

Effectiveness of using vascular plants to select reserves for bryophytes and lichens

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Abstract

There is strong interest in finding surrogates for taxa that are difficult to identify, primarily because of wide-ranging implications for management and conservation. We examined the effectiveness of using vascular plant diversity as a basis for choosing reserves to capture bryophyte and lichen diversity. We surveyed 35, 20×50 m sites for bryophytes, lichens and vascular plants in a forest management district of eastern Australia. Despite being based on a relatively few sites, these results are informative because datasets in which all three taxa are identified to species level are uncommon. We found that a set of sites that reserved 90% of vascular plant species captured 65% of bryophyte species and 87% of lichen species. Also, the sites that were ‘irreplaceable’ for overstorey species in a minimum reserve set captured 88 and 89% of bryophyte and lichen species, respectively. Vascular plant communities defined using clustering predicted highly significant variation in both bryophyte and lichen species composition. However, both vascular plant species richness and genus richness were poor predictors of bryophyte and lichen species diversity. The results indicate that, on a local scale, reserves selected for vascular plants can capture large percentages of bryophytes and lichens, however individual sites important for bryophyte and lichen conservation may not be important for vascular plant conservation. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Bryophytes; Lichens; Reserve selection; Irreplaceability; Sclerophyll forest

1. Introduction

Vascular plants are often used as a surrogate for total biodiversity in conservation evaluation, and play a critical role in land management (Dasman, 1972; Specht, 1975; Noss, 1987; Whitehouse, 1990; York et al., 1991; Belbin, 1993; State Forests of New South Wales, 1995; Caldecott et al., 1996). Vascular plants are a natural choice for an umbrella group because they constitute the bulk of the primary producer biomass, reflect the environmental conditions, provide physical structure for other organisms, and are relatively easily surveyed (Ryti, 1992). Despite being frequently used as a surrogate for biodiversity in general, there is little empirical evidence that this is a sound assumption. Recent evi-

dence has shown that vascular plants may be used as a surrogate for invertebrates in reserve selection (see Panzer and Schwartz, 1998), however, there are currently no data for bryophytes or lichens.

Bryophytes and lichens are difficult to identify to species level, consequently datasets that include these groups in addition to vascular plants are uncommon. An exception to the general rule of under-collection of bryophytes is the British flora, where datasets have been used to examine the overlap of areas species-rich in liverworts with areas species-rich for aquatic plants, breeding birds, butterflies, dragonflies, and ferns (Prendergast et al., 1993; Lawton et al., 1994). Little coincidence in ‘hotspot’ location was detected, although coincidences were strongest for organisms with similar physiologies, such as liverworts and ferns. Simple surrogates, such as the species richness of a well-known group, could be useful to land managers, who are increasingly required to manage for multiple values without having the expertise or resources to carry out extensive surveys.

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There is a reasonably extensive literature examining the overlaps in species diversity patterns of vascular plants and either bryophytes or lichens. However, bryophytes and lichens are often included only in a superficial manner and lumped into groups because of their taxonomic difficulty. Studies that identify these groups to species level generally focus on detecting similarities in community structure (e.g. Lee and La Roi, 1979; McCune and Antos, 1981; Bradfield and Scagel, 1984; Rey Benayas, 1995), rather than explicitly investigating management and conservation questions.

Reasons to expect vascular plants to be a good reserve selection surrogate for bryophytes and lichens range from the micro-scale to the macro-scale. At the micro-scale, particular bryophytes and lichens have been found to be dependent on the microhabitats provided by particular types or species of vascular plant (e.g. Slack, 1976; Schmitt and Slack, 1990; Wolf, 1994). For example, some tree ferns have been found to support obligate epiphytic liverworts (Scott, 1985). On the macro-scale, variables such as topographic position and time since fire appear to be regulating the richness and composition of all three groups (Pharo et al., 1999). In the Australian state of Tasmania, it was found that three rainforest types could be clearly distinguished based both on their vascular plant species composition and their bryophyte and lichen species composition (Jarman and Kantvilas, 1994). However, we do not know whether these results will be repeated in drier forests and other land types.

We investigate whether: (1) vascular plant richness (genus and species) correlates significantly with bryophyte and lichen species richness and composition; (2) 'complementary' sites that are chosen to efficiently capture all vascular plant species also capture all bryophyte and lichen species; (3) there are significant differences in bryophyte and lichen species composition between pre-defined vascular plant communities.

2. Materials and methods

2.1. The study area

We used 35, 20×50 m sites established by the state agency responsible for forests (State Forests of New South Wales, 1995; Fig. 1). The sites were part of an Environmental Impact Assessment (EIA) in coastal lowland forests covering an area of approximately 50×70 km just north of Sydney, New South Wales (State Forests of New South Wales, 1995). The sites ranged from open forest with a grassy understorey to wet sclerophyll forest with a closed canopy and dense understorey. Average daily maximum temperatures for the area range from 15 in July to 27°C in January and annual rainfall ranges from 1200 to 1400 mm (Forestry

Commission of New South Wales, 1984). Rainfall is seasonal with more than twice as much rain falling in summer than winter.

2.2. Sampling

Vascular plants in the 20×50 m site were identified by State Forests of New South Wales (Binns, 1996). Two categories of vascular plants were identified: all vascular plants and overstorey species (dbh > 10 cm). Bryophytes and lichens were sampled in the same 20×50 m sites using five quadrats (ranging from 20 cm² to 1 m²) on each of five different substrata (ground, logs, rocks, tree trunks and fallen branches). Species accumulation curves revealed that our sampling was adequate. The amount of substrate present at each site had no significant effect on numbers or species composition of bryophytes or lichens (Pharo, 1996). For this paper, data from the 25 quadrats were pooled to give species presence per site. Details of bryophyte and lichen sampling are described in Pharo and Beattie (1997).

Nomenclature followed Streimann and Curnow (1989) for mosses, Scott and Bradshaw (1986) for liverworts and hornworts, McCarthy (1991) for lichens, and Harden (1990–1993) for vascular plants. Bryophyte and lichen voucher specimens were lodged in the Macquarie University herbarium.

2.3. Data analysis

Four categories were tested: bryophytes, lichens, overstorey species, and all vascular plants. Overstorey species were examined separately because this group is the focus of forest management and they are particularly easy to survey. Understorey species make up the bulk of the vascular plants and there was very little difference between the species richness and composition of understorey species alone compared to the group 'all vascular plants' (Pharo et al., 1999). Therefore, no further distinction was made.

The relationship between vascular plant richness and richness of bryophyte and lichen species was tested using Pearson product moment correlation (Sokal and Rohlf, 1995). The relationship between overstorey species richness and bryophyte and lichen species was similarly tested. Genera richness as well as species richness was tested for vascular plants. However, for the overstorey, the number of genera varied little and was not included. Correlation was used rather than regression, because both variables were considered to be random (Zar, 1996). Vascular plant richness was related to bryophyte and lichen species composition by; (a) generating ordination axes based on bryophyte and then lichen data using hybrid multidimensional scaling (HMDS, Minchin, 1991; default settings were used); and (b) subsequently fitting vascular plant richness vectors

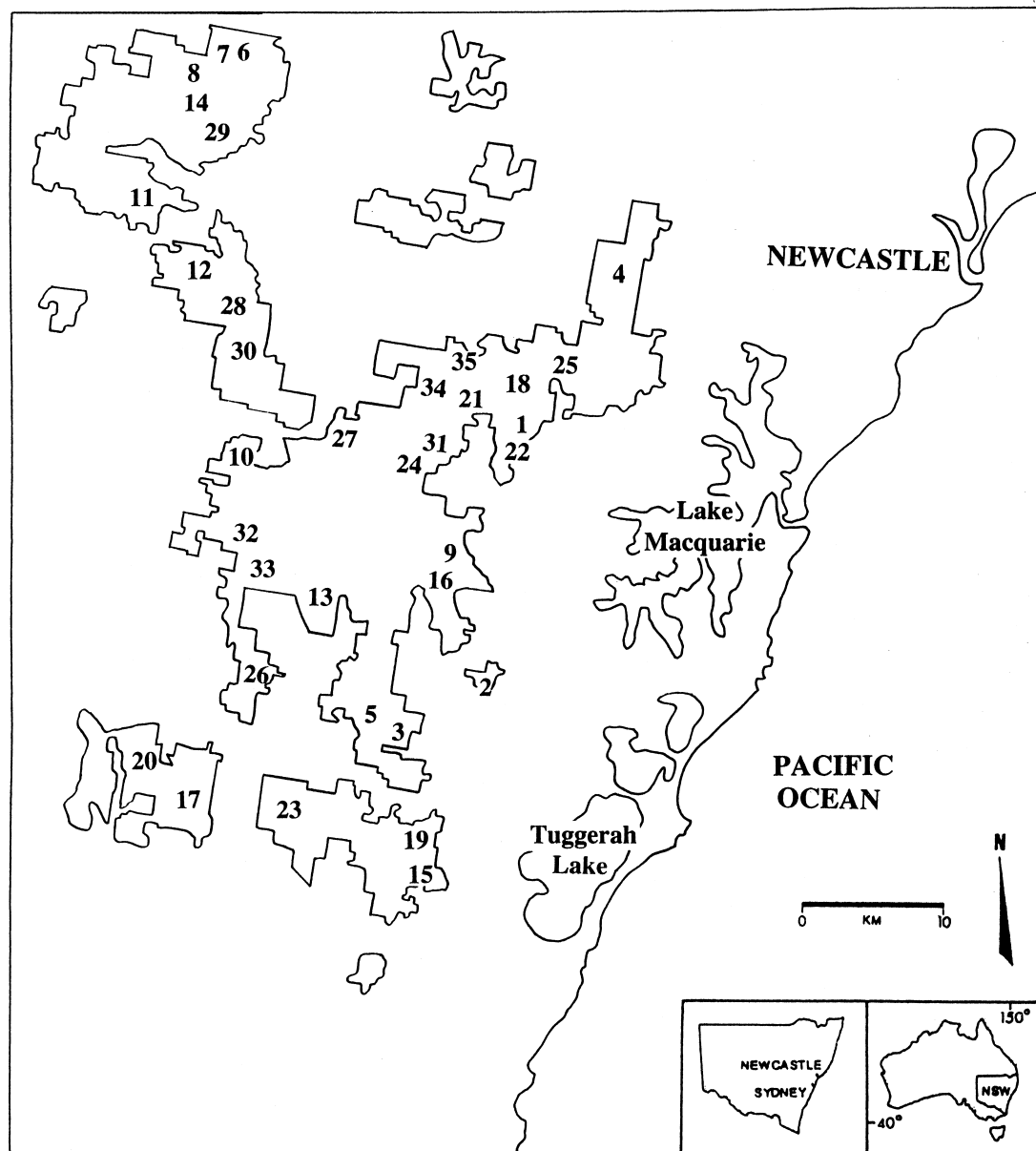


Fig. 1. The study area showing the location of the 35 sites within the Morisset Forest District.

to the two dimensional MDS solution. Correlations were tested using 1000 random permutations of the ordination axes (Minchin, 1991).

Minimum reserve sets are the smallest number of sites that achieves a given reservation target. They were calculated by inspecting all combinations of progressively larger numbers of sites to check if any of the combinations included all species at least once (using programming code developed by New South Wales National Parks and Wildlife Service, Armidale, New South Wales). One of the groups had a unique species at every site, and therefore, all 35 sites were required in the minimum set to include all species at least once. Therefore, we also used a heuristic algorithm to determine the set of sites that

reserves only 90% of all species at least once (MSET in PATN, using site richness algorithm; Belbin, 1991a,b). Heuristic algorithms progressively add sites that are the most complementary in their species composition to those already in the set, but cannot remove sites once added.

The irreplaceability of each site was calculated as the percentage of representative minimum-sized combinations in which it occurred (Pressey et al., 1994). If a site occurred in every minimum set, it had an irreplaceability value of 100%, and if it did not occur in any minimum solution, it had an irreplaceability of 0%, i.e. it was completely replaceable. An additional correlation was performed to investigate the overlap between the 100% irreplaceable sites and species richness.

Table 1

The six vascular plant communities defined at 0.75 level of Bray–Curtis dissimilarity using a clustering technique (flexible unweighted pair group metric averaging, $\beta = 0$; Belbin 1991a,b)^a

Vascular plant community	Number of sites	Dominant tree species	Years since fire	Topographic position
Dry sclerophyll 1	7	Spotted gum (<i>Corymbia maculata</i>) Stringybark (<i>Eucalyptus agglomerata</i>)	8.0 (2.7)	2.7 (0.2)
Dry sclerophyll 2	9	Grey gum (<i>E. propinqua</i>) Ironbark (<i>E. paniculata</i>)	6.7 (1.0)	2.4 (0.2)
Dry sclerophyll 3	6	Blackbutt (<i>Eucalyptus pilularis</i>)	7.6 (1.3)	2.8 (0.2)
Wet sclerophyll	10	Sydney blue gum (<i>Eucalyptus saligna</i>) Round-leaved gum (<i>Eucalyptus deanii</i>) Turpentine (<i>Syncarpia glomulifera</i>)	16.5 (1.3)	3.2 (0.2)
Riparian	2	Coachwood (<i>Ceratopetalum apetalum</i>)	50.0 (30.0)	4.5 (0.5)

^a Included are the mean values and standard errors for two of the environmental variables that best explain the differences between the communities. Topographic position was coded: 1 = ridge, 2 = upper slope, 3 = mid slope, 4 = lower slope, 5 = creek/valley.

Five vascular plant communities were defined at the 0.75 level of Bray–Curtis dissimilarity (Table 1) and seven groupings based on overstorey species only were defined at the 0.8 level of Bray–Curtis dissimilarity (using average-linking clustering: flexible Unweighted Pair Group Metric Averaging (UPGMA), $\beta = 0$, Bray–Curtis association measure, Belbin, 1991a,b). One of the riparian sites separated out from all other sites at dissimilarities of over 0.85 for both the groups ‘all vascular plants’ and overstorey species. Rather than include it as a singleton group, it was excluded from further analysis.

We tested for significant differences in bryophyte and lichen species richness between the pre-defined vascular plant communities using analysis of variance. Differences in bryophyte and lichen species composition between vascular plant communities were investigated using ‘analysis of similarities’ (ANOSIM, Clarke, 1993). ANOSIM is a distribution-free analogue of a one-way ANOVA that compares average rank similarities within pre-selected groups to average rank similarities between groups. ANOSIM constructs a test statistic (R) that is close to 1 if sites within groups, in this case vascular plant communities, have a similar species complement compared to sites in different groups. If there is little difference in the species composition within groups compared to between groups, then R is approximately zero. A significance level for R was generated using 5000 random permutations of the original groups. ANOSIM does not adjust the significance levels of pairwise tests to allow for multiple comparisons, therefore, *P*-values close to 0.05 should be interpreted with caution (Clarke, 1993).

3. Results

3.1. Selection using vascular plant richness

In total we found 472 vascular plant species, 78 bryophyte species and 69 lichen species. Of the vascular

plants, 44 were overstorey species. Neither vascular plant genus nor species richness varied greatly between the 35 sites and any variation present was not significantly correlated with variation in bryophyte or lichen species richness or composition (Table 2). If sites were chosen for reservation solely on the basis of their species richness for vascular plants, 32 sites would be needed to reserve all bryophytes once, since one of the irreplaceable sites was ranked 32nd in species richness. Similarly, for lichens and overstorey species, some of the species-poor sites contained unique species and therefore 29 and 33 sites were required to reserve all lichens and overstorey species respectively. Therefore, vascular plant richness was not a good surrogate for bryophyte and lichen species richness, composition or site irreplaceability.

3.2. Selection using heuristic minimum reserve sets

Each site had at least one unique vascular plant species and therefore all 35 sites were required to include

Table 2

Pearson correlations (*r*) between vascular plant richness, and bryophyte and lichen species richness, composition and irreplaceability

		‘All vascular plant’ richness		Overstorey richness
		Genus	Species	Species
Species richness	Bryophyte	0.26 ^b	0.24	0.41*
	Lichen	−0.33	−0.28	−0.07
Species composition ^a	Bryophyte	0.41	0.38	0.29
	Lichen	0.59**	0.53***	0.31
Irreplaceability	Bryophyte	0.08	0.08	0.23
	Lichen	−0.19	−0.14	0.02

^a Composition was quantified using the site scores of a 2-dimensional ordination (MDS).

^b Figures without asterisks indicate that the correlation was not significant at the $\alpha = 0.05$ level.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

the regional diversity in a set of sites. Although vascular plant species were still being added at the 35th site, the last four sites added only one species each (Fig. 2). In contrast, much lower numbers of sites were required to include at least one of each overstorey species (18 sites), bryophyte species (19 sites) and lichen species (18 sites).

With a reservation target of 90% of all vascular plants, rather than all species, the heuristic algorithm found that 20 sites were needed in the set. These captured 51 of the 78 bryophytes found (65%) and 60 of the 69 lichens (87%). The 18 sites required to reserve all overstorey species at least once captured 56 bryophyte species (72%) and 61 of the lichen species (88%).

3.3. Selection using irreplaceability

Examination of the ‘irreplaceable’ sites for overstorey species (sites required to capture all the overstorey species at least once), found that there were 17 species of bryophyte and lichen that were not found at any of these sites. This figure represents 9 species of bryophyte (*Barbula australasiae*, *Barbula* sp. A, *Cryphaea dilitata*, *Fissidens subhumilis*, *Grimmia pulvinata*, *Isopterygium limatum*, *Lethocolea squamata*, *Orthodontium lineare*, *Sematophyllum contiguum*) and 8 species of lichen (*Cladonia praetermissa*, *Cladonia ochrochlora*, *Hypocenomyce cf. scalaris*, *Hypotrachyna* sp. A, *Neophyllis melacarpa*, *Parmelia erumpens*, *Pertusaria gibberosa*, *Pertusaria schizostomella*). All sites were irreplaceable for the group ‘all vascular plants’ because unique species were present at all 35 sites.

Lichen and overstorey irreplaceabilities were close to being significantly correlated ($r=0.301$, $P=0.079$, $n=35$), but bryophyte and overstorey irreplaceabilities were not ($r=0.211$, $P=0.224$, $n=35$). A significant

positive correlation would mean that sites valuable for overstorey conservation also tended to be valuable for bryophyte or lichen conservation. There was an even poorer correlation between bryophyte and lichen irreplaceabilities ($r=-0.047$, $P=0.787$, $n=35$).

3.4. Selection using vascular plant communities

Bryophyte and lichen species richness was highly significantly different between the five vascular plant communities (bryophyte: $df=4$, $F=5.75$, $P=0.002$; lichen: $df=4$, $F=10.38$, $P<0.001$). There were also significant differences in both bryophyte and lichen species composition between the five vascular plant communities (bryophyte: $R=0.386$, $P<0.001$; lichen: $R=0.268$, $P<0.001$; Fig. 3). Five of the ten pair-wise community comparisons had significantly different bryophyte communities and eight of the ten had significantly different lichen communities (Table 3). Overstorey communities also describe significant variation in bryophyte and lichen species composition (bryophyte: $R=0.252$, $P=0.002$; lichen: $R=0.237$, $P=0.002$).

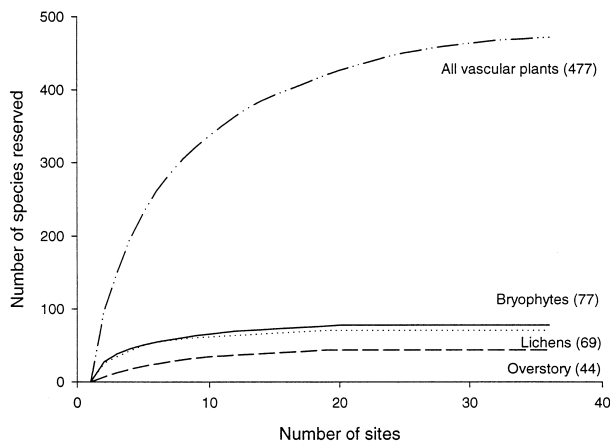


Fig. 2. Species accumulation curves generated using the heuristic algorithm for bryophytes, lichens, overstorey species only and all vascular plants. The number in brackets is the total number of species found in the 35 sites.

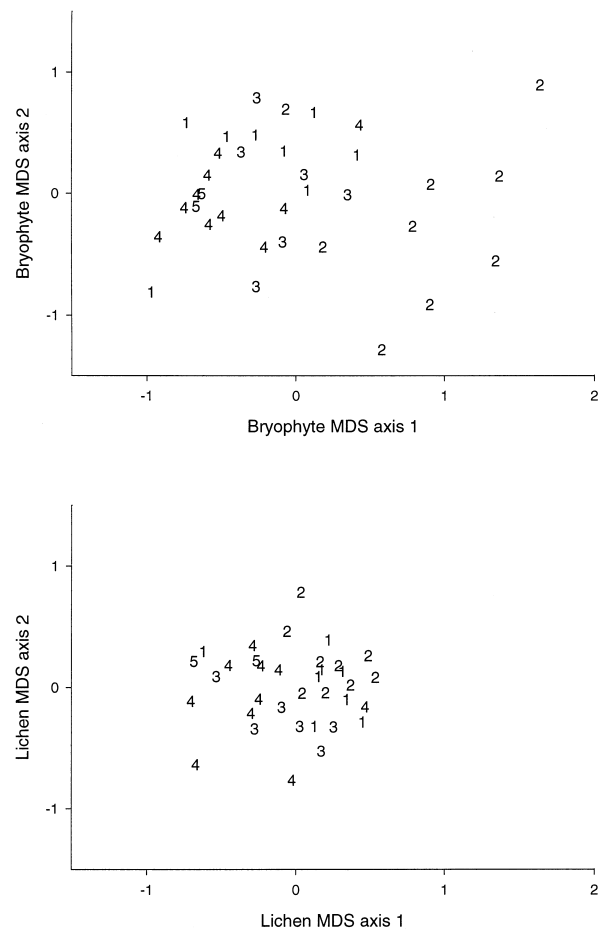


Fig. 3. Ordination diagrams for bryophyte and lichen data with sites labelled by their vascular plant group.

Table 3

ANOSIM results for the difference in bryophyte and lichen communities between the seven 'all vascular plant' communities (R)^a

Forest type	1	2	3	4	5	6
1	■	0.43*	0.71*		0.38*	0.69*
2		■			0.54*	0.39***
3			■	0.56*	0.82*	0.50***
4	0.26***	0.43**	0.35***	■	0.21***	0.31***
5	0.38*	0.34***	0.43**		■	
6	0.67*	0.77**		0.49***		■

^a Bryophyte results are above the diagonal and lichen results are below. A blank indicates there was no significant difference between the communities. For pairs of forest types that include community 5 which has only 2 sites, there are a limited number of possible permutations to compare the coefficient 'R' with, therefore *P*-values appear low.

P* < 0.05, *P* < 0.01., ****P* < 0.001.

4. Discussion

Vascular plants were shown to be reasonable surrogates for bryophytes and lichens using minimum sets of species, irreplaceable sites, and compositional dissimilarity, but not species or generic richness. The group 'all vascular plants' has an order of magnitude more species than bryophytes or lichens, therefore, is it not surprising, that vascular plants cover the variation of the other groups. However, vascular plants were still able to explain highly significant variation in bryophyte and lichen species diversity (both richness and composition) when the data were summarised using site dissimilarity indices. Overstorey species, the least rich of the four groups, also captured significant variation in the species composition of bryophytes and lichens. Therefore, there appears to be good evidence for a general coincidence in species patterns of these vascular and non-vascular groups. In comparison with what appears to be strong similarities in the vascular plant, bryophyte and lichen communities found in different rainforest types in Tasmania (Jarman and Kantvilas, 1994), the coincidences here are weaker.

In comparison to the species composition results, species richness of vascular plants alone was found to be less effective at capturing bryophyte and lichen diversity. Methods that take species identity into account, such as analysis of similarities (ANOSIM) and ordination, are well established as being preferable to simple measures of species richness in reserve selection (Pressey et al., 1993; Faith and Walker, 1996; Williams et al., 1996). However, in turn, these techniques are relatively insensitive at detecting overlaps in unique species or nearly unique species, depending on the relative abundance of the species in question. Reserve selection procedures appear to be a useful complement to techniques

that measure general overlaps. Measures such as irreplaceability are not informative about the general match of assemblages, but are able to detect slight mismatches that could be significant, e.g. when a unique species in one group is not coincident with a unique species in other groups. These methods also yield figures that are more easily interpreted than correlation coefficients.

In this study, there were 17 species of bryophytes and lichens that were not included in a reserve set chosen to include all overstorey species at least once. None of these species found in this study appear to be rare, although one of the species captured by the reserve set is a tropical species at the southern limit of its range (Pharo, 1996). Since most of the bryophytes and lichens found in this study were quite common, non-overlaps with vascular plant groups are perhaps of no special concern.

On the much larger scales that reserve decisions are made, the weakness of the coincidence and the number of unique species not coincident with the vascular plant sets may be of more concern. Specific measures need to be taken to include sites important for the conservation of bryophytes and lichens. Our study had a limited sample size (35 sites), however, these sites were representative of the major forest types in the study area, including riparian areas. Therefore, a more intensive sampling regime would not necessarily discover additional irreplaceable sites and is unlikely to change the pattern and strength of overlap reported here. Forest managers made specific recommendations for the conservation of unusual vascular plants in this study, and particular importance was attached to uncommon tree species (Binns, 1996). Our data show that bryophytes and lichens should be similarly treated. This is often difficult in practice, since on a statewide scale, the conservation status of many bryophytes and lichens is unknown.

We hypothesised in an earlier paper that because lichens have strong similarities in species composition between sites (Pharo and Beattie, 1997) and are tolerant of a wide variety of conditions (Hale, 1967; Pritchard and Bradt, 1984), fewer sites should be required for their reservation. Here we have shown that this is not the case, but that similar numbers of sites were required to reserve overstorey vascular plants, bryophytes and lichens. Only one less site was required to reserve all lichens than to reserve all bryophytes. Instead the difference between the two groups was revealed in terms of the 'flexibility' of the reserve solution (Pressey et al., 1993). These results (not reported in this paper) show that there were 14 minimum reserve set solutions for lichens indicating a great flexibility or substitutability of one site for another in a reserve set (Pharo, 1996). In contrast, only four solutions were available for bryophytes and only one solution for overstorey vascular plant species.

We have shown that vascular plant species are a reasonable surrogate for bryophytes and lichens using minimum reserve sets, irreplaceable sites and compositional dissimilarity. The patterns of species composition were found to be highly significantly correlated, and the sites most species-rich in vascular plants generally contained bryophytes and lichens not found elsewhere, and were, therefore, irreplaceable in a reserve set. However, many of the species-poorer sites also harboured unique bryophytes and lichens and were also irreplaceable. Further investigation of the importance of suitable microhabitat in determining regional patterns of bryophyte and lichen species distributions may point to some of the differences in conservation strategies required for bryophytes and lichens.

The extent to which these results are transferable to other forests types and other vegetation types will depend what the controlling factors are for each group: vascular plants, bryophytes and lichens. Earlier work showed that time since fire and topographic position are important explanatory variables of the species diversity of all three groups (Pharo et al., 1999). If the provision of microhabitat were to explain an additional and substantial portion of the observed variance, then it may be important to firstly compare the general character of these forests and secondly, the diversity and types of substrate available.

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