Morphometric variation in Irish *Sorbus* L. (Rosaceae)

J. PARNELL

Herbarium, School of Botany, Trinity College, Dublin 2, Ireland

and

M. NEEDHAM

Lorrha, Nenagh, County Tipperary, Ireland

ABSTRACT

Sorbus aria (L.) Crantz and *S. hibernica* E. F. Warb. are shown to differ from one another in a number of characteristics not previously noted, in particular, *S. aria* has a longer petiole, longer leaf blade with a more sharply pointed apex, greater number of leaf teeth and more widely spreading veins than *S. hibernica*. It does not appear that *S. aria* is more variable than *S. hibernica* in Ireland as is suggested generally by the literature. In addition, despite the very limited number of *Sorbus devoniensis* specimens available for study in Ireland, this species appears readily distinguishable from other, vegetatively similar, species of *Sorbus* on the basis of its longer petioles, higher number of leaf-teeth, more acutely pointed leaves and widely spaced veins.

KEYWORDS: *Sorbus aria*, *Sorbus hibernica*, *Sorbus devoniensis*, multivariate analysis.

INTRODUCTION

Sorbus is a critical genus represented in Ireland by seven species (Webb, Parnell & Doogue 1996). Two species, *Sorbus aucuparia* L. (Rowan) and *Sorbus intermedia* (Pers.) Ehrh., are readily separable from the rest purely on vegetative characteristics (their leaves are, respectively, pinnate or deeply lobed rather than more or less entire or shallowly lobed); these two species will not be considered in detail further. The other five species – *Sorbus anglica* Hedl., *S. aria* (L.) Crantz, *S. devoniensis* E. F. Warb, *S. hibernica* E. F. Warb. and *Sorbus rupicola* (Syme) Hedl. are usually each placed in one of three aggregate species groups – *S. anglica* in *S. intermedia* agg., *S. aria*, *S. hibernica* and *S. rupicola* in *S. aria* agg. and *S. devoniensis* in *S. latifolia* agg. (Stace 1997). Like *S. aucuparia*, *S. aria* is a diploid; all other species are polyploids and probably apomictic (Proctor, Proctor & Groenhof 1989). Species in the *S. intermedia* agg. and *S. latifolia* agg. probably originated as hybrids of *S. aria* and *S. aucuparia* and the non-Irish *S. torminalis* (L.) Crantz (Clapham, Tutin & Moore 1987).

Undoubtedly the most problematic distinction in this group of species in Ireland is between *S. aria* and *S. hibernica*. When writing the key to *Sorbus* for Webb, Parnell & Doogue (1996) Parnell indicated that the most obvious vegetative distinction between these two species lies in the upswept leaf-teeth of *S. aria* (where the outer margin of each tooth is longer than the inner) whereas the leaf-teeth of *S. hibernica* are straight and symmetrical. Additionally it is clear that the density of the white indumentum on the undersurface of the leaves of *S. hibernica* is usually greater than in *S. aria*. Stace (1997) indicates that while the leaves of *S. hibernica* may have 10 or fewer pairs of lateral veins, *S. aria* always has at least 10 pairs of veins. However he rightly points out both leaves and fruits are required for identification by beginners. These criteria are often difficult to meet; very many specimens in herbaria or in the field and also many brought in for identification are sterile or lack fruit. Whilst the key in Webb, Parnell & Doogue (1996), which relies on vegetative characters only, does allow most Irish material to be keyed out accurately and consistently it is clear that it could be improved; however, any improvement can only come about through a systematic description of the variation in leaf form in *S. hibernica* which currently does not exist. The aforementioned difficulties are compounded by the view of most authors (e.g. Clapham, Tutin & Moore 1987) that *S. aria* is a relatively variable species in comparison to its polyploid relatives.

The present data-set was collected with the object of attempting to ascertain the differences, if any, in quantifiable leaf characters between the five species of *Sorbus* listed above, with special reference to the distinctions between *S. aria* and *S. hibernica* and to discover if there are any new distinctions between these species.

MATERIALS AND METHODS

In order to make a comprehensive survey, all material (146 sheets) of the genus *Sorbus* from the two largest Irish herbaria (**DBN** & **TCD**) was examined. In addition two extensive collections of new material were made from large populations of *S. hibernica* (20 trees from Coolbawn, County North Tipperary, Grid. ref. R/831.923; v.c. H10 and 44 trees from Kilbeggan, County Westmeath, Grid. ref. N/366.371; v.c. H23). The material of all taxa was from wild populations. The number of populations sampled in total was 148 (each herbarium sheet represented materials from a single plant and, as far as it was possible to determine, population). As a minimum, rarely two, and more usually six mature leaves were measured from each plant. Consequently the 148 populations were represented by 672 sets of leaf character measurements. The 672 measurements were then averaged so as to provide a mean value for each of the 148 populations. Of these only four plants assigned to *S. anglica*, another four of *S. devoniensis* and seven of *S. rupicola* were located. Characters (Table 1) were measured on each leaf (measurements were either in degrees or in mm or cm as appropriate).

Unfortunately, as can be seen from Table 1 it proved impossible to effectively measure or code for the degree of upsweptness of the leaf teeth or the density of the indumentum. However it was essential to have some a priori means of assigning names to specimens and these two characters were used as the primary method whereby *S. aria* and *S. hibernica* were initially identified. The other taxa were assigned names on the basis of the key in Webb, Parnell & Doogue (1996). A number of authors refer to pairs of veins in the leaf (vide Stace 1997); however our experience suggests that veins are not always strictly

TABLE 1. CHARACTERS OF *SORBUS* TAXA CODED FOR ANALYSIS IN PCA

Character number and its abbreviation
1. The angle made between the left-hand side of the base of the leaf blade and the petiole (Angbotlf)
2. The angle made between the right-hand side of the base of the leaf blade and the petiole (Angbotrh)
3. The angle made between the third lateral vein from the base of the leaf blade and the midrib (Angof3ve)
4. The angle made between the fourth lateral vein from the base of the leaf blade and the midrib (Angof4ve)
5. The angle made between the margin of the left-hand side of the top of the leaf blade and the midrib (Angtoplf)
6. The angle made between the margin of the right-hand side of the top of the leaf blade and the midrib (Angtoprh)
7. The distance between the excursion points of the third and fourth lateral veins at the midrib (Distbet34)
8. The distance from the third lateral vein from the base of the leaf blade to the base of the leaf blade (Distbot3v)
9. The distance from the third lateral vein from the base of the leaf blade to the top of the leaf blade (Distfrm3v)
10. The distance from the insertion point of first tooth on left-hand side of base of the leaf blade to the base of the leaf blade (Distteel)
11. The distance from the insertion point of the first tooth on left-hand side of the base of the leaf blade to the base of the leaf blade (Distteer)
12. The length of the leaf blade, measured along its midrib (Leaflen)
13. The breadth of the leaf blade, measured at its point of maximal width (Leafwid)
14. The length of the leaf blade, measured along its midrib, to the widest point of the leaf blade (Leaflentwp)
15. The number of secondary veins on the leaf blade (Noveins)
16. The number of teeth present in the top centimetre of the leaf blade (Noteeto)
17. The number of teeth on the left-hand side of the leaf blade (Notthlhs)
18. The number of teeth on the right-hand side of the leaf blade (Notthrhs)
19. The length of the petiole (Petlen)
20. The width of the petiole (Petwid)

paired and therefore we counted individual veins rather than pairs. With the sole exception of character number 20, the width of the petiole (Petwid), all characters were more or less normally distributed (r^2 values of $\geqslant 90\%$ after regression of their normal probability plot values and with values for kurtosis and skewness usually $\leqslant 1$). In a few cases (except Petwid) where the latter values were > 1, r^2 remained $\geqslant 90\%$ and transformation to attain normality was therefore not attempted. Petwid had large values for kurtosis and skewness (9.5 and 2.8 respectively) and a r^2 for regression of its normal probability plot values of 50%. A very large number of transformations were attempted for Petwid in an attempt to normalise its distribution; however no significant increase in normality could be obtained. Trial and error showed that exclusion of Petwid from the analyses undertaken had a minimal effect and therefore it was included in an untransformed state.

A number of different types of analysis were undertaken on these data, and two fundamentally different techniques were used. Firstly the data were ordinated. The ordination technique chosen was Principal Components Analysis (PCA) as produced by Datadesk 5.0.1 (cf. Data Description Inc., Ithaca, New York).

With all biological data sets PCA will extract as many summary axes as there are original variables in the data. However, only the first few of these axes represent effective summaries of the data and are non-trivial. The key question is – which axes are these? Unfortunately, this vital question is virtually ignored in the taxonomic literature. Many, if not most, workers use the heuristic Kaiser-Guttmann criterion to determine which PCA axes are of significance (Jackson 1993). Simply put, this translates into consideration being given only to those axes whose eigenvalues are greater than unity (1), all other lesser scoring axes being ignored. Jackson (1993) argues that this criterion is too lax and permits consideration of components which are trivial explicators of the total variation pattern and which should really be ignored. However, others disagree and some standard ecological texts suggest that where the pattern of the data is weak, where the data-set is exceptionally large or where the investigator is concerned with the preservation of inter-object distances (i.e. pattern) it is possible to obtain perfectly valid plots associated with weak eigenvalues (Legendre & Legendre 1983). Obviously there is no universally accepted solution to this problem. However some, which are non-arbitrary, are discussed by Jackson (1993). According to him the best available single test for the importance of specific eigenvalues in PCA is that of Frontier (1976) who showed that the decrease in the eigenvalues of sequentially extracted axes in PCA generally follows a "broken-stick" distribution-type, where a fixed length is broken at random into a number of segments. Jackson (1993) uses this distribution to argue that any axis with an eigenvalue less than that predicted to occur from the appropriate "broken-stick" distribution could be ignored as insignificant. Comparison of eigenvalues with those in Frontier's table of "broken-stick" values was undertaken: in all cases discussed in this paper the first four axes proved significant.

A second technique, Discriminant Analysis (DSC), was used to test whether pre-defined groups of species visualised on PCA were or were not statistically distinguishable. This multivariate extension of analysis of variance (Marriott 1974) was performed in both a non-stepwise and stepwise manner (all default options, i.e. minimisation of Wilks λ, auto F-to-enter and F-to-remove) using SPSS 6.1 (cf. Norusis & SPSS Inc. 1993).

95% confidence limits are used throughout where appropriate.

RESULTS

The very low number of samples obtained of three taxa (*S. anglica*, *S. devoniensis* and *S. rupicola*) meant that it was not possible to draw firm conclusions relating to any of them. Nevertheless it is worth noting that an initial analysis which included all taxa was useful and that coefficients of variation for characters measured on these species were in the normal range of 10–20%. The four PCA axes which met Frontier's (1976) criteria had eigenvalues (expressed as percentages of the variance) of 28.4%, 17.9%, 11.7% and 9.3% respectively; there were therefore six biaxial plots of potential significance which required examination. Examination of these six plots together with initial DSC analysis showed that *S. devoniensis* was easily and consistently distinguishable from the other species of *Sorbus* measured on the basis of a combination of:

i. character 1 – its longer petioles (>2 cm $\pm$ 0·2 cm as opposed to always c. 1·4(–1·9) cm $\pm$ 0.06);

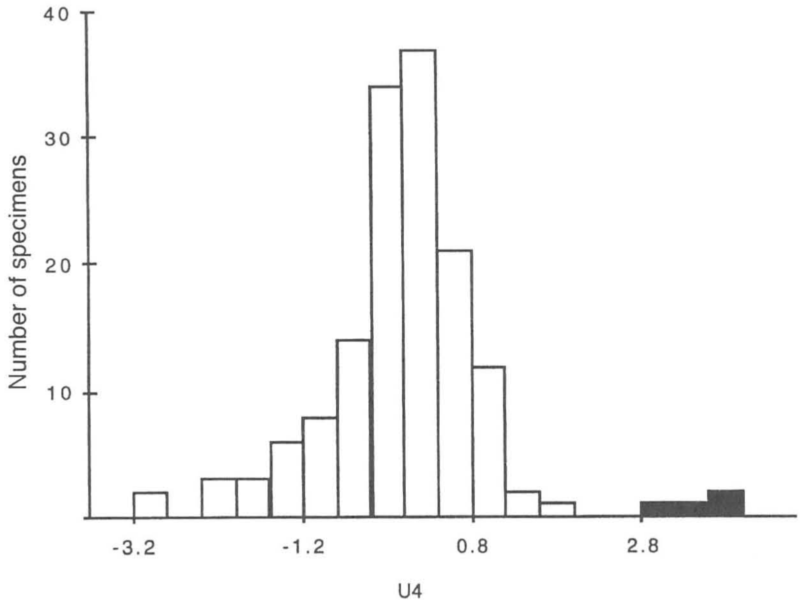

FIGURE 1. Plant scores for *Sorbus* taxa along Axis 4 (U4) which accounts for 9·4% of the total variance in the initial PCA analysis. Scores for *S. devoniensis* plants are indicated in black.

ii. characters 17 & 18 – the number of teeth on the left and right-hand side of the leaf blade (c. 68 $\pm$ 12 as opposed to c. 45(–53) $\pm$ 2);

iii. characters 5 & 6 – its more acutely pointed leaves forming an angle of c. 92° $\pm$ 10° at the apex (as opposed to $\geqslant$106° $\pm$ 1·8°);

iv. character 8 – the greater distance from the third lateral vein to the base of the leaf (2·2 cm $\pm$ 0·42 as opposed to 1·7 cm $\pm$ 0·07); and

v. character 7 – the more widely spaced third and fourth lateral veins 1·4 cm $\pm$ 0·10 as opposed to 0·93 cm $\pm$ 0·04) for the other species taken together.

Fig. 1 shows the distribution of scores along Axis 4 of this initial PCA which, for *S. devoniensis* is dominated by characters 7, 8 & 15 (the distance between the excursion points of the third and fourth lateral veins at the midrib, the distance from the third lateral vein from the base of the leaf blade to the base of the leaf blade and the number of secondary veins on the leaf blade respectively). Table 2 gives the eigenvector scores for this axis for all characters. Evidently at least these strong scoring characters must be further examined with a more comprehensive data set based on British material as it appears that further biometric work on these taxa will allow sufficiently robust algorithms to be calculated so allowing clear distinctions to be made.

Further analysis concentrated on the distinction between *S. aria* and *S. hibernica*. As can be seen from Fig. 2 a–c, PCA offered some support for separation of *S. aria* from *S. hibernica*; however it is clear that this support is limited and that considerable overlap of the taxa occurs. In part this is because the plots in Fig. 2 are simple biaxial plots which maximally account for 47% of the variance. A more accurate picture of the separation between these taxa can be obtained by DSC which gave good separation between these two species. Indeed non-stepwise DSC, the more conservative option, gave an overall misclassification rate of only 5·3% and stepwise DSC a highly significant intergroup F-ratio of 26·9 (d.f. 5, 126; $p \leqslant 0{\cdot}001$). Further discussion will be confined to non-stepwise DSC. In general DSC was more successful at correctly classifying *S. hibernica* (97% success) than *S. aria* (86% success). The univariate F-ratios for differences between the groups for particular characters highlighted a number of the latter as being of particular differential importance (Table 3). Table 4 lists these characters in decreasing differential order together with their means and 95% confidence limits.

As can be seen from these two tables the single most important differential characteristic between

TABLE 2. EIGENVECTOR SCORES FOR AXIS 4 OF THE INITIAL PCA OF *SORBUS* TAXA

Characters are numbered and abbreviated as in Table 1 above.

Character number and its abbreviation	Eigenvector
1. Angbotlf	0·018
2. Angbotrh	0·122
3. Angof3ve	−0·260
4. Angof4ve	−0·262
5. Angtoplf	−0·125
6. Angtoprh	−0·084
7. Distbet34	0·472
8. Distbot3v	0·401
9. Distfrm3v	−0·134
10. Distteel	−0·148
11. Distteer	−0·162
12. Leaflen	−0·010
13. Leafwid	0·031
14. Leaflentwp	−0·039
15. Noveins	−0·448
16. Noteeto	0·273
17. Notthlhs	0·201
18. Notthrhs	0·233
19. Petlen	−0·031
20. Petwid	−0·040

S. hibernica and *S. aria* is the number of secondary veins (character 15); there being an average 22 secondary veins in *S. aria* and 18 in *S. hibernica*. As the distance between the third and fourth veins is not significantly different between the two groups (character 7, Table 3) and therefore the vein spacing over the whole leaf is likely to be similar, then it is unsurprising to find that the leaves are significantly smaller (on average over 1 cm shorter) in *S. hibernica* than *S. aria* and that the third vein from the base is closer to the apex in *S. hibernica* than *S. aria*. Table 4 also shows that the smaller leaves of *S. hibernica* are borne on significantly shorter petioles (character 19), have rather more steeply rising veins (characters 3 & 4) but fewer leaf teeth (character 17).

So far this analysis has been concerned with differences between individual *Sorbus* plants and implicitly populations. As *S. hibernica* is reputedly apomictic it might be expected that the most morphologically similar trees would be in closest physical proximity to one another. Equally if apomixis in *S. hibernica* is not obligate it might also be expected that a regional analysis would show greater similarity between *S. aria* and *S. hibernica* and possibly intermediates where the ranges of the species overlap. The above data were therefore amalgamated on a vice-county basis and vice-county means used to calculate a PCA. Plots of plants against the four significant axes whose eigenvalues exceeded Frontier's criteria are shown in Fig. 3.

As can be seen from Fig. 3 there is almost complete separation between *S. aria* and *S. hibernica* in most plots – examination of these makes it clear that this is largely due to the scores for these species on Axis 1. Indeed the separation between *S. aria* and *S. hibernica* would be perfect if it were not for a single *S. hibernica* point. The data from which this point are derived relate to the only collection available of *S. hibernica* from County Meath. Further examination of this specimen (**DBN**), which is sterile, shows that there has been doubt expressed about its status, with D. Synnott, the original collector identifying it as *S. aria* and D. A. Webb as *S. hibernica*. The specimen is undoubtedly unusual with a mixture of characters of *S. hibernica* and *S. aria* – the somewhat upswept leaf-teeth, very dense indumentum, with the leaf veins rising at a steep angle (c. 43°) of *S. hibernica*, combine with a leaf blade of c. 11 cm, bearing 21 secondary veins, a petiole 1·7 cm long and $\geqslant$51 leaf teeth on the left-hand side of the leaf blade. Quite obviously it would be possible to view this unique specimen as indicating either a hybridisation event linking *S. aria* and *S. hibernica*, or as an aberrant member of either species: the available evidence does not easily allow a decision to be made on this question. In the

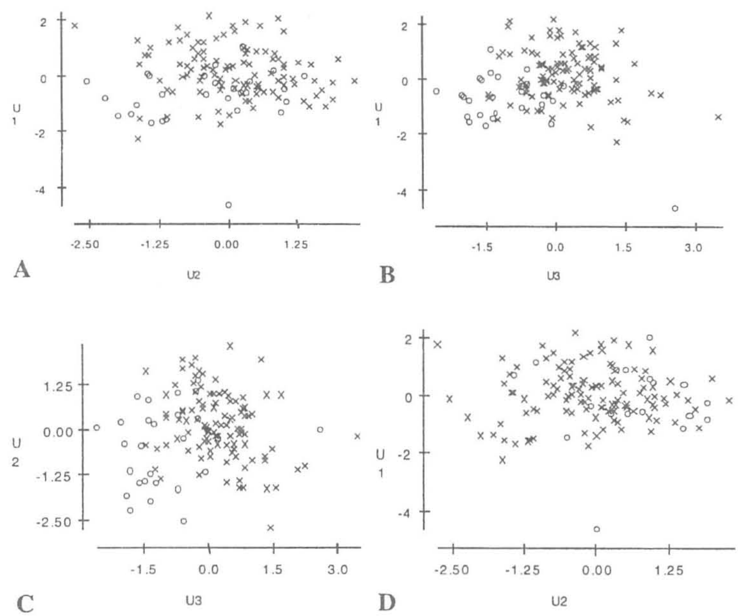

FIGURE 2. PCA plots showing the position of *S. aria* (o) and *S. hibernica* (×) for various combinations of PCA axes 1–3 (U1–U3). Axis 1 accounts for 29·9%, Axis 2 for 16·6% and Axis 3 for 12·8% of the variance respectively. In Fig. 2 D *S. hibernica* populations from v.cc. H15, 16 & 17, South-east, West and North-east Galway, are distinguished by (o), all other material is symbolised by (×).

TABLE 3. F-VALUES FOR A ONE-WAY ANOVA FOR PARTICULAR CHARACTERS MEASURED ON SPECIMENS OF *S. ARIA* AND *S. HIBERNICA*

Character numbers are as in Table 1 (d.f. = 1, 130). All F-values ≥ 3·84 are significant at p ≤ 0·05. F-values significant at p ≤ 0·001 are highlighted, by three stars.

Character number and its abbreviation	F-value
1. Angbotlf	0·01
2. Angbotrh	2·08
3. Angof3ve	27·03***
4. Angof4ve	27·61***
5. Angtoplf	0·36
6. Angtoprh	29·66***
7. Distbet34	2·62
8. Distbot3v	0·00
9. Distfrm3v	33·20***
10. Distteel	0·00
11. Distteer	0·01
12. Leaflen	25·24***
13. Leafwid	7·14
14. Leaflentwp	2·45
15. Noveins	58·67***
16. Noteeto	4·41
17. Notthlhs	13·94***
18. Notthrhs	9·28
19. Petlen	35·95***
20. Petwid	0·67

TABLE 4. MEAN VALUES FOR CHARACTERS WHOSE UNIVARIATE F-RATIOS INDICATE A SIGNIFICANT DIFFERENCE AT P<0·001 BETWEEN *S. ARIA* AND *S. HIBERNICA* TOGETHER WITH THEIR 95% CONFIDENCE LIMITS, PRESENTED IN DECREASING ORDER OF F-VALUE

Character number and its abbreviation	F-value	Mean ± 95% confidence limits for *S. aria*	Mean ± 95% confidence limits for *S. hibernica*
15. Noveins	58·67	22·1 ± 1·2	18·3 ± 0·4
19. Petlen	35·95	1·8 ± 0·1	1·4 ± 0·07
9. Distfrm3v	33·20	8·3 ± 0·5	6·7 ± 0·3
6. Angtoprh	29·66	50·0 ± 1·8	56·0 ± 1·0
4. Angof4ve	27·61	48·6 ± 2·5	43·4 ± 0·8
3. Angof3ve	27·03	50·5 ± 3·1	44·1 ± 1·0
12. Leaflen	25·24	9·9 ± 0·6	8·4 ± 0·3
17. Notthlhs	13·94	50·5 ± 3·8	43·5 ± 1·7

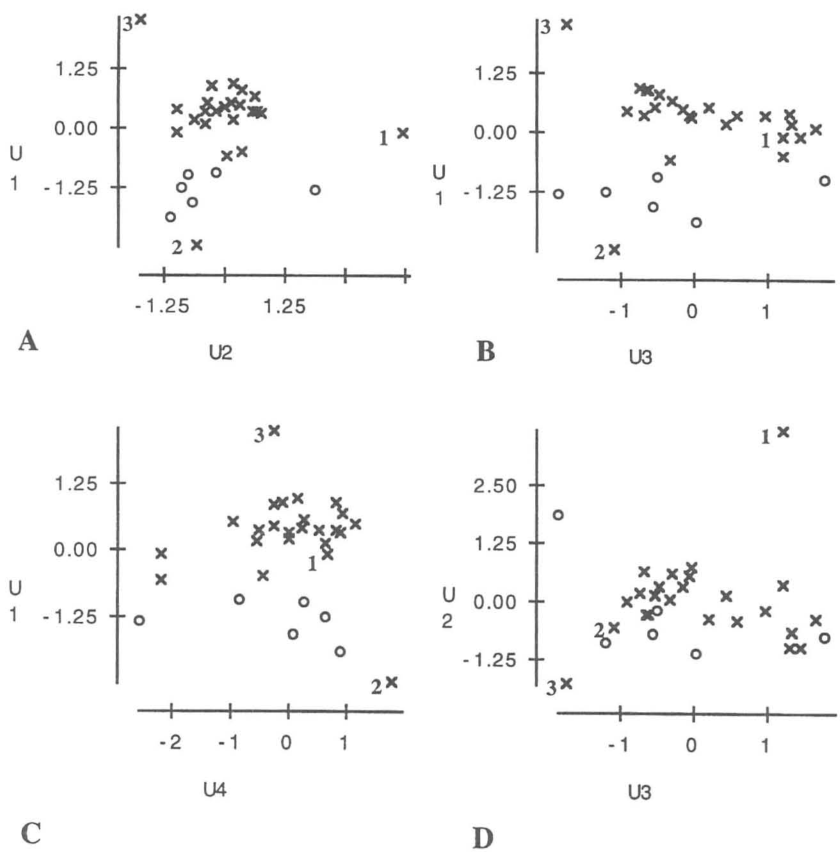

FIGURE 3. PCA plots of Axes 1–4 (U1–U4) for an analysis of individuals of *Sorbus* (*Sorbus aria* (o) and *Sorbus hibernica* (×). Axis 1 accounts for 32·6%, Axis 2 for 17·2%, Axis 3 for 15·1% and Axis 4 for 10·1% of the total variance. Material from v.c. H2 North Kerry, from v.c. H22 Meath and from v.c. H26 East Mayo are indicated by the numbers 1–3 respectively placed to the immediate left of the appropriate symbol.

TABLE 5. MEAN VALUES FOR CHARACTERS WHOSE UNIVARIATE F-VALUES INDICATE SIGNIFICANT DIFFERENCES AT $P \leqslant 0{\cdot}001$ BETWEEN VICE-COUNTY MEAN VALUES FOR *S. ARIA* AND *S. HIBERNICA* TOGETHER WITH THEIR 95% CONFIDENCE LIMITS, PRESENTED IN DECREASING ORDER OF F-VALUE

Character number and its abbreviation	F-value	Mean ± 95% confidence limits for *S. aria*	Mean ± 95% confidence limits for *S. hibernica*
15. Noveins	51·75	22·8 ± 1·2	18·3 ± 0·6
17. Notthlhs	34·91	55·8 ± 7·3	43·2 ± 1·7
19. Petlen	32·01	1·9 ± 0·2	1·4 ± 0·1
9. Distfrm3v	28·02	8·3 ± 0·5	6·6 ± 0·3
12. Leaflen	23·06	10·0 ± 0·6	8·3 ± 0·3
13. Leafwid	17·97	6·5 ± 0·4	5·6 ± 0·2
18. Notthrhs	9·64	53·6 ± 7·0	45·4 ± 2·4

circumstances it may be most useful to accept that this specimen is not determinable at present and that therefore, from the perspective of describing the core characteristics of the species, it is best to lay it to one side. In fact by trial and error it was found that removal of this single point had very little effect on the scatter diagrams produced by PCA and those produced where the specimen had been removed are therefore not reproduced here. DSC analysis of the data, after removal of the aberrant Meath specimen, produced a similar result to that seen before, though naturally less importance should be attached to the values obtained through this analysis as they are based on vice-county means and exclude the, perhaps critical, Meath specimen (Table 5).

Though Table 5 indicates that this DSC gave results broadly similar to the previous analysis shown in Table 4, it is of interest that the new analysis indicates that leaf width is also a taxonomically useful feature enabling distinction to be made between *S. aria* and *S. hibernica* and that the angles that the secondary veins make with the midrib are less diagnostically important.

Further examination of Figs 2 D & 3 showed no evidence whatsoever for a closer morphometric linkage in the variation pattern of *S. hibernica* within a vice-county or for adjacent vice-counties than between geographically remote vice-counties (e.g. note Kerry, Mayo and Meath (nos 1–3 in Fig. 2) are obviously well separated from the rest of the *S. hibernica* records from their province and the wide spread of points in Fig. 2 D for material from Galway).

CONCLUSIONS

The above data analyses clearly show that it is possible to use a range of characters to distinguish *S. aria* from *S. hibernica* and that *S. devoniensis* is relatively easily distinguished from other *Sorbus* species in Ireland. The analyses have indicated a number of extra differential morphological characters, which are particularly useful for distinguishing sterile material. In particular it is clear that the number of teeth on the leaf, the angle of the secondary veins with the midrib and the length of the petiole are useful differential characteristics enabling *S. aria* to be distinguished from *S. hibernica*. It is clear that there are still difficulties associated with differentiation of material but these new characters allow most specimens to be determined without much error or difficulty.

The difficulty experienced in relation to assignment of specimens to either *S. aria* or *S. hibernica* is of relevance to the question of the level, if any, of outcrossing in the polyploid microspecies discussed by Proctor, Proctor & Groenhof (1989). It is clear that there are examples listed by Richards (1975) of apparent hybridisation between *S. aria* and various polyploid microspecies and it may well be that the difficulties faced in this work have arisen in part due to a rare hybridisation event(s).

One of the surprises of this work was the similarity in relative variability of the two species, or occasionally the greater degree of relative variability in *S. hibernica* as compared to *S. aria*. For example the percentage coefficient of variation is 12% and 13% respectively for the number of veins in *S. aria* and *S. hibernica* and the corresponding figures are 18% and 24% respectively for petiole length. This seems to indicate that the assumption in the literature that *S. aria* is a relatively variable species is false, at least in Ireland. Experimental investigation by us of the breeding system of *S. hibernica* has so far proved inconclusive, but if outbreeding does occasionally occur in *S. hibernica* it may go some way towards explaining the relatively high degree of variability in that species.

Webb & Scannell (1983) speculate on the origin of some of the *S. aria* material in East Connaught (East of Galway), which is the main centre of distribution of this species in Ireland. They draw attention to the fact that some of this material may be derived from introductions or plantings. However, after considerable discussion they accept that the species is native. Scannell & Synnott (1987) draw attention to the fact that material in v.c. H21 (Co. Dublin) is probably introduced. However of the four localities cited (Doogue *et al.* (unpublished)), two are in hedgerows, are probably bird-sown and are not clearly non-native. Indeed none of the *S. aria* specimens in our survey appear to have been clearly planted or derived from planted material; however, the possibility remains that much Irish material has been derived from a relatively few introductions, which in turn could explain the relatively low variability of this species in Ireland.

Evidently further work is needed on *S. hibernica* to confirm its apomictic nature and also to look more closely at its relationship to other Irish and, eventually, British material. DNA sequencing, which we intend to commence soon, is likely to be able to resolve these difficulties but such work, interesting though it may well be, is not going to alter the difficulties experienced by field-workers: therefore more biometric work on this complex is required.

REFERENCES

CLAPHAM, A. R., TUTIN, T. G. & MOORE, D. M. (1987). *Flora of the British Isles*. Cambridge University Press, Cambridge.

DOOGUE, D., NASH, D., PARNELL, J., REYNOLDS, S. & WYSE JACKSON, P. (1998). *Flora of County Dublin*. Dublin Naturalists Field Club. (Manuscript in proof).

FRONTIER, S. (1976). Étude de la décroissance des valeurs propres dans une analyse en composantes principales: comparison avec le modèle du bâton brisé. *Journal of experimental marine biology and ecology* **25**: 67–75.

JACKSON, D. A. (1993). Stopping rules in principal components analysis: a comparison of heuristical and statistical approaches. *Ecology* **74**: 2204–2214.

LEGENDRE, L. & LEGENDRE, P. (1983). *Numerical ecology*. Elsevier, Amsterdam.

MARRIOTT, F. H. C. (1974). *The interpretation of multiple observations*. Academic Press, London.

NORUSIS, M. J. & SPSS INC. (1993). *SPSS for Windows. Professional Statistics. Release 6.0.* SPSS, Illinois.

PROCTOR, M. C. F., PROCTOR, M. E. & GROENHOF, A. C. (1989). Evidence from peroxidase polymorphism on the taxonomy and reproduction of some *Sorbus* populations in south-west England. *New phytologist* **112**: 569–575.

RICHARDS, A. J. (1975). *Sorbus* L., in STACE, C. A. ed. *Hybridisation and the Flora of the British Isles*, pp. 233–238. Academic Press, London.

SCANNELL, M. J. P. & SYNNOTT, D. (1987). *Census catalogue of the flora of Ireland*. Stationery Office, Dublin.

STACE, C. A. (1997). *New Flora of the British Isles*, 2nd ed. Cambridge University Press, Cambridge.

WEBB, D. A., PARNELL, J. & DOOGUE, D. (1996). *An Irish Flora*, 7th ed. Dundalgan Press, Dundalk.

WEBB, D. A. & SCANNELL, M. J. P. (1983). *Flora of Connemara and the Burren*. Cambridge University Press, Cambridge.

(*Accepted January 1998*)