

A morphometric study of *Breutelia pendula* and *B. elongata* (Bryophyta, Bartramiaceae)

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Abstract. A morphometric study of the mosses *Breutelia pendula* (Sm.) Mitt. and *B. elongata* (Hook.f. & Wilson) Mitt. was conducted in order to investigate the species delimitation between these two species, and to ascertain the status of *B. elongata* in Australia, in particular Victoria. As a result, *B. elongata* is no longer considered to occur in continental Australia. Useful characters to distinguish between the newly circumscribed species include the size of the marginal teeth, whether or not the alar cells are inflated, the leaf width and the set of the leaves. *Bartramia crassa* Hook.f. & Wilson, which was previously considered a synonym of *B. elongata*, is synonymised with *B. pendula*.

Introduction

Breutelia pendula (Sm.) Mitt. and *B. elongata* (Hook.f. & Wilson) Mitt. are large terrestrial mosses that occur at high altitudes or high latitudes in Australia and New Zealand, and, in the case of *B. elongata*, also southern South America. According to the recent treatment of the genus for 'Flora of Australia' (Gilmore 2006) *B. pendula* is widely distributed in Tasmania and south-eastern Australia, while *B. elongata* in continental Australia is restricted to Tasmania.

Although herbarium specimens from Victoria in the National Herbarium of Victoria (MEL) have been identified as *B. elongata* for several years, the first published report of this species for mainland Australia is very recent (Meagher 2005). Meagher (2005) considered three Victorian specimens from Mt Buffalo and the Blue Range as the only Australian mainland records of *B. elongata* and discarded all earlier Australian mainland records of *B. elongata* as large forms of *B. pendula*. Consequently, *B. elongata* is considered vulnerable in Victoria and has been nominated for listing as threatened under the Victorian Flora and Fauna Guarantee Act 1988 (Department of Sustainability and Environment 2005).

When one of us was asked for advice on this nomination, several Victorian collections in MEL were examined and it was found that, while the specimens identified as *B. elongata* are quite different from specimens more typical of *B. pendula*, there are intermediates and the variation in putatively diagnostic features is fairly continuous. Hence, a morphometric study of *B. pendula* and *B. elongata* was undertaken to investigate the species delimitation between these two species, to evaluate the diagnostic value of characters traditionally used to distinguish the two species, and to ascertain the status of *B. elongata* in Australia, in particular Victoria.

Griffin and Buck (1989: fig. 15) illustrated an axillary hair of *B. elongata*. To our knowledge axillary hairs in *B. pendula* have not been studied before. Although Griffin and Buck (1989)

indicate that axillary hairs are diagnostic mainly at the generic level, their illustrations (Griffin and Buck 1989: figs 13–18) show considerable variation among species of *Breutelia*. In order to evaluate the value of axillary hairs as an independent character to differentiate between *B. pendula* and *B. elongata*, a complementary survey of axillary hairs in these species was conducted.

Material and methods

Specimens

Morphometric data were collected from a total of 71 collections determined as *Breutelia pendula* or *B. elongata* from the following herbaria: ADT, BM, CANB, H, MEL, MELU and NY. Voucher information is given in Appendix 1. Specimens were chosen to represent a good coverage of the geographic distribution of both species and included collections from mainland Australia (24), Tasmania (18), New Zealand (including Auckland and Campbell Islands; 19) and subantarctic Macquarie Island (10). All Victorian specimens identified as *B. elongata* were included in the study. All Tasmanian collections were examined, but 14 of these were considered a sufficient sample for the morphometric analysis.

The specimens scored included the types of *Hypnum elongatum* Hook.f. & Wilson, *Bartramia crassa* Hook.f. & Wilson, and *Breutelia fuscaurea* Broth.

Characters

Characters included in the morphometric analysis are listed in Table 1. A total of 25 characters were scored, including 19 metric (1–19) and six non-metric (20–25) characters. All leaf characters were recorded from five leaves, taken from three shoots where practicable. Microscopic characters were averaged over five measurements that covered the range of variation present in the specimen. The size of the plant (character 1) and size of the leaves (2, 3) were measured under a dissecting microscope. All other

Table 1. Characters measured for morphometric study

Characters 1–19 are metric characters; characters 20–25 are non-metric characters

#	Character
1	Plant size (mm)
2	Leaf length (mm)
3	Leaf width (mm)
4	Distance from insertion to widest part of leaf (mm)
5	Width of insertion (mm)
6	Width of costa at leaf base (μm)
7	Width of costa where leaf is widest (μm)
8	Length of alar cells (μm)
9	Width of alar cells (μm)
10	Number of rows of alar cells
11	Extent of alar cells (fraction of leaf length)
12	Length of marginal teeth (μm)
13	Width of marginal teeth (μm)
14	Upper lamina cell length (μm)
15	Upper lamina cell width (μm)
16	Upper lamina cell wall thickness (μm)
17	Basal lamina cell length (μm)
18	Basal lamina cell width (μm)
19	Basal lamina cell wall thickness (μm)
20	Presence of tomentum
	1. present
	2. absent
21	Shape of leaf insertion
	1. straight
	2. slightly rounded
	3. rounded
22	Extent of costa
	1. percurrent
	2. short-excurrent
	3. long-excurrent
23	Pittedness of upper lamina cells
	1. not pitted
	2. weakly pitted
	3. pitted
	4. strongly pitted
24	Pittedness of basal lamina cells
	1. not pitted
	2. weakly pitted
	3. pitted
	4. strongly pitted
25	Set of leaves
	1. falcate-secund
	2. not falcate-secund, more or less squarrose

metric characters were measured under a compound microscope. Basal lamina cells were measured half-way between the base of the leaf and the widest part of the leaf (Fig. 1). Upper lamina cells were measured in the upper half of the leaf, as were the marginal teeth (Fig. 1). The characters that were scored include all characters that have been considered to be of diagnostic value by previous workers, except the plications of the leaves. Plication of the leaves could not be scored in a meaningful way and moreover was found to vary greatly even within a single specimen.

Pattern analysis

Pattern analysis was undertaken using PATN (Belbin 2004). Association among collections was calculated using the Gower

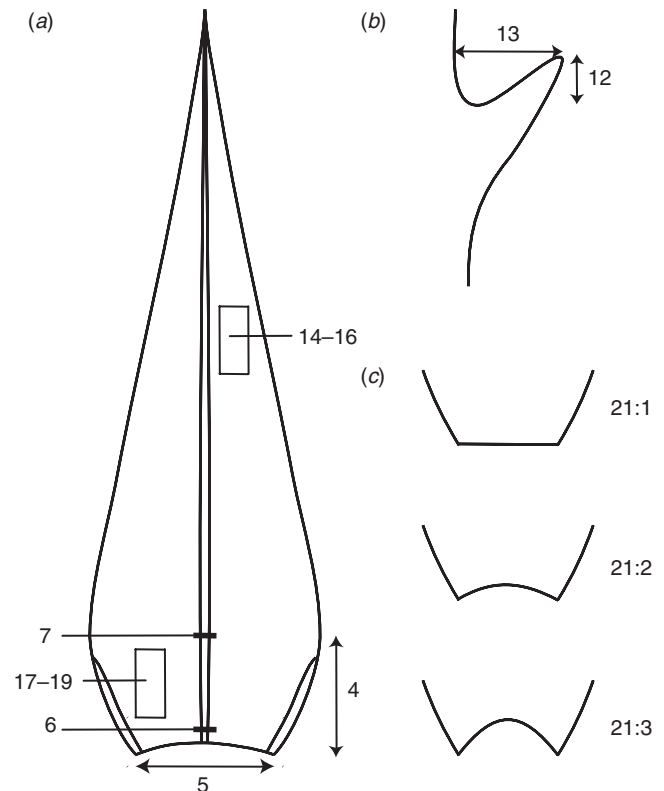


Fig. 1. Schematic drawings of (a) leaf, showing how characters 4 and 5 are measured and locations where characters 6, 7, 14–16 and 17–19 are measured; (b) marginal tooth, showing how characters 12 and 13 are measured; (c) leaf base, showing how character 21 is scored. Characters numbered as in Table 1.

Metric association measure (Gower 1971). Each character contributes equally to the Gower Metric independently of the range of variation in the character and equal differences between values of a character have an equal impact on the metric irrespective of the values. Hierarchical cluster analysis was performed using flexible UPGMA. A slightly dilating value of β (-0.1 , PATN's default for flexible UPGMA) was used to counteract the known underestimation of larger association values. Ordination was carried out by Multidimensional Scaling (MDS). Unlike some other ordination methods, MDS does not require multivariate normality, nor does it require each character to be normally distributed. The only requirement made of the variables is that they are meaningful. PATN performs Semi-strong Hybrid Multidimensional Scaling (SSH), which employs a combination of both metric and non-metric regression. The recommended threshold of 0.9 means that for the present dataset only metric regression is used. In this study a three-dimensional MDS was performed, with 50 iterations and 20 random starts.

In the main analysis all characters were included, except character 20. Character 20, the presence or absence of stem tomentum, was excluded as it showed little variation among the objects. A second analysis was performed which included only characters 2, 3, 5, 6, 9, 13, 14, 15, 16, 21, 23, and 25.

The excluded characters include those that were expected to be strongly correlated with included characters and those with non-significant Monte-Carlo Attributes in Ordination (MCAO; see below) results in preliminary analyses.

Character evaluation

Character evaluation consisted of Principal Component Correlation (PCC) and Kruskal–Wallis tests. PCC uses multiple linear regression to place variables into the ordination space. It calculates the direction of best fit of the variables to the ordination and the correlation of the variable with that direction (r). The coefficient of determination (r^2) of a character may be seen as an indication of the part of the variation in the direction of best fit explained by that character: characters with higher r^2 explain more of the variation. Values of r^2 range from 0 to 1. MCAO was used to test the robustness of the PCC. For each variable, MCAO performs several iterations distributing the values of a variable randomly over the objects and performs PCC on the randomly permuted variables and counts the number of iterations for which r^2 exceeds the actual r^2 of the character. In the present study MCAO comprised 1000 iterations.

While PCC gives an indication of the amount of variation explained by each character, the Kruskal–Wallis statistic (KW) was calculated for each character in order to give an indication of how well characters differentiate between the groups resulting from the pattern analysis. The Kruskal–Wallis statistic uses ranked variables and its value is limited by the number of objects and the number of groups. Characters with high KW values may be considered more useful to differentiate between groups than those with lower KW values. Kruskal–Wallis statistics were calculated and Kruskal–Wallis tests were performed with the Analyse-it add-in for Microsoft Excel (Analyse-it Software Ltd 2006). As an extension to the Kruskal–Wallis tests, pairwise comparisons between groups were made by calculating the difference in mean rank of the groups. These contrasts were then tested for significance using the Conover procedure and Bonferroni-corrected experiment-wise error rates.

Axillary hairs

In order to evaluate the value of axillary hairs as an independent character to differentiate between *B. pendula* and *B. elongata*, axillary hairs were studied in several collections included in the morphometric study. As axillary hairs have not been examined in all material, their characters were not included in the pattern analysis.

Results

Cluster analysis

After visual inspection of the cluster phenogram four groups were recognised at 0.34 dissimilarity (Fig. 2). At this level of dissimilarity a morphological discontinuity is found, indicated by an abrupt increase in increments in dissimilarity as fusion progresses. Below 0.34 the increments are between 0 and 0.036, while above 0.34 they are between 0.083 and 0.154, or at least twice as large. Many of the increments between 0.08 and 0.20 dissimilarity are 0 or very small, indicating that there may be

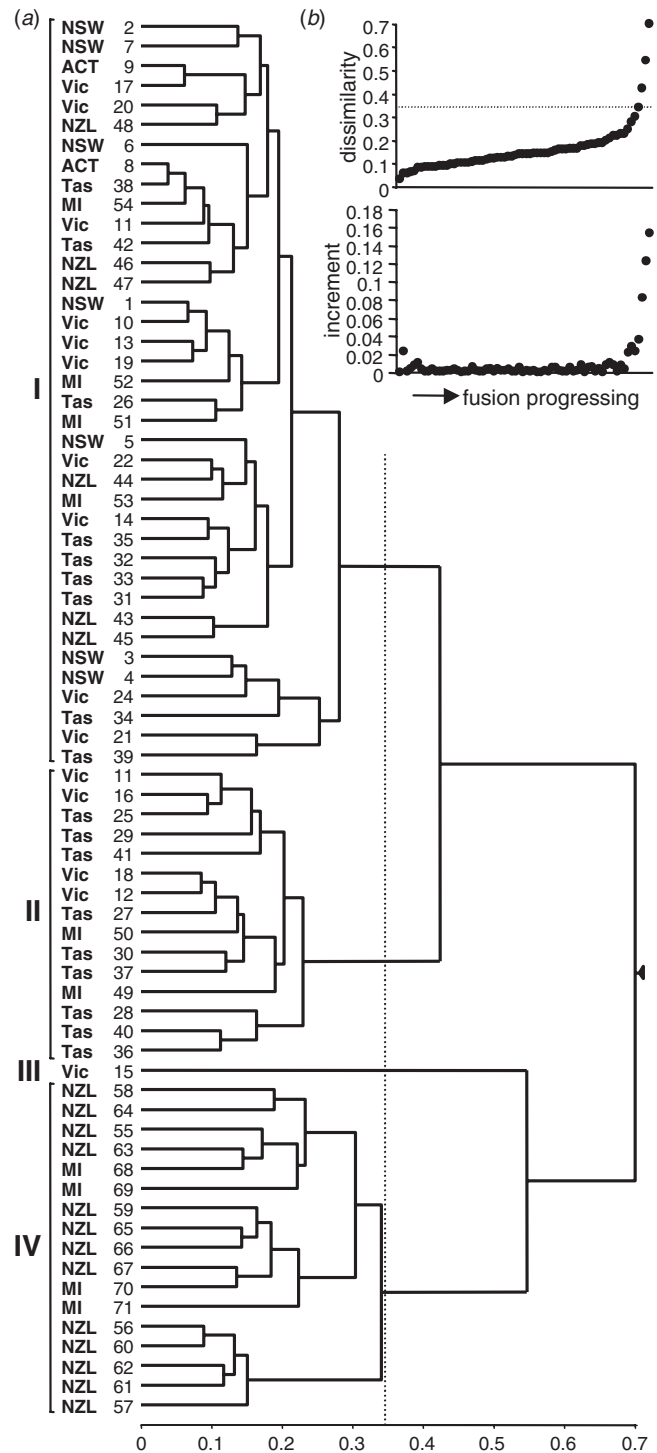


Fig. 2. Cluster phenogram of 71 specimens of *Breutelia pendula* and *Breutelia elongata*, by flexible UPGMA ($\beta = -0.1$) with Gower metric association values, and with all characters except 20 included. (a) Phenogram; (b) graphs of level of dissimilarity (top) and increments in dissimilarity (bottom) as fusion progresses. Four groups, I–IV, were recognised at dissimilarity 0.34. Objects are numbered as in Appendix 1. NSW, New South Wales; ACT, Australian Capital Territory; Vic, Victoria; Tas, Tasmania; NZL, New Zealand, including Auckland Islands and Campbell Island; MI, Macquarie Island.

ties and that some of the groupings at these intermediate levels are arbitrary.

Group I contains specimens from mainland Australia, Tasmania, New Zealand (including Auckland Islands and Campbell Island), and Macquarie Island. Group II contains specimens from Victoria and Tasmania, plus two specimens from Macquarie Island. Group III consists of a single specimen from Mt Baw Baw, Victoria. Group IV contains specimens only from New Zealand and Macquarie Island.

Groups I and II group together. Group III clusters with group IV, but the single specimen making up this group is an outlier and its clustering with group IV is artefactual. When β is set to 0 this specimen is the last one to agglomerate.

Hierarchical clustering with only characters 2, 3, 5, 6, 9, 13, 14, 15, 16, 21, 23 and 25 included yields the same group composition and the same relationship between groups I, II, and IV. However, group III fuses with group I and when β is set to 0 with groups I and II.

Ordination

Figure 3 shows the results of MDS of the dataset with all characters except 20 included. Group IV is clearly separated from groups I and II, while groups I and II are more weakly separated in the ordination plot. The outlier position of group III, specimen 17, is confirmed by the ordination. Stress of this ordination is 0.13. Exclusion of uninformative variables and variables that were expected to be strongly correlated with others before the analysis reduces stress to 0.09. The separation between group IV and groups I and II becomes slightly wider, while the separation between groups I and II remains

unchanged. Group III is now slightly closer to group I, but is still an outlier.

Character evaluation

Results of the character evaluation are given in Table 2. PCC r^2 and MCAO values are given for the ordination in which all variables (except 20) are intrinsic. Almost all characters show high correlation with ordination space as indicated by high r^2 values, only the presence or absence of stem tomentum (20, extrinsic) and the extent of the costa (22) having non-significant MCAO values (MCAO > 5%). Furthermore, plant size (1) has a low r^2 and will have contributed little to the position of objects in ordination space. The same three variables are the only ones that have non-significant Kruskal–Wallis values ($P > 0.05$).

While the values of the Kruskal–Wallis statistics tell us how much of the among-group variation in each character is unaccounted for by within-group variation, pairwise contrasts between groups were calculated for each character in order to ascertain which characters differentiate between which groups. As group III contains only a single object, comparisons involving this group will never yield a significant contrast and contrasts involving group III are not shown in Table 2, although they have been calculated, thereby increasing the number of pairwise comparisons and hence decreasing the experiment-wise error rate, making it less likely for other groups to show significant contrasts.

Significant contrasts between groups I and IV and groups II and IV are found in the length and width of the marginal teeth (12, 13) and the set of the leaves (25), and to a lesser extent the length and width and number of rows of alar cells (8, 9, 10), leaf width (3), the width of the leaf insertion (5) and the distance from insertion to the widest part of the leaf (4). Marginal teeth in group IV are significantly longer (Fig. 4f) and wider than in groups I and II, while they are similar in size in groups I and II and there is very little overlap between groups I and II on the one hand and group IV on the other. In group IV the leaves are wider (Fig. 4b) and the alar cells longer and wider (Fig. 4e) than in groups I and II, but in these characters there is overlap and group II is intermediate between groups I and IV. The number of rows of alar cells tends to be higher in group IV than in group II, but the number of rows of alar cells in these groups overlap completely with that of group I. The distance between the insertion of the leaf and the widest part (Fig. 4c) is most variable in group I, while in group II it is at the upper end of that in group I and in group IV in the lower end or shorter. The width of the leaf insertion is similar in groups I and II, but wider in group IV, although there is considerable overlap. In all but two objects (both in group I) in groups I and II the leaves are more or less squarrose and in all but three objects in group IV the leaves are falcate-second (Fig. 4j).

Costa width, both at leaf base (6) and where the leaf is widest (7), length of the basal lamina cells (17) and the shape of the leaf insertion (21) differ significantly between groups I and IV, but not between groups I and II or between II and IV. Group IV has a wider costa, both at the base and in the widest part of the leaf (Fig. 4d), and longer basal lamina cells than both groups I and II. The length of the basal lamina cells of group II is intermediate between and overlaps completely with that of groups I and IV.

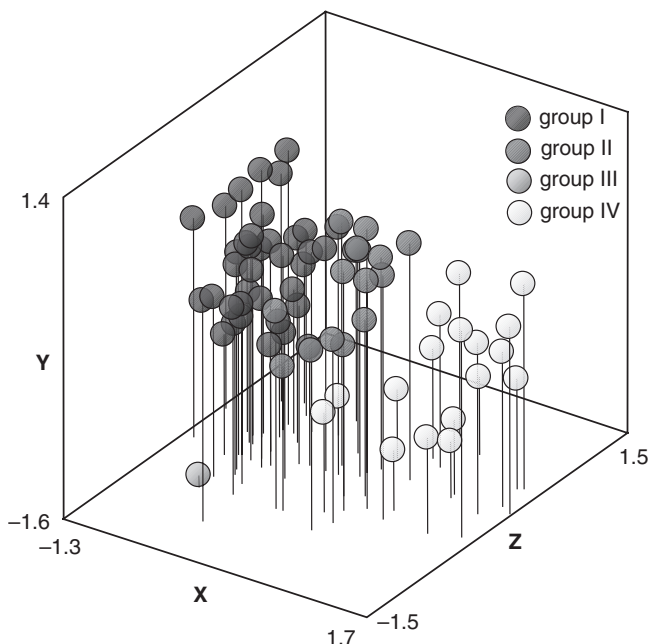


Fig. 3. Ordination of 71 specimens of *Breutelia pendula* and *Breutelia elongata*, by Semistrong Hybrid Multidimensional Scaling (threshold = 0.9) with three dimensions, association calculated using the Gower metric, and all characters except 20 included. Stress: 0.1278. Groups as in Fig. 2.

Table 2. Results of the character evaluations

KW, Kruskal–Wallis statistic; PCC r^2 , coefficient of determination in direction of best fit, calculated by PCC; MCAO, percentage of replicates with characters with permuted values of which r^2 exceeds actual r^2 , calculated by MCAO with 1000 replicates. * $0.01 \leq P < 0.05$; ** $0.001 \leq P < 0.01$; *** $P < 0.001$. Variables are numbered as in Table 1

Variable	KW	Contrasts ^A			PCC r^2	MCAO (%)
		I v. II	I v. IV	II v. IV		
1	2.96	0.06	−0.76	−0.82	0.162	0.9
2	40.97***	−22.04**	−35.96***	−13.92	0.761	0
3	36.60***	−14.51	−34.92***	−20.42*	0.862	0
4	14.43**	−6.69	16.63*	23.33**	0.424	0
5	19.32***	−2.57	−24.35***	−21.77*	0.822	0
6	13.01**	−1.83	−18.70*	−16.86	0.764	0
7	14.12**	−4.71	−20.06**	−15.34	0.605	0
8	39.06***	−13.30	−36.22***	−22.92*	0.722	0
9	37.38***	−13.33	−35.46***	−22.13*	0.696	0
10	39.06***	−13.30	−36.22***	−22.92*	0.260	0
11	8.12*	5.32	14.70	9.38	0.313	0
12	40.60***	7.57	−33.35***	−40.92***	0.582	0
13	39.05***	5.04	−33.83***	−38.87***	0.608	0
14	34.40***	−22.34**	−32.49***	−10.15	0.675	0
15	10.35*	12.32	14.32	2.01	0.547	0
16	11.71**	−15.05	−14.79	0.25	0.593	0
17	16.98***	−9.50	−22.56**	−13.06	0.269	0
18	11.96**	18.68*	3.19	−15.49	0.488	0
19	13.10**	−18.72*	−13.01	5.70	0.662	0
20	0.61	−1.43	−1.15	0.28	0.019	77.8
21	29.98***	−13.27	−28.57***	−15.30	0.574	0
22	7.67	2.57	−11.45	−14.02	0.071	20.1
23	58.47***	−37.70***	−32.77***	4.94	0.797	0
24	57.29***	−36.11***	−34.09***	2.02	0.809	0
25	45.35***	1.87	−27.37***	−29.24***	0.632	0

^A $n_I = 38$; $n_{II} = 15$; $n_{III} = 1$; $n_{IV} = 17$. Contrasts between group III and other groups, none of which is significant, are not shown.

Costa width of group II is in the higher end of the range of that of group I. The leaf insertion is straight to slightly rounded in group I and straight to rounded in groups II and IV (Fig. 4h). However, all but one objects in group II have straight to slightly rounded insertions, while most objects in group IV have rounded insertions.

Significant contrasts between groups I and II and between groups I and IV are found in the length of the leaves (2) and the upper lamina cells (14) and in the pittedness of both the upper (23) and basal lamina cells (24). Group I has shorter leaves and upper lamina cells (Fig. 4g) than groups II and IV, but for both metric characters there is much overlap between the groups and group II is intermediate between groups I and IV. Upper and basal lamina cells are not pitted to weakly pitted in group I, pitted to strongly pitted in group II and weakly to strongly pitted in group IV (Fig. 4i).

The width of the basal lamina cells (18) and the thickness of the walls of the basal lamina cells (19) differ significantly between groups I and II only. No significant contrasts were found in the extent of the alar cells (11) and the width and wall thickness of the upper lamina cells (15, 16).

Axillary hairs

Axillary hairs in both *B. pendula* and *B. elongata* consist of several brown-walled basal cells and one or more hyaline, more or less inflated top cells. The numbers of both basal and top cells are variable. Axillary hairs in groups I and II have 2–4(–5) basal

cells and a single top cell. Axillary hairs in group IV are generally longer than in groups I and II and consist of 2–5 coloured basal cells and (1)–2–4 hyaline top cells. No differences were found between axillary hairs in groups I and II. Some examples of axillary hairs are illustrated in Fig. 5. For comparison, a single axillary hair of the common Australasian species *B. affinis* (Hook.) Mitt. is illustrated as well.

Discussion

Species delimitation

Four groups were recognised from the cluster analysis. Group IV contains the type of *Hypnum elongatum* (objects 63, 64), and hence corresponds with *B. elongata*. The type of *Mnium pendulum* Sm. was not located, but objects in group I share the characters that have traditionally been associated with *B. pendula*, so group I corresponds with this species. Group II contains both included specimens on which Meagher's (2005) Victorian report of *B. elongata* was based (objects 12, 18), plus many other Victorian and Tasmanian collections that have previously been identified as *B. elongata*. Hence, group II corresponds with *B. elongata* as it has been recognised in Australian treatments (Scott and Stone 1976; Gilmore 2006).

The cluster analysis shows that specimens that have been recognised as *B. elongata* in Australia (group II) are more similar to 'typical' *B. pendula* (group I) than to *B. elongata*

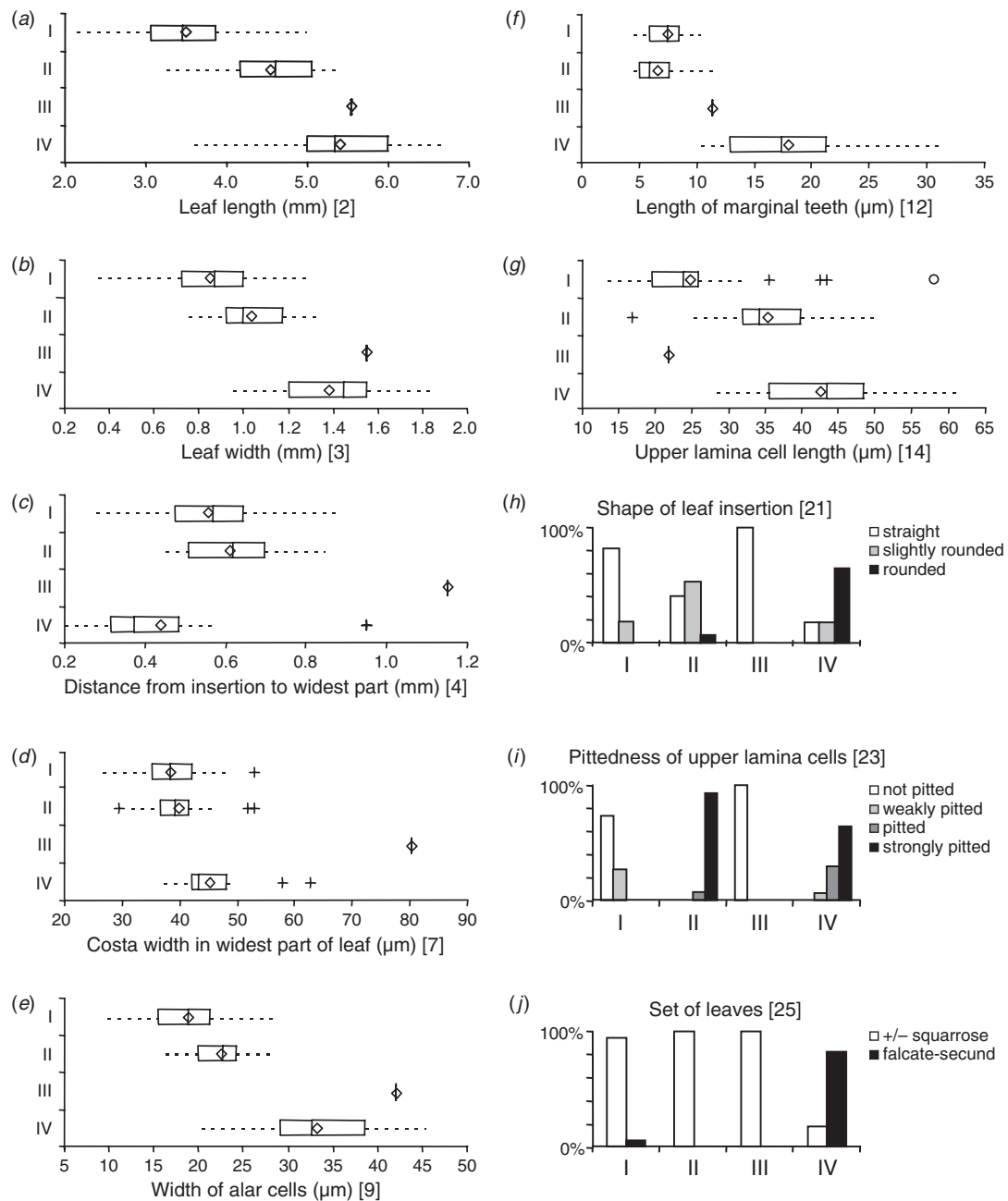


Fig. 4. Box-and-whisker plots and histograms for selected metric and non-metric variables. Box-and-whisker plots: means are indicated by diamonds (\diamond), medians by vertical lines ($|$); boxes represent the interquartile range (IQR); dotted lines connect the observations within 1.5 IQRs from the lower and upper quartiles; crosses (+) and circles (\circ) indicate possible outliers: observations more than 1.5 and 3.0 IQRs away, respectively, from the quartiles. Groups I–IV as in Fig. 2.

(group IV) (Fig. 2a). In the ordination, while *B. elongata* is clearly separated, objects belonging to groups I and II do not form separate clouds, although they spread to opposite ends of the same cloud. Few characters show significant contrasts between the two groups and all of these show large overlaps. While group II is intermediate between groups I and IV in many individual characters, the ordination scattergram shows that it is no longer intermediate when the whole of the morphology is

considered, as objects in groups I and II spread in a different direction from that in which group IV is separated.

The morphological gap between groups I and II found in the cluster analysis, as indicated by the large increment in dissimilarity between the dissimilarity level where group IV is formed and that where groups I and II agglomerate, may be an artefact of the value of β used (-0.1) and the inclusion of an outlier. When β is set to 0, groups I and II, while still visible in

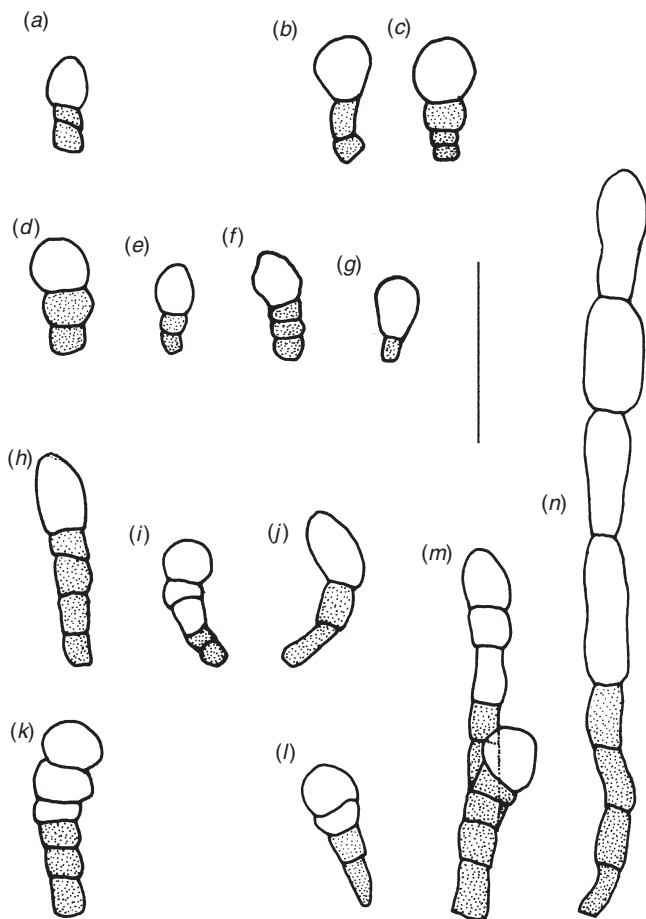


Fig. 5. Axillary hairs. (a) *Breutelia affinis*; (b, c) *Breutelia pendula*, group I; (d–g) *B. pendula*, group II; (h–n) *B. elongata*. (a) Australia, Victoria, Mount Cole State Forest, 28 km E of Ararat, *H. Streimann 55442* (MEL 2053250); (b) MEL 2075767 (44); (c) CBG 7906717 (7); (d) CBG 9004075 (25); (e) CBG 8205871 (36); (f) MUCV 7214 (18); (g) MUCV 3742 (12); (h) ADT [*R.D. Seppelt 21433*] (66); (i) ADT [*R.D.S. 21460*] (67); (j) CBG 9306624 (61); (k) CANB 266352 (60); (l–n) ADT [*R.D.S. 21471*] (65). Scale bar = 50 μ m.

the phenogram, are not recognised at any level of dissimilarity, as there are two subgroups of group IV that agglomerate at a higher level of dissimilarity. On the other hand, when the outlying specimen (object 15) is excluded, even with a value of β of -0.1 , the difference in dissimilarity between where groups I and II agglomerate and the previous agglomeration is still larger than all increments at lower levels of dissimilarity, but not that much, and more than three times as small as the next increment. We do not expect a genetic basis to these groups and find splitting of *B. pendula* into two species, or at the infraspecific level, not warranted.

The specimen that is considered an outlier (15) was found in a swamp on Mt Baw Baw, Victoria. The specimen is the largest specimen measured and for many of its characters the values are among the highest we found, even for characters that generally have lower values in *B. elongata* than in *B. pendula*. The non-metric characters agree with *B. pendula*. While *B. pendula* is

found regularly in swamps at higher latitudes (Seppelt 2004) this is not the case in mainland Australia. We believe this strange form of *B. pendula* is habitat-induced.

Two more types were included in the morphometric study. The type of *Breutelia fuscoaura* (4) groups with group I, and the type of *Bartramia crassa* (39), from Tasmania, with group II. While *B. fuscoaura* was already considered a synonym of *B. pendula*, *Bartramia crassa* was synonymised with *B. elongata* by Sainsbury (1955b). Like other specimens in *B. pendula* group II, the type of *B. crassa* shows characters, including elongated, pitted upper lamina cells, that were previously associated with *B. elongata* only. Also this name should be treated as a synonym of *B. pendula*.

Character evaluation

The failure of previous Australian flora treatments (Scott and Stone 1976; Gilmore 2006) to correctly circumscribe *B. pendula* and *B. elongata* probably has its origin in the translation of a local treatment of the species for New Zealand (Sainsbury 1955a) into the Australian situation by Scott and Stone (1976), without having seen enough New Zealand material of *B. elongata*. The present study shows that the Australian situation is very different from the New Zealand one, as *B. pendula* is much more variable in Australia than in New Zealand, while *B. elongata* proves not to occur in Australia. The characters used by Sainsbury (1955a) to distinguish between the two species, not so much in the key to the species as in the description under *B. elongata*, and that were adopted by Scott and Stone (1976), in particular the length and pittedness of the upper lamina cells (our characters 14 and 23), may serve well to distinguish between *B. pendula* and *B. elongata* in New Zealand, but do not distinguish between the species in their entire distribution range or in Australia. Sainsbury (1955a) did already state that *B. pendula* shows great variation in the set of the leaves and in the leaf areolation, including the length of the upper lamina cells and the development of the alar patch.

While Sainsbury (1955a) mentioned the longer and more conspicuously pitted upper lamina cells in the description of *B. elongata*, his key diagnostic characters for *B. elongata* were the very robust habit, the more densely foliose stems and the subsecund leaves, the leaves in *B. pendula* (and *B. affinis*) spreading all around the stem. The latter character equates with our character 25, which in most cases does differentiate between *B. pendula* and *B. elongata*. The robustness of a plant apparently does not equate with the size of the plant (character 1), as the latter does not differ between the species at all. Seppelt (2004) already gave a slightly higher maximum height for *B. pendula* than for *B. elongata*. Seppelt (2004) also used the diameter of the shoots, which is perhaps a better indicator of the robustness of a plant, to distinguish between *B. pendula* and *B. elongata*.

Another character that Sainsbury (1955a) suggests can be used to distinguish small plants of *B. elongata* that have weakly falcate leaves from *B. pendula* is the non-tomentose stems. Among the 71 specimens studied, we found only three with very scarce tomentum, two of which belong to *B. pendula*. Scott and Stone (1976) noted that both species generally have dense tomentum but that in *B. elongata* the tomentum is less

conspicuous, because of the densely overlapping leaves. It is in this sense that the character will be accepted in the future moss flora of New Zealand (A. Fife pers. comm.). Thus, the inconspicuousness of tomentum is more an aspect of the setting of the leaves (our character 25) than of the density of the tomentum.

Two more characters to distinguish between *B. pendula* and *B. elongata* are suggested (Gilmore 2006) in the first moss volume of the Flora of Australia. According to Gilmore (2006) in *B. elongata* the costa is less than 40 µm wide at leaf base, while in *B. pendula* it is more than 40 µm wide. Of the 71 specimens in the morphometric analysis, only two, both belonging to *B. pendula*, had costas less than 40 µm wide (our character 6) and the costa was found to be wider rather than smaller in *B. elongata* than in *B. pendula*. The *B. pendula* group I and the group that we believe is what Scott and Stone (1976) and Gilmore (2006) considered to be *B. elongata*, group II, show no difference in costa width.

The second new character Gilmore (2006) suggests will distinguish *B. elongata* from *B. pendula* is that the former generally has a more rounded leaf base, due to a 'narrower point of attachment'. However, if *B. elongata* has more rounded leaf bases than *B. pendula* it is not caused by a narrower attachment, as the leaf insertion (character 5) is wider in *B. elongata*. More rounded leaf bases in *B. elongata* are more likely a result of the wider leaves (character 3) and the shorter distance between the insertion and the widest part of the leaf (4).

A few new characters that may be helpful in distinguishing between *B. pendula* and *B. elongata* have come to light in the present morphometric study. Of these the most promising as a diagnostic character is the size of the marginal teeth (characters 12, 13). Both length and width of the marginal teeth show highly significant contrasts between *B. elongata* and both groups I and II of *B. pendula* and show very little overlap between the species. Marginal teeth are 4.5–11.4 µm long and 3.5–8.4 µm wide in *B. pendula* and 10.4–31.1 µm long and 7.9–14.8 µm wide in *B. elongata*.

Other characters that differ between the two species are the length, width and number of rows of alar cells (characters 8–10), all being larger in *B. elongata*. Although by themselves of little diagnostic value, as there is large overlap in all three characters, these characters are indicative of a feature that is of diagnostic value, namely that the alar cells in *B. elongata* are inflated or enlarged while those in *B. pendula* are not. This difference between the species was described and well illustrated by Seppelt (2004: figs 27 and 28). Three more characters that were shown to differ significantly between *B. pendula* and *B. elongata*, the width of the leaves (3), the distance from insertion to the widest part of the leaf (4) and the width of the attachment (5), have already been discussed above. All show significant overlap between the species and hence are of very limited diagnostic value by themselves, but have been important in separating the species in ordination space and, again, may point to more diagnostic, but harder to measure, features such as leaf shape.

Although none of the morphometric characters show clear gaps between the species and no single character will always distinguish *B. elongata* from *B. pendula*, as was previously observed by both Scott and Stone (1976) and Gilmore (2006),

the entire morphometric data clearly separated the two species. Where both species co-occur *B. pendula* tends to be less variable and the species may be distinguished by characters used in the treatments for these areas (Sainsbury 1955a; Beever *et al.* 1992; Seppelt 2004). In Macquarie Island, where the species co-occur and from which some collections belonging to *B. pendula* group II were found, the species may be distinguished by 'Gestalt' characters such as the robustness and colour of the shoots, which, along with the set of the leaves, were used by Seppelt (2004). The latter characters are impractical to measure for a morphometric study or cannot be reliably scored from herbarium specimens, but will serve well in the field.

The axillary hairs independently confirm the taxonomic results of the morphometric study. No differences were found in axillary hairs between *B. pendula* groups I and II, while *B. elongata* tends to have longer axillary hairs with especially more hyaline top cells. Often in *B. elongata* specimens short axillary hairs, similar to those in *B. pendula*, were found along with the longer hairs, sometimes on the same leaves. It is one of those shorter hairs that was illustrated by Griffin and Buck (1989: fig. 15).

Distribution

In our study area *B. elongata* is restricted to New Zealand (including Auckland Islands and Campbell Island) and Macquarie Island. Matteri (1981) moreover reported *B. elongata* from Patagonia, Chile, after earlier (Matteri 1973) discarding all previous Patagonian reports of the species. We have not seen the Patagonian specimens of *B. elongata*, but from Matteri's (1981) illustration and description are confident that these specimens do indeed belong to *B. elongata*. Hence the total known geographic range of *B. elongata* comprises New Zealand (including Auckland Islands and Campbell Island), Macquarie Island, and Patagonia. In Patagonia *B. elongata* is most similar to *B. plicata* Mitt., which differs by its sheathing leaf base and leaves that are spirally twisted when dry. Matteri (1981) recognised both *B. elongata* and *B. plicata* in *Breutelia* sect. *Lycopodiobryum* (Müll.Hal.) Broth, but Griffin and Buck (1989) consider this section monotypic, consisting only of *B. grandis* (Hampe) Paris, and transferred *B. elongata* to sect. *Acoleus* (Müll.Hal.) Herzog, to which also *B. pendula* belongs. *B. pendula* is not known outside Australasia, but is widespread in Macquarie Island, New Zealand (including Auckland Islands and Campbell Island), and south-eastern Australia.

Status of *Breutelia elongata* in Victoria

The morphometric study has resulted in a narrower circumscription of *B. elongata* and a more restricted known geographic distribution of the species. Not only does *B. elongata* not occur in Victoria, but the form of *B. pendula* to which the Mt Buffalo and Blue Range specimens on which Meagher's (2005) Victorian report is based belong, and to which we will not give any taxonomic status, is more common in Victoria than previously thought. *B. elongata* is not known to have ever occurred in Victoria, and therefore does not need to be listed as threatened under the Victorian Flora and Fauna Guarantee Act. This study emphasises once more that conservation needs to be underpinned by sound taxonomy (Leadley *et al.* 2006).

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Appendix 1. Specimens scored for morphometric study

Breutelia pendula

NEW SOUTH WALES. 1. Shire of Nymboida, *D.G. Catcheside 65.132* (CANB 266741); 2. Barrington Tops State Forest, Polblue Falls, *H. Streimann 44393* (CBG 9008817 at CANB); 3. Blue Mountains, Blackheath, *T. Whitelegge 251* (MEL 1036641); 4. Blue Mountains, Lawson, *A.A. Hamilton 88* (H-BR 0485 001 at H), type of *Breutelia fuscoaurea* Broth.; 5. Mt Kosciuszko, *N. Klazenga 6432* (MEL 2294619); 6. *ibid.*, *N. Klazenga 6241* (MEL 2294622); 7. Gang Gang Creek, *H. Streimann 7371* (CBG 7906717 at CANB). AUSTRALIAN CAPITAL TERRITORY. 8. Brindabella Range, Snowy Flats, *M.D. Crisp 2030* (CBG 8008697 at CANB); 9. Brindabella Range, Ginini Swamp, *N.T. Burbidge 7725* (CANB 185692). VICTORIA. 10. Grampians, Major Mitchell Plateau, *A.W. Thies 1563L* (MEL 1052878); 11. Grampians, The Fortress, *Austr. Bryol. Group s.n.* (MEL 2055385); 12. Blue Range, *B. Duncan s.n.* (MUCV 3742 at MELU); 13. Warburton, Acheron Way, *I.G. Stone 615* (MEL 2118921); 14. Mt Baw Baw National Park, *A.C. Beauglehole 15205* (MEL 1043575); 15. Mt Baw Baw, *H. Streimann 50827* (CBG 9303461); 16. Upper West Tyers River, *N.H. Scarlett 97–200* (MEL 2040503); 17. West Tyers River, Growler's Creek Bridge, *N.H. Scarlett 98–69* (MEL 2087358); 18. Mt Buffalo, *G.A.M. Scott & B.A. Fuhrer s.n.* (MUCV 7214 at MELU); 19. Alpine National Park, Lankey Plain, *H. Streimann 53244* (MEL 2053237); 20. Alpine National Park, Watchbed Creek, *H. Streimann 53601* (MEL 2053236); 21. Tangambalanga, *W. Bennett 54* (MEL 1036635); 22. Upper Nariel, *I.G. Stone 2042* (MEL 2122219); 23. Mt Cobberas, *J.H. Willis s.n.* (MEL 2084458); 24. Genoa Flats, *Unknown collector s.n.* (MEL 1036606). TASMANIA. 25. Mt Michael, *A. Moscal 13204* (CBG 9004075 at CANB); 26. Cradle Mountain–Lake St Clair National Park, S of Dove Lake, *N. Klazenga 5768* (MEL 2111006); 27. Cradle Mountain National Park, *D. McVean 267119* (CBG 9004183 at CANB); 28. Pine Lake, *A. Moscal 13415* (MEL 2052463); 29. *ibid.*, *A. Moscal 13428* (CBG 9004081 at CANB); 30. *ibid.*, *A. Moscal 13428* (MEL 2052464); 31. Lakes Highway, *J.A. Curnow 2389* (CBG 8807754 at CANB); 32, 33. King River, *W.A. Weymouth 2803* (MEL 234985, CBG 8409897 at CANB); 34. Cat Gut Gully, *A. Moscal 19656* (MEL 229251); 35. Mt Field West, *D. McVean 267112* (CBG 9004197 at CANB); 36. Mt Field National Park, *A.V. Ratkovsky H138* (CBG 8205871 at CANB); 37. Wellington Falls, *R.A. Bastow 347* (MEL 1036634); 38. Mt Wellington, *A.V. Ratkovsky H142* (CBG 8205873); 39. *ibid.*, *Oldfield 101* (BM 918496), type of *Bartramia crassa* Hook.f. & Wilson; 40. South-West National Park, Mt Anne, *J.R. Croft 10184* (CBG 8904409 at CANB); 41. Mt La Perouse, *Oldfield s.n.* (MEL 1036532); 42. no locality given, *W. Archer s.n.* (NYBG 714770 at NY). NEW ZEALAND. 43. North Island, Mt Egmont National Park, *N. Klazenga 5297* (MEL 2075777); 44. *ibid.*, *N. Klazenga 5287* (MEL 2075767); 45. North Island, Urewera National Park, *B.O. van Zanten 7402617* (MEL 1031306); 46. North Island, Waipoua Reserve, *D.M. Henderson 9687* (MEL 1029007); 47. South Island, Canterbury, *A.M. Buchanan 3685* (MEL 2054993); 48. Campbell Island, Perseverance Harbour, *R.D. Seppelt 21594* (ADT). MACQUARIE ISLAND. 49. Prion Lake, *R.D. Seppelt 5221* (ADT); 50. Mt Haswell, *R.D. Seppelt 6298* (ADT); 51. Perseverance Bluff, *R.D. Seppelt 4197* (ADT); 52. Green Gorge, *R.D. Seppelt 7268* (ADT); 53. Mt Hamilton, *R.D. Seppelt 7894* (ADT); 54. Nuggets Creek, *R.D. Seppelt 14760* (ADT).

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NEW ZEALAND. 55. North Island, Uriwera Country, Mt Maungapohatu, *L.B. Moore 428* (MEL 29435); 56. North Island, Ruahine Range, Mt Whaingapuna, *B.O. van Zanten 1475* (CANB 266401); 57. North Island, Moechau Range, *G.O.K. Sainsbury s.n.* (CANB 362170); 58. South Island, Westland, near Moeraki, *B.O. van Zanten 7402836* (MEL 1059616); 59. South Island, Westland, Sewell Peak, *N. Klazenga, N. 5661* (MEL 2099639); 60. South Island, Westland, Moeraki, *B.O. van Zanten 7402836* (CANB 266352); 61. South Island, Mt Rochefort, *H. Streimann 51174* (CBG 9306624 at CANB); 62. Auckland Island, Mt Easton, *D.H. Vitt 9027* (CBG 9405268 at CANB); 63, 64. Auckland Islands, *J.D. Hooker 77* (BM 851270, BM 851271), type of *Hypnum elongatum* Hook.f. & Wilson; 65. Campbell Island, Perseverance Harbour, *R.D. Seppelt 21471* (ADT); 66. *ibid.*, *R.D. Seppelt 21433* (ADT); 67. *ibid.*, *R.D. Seppelt 21460* (ADT). MACQUARIE ISLAND. 68. Jessie Nicol Creek basin, *R.D. Seppelt 7910* (ADT); 69. Scoble Lake, *R.D. Seppelt 10617* (ADT); 70. Tiobunga Lake, *R.D. Seppelt 7548* (ADT); 71. Sawyer Creek Gorge, *R.D. Seppelt 6426* (ADT).