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A FLORISTIC SURVEY OF KU-RING-GAI CHASE NATIONAL PARK

R. OUTHRED, R. LAINSON, R. LAMB* & D. OUTHRED

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ABSTRACT

Outhred, R., Lainson, R., Lamb, R. & Outhred, D. (School of Life Sciences, New South Wales Institute of Technology, Westbourne Street, Gore Hill, New South Wales, Australia 2065) 1985. A floristic survey of Ku-ring-gai Chase National Park. Cunninghamia 1(3), 313–338. A floristic classification scheme for the vegetation of Ku-ring-gai Chase National Park, New South Wales, is presented and a field key to the scheme is described. The relationship to earlier structural/floristic classification schemes is discussed. Some of the physiographic and edaphic factors underlying the floristic variations are documented. A semi-quantitative technique for collecting floristic survey data is evaluated. It appears to have some advantages when compared with conventional presence/absence recording.

INTRODUCTION

Ku-ring-gai Chase National Park is situated on the northern outskirts of Sydney, New South Wales. It is 146 km^2 in area and consists mainly of a dissected sandstone plateau bordering Broken Bay. The vegetation ranges from heath through to closed forest with rainforest elements.

There appear to be few published data relating specifically to the plant ecology of Ku-ring-gai Chase. Pidgeon (1937, 1938, 1940, 1941) made a general study of the plant ecology of the central coast of New South Wales. Beadle (1954, 1962) considered the influence of soil phosphate in determining the distribution of coastal plant communities.

Specht, Roe & Boughton (1974) surveyed the conservation status of plant communities in Australia and Papua New Guinea. They listed nine major communities for Ku-ring-gai Chase National Park, ranging, in their nomenclature, from open-forest through to low open-forest, open-scrub, open-heath, grassland/herbland and open-grassland; however, the floristic composition of those communities was not described in detail.

Buchanan (1980) has studied the freshwater swamps that occur on the West Head Peninsula and has identified areas of podzol soils within the Park.

The aims of the present project were to produce a floristically-based classification scheme for the Park's vegetation, to generate a field key to that classification scheme and to relate the floristic variations to factors such as the structural form of the vegetation and environmental parameters. It was intended that the classification scheme would summarize the range of vegetation currently present in the Park and provide a framework for future field studies. It followed that the range of vegetation sampled should be as broad as practicable and that a floristic key to the vegetation types should be developed so that unsampled areas could in the future be identified in terms of the classification scheme.

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METHODS

Selection of sampling and analysis procedures

It was necessary to select sampling and analysis techniques that were appropriate to the above aims. Considerable literature exists on the acquisition and analysis of vegetation survey data. Clifford & Stephenson (1975) reviewed progress to that time. Many authors have attempted to assess particular techniques. Williams *et al.* (1973) investigated a variety of sampling and analytical procedures with reference to rainforest vegetation. Smartt, Meacock & Lambert (1974, 1976) applied various sampling procedures to heath and grassland.

One common theme to emerge from these and other studies is that the analysis technique should be asymmetric: two sites should not be considered similar because a particular species is absent from both. As might be expected, polythetic classification techniques have been found to be superior to monothetic ones, producing fewer obvious misclassifications. Smartt *et al.* (1974) note that divisive techniques are theoretically more efficient than agglomerative ones as far as the important upper levels of a hierarchy are concerned, although this superiority has yet to be conclusively demonstrated in practice. Lambert *et al.* (1973) reported good results from their polythetic divisive algorithms AXO and MONIT, while our own limited experience has been that indicator species analysis (ISA) described by Hill, Bunce & Shaw (1975) performs at least as well on field data as flexible sorting (Lance & Williams, 1967), one of the more commonly used agglomerative techniques.

Indicator species analysis was selected for the present application. ISA is a polythetic divisive technique that sorts the quadrats into a dichotomous hierarchy. ISA is insensitive to species richness; a quadrat is evaluated according to the average affinities of the species that it contains, irrespective of their total number. In the course of the classification procedure ISA produces a polythetic key to the hierarchy in terms of indicator species. Moreover, ISA orders both quadrats and species before each division, facilitating the subsequent production by the computer of diagonalized association tables.

There appears to be a general consensus that in order to produce a phytosociological classification, the sampling and analysis procedures should avoid situations where a few species dominate the data from a site. Smartt *et al.* (1976) and Strahler (1978) found little benefit in departing from simple presence/absence data. On the other hand, Williams *et al.* (1973) concluded that quantitative data yielded a superior classification of rainforest vegetation provided that the analysis techniques prevented very abundant species from exerting a dominating influence.

For the present project we decided to test a variant of the traditional presence/absence sampling procedure. Under the procedure adopted, a large quadrat is subdivided into concentric subquadrats. Species are recorded from the central subquadrat and then additional lists are made of new species appearing in each of the succeeding subquadrats.

The use of the concentric subquadrats follows a suggestion by Bunce & Shaw (1973). The procedure promotes a systematic search of the quadrat and allows considerable flexibility in comparisons with other surveys based on different sized quadrats. It is as economical of survey effort as the normal presence/absence recording procedure and is thus much more economical than any of the traditional quantitative approaches. However, it has the theoretical advantage over the presence/absence method that in an area of homogeneous vegetation, species that occur in the inner subquadrats are likely to be those that are most abundant in the area. That is, the method can be semi-quantitative; some information relating to abundance is retained. On the other hand, if the quadrat is sited on an ecological gradient, then the centrally occurring species will best typify one particular point on the gradient. In either case there may be an advantage in according the inner-subquadrat occurrences higher weight in the subsequent analysis. In order to test whether the postulated advantage would be realized in practice, analyses of the data were performed with and without extra weighting for inner-subquadrant occurrences.

Data acquisition

At each site to be sampled, a square 1000 m² quadrat was delineated by means of four corner pegs connected by diagonal cords to a central peg. Markers on the cords divided the total quadrat into eight square concentric subquadrats of cumulative area 5, 10, 20, 50, 100, 200, 500 and 1000 m² (Figure 1). These subquadrats will be designated by the numbers 1 (central) to 8 (outermost). Species occurrences were recorded progressively, commencing with subquadrat 1 and noting for each species the subquadrat in which it was first encountered.

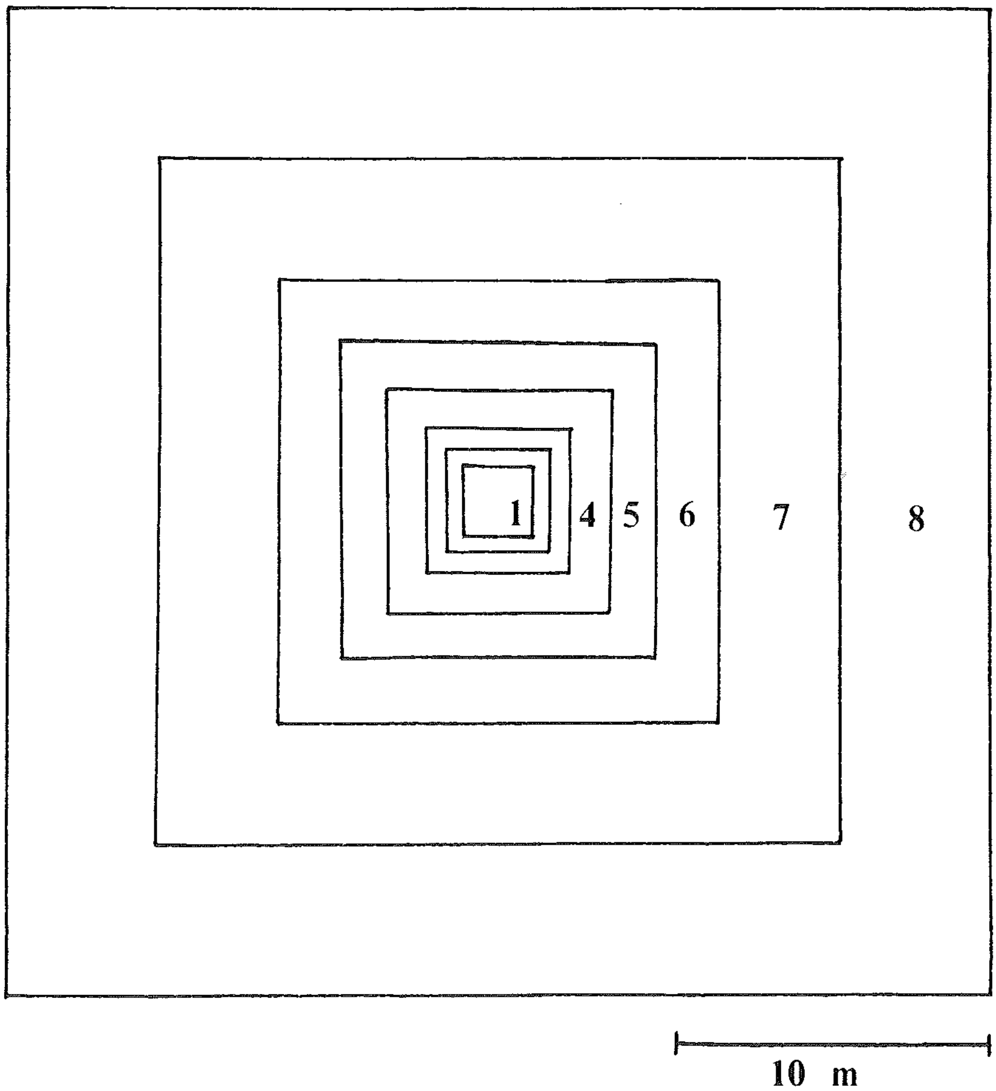

Figure 1. Division of quadrat into eight subquadrats.

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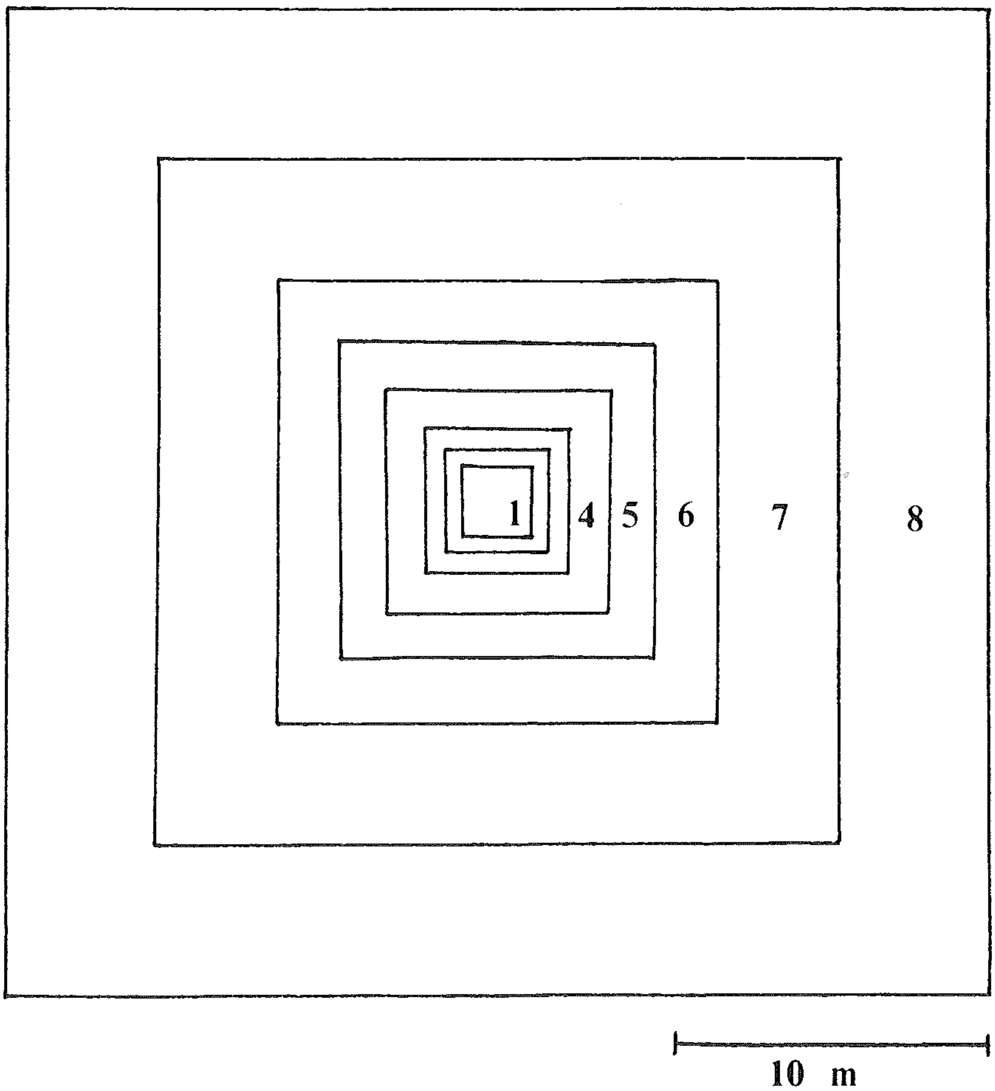


Figure 1. Division of quadrat into eight subquadrats.

The quadrats were considerably larger than the 200 m² ones used by Bunce & Shaw (1973) in European grassland and woodland. In the absence of any firm evidence as to what would be an adequate quadrat size in this situation, we elected to use as large an area as practicable to ensure that sufficient information was collected from each site. The adoption of the nested-subquadrat system meant that smaller quadrats could be used if desired in any supplementary surveys. It also enabled the effective quadrat size to be varied in the analysis.

The floristic data set encompassed all classes of tracheophytes. Normally, plants were differentiated to species level. The few exceptions concerned species that were difficult to distinguish reliably on vegetative characters. Where we were not certain of having correctly resolved such species in every quadrat, they were aggregated for the purpose of the indicator species analysis or, in the case of a few infrequently encountered Cyperaceae, excluded from it.

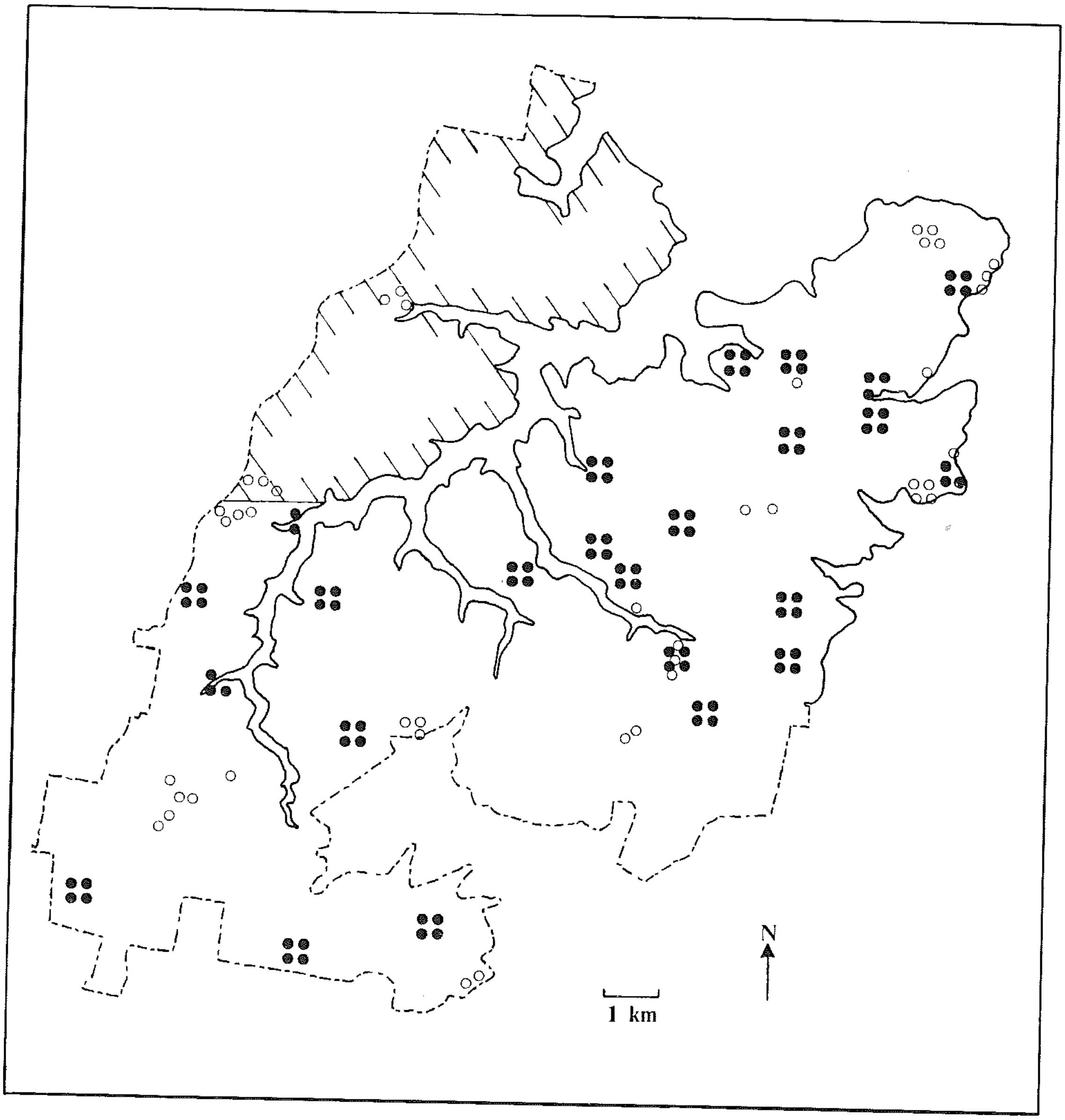


Figure 2. Locations of the sampling sites within Ku-ring-gai Chase (filled circles denote set 1 sites, open circles set 2 sites; the shaded zone in the north-west of the Park was excluded from survey in set 1).

Authorities for names of angiosperms used in this paper are listed by Jacobs & Pickard (1981). Fern names are as used by Beadle, Evans & Carolin (1972).

Estimates were made at each site of several structural features — tree height and cover, shrub cover and herb cover. All cover estimates were subjective. Some features of the physical environment were noted — altitude, slope, aspect and percentage rock outcropping. The type of rock was recorded.

Two sets of sites were surveyed. The first set comprised 91 sites, positioned randomly on a grid. The second set of 43 sites was designed to obtain additional samples from areas of limited extent possessing special environmental features. It included four sites on dolerite, five on Wianamatta Shale at Duffys Forest and Terrey Hills, five on or near podzolized soils, 13 along stream margins and 10 adjacent to salt water. The overall distribution (Figure 2) was designed to sample as broad a range of vegetation as practicable while also acquiring data on the abundance of species and vegetation types.

Sites in the first set were located in groups of four at the apices of 300 m squares centred in randomly selected 0.5 km squares of a cartographic grid (Figure 3). Sites that would have fallen below the high tide mark or outside the Park were excluded. Each group of four sites could be visited in one day but the members of the group were sufficiently separated to sample a range of habitats. An area of 27 km^2 north of Berowra and west of Cowan Creek (Figure 2) was excluded from sampling in set 1 because of access difficulties. However, six sites in set 2 were located in that area.

For both sets of sites, the final locations of the quadrats on the ground were either predetermined or randomized. Care was taken **not** to deliberately select supposedly representative stands.

Analysis

A program to perform ISA was written in FORTRAN for an ICL 1904 computer. Analysis to 32 groups required 30 to 60 minutes of processor time. The program was designed primarily for presence/absence data, but occurrences could, when necessary, be weighted by repetition. A companion program generated association tables for species against quadrat groups.

Other programs were written to summarize statistically the structural and environmental data for the quadrat groupings produced by the classification procedure and to list descriptive summaries of nominated groups of quadrats from a master file of such descriptions.

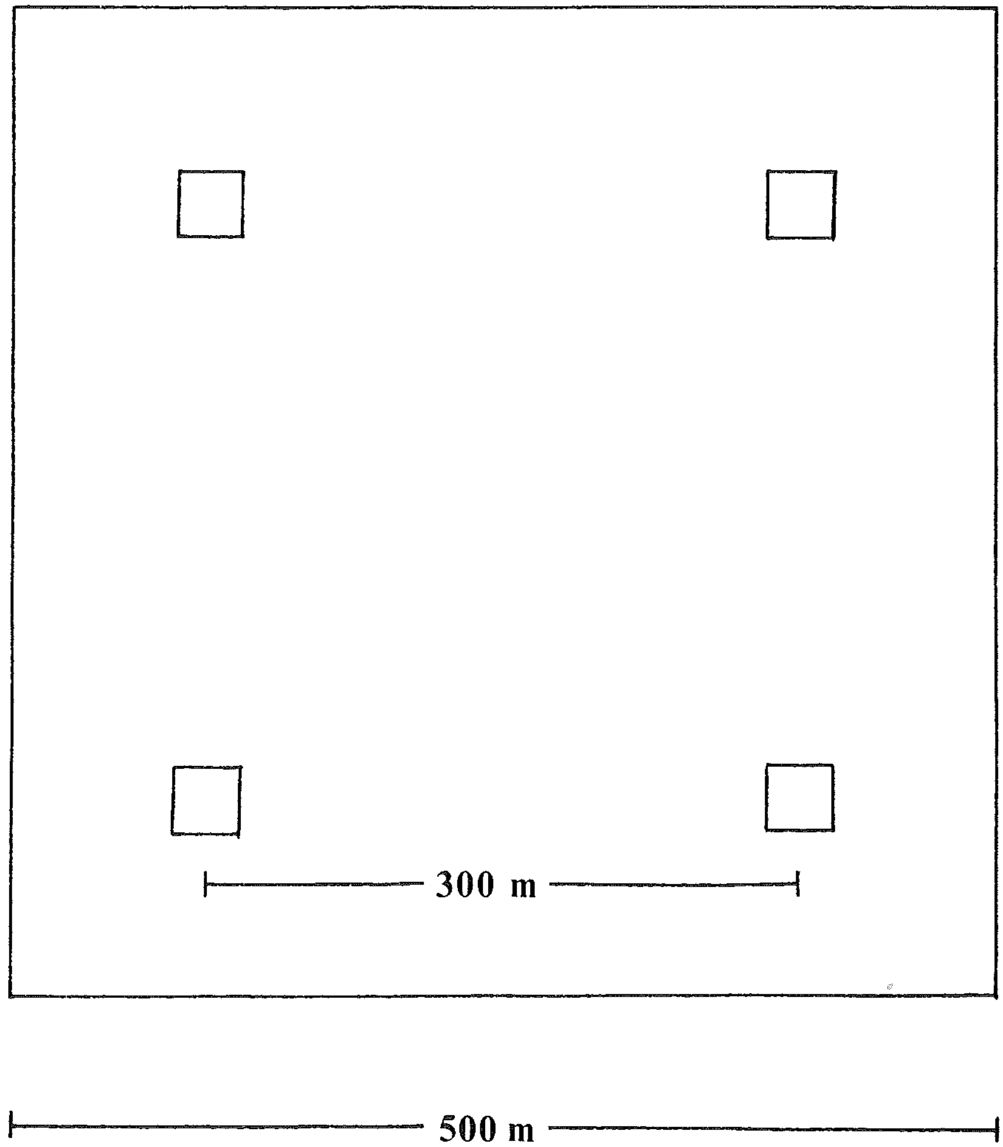
Four classifications of the floristic data were performed to investigate the benefits of including data from the outer subquadrats and according higher weights in the analysis to species occurring in central subquadrats. The essential parameters of the analyses are shown in Table 1.

TABLE 1

Parameter settings for the four ISA classifications

Analysis no.	Effective quadrat size (m^2)	Subquadrat weights	Rarity threshold
1	50	equal	20
2	1000	equal	20
3	1000	4:4:3:3:2:2:1:1	40
4	1000	4:4:3:3:2:2:1:1	80

Figure 3. Position of set 1 quadrats within an 0.5 km grid square.



Analysis 1 was confined to occurrences in the inner four subquadrats; effectively the analysis was based on equally weighted presences in 50 m^2 quadrats. Analysis 2 assigned equal weight to all occurrences in the entire 1000 m^2 quadrats. In the third and fourth analyses, subquadrats 1 to 8 were weighted in the ratio 4:4:3:3:2:2:1:1.

ISA has one adjustable parameter, the threshold of rarity (Hill *et al.,* 1975). Its effect is roughly analogous to that of β in the flexible-sorting strategy of Lance & Williams (1967). A high rarity threshold, like a negative β, causes groups to be more evenly sized. A traditional value for presence/absence data is 20 per cent of the number of quadrats. This value was adopted for analyses 1 and 2. To achieve a comparable effect with multi-level data, a higher value must be used. The threshold was therefore increased to 40 per cent for analysis number 3. To check whether the necessarily somewhat arbitrary value of the rarity threshold was critical, a fourth analysis was performed using an 80 per cent threshold.

RESULTS AND DISCUSSION

Evaluation of subquadrat weighting schemes

The classification schemes produced by the four analyses of the data set were first compared by examining how they had dealt with three special groups of sites. The outcropping rock in the Park is predominantly sandstone of the Hawkesbury Series. However, five sites from set 2 were located on the overlying Wianamatta shales in the south of the Park, near Duffys Forest and Terrey Hills, and four other sites were on eroded dolerite near West Head. These provided two edaphically distinct groups. The third special group of sites sampled stream margins in the deep valleys, a physiographically distinct habitat.

There is no reason why these groups **must** be floristically distinct from other surveyed sites and, if they are not, then not even a "perfect" analysis technique would isolate them, but if one technique did succeed in isolating them while another did not, it would seem reasonable to consider the former technique superior.

Analysis 1, based on data from a 50 m^2 quadrat, did not isolate any of the groups. Increasing the quadrat to 1000 m^2, as in analysis 2, enabled the Wianamatta Shale and dolerite sites to be extracted successfully. Finally, analyses 3 and 4, which used information from the entire 1000 m^2 but accentuated the inner subquadrat occurrences, isolated stream margins as well.

We conclude from these results that presence/absence data from a single 50 m^2 quadrat does not adequately characterize the types of vegetation sampled here. Increasing the quadrat area to 1000 m^2 produces a useful increase in information but the additional data can be distracting when dealing with situations such as stream margins where the quadrat is located in a pronounced environmental gradient. This can be corrected by increasing the weight accorded to the inner-subquadrat data. The data from the outer subquadrats then provide a floristic context without confusing the local ecological picture defined by the inner subquadrats. That there is value in recording the context is evidenced by the superiority of analyses 3 and 4 over analysis 1 in dealing with stream margins.

There are other regions within the Park that have reasonably distinct vegetation without, however, being associated with such clearly defined physical and edaphic features as were the three discussed above. Three of the most obvious are: areas of wet heath usually associated with impeded drainage on hillsides; dry *Casuarina* forests on steep hillsides; and marginal rainforest at low altitudes with *Acmena smithii* and *Ceratopetalum apetalum* in the canopy. In fact, all of these areas were extracted by analyses 3 and 4 as floristically distinct units. Analyses 1 and 2 were less successful.

In general, the groupings produced by analyses 3 and 4 were more readily interpreted than those resulting from numbers 1 and 2, particularly number 1.

An alternative approach to evaluating the analyses is to consider the environmental and structural homogeneity of the groups they produce. It would seem reasonable to prefer the analysis that sorts the sites into groups whose members are most similar in terms of vegetation structure and environmental factors.

Analyses of variance were performed to assess the homogeneity of the site groups in terms of six environmental factors: altitude, aspect, slope, rock cover, east-west location and north-south location; and five structural factors: canopy height, tree diameter, tree cover, shrub cover and herb/fern cover. To permit intercomparisons, standardized conditions were necessary — for each classificatory analysis, the site groups considered were the 16 produced by four levels of dichotomous division. The ratio of the between-groups to within-groups variance was computed for each of the 11 factors, the computations being repeated for the four sets of site groups arising from the different classificatory analyses.

The resulting 44 variance ratios were all significantly greater than one (F-test, $p<0.01$); all four floristically-based analyses were significantly related to all the 11 non-floristic factors.

The strengths of the relationships were then examined. Paired-sample t-tests did not reveal any significant differences between the variance ratios derived from analyses 3 and 4, either when all 11 factors were considered together or when structural and environmental factors were considered separately. The figures for analyses 3 and 4 were therefore pooled in subsequent comparisons with analyses 1 and 2. Analyses 1 and 2 performed worse overall than did analyses 3 and 4 ($p<0.01$). Analysis 1 was inferior in its treatment of the environmental parameters and analysis 2 in its treatment of the structural parameters.

In summary, it was beneficial to use the large quadrats, provided that increased weight was given to species encountered near the centres of the quadrats.

The weights adopted (Table 1) were linearly related to the logarithm of the area (rounded to integer values). They were a necessarily arbitrary selection from the infinity of possible sets of weights and the question arises as to whether further benefits might have been gained by giving central occurrences even greater emphasis. The present data are not sufficiently extensive to allow this question to be answered reliably. However, one effect would have been to increase the importance of small but abundant plants. In the extreme, that would have been likely to adversely bias the classification.

It is likely that the above conclusions will prove to be applicable to other types of vegetation. A subjective assessment of unpublished analyses of two other data sets, one from subalpine forest and heath on the Boyd Plateau west of Sydney and the other from an upland moorland area in northern England, suggests that in both of those situations there was an advantage to be gained from emphasizing central occurrences or locally abundant species.

The plant ecology of Ku-ring-gai Chase

Altogether, 365 species were recorded from the 134 quadrats. The number of species per quadrat ranged from 22 to 136.

Analysis 3 was selected as the basis for the final classification scheme. The classification process was continued through five levels of dichotomous division, generating a dendrogram with 2^5 ultimate branches. The floristic, structural and environmental parameters of the sites in the 32 ultimate groups were critically examined and field testing of the classification scheme was performed. In several instances, little ecological meaning was discernible in the lowest dichotomies and/or the group populations were very small. In these areas the relevant sectors of the dendrogram were truncated above the final division. This left 23 groups that we considered distinguishable not only floristically but usually also on the basis of the vegetation structure and habitat requirements.

The above result is necessarily a compromise between the opposing risks of discarding worthwhile information or retaining meaningless distinctions. Arguably more or fewer than 23 groups could have been retained. Some of the distinctions preserved are based on few quadrats, albeit supported by subsequent field trials, and must be considered tentative.

An alternative strategy would have been to invoke a numerical stopping rule. However, many such rules exist and the selection of a particular one would perforce be no less subjective and arbitrary than the procedure actually adopted. They have not always been found entirely satisfactory in practice (Siddiqui, Carolin & Anderson, 1972) and have not traditionally been used with ISA.

For purposes of discussion we shall regard the 23 quadrat groups as samples from corresponding vegetation types. The properties of the 23 types are inferred from the observed properties of the groups. The groups' floristic properties are summarized in Table 2. Table 3 shows the affinities of the common tree species. The structural and physiographic properties are detailed in Table 4.

There are two widely used structural/floristic classification schemes for Australian vegetation (Specht *et al.*, 1974 and Carnahan, 1976). The present floristically derived classification scheme proved to be strongly correlated with structural variations. These correlations encouraged us to attempt to describe the upper divisions within the classification scheme in terms of their structural correlates, with the results shown in Table 5.

Our structural terminology is defined in Table 6. It is broadly consistent with that of Specht *et al.* (1974), but height and cover are more finely partitioned and we have elected to describe vegetation with light tree cover and dense shrub cover as belonging to the appropriate shrub class but with emergent trees.

The correlation between floristic and structural characters is not perfect. Therefore, our structural or environmental descriptors applied to a floristically derived classification scheme typify rather than define. The descriptors applied to the lower divisions in particular should be regarded as tentative.

We recognize five series of floristic types. Each series corresponds to a particular sector of the hierarchy. We denote the series as S (scrub/heath), L (low woodland or open forest), M (moderately low open forest), MT (medium or moderately tall sclerophyll forest) and R (marginal rainforest).

The five series represent gradations along the major trend in the data — from heath and scrub to closed forest. The S, L and M series are characterized by the presence of the tree *Eucalyptus gummifera* and a variety of shrubs such as *Leptospermum attenuatum, Platysace linearifolia* and *Xanthorrhoea media. Casuarina torulosa, Pteridium esculentum* and *Dianella caerulea* are often present at MT and R series sites.

FOOTNOTE TO TABLE 2

The symbols used to denote the quadrat groups are explained in the text. The species have been arranged in order of their scores on the first axis of a reciprocal averaging ordination. The quadrat groups have likewise been ordered according to the mean scores of their members on the same ordination, insofar as this has been possible without overlapping adjacent sectors of the classificatory dendrogram. The Table was compiled from mean occurrence-scores for the species in the quadrat groups. Occurrences were scored in the manner used in the classificatory analysis, viz: first encountered in the subquadrats 1 or 2: 4, 3 or 4: 3, 5 or 6: 2 and 7 or 8: 1. An entry of + + + indicates a mean occurrence-score of at least 3.5; that is, the species was nearly always encountered within subquadrats 1 and 2 in quadrats belonging to that group. The other symbols indicate the following ranges: + +: 3 to 3.5; +: 2 to 3; ■: 1 to 2. Lesser scores are blank. Species have been included only if they achieved a + + + score in at least one quadrat group.

TABLE 2

Abundance of species in quadrat groups

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acmena smithii																				+++	+++	+++	+
Ceratopetalum apetalum																				++	+++	+++	+++
Blechnum cartilagineum																			.	+++	++	++	.
Tristania laurina																				.		.	+++
Lomatia myricoides																				.		.	+++
Synoum glandulosum																		+++	++	++		.	.
Oplismenus aemulus																+	+++	.	+	++			.
Sticherus flabellatus																					+++		+
Eustrephus latifolius																.	+	++	+	+++	++		
Hibbertia dentata																	++	+++	+	+			
Pittosporum undulatum																				.	+++		
Pandorea pandorana																.	.	+++	.	+	.		
Glycine clandestina																	.	+++	+	.	.		
Acacia floribunda																		+++	.	.	.		
Clematis glycinoides																		+++					
Macrozamia communis																		+++					
Casuarina torulosa														.		+	+++	.	+	+	.	.	+
Culcita dubia														.	.	.	.	.	+++	+++	+	+	.
Astrotricha floccosa																+		+		+++	.		
Themeda australis										+						.	+++	+		.			
Lomandra longifolia								.			.	.	.	+	++	+	+++		+++	+++	+++	.	.
Dianella caerulea							.	.	+	.	.		+	++	++	+++	+	+	+	.	+++	+	+
Pteridium esculentum								.	.	++	+	++	+	++	++	+++	+++	+++	++	+++			
Entolasia stricta		.				.	+	+	+++	+		++	.	++	+	+++	.	++		+	+		.
Lepidosperma laterale	.	+	+	+++	.	+	.	.	++		+	+		++	+	+	+	.		.			
Caustis flexuosa		.					+	+			.	+++	+	+	+					.			
Persoonia levis		.			.	.	+	+	.	+++	.	+	+	+	.								
Hibbertia bracteata		.		++	+	.	+	.		+++	.	+	.	.									
Patersonia sericea	.	+	+	.	++	++	.	++	++	+++		++	.					+					
Micrantheum ericoides					.	.	+	+	+	+++			.										
Banksia serrata		.	+		++	+	+	+	.	++	++	+++	+	++	.								
Acacia suaveolens	.			+++	.	+	.	+			+	.	.	.	+								

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acacia myrtifolia										+++													
Lomandra glauca		+	+	+	+	+++	.	+++	+++	++	+++	+++	.	.									
Platysace linearifolia	.	+	+	+	++	+	+++	++	+++	+++	+	+++	++	.		.							
Leptospermum attenuatum	+	+++	++	++	+++	+++	+++	+++	++		+++	+++	+	+	.	.				.			
Grevillea sericea	.	+			++	+	++	++	+			.	+++	.	.					.			
Eucalyptus gummifera		+	+	.	++	+++	++	++	.	+	+	+	+	.		.							
Dillwynia retorta	.	+++	+	+++	+++	++	++	+++			+	+	++	++									
Boronia pinnata	.	+++	.	.	+++	.	+	++		+++	+	.	+	.	.								
Xanthorrhoea media	+++	+++	+++	+	+++	+++	+	+	+	.	++	++	+	.									
Pultenaea elliptica	.	+	++	+	+	+	+++	+				+	.										
Phyllota phylicoides		+	+++	+	++	+++	+	++	.	.	+	.	.	.									
Petrophile pulchella	+	+++	.	.	++	+	+	+	.	.	.	++	+										
Lambertia formosa	.	+++	+	.	++	+	++	+	+	+	.	+	.										
Dampiera stricta	++	+			+++	+	+	++	++	.	.	.	+										
Conospermum longifolium		.			++	+	.	+	+	++			.										
Lepyrodia scariosa	+	+++	++	+++	++	++	+++	+	.			+	+										
Dillwynia floribunda	+++	.				.			.		.	++											
Bauera rubioides	+++	.	.	.			.							.									
Banksia ericifolia	+++	++	+++	+	++	+	+	.				.	.			.							
Actinotus minor	+	++	++	+++	+++	+++	+++	+++			.		+	.									
Schoenus imberbis		.	+++	+++	.	.	.				.												
Leptospermum squarrosum	+++	.	.	++			+					.											
Isopogon anethifolius	.	+	+	+++	.	+	.						.										
Hakea teretifolia	+++	+++	+++		+	.	+++					+	.										
Cyathochaeta diandra	++	++	+++	+	+	+	+	+	++	+++	.												
Phebalium squamulosum				+++																			
Leucopogon microphyllus	+	+++	+++	+++	+++	+++	++																
Casuarina distyla	.		+++	+++		.																	
Grevillea speciosa	+++	++	+	+++			.					.											
Epacris microphylla	+++	.	+	+			.					.											
Caustis pentandra			+	+++		.																	
Mirbelia rubiifolia		.		+++																			
Kunzea capitata	++	+	+	+++	.	.																	
Banksia aspleniifolia	+++	+	++	.	+	.	+																
Stylidium lineare	+	+++	+																				

TABLE 3

Abundance of tree species in the quadrat groups

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acmena smithii																				+++	+++	+++	+
Ceratopetalum apetalum																				++	+++	+++	+++
Tristania laurina																				.		.	+++
Lomatia myricoides																				.		.	+++
Callicoma serratifolia																					.	+	+
Acacia elata																						.	
Pittosporum undulatum																				.	+++		
Eucalyptus botryoides																			.	.			
Eucalyptus paniculata																			.				
Casuarina torulosa														.		+	+++	.	+	+	.	.	+
Angophora floribunda																.	+		.				
Syncarpia glomulifera												.		.				++	.				
Eucalyptus umbra				.		.			.		.	.		.	+			+					
Eucalyptus piperita								.			.	+	+	+	.			.					
Angophora costata				.			.	+	+	+	.	+	+	+	++								
Casuarina littoralis								+	+	+						+	.						
Eucalyptus racemosa									.														
Eucalyptus sieberi								.		+													
Eucalyptus punctata				.					.														
Eucalyptus gummifera		+	+	.	++	+++	++	++	.	+	+	+	+	.		.							
Eucalyptus haemastoma	.	+	.	.	.		.			.													
Eucalyptus oblonga		.			.																		
Casuarina distyla	.		+++	+++		.																	
Angophora hispida	+	+	+		.																		

FOOTNOTE TO TABLE 3

Callicoma serratifolia, *Lomatia myricoides*, *Casuarina distyla* and *Angophora hispida* have been classified as trees for the purpose of this Table. The ordering of species and quadrat groups and the scaling of abundance are as described for Table 2.

The S series

The first split within the S series appears to relate to drainage characteristics and correlates well with the amount of outcropping rock, rocky areas generally being better drained. The less rocky group then divides into types S1 (wet closed heath) with *Leptospermum squarrosum, Epacris obtusifolia* and *Bauera rubioides* and type S2 (dry scrub) often with emergent *Eucalyptus gummifera* and *E. haemastoma.*

The distinction between S3 and S4 is necessarily tentative as S4 was representated by only two quadrats. However, subsequent field experience suggests that the distinction is meaningful, type S4 occurring in rockier and more exposed situations.

The L series

The L series contains three types. Type L1 tends to occur on low-rock, low-slope sites on or near broad ridges. It has floristic affinities with S2 (dry scrub) but lacks some of the heath plants such as *Stylidium lineare* and *Grevillea speciosa* and contains open forest species such as *Banksia serrata, Bossiaea heterophylla* and *Hibbertia bracteata.* Type L2 is associated with rockier areas, often above low cliffs. *Eucalyptus umbra* is often present. Type L3 is typically found slightly further from the ridgetops. Seepage zones bear species such as *Leptospermum squarrosum, Bauera rubioides* and *Lepyrodia scariosa.*

The M series

Angophora costata is typical of M-series sites. *Eucalyptus gummifera* is usually also present. The first division within this series separates the Wianamatta Shale sites (floristic type M3) and the related types M1 and M2 from forest on more or less sheltered sandstone slopes. We have tentatively described the M1 and M2 types as "shale influenced and/or drier". They sometimes occur on ridgetops or benched hillsides where the presence of nearby shale bands may be surmised, although the outcropping rock may be sandstone. These vegetation types can be found on sandstone ridges leading east from the Wianamatta Shale at Mt Ku-ring-gai, but on similar ridges further to the north or east they are replaced by the more stunted vegetation of types L1 and L2.

Micrantheum ericoides, Phyllanthus thymoides, Lomatia silaifolia, Casuarina littoralis and *Lasiopetalum ferrugineum* were more prevalent in the quadrats allocated to types M1 to M3 than at most other sites.

The survey quadrats classified as M3 were all situated on Wianamatta Shale near Terrey Hills or Duffys Forest. *Eucalyptus sieberi, Acacia myrtifolia* and *Bossiaea obcordata* are usually present in M3 vegetation, the last being the most faithful. *Eucalyptus sieberi* forest on a shale lens where the West Head road crosses Salvation Creek is closely related floristically, but shale lenses within the Hawkesbury sandstones do not always so detectably influence the vegetation.

Types M4 to M7 occur on sandstone slopes. Particularly in the case of type M7, the site is steep, well drained, and is often south-facing. The most common trees are *Angophora costata, Eucalyptus gummifera* and *E. piperita. Stylidium productum, Pteridium esculentum, Xanthosia pilosa, Caustis flexuosa* and *Woollsia pungens* are also frequent. There is a gradation from M4, which contains species with ridgetop affinities (e.g. *Phyllota phylicoides*), through to M7, which is mostly found on lower slopes with *Dodonaea triquetra.*

TABLE 4

Group averages of physiographic factors, structural properties and species numbers

DATA FROM SET 1 SITES

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4	MEAN	SD
Number of sites	8	7	6	2	8	8	10	7	4	0	3	5	6	4	3	5	1	0	2	2	0	0	0		
East-west coordinate			+					--		*		+						*	++		*	*	*	355	46
North-south coordinate								-		*		++						*	++		*	*	*	768	33
Slope (degrees)		-			-					*			++				++	*			*	*	*	15	10
Aspect: angle from north		+								*					++			*		++	*	*	*	91	63
Altitude (m)						+				*		-				--	--	*	--	--	*	*	*	108	43
Rock cover (%)			+	++	-			-		*			++					*			*	*	*	19	17
Canopy height (m)	--	-	--	--	-			+		*		+	+	++	++	+		*	++	++	*	*	*	11	6
Tree diameter (cm)	--	-	--	--	-					*				++	+			*	++	++	*	*	*	51	37
Tree cover (%)	--	-	--	--						*				++	++	++		*	++	++	*	*	*	36	21
Shrub cover (%)							+			*		+		+			--	*	--		*	*	*	65	25
Herb and fern cover (%)					-			-		*	-							*	++		*	*	*	24	21
species in quadrat							+	+	--	*			+			--		*	--		*	*	*	58	14

DATA FROM ALL SITES

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Number of sites	8	7	6	2	9	10	10	7	5	5	8	5	8	7	4	5	5	4	3	3	2	4	7
East-west coordinate			+					--		-		+						++	++			--	
North-south coordinate								-		--	+	++					++	++				--	
Slope		-			-	-				--				+			++						
Aspect: angle from north		+								-				+			-			++	++		
Altitude					+	+				++	+	-				--	--	++	--	--	--	--	--
Rock cover			+	++	-			-		--			+					--				++	++
Canopy height	--	-	--	--	-			+		+	+	+	+	++	++	+		++	++	++	++		++
Tree diameter	--	-	--	--	-	-								+	+				++	++			
Tree cover	--	-	--	--										++	++	++		++	++		++	++	++
Shrub cover							+					+		+		-	--		--		--	--	--
Herb and fern cover					-			-		+	-			-				++	++			-	-
species in quadrat							+	+	-	-	-					--	--		--		--	--	-

TABLE 5

The hierarchical classification scheme derived from the floristic data, interpreted as far as possible in terms of the associated environmental and structural trends

SERIES S: SCRUB/HEATH, with or without emergent low trees	less rocky; poorly drained	wet closed heath	S1
		dry scrub	S2
	rocky; well drained	rocky	S3
		very rocky	S4
SERIES L: LOW WOODLAND, with dense shrub layer	dry; on or near ridges	broad ridges & slopes	L1
		rocky spurs & slopes	L2
	on seepage zones, e.g. under minor cliffs		L3
SERIES M: MODERATELY LOW OPEN FOREST	shale & shale-influenced or drier	species rich	M1
		species poor	M2
		Wianamatta shale	M3
	more or less sheltered sandstone hillsides, often with seepage zones	upper slopes	M4
			M5
			M6
		lower slopes	M7
SERIES MT MEDIUM OR MODERATELY TALL SCLEROPHYLL FOREST	on sandstone	WSF	MT1
		DSF; Casuarinas	MT2
	on dolerite, or on shale-influenced sites on lower slopes	DSF; Casuarinas	MT3
		WSF; on dolerite	MT4
		WSF; sheltered slopes	MT5
SERIES R: MARGINAL RAINFOREST medium or moderately tall, canopy more or less closed	sheltered slopes	WSF/RF	R1
		RF	R2
	stream-side gallery forest		R3
			R4

FOOTNOTE TO TABLE 4

The first part of the Table is based on the 91 random-grid sites comprising set 1. A + or − symbol denotes that a t-test or, when the data derived from less than three quadrats, a direct computation of probability, indicated a probably substantive difference between the group mean and the set 1 mean shown in the right-hand columns. The significance level was nominally 5 per cent; however, with survey data, possible spatial coherence precludes a precise interpretation. Duplication of the symbol indicates that in addition to meeting the above criterion, the difference exceeded the set 1 standard deviation. Asterisks denote groups for which no set 1 data were available. The second part of the Table contains equivalent data derived from set 1 and set 2 combined. As before, comparisons are with the set 1 means. In the 10 groups that included members from both set 1 and set 2, differences between the set 1 and set 2 groups means did not exceed those anticipated through chance.

TABLE 6

The relationship of the structural terminology used in the present paper to that of Specht et al. (1974) and Carnahan (1976)

STRUCTURAL CHARACTER	DESCRIPTOR Specht et al	Carnahan	Present Paper
a) Height of tallest stratum (metres); trees present			
> 30	tall	T	tall*
20 - 30	no prefix	M	moderately tall*
15 - 20	no prefix	M	medium*
10 - 15	no prefix	M	moderately low*
< 10	low	L	low*
b) Height of tallest stratum (metres); trees absent, shrubs present			
> 2	scrub or shrubland#	S	scrub or shrubland#
< 2	heath or low shrubland#	Z	heath or low shrubland#
c) projective cover of tallest stratum (%); trees present			
< 10	open woodland	1	sparse woodland*
10 - 30	woodland	2	woodland*
30 - 50	open forest	3	open forest
50 - 70	open forest	3	forest
70 - 100	closed forest	4	closed forest
d) projective cover of tallest stratum (%); trees absent, shrubs present			
< 10	open shrubland	1	sparse shrubland
10 - 30	shrubland	2	shrubland
30 - 50	open scrub/heath	3	open scrub/heath
50 - 70	open scrub/heath	3	scrub/heath
70 - 100	closed scrub/heath	4	closed scrub/heath

* If tree cover is less than 30% and shrub cover is much greater than tree cover, name in terms of shrub layer and add the qualifier: 'with emergent trees'.

\# Shrubland if shrub cover is less than 30%.

The MT series

The medium or moderately tall forests of the MT series are mainly confined to the middle and lower slopes. An important exception is the area of MT4 vegetation on dolerite near West Head. Trees often present on MT sites include *Casuarina torulosa, Angophora floribunda* and *A. costata.*

Type MT1 represents an extension of the continuum underlying types M4 to M7. Common trees are *Angophora costata* and *Eucalyptus umbra.* MT1 typically occurs on well drained south or east-facing slopes.

Type MT2 is a drier forest on slopes that are often steep and of northerly aspect. *Casuarina littoralis* and *C. torulosa* dominate the canopy and there is an open shrub layer.

Type MT3 has strong affinities with the preceding type. However, *Casuarina torulosa* is much more prevalent than *C. littoralis,* and the shrub layer is even more open and contains fewer "ridgetop" species. MT3 occurs at very low altitudes, being common on north-east and north-west slopes fronting Pittwater and Cowan Creek. It is often associated with shale of the Hawkesbury or Narrabeen series.

The two remaining types in the MT series, MT4 and MT5, have open to very open shrub layers and a ground cover containing many ferns. We have recorded MT4 only from the dolerite near West Head. *Syncarpia glomulifera* is frequent and *Macrozamia communis* occurs in the understorey. MT5 occurs on east-facing sites above Pittwater. There are many species in common with MT4. *Angophora floribunda, Eucalyptus botryoides* and *E. paniculata* are more frequent in the canopy and the shrub layer is even more open. *Culcita dubia* and *Lomandra longifolia* are prevalent. Like MT3, type MT5 may be associated with shale.

The R series

The forests of the R series have the rainforest species *Ceratopetalum apetalum* and *Acmena smithii* in the canopy. The shrub cover is low, as too is the count of species in a 1000 m² quadrat. The principal dichotomy within the series separates stream-side gallery forests (R3, R4), with, for example, *Tristania laurina, Lomatia myricoides* and *Hymenophyllum cupressiforme,* from forests on sheltered hillsides above salt water (R1, R2), typically containing *Eustrephus latifolius* and *Cissus hypoglauca.* The distinction between R1 and R2 is based on few quadrats, but field experience indicates that it is meaningful, R2 having stronger rainforest affinities. R3 vegetation frequently contains the exotic species *Ligustrum sinense* and *Ageratina riparia,* which were not found at R4 sites. At present, we have recorded R3 only in the south-west of the Park from streams whose headwaters have been affected by urban development.

Relative abundance of the floristic types

The relative areas covered by the different floristic series can be estimated from the numbers of quadrats from set 1 classified into each category, since those quadrats were positioned on a randomized grid. The results are shown in Table 7. The S, L and M floristic series are all widely distributed and among them cover around 85 per cent of the region surveyed by set 1, whereas the marginal rainforests of the R series cover only a few per cent. Type M3, associated with Wianamatta Shale, and type MT4, associated with dolerite, are also very restricted in distribution, reflecting the scarcity of the relevant parent rocks.

Small areas of freshwater swamp occur within the Park. No set 1 quadrat fell within a swamp. They were not sampled in set 2 as a study of the swamp vegetation has been reported elsewhere (Buchanan, 1980).

Mangrove communities also exist within the Park. They are floristically very simple, containing only *Avicennia marina* and *Aegiceras corniculatum* in the canopy. They were excluded from the present survey, which was restricted to the strictly terrestrial vegetation.

Local areas of podzol soil within the Park have been identified by Buchanan (1980). Four set 2 quadrats were placed on such areas and one on an adjoining area

TABLE 7

Percentages of the 91 set 1 sites classified into the various floristic series

Series	S	L	M	MT	R
Percentage	25	29	32	12	2

TABLE 8

Floristic affinities of four quadrats placed on podzolized sites identified by Buchanan (1980) and one placed on a topographically similar non-podzol site adjoining Buchanan's podzol number 4

Soil	Buchanan's reference no.	Floristic type
Podzol	24	MT1
Podzol	14	M4
Podzol	12	M4
Podzol	4	M7
Non-podzol	—	M6

with non-podzol soil. As shown in Table 8, the similarities among the podzol sites were not sufficiently strong for the analysis to assign them all to a single type. However, they were all placed within the continuum of types M4 to MT1, which were typically found to occur on well drained, often south-facing, sandstone slopes, whereas the podzols sometimes occurred in more level, more exposed sites.

Occurrences of exotic plants

Fourteen species of exotic plants were recorded from the 134 survey quadrats, 4 per cent of the total number of species encountered. No doubt the figure would have been considerably higher if disturbed areas such as roadsides, picnic places, etc., had been surveyed.

The exotics were unevenly distributed among the floristic types as indicated in Table 9. Type MT3 (*Casuarina* forest) and the marginal rainforest types of the R series were the most affected. No exotics were found in any quadrat assigned to series S (heath and scrub) or L (low woodland), and very few in series M (moderately low open forest).

The uneven distribution probably reflects the inability of most exotic species to compete successfully on the arid and infertile sites occupied by vegetation of series S and L. Other factors may also be influential. Streams bordered by gallery forests (types R3 and R4) may bring periodic inputs of seeds from residential areas in their catchments. Types MT2, MT3, R1 and R2 occur along estuarine foreshores where the easy access by water has resulted in considerable human visitor numbers with accompanying disturbance.

TABLE 9

Presence of exotic species in the various quadrat groups

	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Arum italicum																*
Cassia coluteoides													*	*		
Cinnamomum camphorum								*								
Cirsium vulgare														*		
Erigeron floribundus		*								*			*			
Eupatorium adenophorum †				*									*			*
Eupatorium riparium															*	
Gladiolus sp.															*	
Hypochoeris radicata										*						
Lantana camara										*						
Ligustrum sinense															*	*
Passiflora edulis													*	*		
Rubus vulgaris								*							*	*
Tradescantia albiflora															*	

† Since this paper was submitted, a number of name changes have occurred. These appear at the end of the List of indicator species.

Implications for management

The findings reported in this paper have several implications for the management of the Park. The vegetation on the limited area of Wianamatta Shale within the Park has been shown to be distinctive. Few equivalent areas would exist elsewhere in the State's system of national parks and reserves, and it would therefore seem worthwhile to ensure that this particular area is conserved. A similar case can be made for the dolerite area on the West Head peninsula.

There is also an argument for giving special consideration to areas carrying vegetation of the MT and R series. These series have a limited distribution within the Park and appear to be particularly vulnerable to invasion by weeds.

Keys to the floristic types

The usefulness of the proposed classification scheme for future management and scientific studies depends on being able to identify any vegetation types as belonging to the appropriate category.

An indicator species key to the floristic types was produced as a by-product of the ISA classification process and is included as an Appendix 1 to this paper.

Ten indicator species are listed for each dichotomous division. A score is derived from the local abundance of these indicators, the right-hand indicators scoring positively, the left-hand ones negatively. The score is compared with the threshold value specified for the division in order to decide which branch to follow.

Strictly, the key should be applied to objectively sited quadrats of the same form as those used in the present survey. A contribution of four units should be entered for indicator species occurring in the innermost 10 m^2, three for indicators within 50 m^2 and so on. However, we have found that the key gives accurate results when used under less stringent conditions. Under the less stringent procedure, indicators estimated visually to be present at local abundances of greater than one individual per 10 m^2 are allowed four points, with less abundant indicators contributing progressively smaller amounts. For many purposes, this less stringent procedure may be adequate, particularly if verified occasionally by formally keying properly defined quadrats.

Whichever procedure is used, misclassifications will sometimes occur. The outcome should therefore be confirmed by comparing the range of plants actually present with the average profile for the floristic type, as summarized in Table 2.

The vegetation within the Park is similar to that in many nearby undisturbed areas. The question therefore arises as to whether the indicator key could be legitimately applied outside the Park. We feel that the answer is yes, provided that its limitations are clearly recognized. The key contains no provision for dealing with vegetation outside the range of the present classification scheme — **any** site will key out to one of the 23 types. Only if the site has many species in common with the sites included in the present survey will the result be meaningful. An identification should certainly be checked by referring to Table 2.

There will also be sites within the Park that carry types of vegetation that were not sampled during the survey. However, the inclusion of the set of special-purpose quadrats in the survey greatly extended the range of floristic types that it encompassed and reduced the number of unsampled types. Two examples that are known to remain are the freshwater swamps and the mangrove communities. The key cannot be validly applied to either of those types.

The floristic types as local averages

The analysis identified 23 floristic types differing in floristic, structural and ecological parameters. We do not wish to imply, however, that the Park's vegetation is divided into 23 discrete and isolated categories. On the contrary, the floristic composition of the vegetation seems to be more or less continuously variable. The 23 types are for the most part local averages in a continuum. Thus, there can be variation within the vegetation ascribed to a particular type.

In the event of further data becoming available, it may be possible to subdivide some of the present types. In the interim, it may sometimes be meaningful to describe a site's vegetation as being "of type X but with elements of type Y". We have observed, for example, that some low woodland on a shale-capped ridge bordering Bobbin Head Road keys out as type L1 (low woodland; ridgetops) but has affinities with M1 (moderately low open forest; shale influenced). We suspect that further investigation would show that type L1 could be subdivided in a dichotomy analogous to that which separates M1 to M3 from M4 to M7.

Projected uses of the classification scheme

The potential uses of the classification scheme derive from its properties. It is detailed and hierarchical — differentiation can be to type or series level as the application warrants. The scheme is ecologically meaningful, on both subjective and objective criteria. It can be objectively applied, using the key described in the Appendix.

This last property suits the classification scheme to baseline mapping work, where repeatability between observers is essential. The scheme could also be used for detailed comparisons between areas, as required, for example, in environental impact assessment, evaluation of alternative management regimes, or assessment of an area's conservation status.

CONCLUSIONS

1. Indicator species analysis of the floristic data from 134 quadrats produced 23 distinguishable vegetation types.
2. The dominant axis within the floristic data placed heathland at one extreme, marginal rainforest at the other.
3. The floristically based classification scheme correlated strongly with structural, edaphic and physiographic factors. The most strongly related structural parameter out of those that were recorded was canopy height. The most strongly related physiographic parameter was altitude.
4. The upper divisions in the classification scheme could be well described in structural terms that were more or less consistent with those used by other authors in structurally based classification schemes.
5. The floristic types could be regarded as belonging to five series: S (scrub/heath), L (low woodland), M (moderately low open forest), MT (moderately tall forest) and R (marginal rainforest).
6. The vegetation growing on Wianamatta Shale within the Park constituted a distinct type.
7. The vegetation growing on dolerite constituted a distinct type.

8. The most widely distributed vegetation types were those of the S, L and M series, together covering around 85 per cent of the Park's surface. Marginal rainforest occupied an estimated 2 per cent of the Park's surface.
9. Fourteen species of exotic plants were recorded from survey quadrats. Exotic plants had not invaded scrub and low woodland types (series S and L). They were most abundant in type MT3 and the R series.
10. An indicator species key to the floristic types was found to be reliable in the field.
11. It is suggested that special management effort be directed to areas carrying vegetation of types M3 and those of the MT and R series.

In addition, the following methodological conclusions were drawn:

1. Presence/absence data from 1000 m^2 quadrats produced a superior classification to that obtained with equivalent data from 50 m^2 quadrats.
2. The classification scheme was further improved if higher weights were accorded to occurrences near the quadrat centres.
3. In ecological gradients such as occur near stream margins, it appears to be beneficial to record the nearby floristic context provided that the centrally occurring species are given more weight in the subsequent analysis.
4. The floristic range encompassed by the classification scheme was considerably extended through the inclusion of 43 specific purpose quadrats in the survey.

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APPENDIX 1

Indicator species key to the vegetation types

Ten indicator species are listed for each dichotomous division. A score is derived from the local abundance of these indicators, the right-hand indicators scoring positively, the left-hand ones negatively. The score is compared with the threshold value specified for the division in order to decide which branch to follow. The species abbreviations* are expanded at the end of the key. The interpretive comments are included merely as a guide; the key itself is based solely on floristic characters.

```
1.  Ku-ring-gai Chase vegetation
    -ve: Acti mino  Cyat dian  Damp stri  Dill reto          <= -8 ............ 2
         Euca gumm  Lamb form  Lept atte  Phyl phyl          >= -7 ............ 4
         Plat line  Xant medi

2.  Heath, woodland or moderately low open forest
    -ve: Acti mino  Bank aspl  Bank eric ! +ve: Ango cost    <= -7 ............ 3
         Hake tere  Hibb cist  Kunz capi !      Pter escu    >= -6 Series M... 10
         Leuc micr                       !      Xant pilo

3.  Heath/scrub or low woodland with dense shrub layer
    -ve: Ango hisp  Darw fasc ! +ve: Boss hete  Cono long    <= -3 Series S.... 5
         Epac micr  Grev spec !      Hibb brac  Phyl thym    >= -2 Series L.... 8
         Kunz capi  Styl line !

4.  Medium or moderately tall forest
    -ve: Loma grac ! +ve: Acme smit  Blec cart  Call serr    <=  6 Series MT.. 17
         Pter escu !      Cera apet  Hyme cupr  Loma myri    >=  7 Series R... 21
                   !      Smil glyc  Tris laur
-------------------------------------------------------------------------------

5.  Series S: heath/scrub with or without emergent low trees
    -ve: Damp stri  Dill flor ! +ve: Casu dist  Caus pent    <= -1 ............ 6
         Epac obtu  Hake dact !      Erio aust  Phyl phyl    >=  0 ............ 7
         Petr pulc            !      Scho imbe

6.  Not well drained
    -ve: Baue rubi ! +ve: Boro pinn  Dill reto  Epac pulc    <=  2 ........... S1
         Epac obtu !      Euca gumm  Loma glau  Loma obli    >=  3 ........... S2
         Lept squa !      Phyl phyl

7.  Rocky, well drained
    -ve: Ango hisp  Baec dios  Bank aspl ! +ve: Acac suav    <= -3 ........... S3
         Boro ledi  Hake tere  Hibb cist !      Mirb rubi    >= -2 ........... S4
         Styl line                       !      Pheb squa
-------------------------------------------------------------------------------

8.  Series L: low woodland
    -ve: Loma glau ! +ve: Acac term  Baue rubi  Caus flex    <=  7 ............ 9
         Tetr eric !      Gahn sp.   Halo teuc  Lept squa    >=  8 ........... L3
                   !      Hake tere  Micr eric

9.  Dry, on or near ridges
    -ve: Ango hisp  Bank aspl ! +ve: Acac ulic  Erio aust    <= -4 ........... L1
         Boro pinn  Gomp gran !      Euca umbr  Hibb line    >= -3 ........... L2
         Hake dact  Hake gibb !
-------------------------------------------------------------------------------
```

* Since this paper was submitted, a number of name changes have occurred. These appear at the end of the List of indicator species.

```
10. Series_M: moderately low open forest
    -ve: Acac myrt  Cono long ¦ +ve: Acac term  Styl gram    <= -3 ........... 11
         Cyat dian  Micr eric ¦      Wool pung  Xant arbo    >= -2 ........... 14
         Pate seri  Phyl thym ¦

11. Shale and shale related or drier
    -ve: Acti mino  Boro ledi  Boss hete ¦ +ve: Acac myrt    <= -4 ........... 12
         Dill reto  Grev seri  Halo teuc ¦      Boss obco    >= -3 ........... 13
         Lept atte  Lepy scar            ¦

12. Not on Wianamatta shale
    -ve: Acac lini  Acac suav  Acti mino  Boro pinn          <= -6 ........... M1
         Dill reto  Halo teuc  Lept flav  Loma long          >= -5 ........... M2
         Tetr eric  Xant trid

13. Usually on Wianamatta shale
    -ve: Anis aven ¦ +ve: Acac myrt  Boro pinn  Boss obco    <=  3 ........... M2
         Lepi late ¦      Cyat dian  Hibb brac  Micr eric    >=  4 ........... M3
                   ¦      Pate seri  Pers levi

14. Sheltered sandstone hillsides
    -ve: Dill flor  Erio aust ¦ +ve: Bill scan  Crow sali    <=  1 ........... 15
         Leuc eric  Loma glau ¦      Dian caer  Grev seri    >=  2 ........... 16
                              ¦      Smil glyc  Xant trid

15. Upper slopes
    -ve: Phyl phyl ¦ +ve: Boro ledi  Cass pube  Caus flex    <=  6 ........... M4
                   ¦      Ento stri  Euca pipe  Hake gibb    >=  7 ........... M5
                   ¦      Lepy scar  Pate seri  Styp tubi

16. Lower slopes
    -ve: Boro ledi  Cono long  Damp stri ¦ +ve: Dodo triq    <= -3 ........... M6
         Epac pulc  Grev seri  Lepy scar ¦      Lepi late    >= -2 ........... M7
         Petr pulc                       ¦      Plat lanc
-------------------------------------------------------------------------------

17. Series_MT: medium or moderately tall sclerophyll forest
    -ve: Anis aven ¦ +ve: Eust lati  Glyc clan  Hibb dent    <=  6 ........... 18
                   ¦      Hydr acut  Impe cyli  Opli aemu    >=  7 ........... 19
                   ¦      Prat purp  Syno glan  Viol hede

18. On sandstone slopes
    -ve: Acac term  Anis aven  Bank spin ¦ +ve: Astr floc    <= -4 .......... MT1
         Caus flex  Ento stri  Euca umbr ¦      Casu toru    >= -3 .......... MT2
         Loma sila  Pult daph            ¦

19. On dolerite or lower slopes
    -ve: Casu toru ¦ +ve: Acac flor  Clem glyc  Euca pilu    <=  2 .......... MT3
         Loma long ¦      Macr comm  Sync glom  Syno glan    >=  3 ........... 20
         Them aust ¦      Viol hede

20. Wet sclerophyll with +- closed fern layer
    -ve: Clem glyc  Come volu  Ento stri ¦ +ve: Culc dubi    <= -4 .......... MT4
         Loma sila  Loma grac  Macr comm ¦      Loma long    >= -3 .......... MT5
         Pate seri  Pros dent            ¦
-------------------------------------------------------------------------------

21. Series_R: marginal rainforest
    -ve: Astr floc  Ciss hypo ¦ +ve: Aust tenu  Call serr    <= -1 ........... 22
         Eust lati  Pter escu ¦      Hyme cupr  Loma myri    >=  0 ........... 23
         Sche undu            ¦      Tris laur
```

```
22. Sheltered slopes
    -ve: Astr floc  Ciss hypo ¦ +ve: Gloc ferd  Gram bill     <=  0 ........... R1
         Hibb dent  Lepi elat ¦      Hyme cupr  Mori jasm     >=  1 ........... R2
                              ¦      Stic flab  Tode barb

23. Stream-side gallery forest
    -ve: Acme smit  Blec cart ¦ +ve: Aust tenu  Ento stri     <=  0 ........... R3
         Eupa ripa  Ligu sine ¦      Gram bill  Loma myri     >=  1 ........... R4
                              ¦      Pheb dent  Tris laur
```

List of indicator species

Acacia floribunda
Acacia linifolia
Acacia myrtifolia
Acacia suaveolens
Acacia terminalis
Acacia ulicifolia
Acmena smithii
Actinotus minor
Angophora hispida
Angophora costata
Anisopogon avenaceus
Astrotricha floccosa
Austromyrtus tenuifolia

Baeckia diosmifolia
Banksia aspleniifolia
Banksia ericifolia
Banksia spinulosa
Bauera rubioides
Billardiera scandens
Blechnum cartilagineum
Boronia ledifolia
Boronia pinnata
Bossiaea heterophylla
Bossiaea obcordata

Callicoma serratifolia
Cassytha pubescens
Casuarina distyla
Casuarina torulosa
Caustis flexuosa
Caustis pentandra
Ceratopetalum apetalum
Cissus hypoglauca
Clematis glycinoides
Comesperma volubile
Conospermum longifolium
Crowea saligna
Culcita dubia
Cyathochaeta diandra

Dampiera stricta
Darwinia fascicularis
Dianella caerulea
Dillwynia floribunda
Dillwynia retorta
Dodonaea triquetra

Entolasia stricta
Epacris microphylla
Epacris obtusifolia
Epacris pulchella
Eriostemon australasius
Eucalyptus gummifera
Eucalyptus pilularis
Eucalyptus piperita
Eucalyptus umbra
Eupatorium riparium
Eustrephus latifolius

Gahnia sp.
Glochidion ferdinandi
Glycine clandestina
Gompholobium grandiflorum
Grammitis billardieri
Grevillea sericea
Grevillea speciosa

Hakea dactyloides
Hakea gibbosa
Hakea teretifolia
Haloragis teucrioides
Hibbertia bracteata
Hibbertia cistiflora
Hibbertia dentata
Hibbertia linearis

Hydrocotyle acutiloba
Hymenophyllum cupressiforme

Imperata cylindrica

Kunzea capitata

Lambertia formosa
Lepidosperma elatius
Lepidosperma laterale
Leptospermum attenuatum
Leptospermum flavescens
Leptospermum squarrosum
Lepyrodia scariosa
Leucopogon ericoides
Leucopogon microphyllus
Ligustrum sinense
Lomandra glauca
Lomandra gracilis
Lomandra longifolia
Lomandra obliqua
Lomatia myricoides
Lomatia silaifolia

Macrozamia communis
Micrantheum ericoides
Mirbelia rubiifolia
Morinda jasminoides

Oplismenus aemulus

Patersonia sericea
Persoonia levis
Petrophile pulchella
Phebalium dentatum
Phyllanthus thymoides
Phyllota phylicoides
Platysace lanceolata
Platysace linearifolia
Pratia purpurascens
Prostanthera denticulata
Pteridium esculentum
Pultenaea daphnoides

Schelhammera undulata
Schoenus imberbis
Smilax glycinoides
Sticherus flabellatus
Stylidium graminifolium
Stylidium lineare
Styphelia tubiflora
Syncarpia glomulifera
Synoum glandulosum

Tetratheca ericifolia
Themeda australis
Todea barbara
Tristania laurina

Viola hederacea

Woollsia pungens

Xanthorrhoea arborea
Xanthorrhoea media
Xanthosia pilosa
Xanthosia tridentata

Name changes

Since this paper was submitted, a number of name changes have occurred. These are: *Eupatorium adenophorum* to *Ageratina adenophora; Eupatorium riparium* to *Ageratina riparia; Haloragis teucrioides* to *Gonocarpus teucrioides; Hydrocotyle acutiloba* to *H. peduncularis; Smilax glycinoides* to *S. glyciphylla; Stylidium graminifolium* to *S. productum.*