		
<i>E.obli</i>						r						+		r	
<i>E.vimi</i>								4					3	+	
<b>Character species</b>															
<i>E.glob</i>						+	r	4							3
<i>E.aggl</i>	5							3							
<i>E.cons</i>								4							
<i>E.elat</i>															+
<i>E.frax</i>									2						
<i>E.maid</i>									r						
<i>E.side</i>						4									
<i>E.smit</i>															1
	A					B					C				
	<i>E.sieberi</i>					<i>E.muellerana</i>					<i>E.cypellocarpa/E.obliqua/E.viminalis</i>				
	Community					Community					Community				

Key to codes: r = solitary occurrence, + = <5 trees, 1 = <5% of plot cover,  
 2 = 5-24% of plot cover, 3 = 25-49% of plot cover, 4 = 50-74% of plot cover,  
 5 = 75-100% of plot cover

<sup>1</sup> This is Plot A in Table 1  
<sup>2</sup> This is Plot B in Table 1

expert's knowledge (C9). Non-expert system computer Braun-Blanquet programs, such as TWINSpan, have been written, however these differ from the original method in many ways.

The nomenclature (C10) of the Braun-Blanquet method is based on the main species, as shown in Table 3. This provides a simple and effective nomenclature for the classification, although, as mentioned previously, in a complex forest these tags can become long.

Large modifications would be required to make the scheme practical for many purposes and at the same time user-friendly (C1, C2). A number of complex stages are involved, some requiring subjective input from a botanist or ecologist. Incorporating new floristic data into the classification (C4) would also involve the creation of new tables. Unfortunately, unautomated table creation and rearrangements are slow, tedious tasks.

Forest resource parameters, such as yield (C4a), may be modelled with a knowledge of the commercial value and typical physical attributes of each species (although it is recognised that individuals of a species can vary significantly in productivity over a small area).

The ability to represent vegetation data as a continuum (C7) (spatially, say within a GIS) is limited, although proximity in the final differentiated table may suggest similarity and the table may also be used for suggesting plots which might represent ecotones.

Finally, the analysis is not standardised and reproducibility (C11) is poor. The need for extensive data sets, tabular manipulation and expert knowledge makes this unnecessarily complex, particularly for forestry planning and management.

**TWINSpan classification**

TWINSpan, a two-way indicator species analysis, is a computer package designed for use with data detailing species presence and abundance in plots. It is based partially on the Braun-Blanquet method (Belbin and McDonald 1993). TWINSpan is firstly a polythetic divisive method of classification. A second classification involves ordering the results of the primary classification according to ecological preference. Classes with similar ecological preferences are moved closer than those with different ecological preferences. The two classifications are used together to create a two-way table which expresses the species relationships (Paling 1986). TWINSpan is a popular computation alternative to the Braun-Blanquet method and has been used in classifying many different types of communities, for example coral (Paling 1986) and Tanzanian forest (Mwasumbi *et al.* 1994).

Vegetation data are encoded into tables of species (rows) and plots or samples (columns). Rare species do not perform as good indicators of environmental conditions, sometimes obscuring general patterns (Paling 1986). For this reason rare species, those with less than 5 occurrences, are omitted. Numbers of each species in each plot are re-coded into absent (class 0), rare (class 1: less than 10% of trees in plot), common (class 2: 10 to 49% of trees in plot) and abundant (class 3: 50% or more of trees in plot).

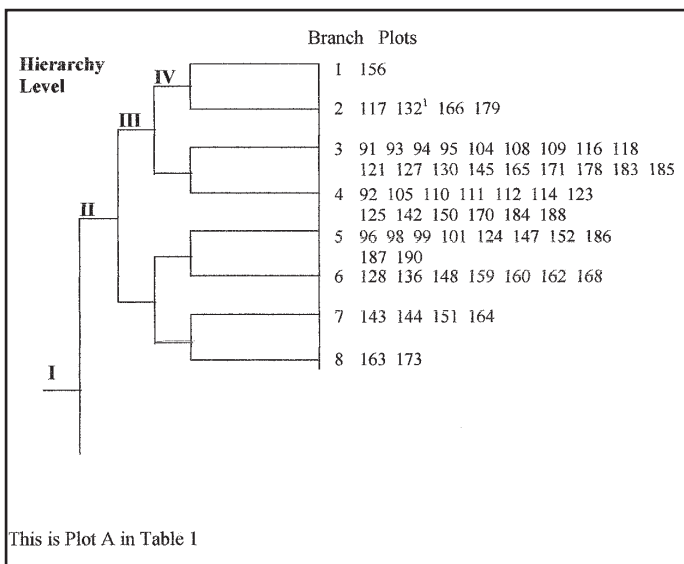
In TWINSpan the data are ordinated by reciprocal averaging (RA). RA is an eigen analysis, similar to principle component analysis (PCA). As with PCA the extracted eigenvalues in RA decrease so that the first axis maximises correlation between species and plots (Kershaw and Looney 1985).

TWINSpan uses RA to determine the major variation in the data, and uses this as a division into two sets or clusters. Those species which characterise the RA axis extremes are emphasised, polarising the plot data. The axis is divided by breaking the ordination axis near its centre. This keeps similar plots close to each other. The sample division is refined by a reclassification using species with maximum values to indicate the poles of the ordination axis. The division process is then repeated on the two separate samples. Hence, the initial sample cluster is subdivided into two, and then four clusters, and so on until each cluster has no more than a user defined minimum number of species, or the investigator is satisfied with the classes proposed. The resultant clusters of species become the new classification.

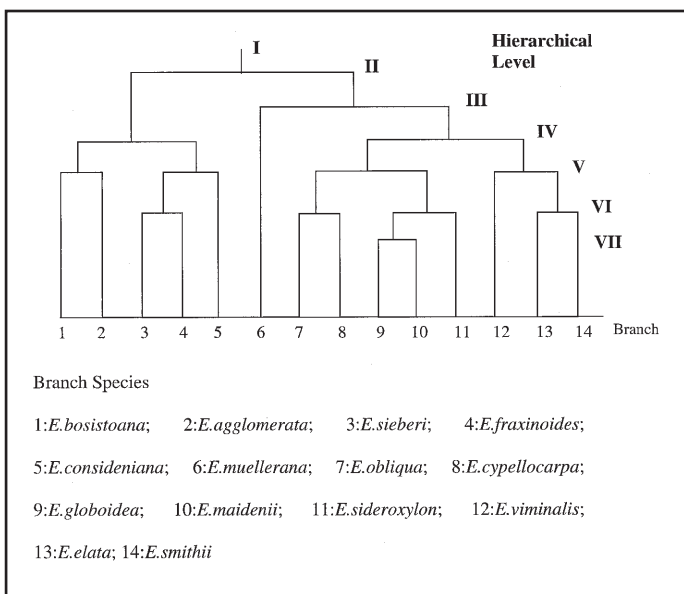
Interpretation of the end result requires a detailed knowledge of the ecology of the species (Kershaw and Looney 1985). The TWINSpan results may be displayed in the form of a dendrogram, which is a branching arrangement illustrating the relative similarity of plots or species.

TWINSpan was applied to Nullica State Forest data in the following manner. A table of species and plots was constructed using a sub-sample of 100 of the Delaney (1996) plots. Rare

**Figure 1.** Part of plot dendrogram grouping plots from like environments



**Figure 2.** Species dendrogram: similar species are joined at lower levels and dissimilar ones higher levels



species were discarded and TWINSpan was executed. A section of the plot (sample) dendrogram is shown in Figure 1 and the species dendrogram is shown in Figure 2.

In the sample dendrogram (Figure 1) plots from like environments have been grouped together. For example, branch four contains plots found on a dry, northerly aspect on ridge tops. In the species dendrogram (Figure 2) similar species are joined lower in the branches and dissimilar ones are joined higher. In the full species dendrogram, each species is

represented as a unique branch. Groups are defined by hierarchical level and branch number, such as hierarchical level V, branches 3, 4 and 5 (Figure 2). These classes are *E.sieberi*, *E.fraxinoides* and *E.consideniana*. Visually we can tell that *E.sieberi* and *E.fraxinoides* plots are very similar, and they are both similar, although to a lesser extent, to *E.consideniana* plots. Plot A (Table 1) is a representative of the *E.consideniana* type (hierarchy level V, branch 5) and Plot B (Table 1) is an example of the *E.muellerana* type (hierarchy level III, branch 6).

TWINSpan is viable and efficient (C2) in classifying species or plots, or both. The analysis is rapid, providing numerical sufficiency for the ecologist to organise and analyse large data sets.

As described in the methods, TWINSpan is able to classify vegetation at a range of scales of resolution (C6) represented by hierarchy levels in the dendrogram.

Many of the criteria suggested as being useful for a successful forest classification are close to being satisfied by the TWINSpan classification. TWINSpan is relatively easy to implement (C1). However, the preparation and interpretation of the data set requires knowledge of the location and species relationships.

The basis for TWINSpan classification is primarily floristic, with a structural element remnant from the Braun-Blanquet theory (C3). It is possible to include a structural element in the selection of species, such as restricting input to trees over 10 metres in height.

TWINSpan can be updated rapidly (C4), as it is an automated program. This means that new data can be used to update or reclassify with ease, once the data has been encoded into a digital format.

Complementary studies (C5) may be undertaken with only a slight modification of TWINSpan. For example, combining the plot dendrogram and the species dendrogram allows an ecological interpretation of the data. The method could also be used to classify fauna and understorey species as well as Eucalyptus vegetation.

The program represents a technological aid and this can be interfaced with other software, such as GIS, to show the spatial extents of the classes (C9).

The output from TWINSpan may be wholly or partially reproducible (C11). For example, defining what constitutes a rare species or applying strict stopping rules for a particular study and site can remove limitations to reproducibility.

As with the Braun-Blanquet method, TWINSpan would require more extensive alteration, or the acceptance of further generalised assumptions, to provide a measure of factors such as potential yield (C4a).

Illustrating the output of TWINSpan as a continuum of vegetation change (C7) is, like the Braun-Blanquet method, difficult although the dendrogram implies a relationship between classes.

Pre-classified data (C8) has little potential to contribute to the classification method unless it could be used to lower the need for field data collection.

Currently the nomenclature (C10) needs to be developed by the user and requires an extensive knowledge of the locality (for a plot dendrogram) or the ecology (for the species dendrogram).

**Association analysis classification**

A rarer quantitative or statistical method of vegetation classification is an extension of association analysis. This method, developed by Williams and Lambert, is detailed in Gauch (1986). This is monothetically divisive (sequentially dividing the data based one variable) and offers an interesting comparison with the Braun-Blanquet and TWINSPLAN methods.

The initial step in association analysis, as outlined in Ludwig and Reynolds (1988), is determining the first divisive species. This is the one which has the maximum ability to differentiate between the species. To calculate this differential ability two by two contingency tables are constructed and chi-square values are calculated. These are in the format shown in Table 4. Each species undergoes this chi-square analysis with every other species. Once the analyses have been completed the chi-square values are summed for each species (discarding insignificant

**Table 4.** An example contingency table

	Sites with species 1	Sites without species 1	Total
Sites with species 2	49	15	64
Sites without species 2	11	78	89
Total	60	93	153

results, chi-square values less than 3.84 and tables with very low cell counts). The largest value (summation of chi-square values) is the first divisive species.

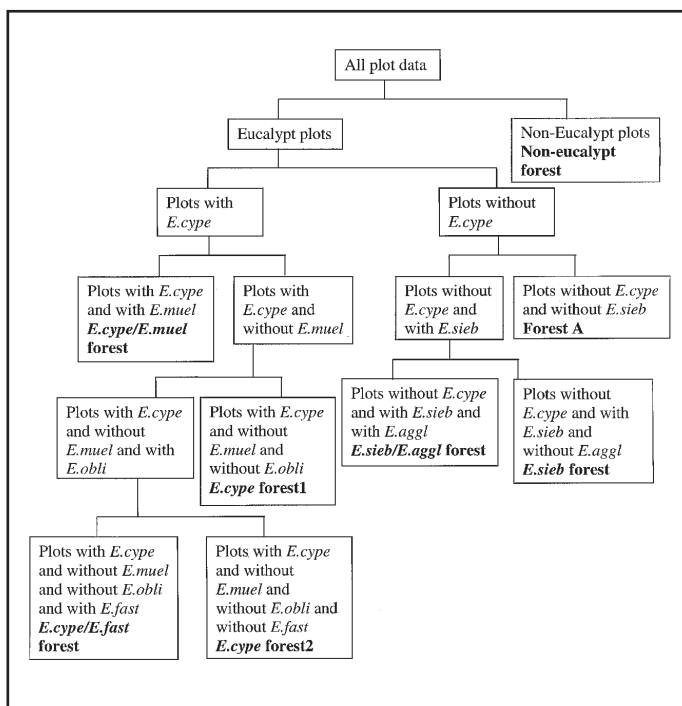
The data is then split into two data sets - one in which all plots have the divisive species and the other in which this species is absent. This procedure is repeated for each of the two data sets independently and the second level divisive species are used to split the data into two resulting in four data sets. This continues until none of the contingency tables have a significant chi-square or until some user defined threshold is met. Ludwig and Reynolds (1988) suggest some appropriate stopping rules. The result is displayed in a decision tree type format.

A large subset, 190 plots, of the Delaney (1996) plots was used for this analysis. Initially, a division was made based on presence/absence of *Eucalyptus* in the plot. The first divisive species was *E.cypellocarpa*, with *E.muellerana*, *E.sieberi*, *E.obliqua*, *E.agglomerata* and *E.fastigata* being recognised as further divisive species. The resultant diagram is shown in Figure 3. Plots A and B (Table 1) were both classified as Forest A (no *E.cype*, no *E.sieb*).

None of the 11 criteria of a successful forest vegetation classification are met by this method in its original form.

Stopping the classification with varying stop rules may allow for different scales of classification (C6). The number of sub-branches in the flow chart may offer an indication of the complexity of the forest, however rare species are often overlooked and discounted as insignificant, perhaps over-simplifying the output for some purposes. However, the

**Figure 3.** Association analysis classification decision tree



setting of standard stop rules would make the process repeatable (C11).

More intensive alteration of the classification method would be required to achieve the following criteria.

If association analysis were to be presented as a computer-based program with a user-friendly interface, practical application more would be more achievable (C1, C2). Association analysis could be implemented within a GIS software package (C9), allowing the results to be displayed spatially. Without this automation it is a demanding and time consuming classification technique, particularly when species diversity is high.

The ability to update or reclassify using new data (C4) is limited, requiring re-calculation of all chi-square values. The ability to adapt to other ecological studies is also questionable (C5).

The nomenclature (C10) is confusing and limiting, not the least as some classifications are based on the absence of some species (such as Forest A, no *E.cype*, no *E.sieb*, in Figure 3).

As association analysis does not balance a structural and floristic element (C3), yields (C4a) would need to be interpolated using estimates of species values (although this is impossible where a classification is based on absence of a species).

The method does not allow a continuum of vegetation to be described (C7) and there is little scope for including pre-classified data (C8).

**FAO/UNEP forest classification**

The United Nations Food and Agriculture Organisation/United Nations Environmental Program (FAO/UNEP) method is described briefly by Brown *et al.* (1989). It is a simple classification used internationally for classifying natural woody vegetation based upon the following factors: composition;

density; degree of alteration by agriculture; production capacity; management status; physical accessibility; and logging history.

The FAO/UNEP natural woody vegetation classification is designed to be simple and pragmatic. A forest, or a portion thereof, is assessed using a flow chart (see Brown *et al.* 1989 for a copy of this chart). Choosing the flow chart branch to follow involves assessing the forest in terms of the factors listed above. The factors used for this assessment are site specific and their definition can vary somewhat from country to country or even site to site.

Each forest class is described by seven levels of code letters and numbers which relate to the seven levels of the flow chart hierarchy. The first letter distinguishes between trees (**N**) and shrubs (**n**). The second letter distinguishes between broadleaved (**H**) and coniferous forest (**S**). The third letter refers to broadleaved forest only and distinguishes between closed (**C**), bamboo (**B**) and mixed forest/grassland (**c/O**). The fourth letter differentiates between broadleaved or coniferous forest unaltered by agriculture (**f**), fallow forest/grassland or coniferous forest (**a**) and no letter is given if forest is broadleaved fallow forest or unfallowed forest/grassland. The fifth part of the code is a number, **1** if the forest is productive and **2** if the forest is unproductive. The sixth level highlights the need for management, nil (**u**) or intense management required (**m**), and identifies reasons for being unproductive, either physical (**i**) or legal (**r**). The seventh level of the code refers to absence (**v**) or presence (**c**) of past logging activity.

Two plots have been classified using this method and the coding scheme. These plots, Plots A and B (as described in Table 1) are both **NHCf1uv**, that is a productive closed broadleaved forest unaltered by agriculture and as yet unaffected by logging.

This method is quick and easy to implement when the required data are available (**C2**).

With slight modification the scheme could be user-driven (**C1**). Currently the users of such a flow chart would need to be well informed in a number of backgrounds (history of the site, forestry practices and economics, for example) in order to make the correct decisions.

The required floristic and structural basis is alluded to through terms such as closed broadleaved forest (**C3**). These are not specific enough to be of ecological value. The classification, however, makes no claim to be ecologically sound and is purely driven by the need to select land for logging.

The classification can integrate new and old data easily (**C4**). For example, should research suggest new logging methods, which involve minimum management for sites which previously required intensive management, the classification could be updated quickly and easily.

The level of resolution can be altered from local to international scales without altering the actual classification method, although each classification process only allows one level of resolution (**C6**).

Pre-classified data, such as a land-use GIS theme, can become a fundamental component of the classification (**C8**). Technology can therefore be incorporated easily, for example, GIS and imagery could be used to map the extent of agricultural

activities or the code altered based on the impact of logging activity (**C9**).

The nomenclature is reminiscent of the Specht method. This is relatively easy to interpret, without the need for complicated description and certainly adequate for the intended purpose of the scheme although limited for the case at hand (**C10**).

Criteria not currently satisfied by the FAO/UNEP include the adaptability to other studies (**C5**), such as faunal studies, the ability to access or model yield (**C4a**) and the representation of the complexity of the environment or vegetation. The subjective decision making and flexible definitions reduce reproducibility (**C11**). Deciding whether a forest will need minimal or intensive management is such an example. This method does not allow a continuum of vegetation to be realised (**C7**).

This method relates to an early stage in classifying usually disturbed vegetation in underdeveloped countries and does not have a great deal of relevance to modern Australia.

### Baur's Forest Types

Forest Types are floristically oriented classifications with a bias towards commercially valuable tree species. This definition was proposed by Baur in 1965 and updated in 1989. Baur's classification has been used in a number of states and territories of Australia (Bureau of Rural Resources 1990) for both forestry and conservation based studies.

A Forest Type represents a group of tree species exhibiting a homogenous and repeatable pattern. Sites of one type are expected to require the same management and respond similarly to treatment, such as logging. The behaviour of a Forest Type can be used in recognition of land utilisation potential. The Forest Type also provides a hierarchy of community descriptions in state level policy determination for conservation and management.

Baur's Forest Type classification describes vegetation in terms of floristic composition, structure and habitat. In a Forest Type the vegetation community is not necessarily a climax community and, as such, may be more valuable than an association (Baur 1989). Each type has a unique reference number and name. The Forest Types are named based on the occurrence of one or more indicator species, which are the dominant plot species.

Types can be agglomerated into leagues (equated with alliances) and leagues classified into groups (Johnston and Lacey 1984). The three main groups are:

- communities with rainforest structure;
- the sclerophyll forest and woodland communities typically *Eucalyptus* dominated; and
- other types which are artificial or lack a domination of trees (e.g. scrub).

The second edition of Baur's classification (Baur 1989) defined 192 types for New South Wales. These include 24 in the rainforest group, 151 in the Eucalypt group and 17 non-forest types.

Sub-types, or site specific variants of a type, can be indicated by the use of a letter (e.g. 'a'); where two types occur within a plot both numbers can be given, separated by a slash (e.g. 112/114).

In the extensive key, subordinate or associated species for each type are given along with notes concerning the main environmental features which play a role in determining the characteristic of the type. An example location is also given, allowing investigators to visit a site and see the characteristics described in the key. Data used in the classification include all trees, or erect woody plants with a single stem at ground level and exceeding 7.5 m in height.

The classification (using Baur 1989) of Plots A and B of Nullica State Forest (Table 1) is given in Table 5.

**Table 5.** Forest Type classification

	Plot A	Plot B
Group	Eucalypt and related	Eucalypt and related
League	Scribbly gum-stringybark-silvertop ash/messmate-brown barrel	Messmate-brown barrel
Forest Type name	Yertchuk/yellow stringybark	Yellow stringybark
Forest Type number	102/169	169
Dominant species	Yertchuk/ yellow stringybark	Yellow stringybark
Associated species	Roughbarked apple, stringybarks, narrowleaved peppermint, grey box, scribbly gum, messmate, red bloodwood, silvertop ash, brown barrel and gums	Silvertop ash, messmate, brown barrel, coastal grey box, stringybarks and gums
Preferred environment	Dry ridges or exposed slopes/dry ridges or moist coastal slopes	Dry ridges or moist coastal slopes
Example location	Bodalla State Forest/Nullica State Forest	Nullica State Forest

As this simplistic classification was developed for forestry it is understandable that it satisfies many of the criteria set out above. The scheme meets the needs of the client in an user driven and efficient manner (minimal data collection) (C1, C2). The resolution is able to be adapted to a national scale (groups), a regional level (leagues or types) or a local level (types) (C6).

Criteria partially met include the need to balance structural and floristic information (C3). Forest Types are classified using only the dominant species (over 7.5 m in height) hence a small structural consideration. The classification is, nonetheless, largely floristic.

New data can be integrated in the classification scheme. However, this provides a new classification rather than altering or updating a dated classification (as with other methods, such as the Specht method) (C4). One of the main disadvantages of the Forest Type classification is that a type is not necessarily a

climax community and changes in types may occur within a few years. This may not be problematic for some purposes. However, discarding all trees under 7.5 metres in height results in a loss of information on future Forest Types.

Specific qualities important to forestry, such as yield or character of the Forest Type can be inferred using the literature descriptions of the quality of each species as a logging product (C4a).

Forest Types can be adapted to incorporate fauna or understorey studies (C5). Relationships can be implied from the species present in a forest type and the detailed key. The key does often describe the density (and sometimes species) of understorey typically associated with a Forest Type. Forest Types are not intended as an ecological classification, rather as an aid for forestry management. Nonetheless, there is an ecological element in the classification scheme highlighting relationships between species and between vegetation and the environment. There are also statements regarding habitat potential and value in the key.

The ability to view the vegetation classification as a continuum of change is perhaps easiest in this classification (C7). The ability to define more than one Forest Type per plot can help to identify ecotones and areas where Forest Types are undergoing transition. For example, a silvertop ash forest type may change into a silvertop ash-stringybark type and then into a stringybark type.

Air photo interpretation, or the use of other remotely sensed imagery, has the potential to limit the amount of fieldwork required in collecting plot data prior to the classification process (C8). As such, it is possible to link this classification with a number of technologies including GIS (data such as topographic position) to improve the classification process (C9).

Nomenclature, consisting of names and numbers, provides an easy reference system (C10). Use of common names may be viewed as user friendly, but can be confusing where the same or similar common names are applied to the different species. For example grey gum may refer to *E.propinqua* or *E.punctata* (Boland *et al.* 1992).

A potential disadvantage of the Forest Type classification is its lack of a quantitative basis. Such a basis can be devised (see SIFT, described in Delaney 1996) and used effectively for one study region, making the classification repeatable (C11).

### Selecting the preferred method for forest classification

The methods of vegetation classification addressed in this paper are compared in Table 6. The table is based on the eleven criteria for a successful forest classification described earlier in the paper. The table is an attempt to describe the best method for a particular project. At any stage it could need updating as, perhaps, automated software tools or new remotely sensed imagery become available.

Most of the classification methods are able to be user driven and appear to be practical and viable tools, or else these features could be achieved with minor alteration to the method. The exceptions are the complex Johnston and Lacey and Braun-Blanquet classifications.

**Table 6.** Classification scheme comparison table

Essential qualities of a forest classification scheme	Specht	Johnston and Lacey	Braun-Blanquet	TWIN-SPAN	Association Analysis	FAO/UNEP	Forest Types
(1) User driven	1	3	3	2	3	2	1
(2) Viable/practical	1	3	3	1	3	1	1
(3) Structural/floristic basis	3	2	1	2	4	2	2
(4) Integration of studies	2	2	3	2	3	2	2
(4a) Yield assessment	3	3	3	3	4	3	2
(5) Adaptable to fauna, heritage/other studies	2	2	2	2	3	3	2
(6) Range of scales of resolution	1	1	1	1	2	2	1
(7) Able to illustrate vegetational continuums	4	4	3	3	4	4	2
(8) Ability to incorporate pre-classified data	2	3	2	3	4	2	2
(9) Technology compatible (e.g. GIS)	2	2	2	2	3	2	1
(10) Appropriate nomenclature	2	3	2	3	3	2	2
(11) Repeatable	2	2	3	2	2	3	3
Score (Rank)	25 (2)	30 (6)	28 (4)	26 (3)	37 (7)	28 (4)	20 (1)

Score: 1 satisfies criteria  
 2 requires slight modification  
 3 requires large modification or has inappropriate assumptions  
 4 does not satisfy criteria

The Braun-Blanquet classification is the only technique with a balanced structural and floristic basis, although this is achievable through minor or major alterations to most other methods.

None of the methods is successful in providing means to easily integrate vegetation data collected in a temporal series. This facility can be made available through alteration to all schemes, although most problematic for the Braun-Blanquet and Association Analysis schemes.

All methods perform poorly in providing a yield assessment as they were not designed for this purpose. The Forest Type is the preferable scheme in this respect as it requires only slight modification to approach a realistic estimate of yield.

Most classification methods can be altered to help support other natural resource studies, such as fauna studies, however the Association Analysis and FAO/UNEP require greatest modification.

All methods satisfy the need for a range of resolutions, although the Association Analysis and FAO/UNEP methods do require some minor alteration.

All classification techniques are limited in the ability to illustrate a continuum of vegetation, although the Forest Type classification can achieve this to some degree.

The ability to use pre-classified data to aid in the classification process ranges from potentially integral (FAO/UNEP) through to very difficult (Association Analysis).

All techniques are able to gain advantage through the use of a technologically rich component, be it remote sensing or computer automation.

None of the classification techniques offers an ideal nomenclature although those offered by Specht, Braun-Blanquet, FAO/UNEP and Forest Types are superior.

All classification techniques require modification in order to be repeatable. The role of the subjective expert is a common component.

It is important to note how the volume of data available for classification can affect the choice of a scheme. Some schemes work well with limited data sets, such as the Johnston and Lacey method, whereas others, such as TWINSPAN, require large data sets in order to construct a sensible scheme.

Where all factors in the matrix are equally weighted the Forest Type method is the preferred form of vegetation classification. However, the values assigned to each criteria may need to be re-evaluated and perhaps weighted for a specific project. For example, if the project is a forestry resource study to be conducted where GIS and remote sensing are not available, the technology concerns may be less important than finding a practical, user-driver technique.

This matrix is therefore suggested as a starting point in determining the best method for vegetation classification in a forestry based study.

## Conclusion

A review of a select number of vegetation classification methods suggests that the Forest Type is a useful method for forest planning and management. Other methods have advantages over Forest Typing where, for example, a better structural/floristic balance is required. A matrix method for determining the best classification technique for a forestry project is suggested. Alterations to the matrix can be made to tailor the table to a specific study.

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