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THE TAXONOMY OF *CAREX PETRICOSA* (CYPERACEAE) AND RELATED SPECIES IN NORTH AMERICA

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ABSTRACT

In North America the *Carex petricosa* group has generally been considered to consist of three species, *C. petricosa* and *C. franklinii* in western Canada and Alaska, and *C. misandroides* in eastern Canada. In addition a number of other species and varieties have been described in the past fifty years, but these have generally not been given formal recognition by subsequent authors. A morphological study of herbarium specimens of this group led to the conclusion that all of these taxa should be treated as a single species. The western and eastern populations differed in the proportion of flowers that were distigmatic. Western plants were mostly tristigmatic or had not more than 50% distigmatic flowers. Eastern plants were mostly distigmatic or had more than 50% distigmatic flowers. Consequently two varieties were recognised in *C. petricosa*, var. *petricosa* from the west, and var. *misandroides* (Fernald) Boivin from the east.

Key Words: *Carex* sect. *Aulocystis*, taxonomy, distribution, North America

INTRODUCTION

Carex petricosa Dewey is a member of the large section Aulocystis Dumortier. The section has been known under a variety of names, in particular section Ferrugineae (Mackenzie, 1935) and section Frigidae (Kükenthal, 1909). Kükenthal (1909) recognised over 50 species in the section, of which only 6 occurred in North America. In his monograph of North American *Carex* Mackenzie (1935) recognised 10 species in the section, of which 5 were endemic to the western mountains of the United States, just extending into southern British Columbia, 2 were widespread circumboreal arctic-alpine species, and 3 were subarctic-montane species endemic to Canada and Alaska. These latter 3 species, *C.*

petricosa, C. franklinii Boott and *C. misandroides* Fernald, form the group of species which is the subject of this paper.

The *Carex petricosa* group of species is difficult to define morphologically in an unambiguous way. The perigynia are more or less erect when mature, sparsely setose on the surface and tapering at the apex to an indistinct beak. The distribution of staminate and pistillate flowers in the inflorescence is extremely irregular, some individuals having a single terminal staminate spike and several lateral pistillate spikes, while others have an androgynous terminal spike (staminate at the apex, pistillate at the base), with some pistillate and some androgynous lateral spikes, often arranged in an irregular manner. The stigma number is also variable as all three species can have 2 or 3 stigmas, although 3 is predominant in *C. petricosa* and *C. franklinii* and 2 is predominant in *C. misandroides*. When Mackenzie prepared his monograph these species were known from very few collections. *Carex franklinii* and *C. petricosa* were known from a very few stations in the Rocky mountain range in Canada, while *C. misandroides* was known from a single station in Newfoundland and another in the Gaspé peninsular in eastern Quebec. Subsequent collections have extended the range of *C. franklinii* and *C. petricosa* to Alaska and the western Northwest Territories, and additional sites for *C. misandroides* have been found in Newfoundland and Quebec.

Since the publication of Mackenzie (1935) the North American species of the group have been the subject of two revisions. In both of these a number of new or additional taxa were recognised or described. Boivin (1948) described one new species, *C. distichiflora,* and two new varieties, *C. franklinii* var. *nicholsonis,* and *C. petricosa* var. *edwardsii.* Not to be outdone Raymond (1952) added two new species, *C. magnursina* and *C. lepageana,* and the first North American record of the Asian species *C. stenocarpa* Turcz. ex Besser. However, Raymond included *C. distichiflora* in the synonymy of *C. franklinii,* and treated *C. misandroides* as a variety of *C. franklinii.* Subsequent authors have tended to take a more conservative view of the group and have usually recognized two species in the west, *C. franklinii* and *C. petricosa,* with *C. misandroides* being included as a synonym or variety of *C. franklinii* (e.g., Hultén, 1968; Porsild and Cody, 1980; Packer, 1983). Boivin (1967) and Scoggan (1978) recognised only a single species with four varieties, and Welsh (1974) treated *C. franklinii* as a synonym of *C. petricosa.* The report of *C. stenocarpa* from

Alaska (Raymond, 1952) seems to have been overlooked as it is not mentioned in Hultén (1968) or Welsh (1974). In addition to North American names, Hultén included the Asian species *C. macrogyna* Turcz. ex Besser as a synonym of *C. franklinii.* Another, unpublished, name also appears on herbarium sheets. As noted by Raymond (1952), Fernald had named the earlier collections from Lac Mistassini, Quebec, as *C. mistassinica,* but this name was never validly published and Raymond treated the specimens so named as *C. franklinii* var. *misandroides.*

Initially the investigation was aimed at determining the status of *C. misandroides,* whether it could be retained as a taxon distinct from the western species, and also whether it was most similar to *C. franklinii* or *C. petricosa.* As the investigation progressed it became apparent that these questions could not be adequently addressed without a more thorough examination of the status of the western taxa of the group, including those published since Mackenzie (1935).

METHODS

The study was based entirely on herbarium specimens collected from North America and a small number from north east Asia. Approximately 250 specimens were examined from the following herbaria: ALA, CAN, DAO, MT, TRT, TRTE (acronyms according to Holmgren et al. 1990). The North American specimens represented a high proportion of the known stations of the taxa under investigation.

It proved difficult to classify specimens on the basis of morphology, so all plants from Newfoundland and Quebec were assigned to *C. misandroides,* except for the specimens named *C. mistassinica,* which were provisionally treated as a separate taxon. The post-1935 taxa are known only from specimens cited in the protologue and these were also treated as separate taxa, although in some cases the specimens were too immature to include in the morphologic analyses. *Carex petricosa* and *C. franklinii* proved difficult to distinguish based either on the names on specimens, or on the characters utilized in such works as Packer (1983). The specimens were eventually separated arbitrarily based on the width of the mature perigynium, specimens with the perigynium wider than 1.7 mm being allocated to *C. franklinii,* those with the perigynium narrower than 1.7 mm being allocated to *C. petricosa,*

and those with the perigynium 1.7 mm wide being allocated according to the name on the label.

Characters were selected based on those utilized by Mackenzie (1935), Boivin (1948) and Raymond (1952) to separate the taxa that they recognized. A few proved impossible to record satisfactorily, particularly the "curved" basal leaves emphasized by Raymond (1952) in his diagnosis of *C. magnursina*, and the color of the perigynia (dark brown versus yellowish brown) which to some extent depends on the age and state of development of the inflorescence. The number of stigmas was found to be quite variable on one individual. This was recorded by randomly choosing 5 perigynia in an inflorescence and reporting the number which had 2 stigmas. For specimens which had shed their stigmas the stigma number was based on the cross-sectional shape of the achene, biconvex for 2 stigmas and triangular for 3 stigmas. Because examination of the achenes is destructive only 3 perigynia were examined in these specimens. In a few specimens a large number of perigynia were available with visible stigmas and these were used to confirm that the method outlined above gave a reasonable estimate of the frequency of the two stigma numbers on one individual.

A total of 20 characters were recorded from the specimens examined, but not all could be utilised in the numerical analyses. Specimens were selected based on the presence of reasonably well-developed perigynia. Many specimens were collected too early in the season to have reached this stage of development, consequently it was sometimes necessary to use duplicate specimens to obtain a reasonably large sample for analysis. A total of 101 specimens were eventually included in the data set, 29 specimens of *C. petricosa* (including 2 determined as var. *edwardsii*), 27 specimens of *C. franklinii*, 24 specimens of *C. misandroides*, plus 2 specimens determined as *C. mistassinica*, 15 specimens of *C. macrogyna*, 2 specimens of *C. lepageana*, and 1 each of *C. distichiflora*, *C. magnursina* and *C. stenocarpa* (from Alaska).

Principal components analysis (PCA) and discriminant functions analysis (DFA) were performed using SYSTAT 5.0 (Wilkinson, 1990). PCA was used to obtain a broad overview of the variation in the data set and to determine whether there was any tendency to form groups. The data used in this analysis were standardised to zero mean and unit variance. All characters listed in Table 1 were included in the analysis except for STS which

Table 1. List of morphological characters recorded for the *Carex petricosa* group.

Character	Character Abbreviation
Stem height (cm)	STHT
Bract length (mm)	BRL
Bract sheath length (mm)	BRSL
Sex of the terminal spike	STS
Number of pistillate spikes	FSPN
Number of staminate spikes	MSPN
Number of hermaphrodite spikes	HSPN
Pistillate spike width (mm)	FSPW
Pistillate spike length (mm)	FSPL
Width of the staminate portion of the terminal spike (mm)	MSPW
Length of the staminate portion of the terminal spike (mm)	MSPL
Staminate scale length (mm)	STSCL
Staminate scale width (mm)	STSCW
Pistillate scale length (mm)	PSCL
Perigynium length (mm)	PERL
Perigynium width (mm)	PERW
Perigynium beak length (mm)	PERBL
Perigynium nerve number	PERNN
Stigma number	STN

was considered to be a variable that was not independent from MSPN.

DFA was used to obtain maximum separation of the four major taxa, *C. franklinii, C. macrogyna, C. misandroides* and *C. petricosa.* PERW was not included in this analysis as this character was used to define *C. franklinii* and *C. petricosa.* The other two taxa were defined using distribution as the main criterion. A classification procedure was used to assign the remaining taxa to one of the four groups.

RESULTS

Taxonomic Characters

It is not intended to review all the characters included in this study, but rather to consider those on which considerable emphasis has been placed in the past. Except as discussed below

none of the characters examined showed any significant difference between the four main taxa included in this study.

1. STEM HEIGHT. This character has been used to distinguish *C. franklinii* and *C. petricosa* (e.g., Porsild and Cody, 1980, Packer, 1983), and *C. franklinii* and *C. misandroides* (Raymond, 1952). Stem height was very variable and was poorly correlated with other diagnostic characters, particularly perigynium width (correlation coefficient 0.252).

2. TERMINAL SPIKE. Kükenthal (1909) placed *C. franklinii* and *C. petricosa* in different subsections of sect. Frigidae based on differences in the terminal spike. *Carex franklinii* was described as having an androgynous terminal spike, while *C. petricosa* was said to have a mainly staminate terminal spike. As pointed out by Raymond (1952) this character is very variable. Boott (1839) in his diagnosis of *C. franklinii* noted that the terminal spike could be both staminate and androgynous. Two collections from a population near Jasper, Alberta, close to the area from which the type of *C. franklinii* was collected, emphasize the point. Porsild 22537 (CAN) has an androgynous terminal spike (with perigynia 1.7 mm wide), and Porsild 22538 (CAN) has a staminate terminal spike (with perigynia 2.2 mm wide). In both *C. petricosa* and *C. misandroides* a staminate terminal spike is more frequent, but in both taxa androgynous spikes occur in about 50% of the specimens examined. This variation may occur in a single clone suggesting that this character is not under direct genetic control. There is a tendency for robust plants to have an androgynous terminal spike and for small plants to have a staminate terminal spike, but this is not at all consistent (the two Porsild collections cited above have stem heights of 48 cm and 51 cm respectively).

3. LATERAL PISTILLATE SPIKE SIZE. Raymond (1952) emphasized this character when describing *C. lepageana* and *C. magnursina,* stating that these two species had pistillate spikes 8–25 × 3–4 mm, while *C. petricosa, C. franklinii* and *C. misandroides* had pistillate spikes 8–15 × 6–9 mm. *Carex petricosa* was found to have a spike length of 7–29 mm (mean 15 mm), while *C. misandroides* and *C. petricosa* had a similar mean but narrower range. Spike width showed a similar pattern, with *C. petricosa* having spikes 3–7 mm wide. All three taxa had a mean width close to 5 mm.

4. PERIGYNIUM SIZE. Perigynium width is the character most frequently used to separate *C. petricosa* and *C. franklinii.* Ray-

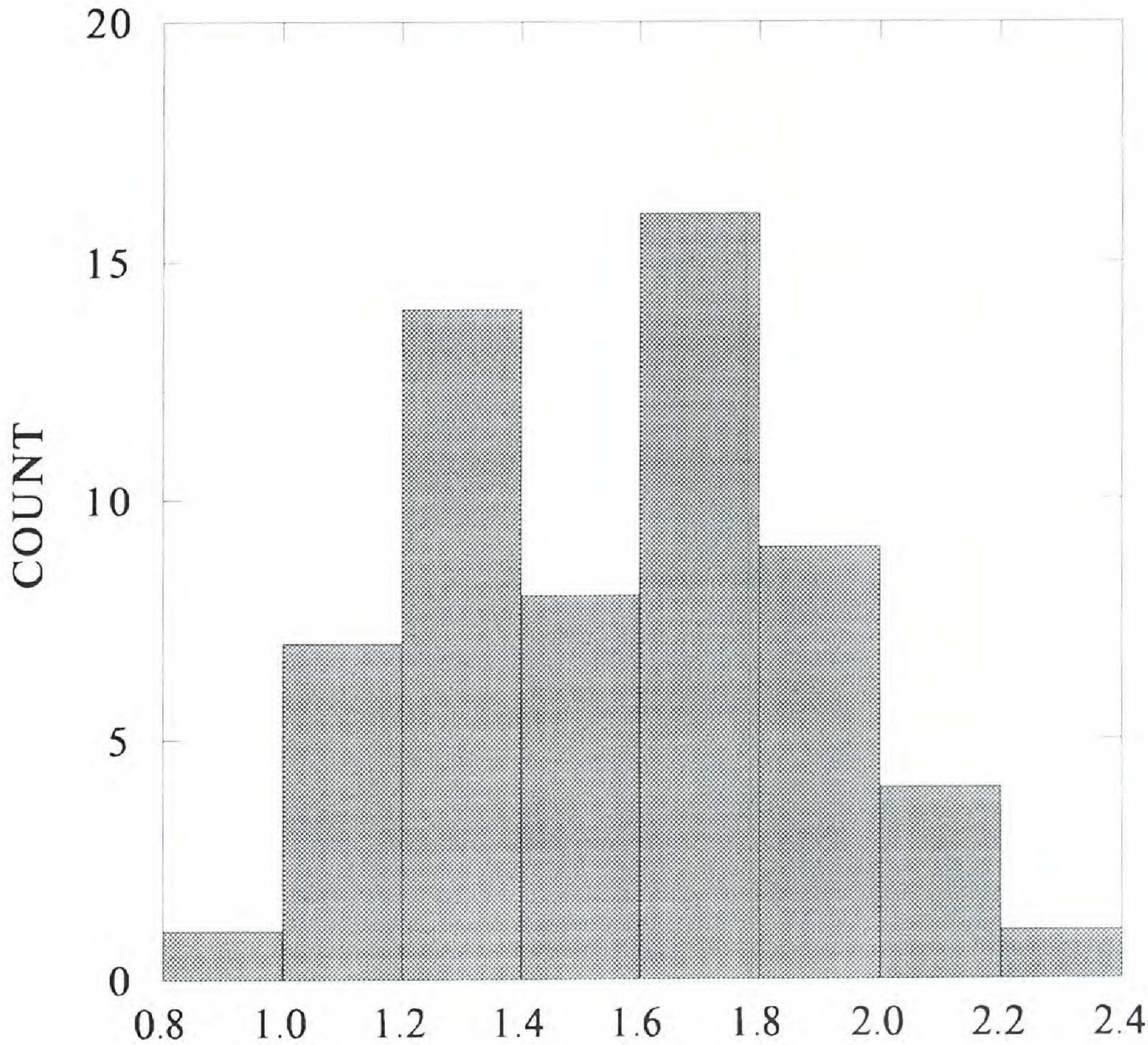

Figure 1. Histogram of perigynium width (mm) of western North American specimens of the *Carex petricosa* group.

mond (1952) gave the perigynium width of *C. petricosa* as 1.5–1.75 mm and that of *C. franklinii* and *C. misandroides* as 2–2.5 mm. Other authors, such as Mackenzie (1935), gave a similar difference. Porsild and Cody (1980) claim a difference in perigynium length giving 5–6 mm for *C. franklinii* and 4–5 mm for *C. petricosa*. In this investigation perigynium length showed no clear difference between the three main North American taxa. *Carex petricosa* was the most variable with a range of 3.5–5.5 mm, while *C. franklinii* had a range of 3.8–5.3 mm and *C. misandroides* 3.9–5.2 mm. Perigynium width was eventually used to arbitrarily separate *C. franklinii* from *C. petricosa*. The clear disjunction in perigynium width claimed by Raymond (1952) and others does not exist. A histogram of perigynium width (Figure 1) for the

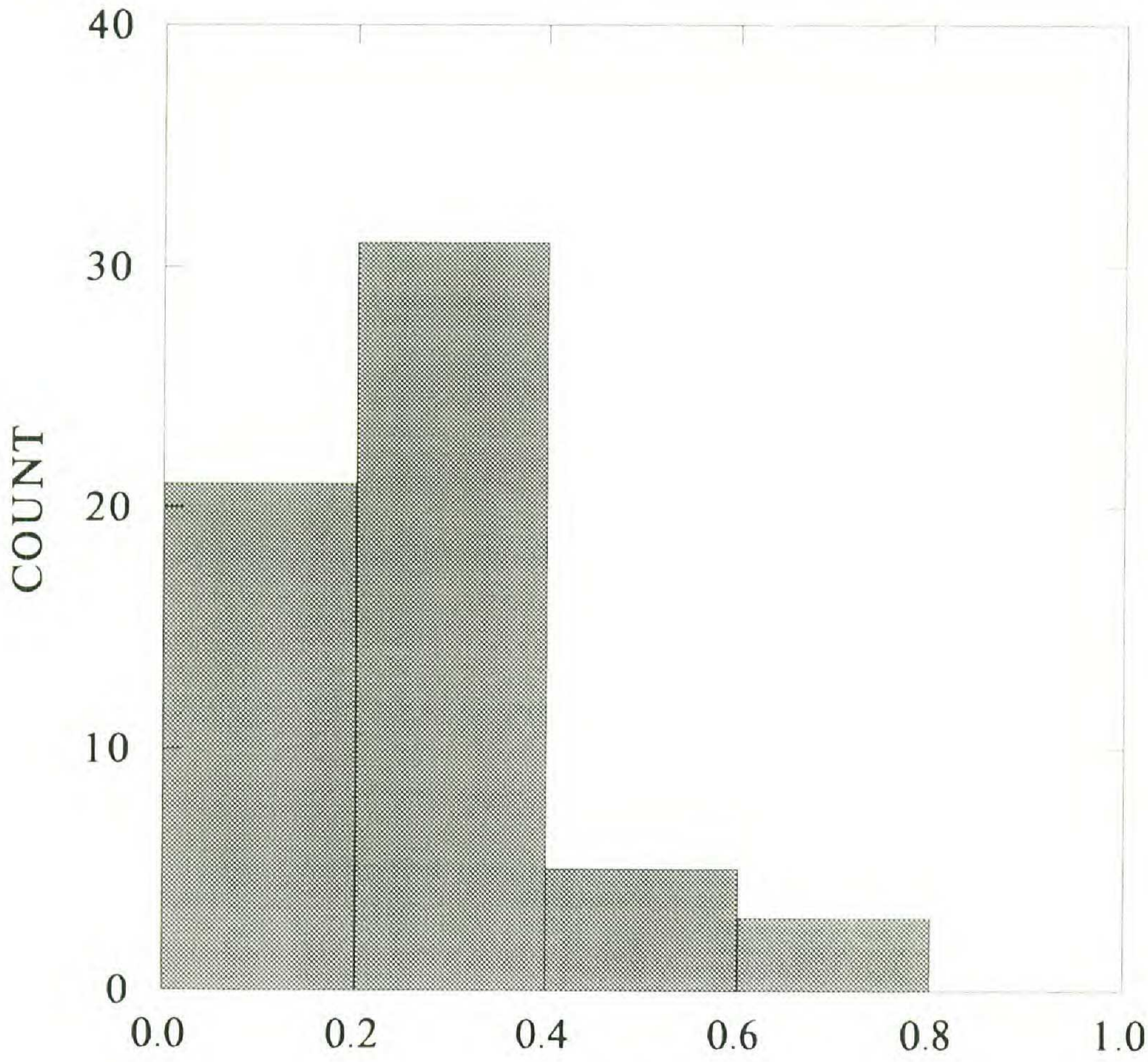

Figure 2. Histograms of the proportion of flowers, on each specimen, with two stigmas. **A.** Western North America.

western North American taxa shows a somewhat bimodal distribution with peaks at about 1.3 mm and 1.7 mm but there is no discontinuity. *Carex misandroides* has a perigynium width matching that of *C. petricosa* rather than that of *C. franklinii.*

5. STIGMA NUMBER. This character was emphasized by Fernald (1915) and Mackenzie (1935) in their descriptions of *C. misandroides.* Both acknowledged that there was some variation in the stigma number, but no data were presented to indicate the extent of the variation. In this study it was found that the eastern populations have a preponderance of flowers with two stigmas, while the western populations have a preponderance of flowers with three stigmas (Figure 2). Approximately 10% of the western specimens examined either had a preponderance of flowers with

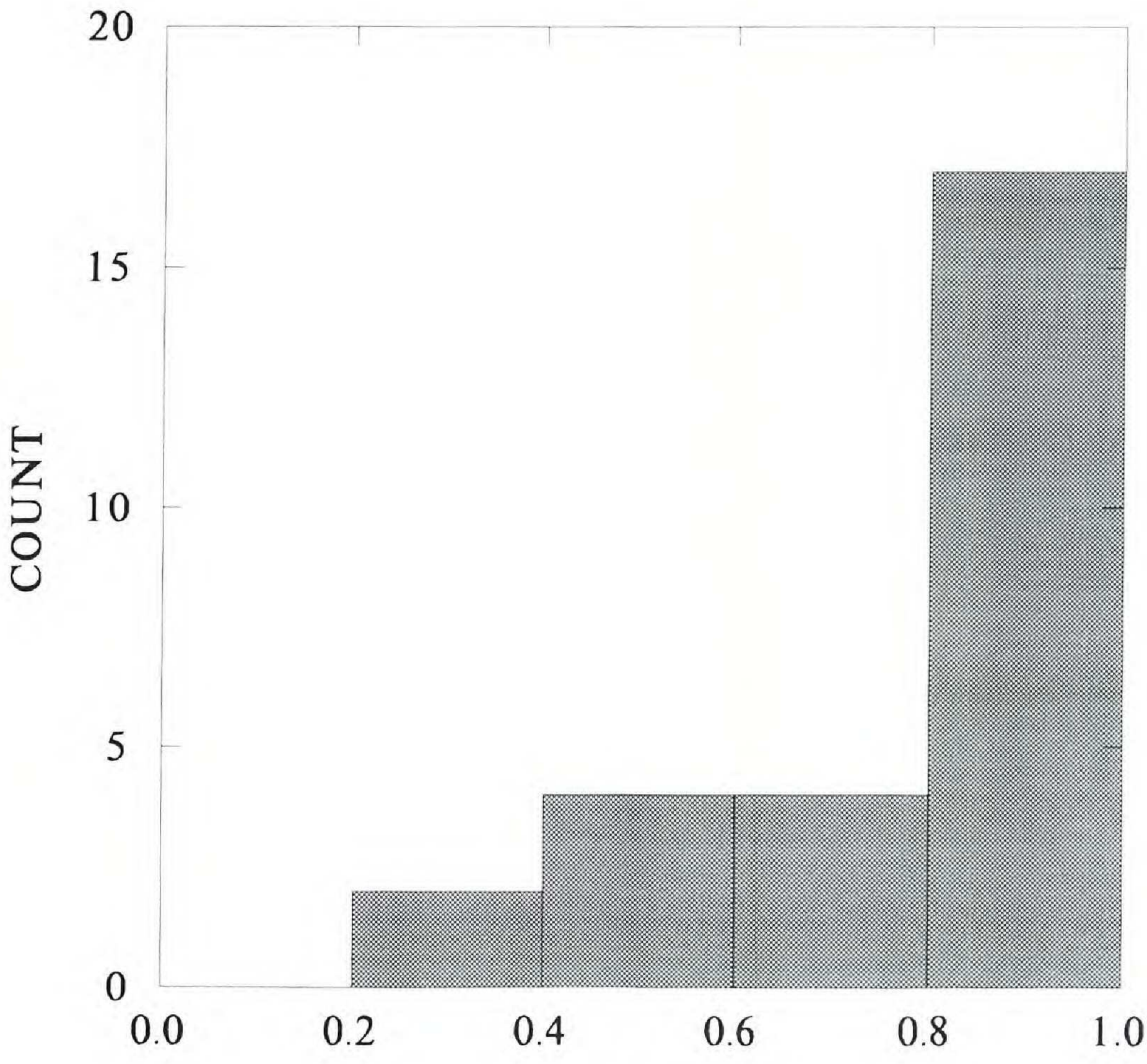

Figure 2. Continued. **B.** Eastern North America.

two stigmas or had flowers with two and three stigmas about equal in frequency. In the east about 20% of plants had a preponderance of flowers with three stigmas or had flowers with two and three stigmas about equal in number. No western specimens were entirely distigmatic and no eastern specimens were entirely tristigmatic. The Asian species, *C. macrogyna,* was similar to the western North American taxa in this character.

Multivariate Analyses

PCA showed a more or less normal distribution of specimens in the space defined by the first three components, with no tendency to form clusters (Figure 3). The first component accounted for 23.7% of the variance in the data set, with a large number of

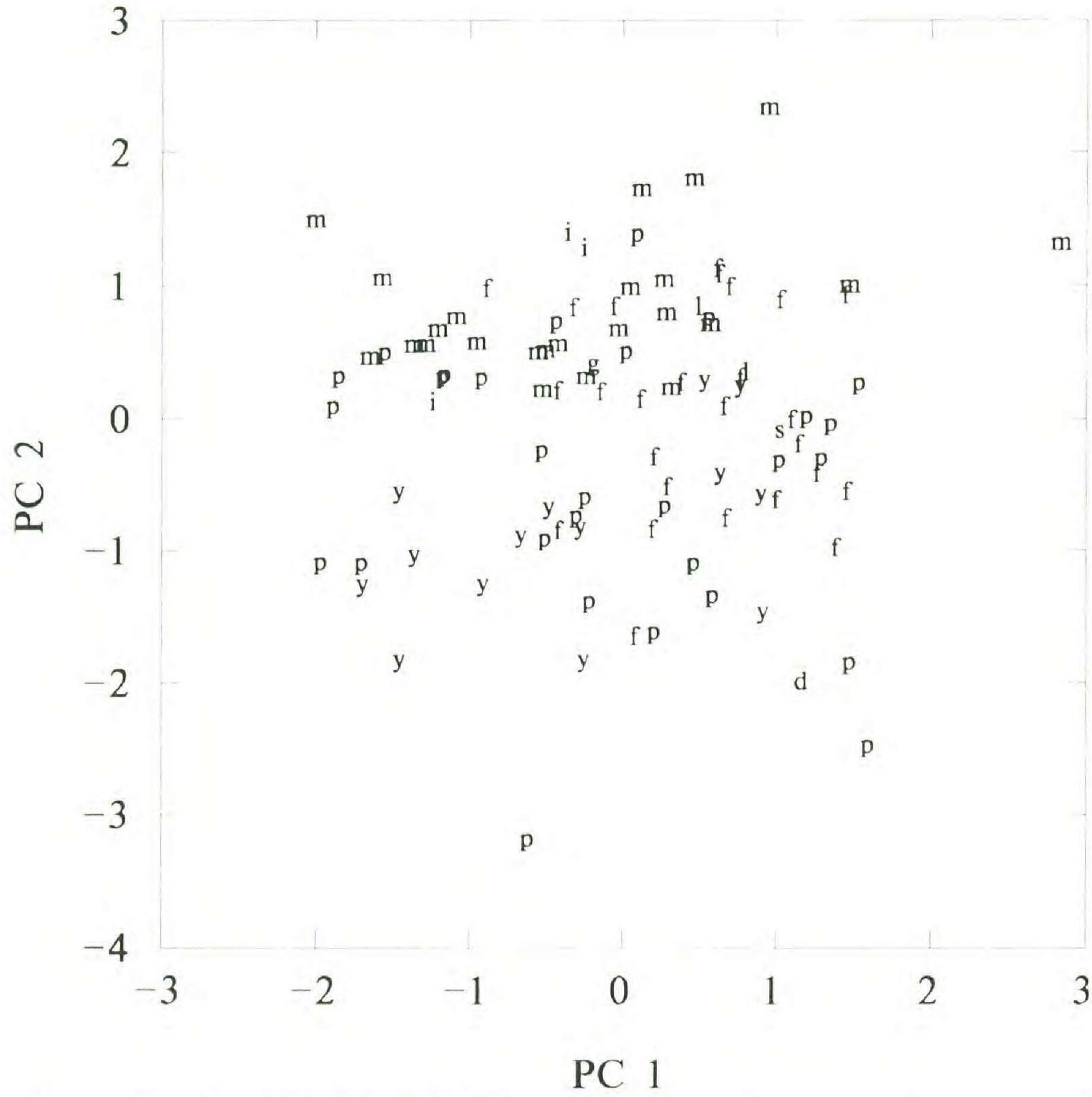

Figure 3. Bivariate plot of OTU's of the *Carex petricosa* group on principal components 1 and 2. Letters identify taxa according to Table 2.

size variables having high loadings. Most specimens of *C. franklinii* had a positive score on this axis, while *C. macrogyna, C. misandroides* and *C. petricosa* had individuals with both high positive and high negative scores. The second component accounted for 10.6% of the variance in the data set, with staminate spike number, stigma number, perigynium beak length and pistillate spike number having high loadings. *Carex misandroides* (together with *C. mistassinica*) had positive scores on this axis, but they were mixed with individuals from the other main taxa. The third component showed no useful groupings. The specimen determined as *C. stenocarpa* was placed well within the main cluster, and was neither marginal nor disjunct from the other taxa.

DFA gave only a slightly better grouping of specimens than the PCA (Figure 4). *Carex misandroides* formed a reasonably discrete group on the first DF, with only 4 of 24 specimens being misclassified (Table 2). The two specimens labelled as *C. mistassinica* were classified in this group, as might be expected. Stigma number was the most important discriminating variable, with bract sheath length as a secondary character. The second DF weakly separated *C. franklinii, C. macrogyna* and *C. petricosa.* With *C. petricosa* only 16 of 29 specimens were correctly classified, the remaining 13 specimens being evenly distributed among the other three taxa. *Carex franklinii* had 19 of 27 specimens correctly classified, and *C. macrogyna* had 10 of 15 correctly classified. The type of *C. magnursina* was classified with *C. misandroides,* but was close to the boundary with *C. petricosa.* A specimen from Nome, Alaska, determined by Raymond as *C. stenocarpa* was classified as *C. franklinii,* although it was close to the boundary with *C. petricosa.* The specimens of *C. lepageana* were also classified as *C. franklinii.*

DISCUSSION

The complete failure of the multivariate analyses to satisfactorily differentiate the taxa included in this study is strong evidence to support the view that there is only one species in this group. The exclusion of perigynium width from the DFA might account for some of the problems with group separation in that analysis, but it is clear from Figure 1 that there is no clear disjunction in this character as suggested by previous authors. *Carex lepageana, C. magnursina* and *C. distichiflora* fall well within the range of variation exhibited by the group as a whole. Likewise the specimen determined as *C. stenocarpa* appears to be a part of this group. Although no reliably determined Asian specimens of *C. stenocarpa* were examined, this species is described as having the larger leaves 4–6 mm wide (Kreczetowicz, 1935), while the Alaskan specimens have leaves not exceeding 3 mm wide, the same range as the *C. petricosa* group. The status of *C. macrogyna* is still unclear. The analyses support Hultén's (1968) view that *C. macrogyna* should be treated as a synonym of *C. petricosa,* especially given the broader circumscription of *C. petricosa* proposed above. However, most of the specimens included in the analyses came from the subarctic regions of Russia, while *C. macrogyna* was described from the mountainous area bordering

Table 2. Classification of specimens in the *Carex petricosa* group based on DFA. Rows are the groups to which specimens were assigned; columns are the classification according to the DFA.

	P	M	F	Y	Total
C. petricosa P	14	3	7	5	29
C. misandroides M	1	20	2	1	24
C. franklinii F	1	1	19	5	26
C. macrogyna Y	2	1	0	11	14
C. lepageana L	0	0	2	0	2
C. mistassinica I	0	3	0	0	3
C. magnursina G	0	1	0	0	1
C. stenocarpa S	1	0	0	0	1
C. distichiflora D	1	0	0	0	1
Total	20	29	30	22	101

Mongolia. Without a more extensive study of the group in Asia it seems prudent to not include *C. macrogyna* as a synonym of *C. petricosa* at this time. It does seem clear that the Asian subarctic populations are not distinct from *C. petricosa,* and these should be included in that species.

The final question concerns the status of *C. misandroides.* This taxon is disjunct from all the others by several thousand kilometers. Between 80% and 90% of specimens can be correctly classified using stigma number alone, without knowledge of the origin of the specimen. No other characters can be used to distinguish *C. misandroides* from the western taxa. Bract sheath length, which had a high value on the first DF together with stigma number, is much too variable. *Carex misandroides* has the highest mean value for this character, but the range, 3–38 mm, completely includes all the western taxa. Stem height shows some slight difference, with *C. misandroides* tending to be shorter than other taxa. Most plants of *C. misandroides* have stems in the range 20–35 cm high, with the extremes in the range 10–55 cm. In the western taxa the normal stem height is in the range 20–50 cm,

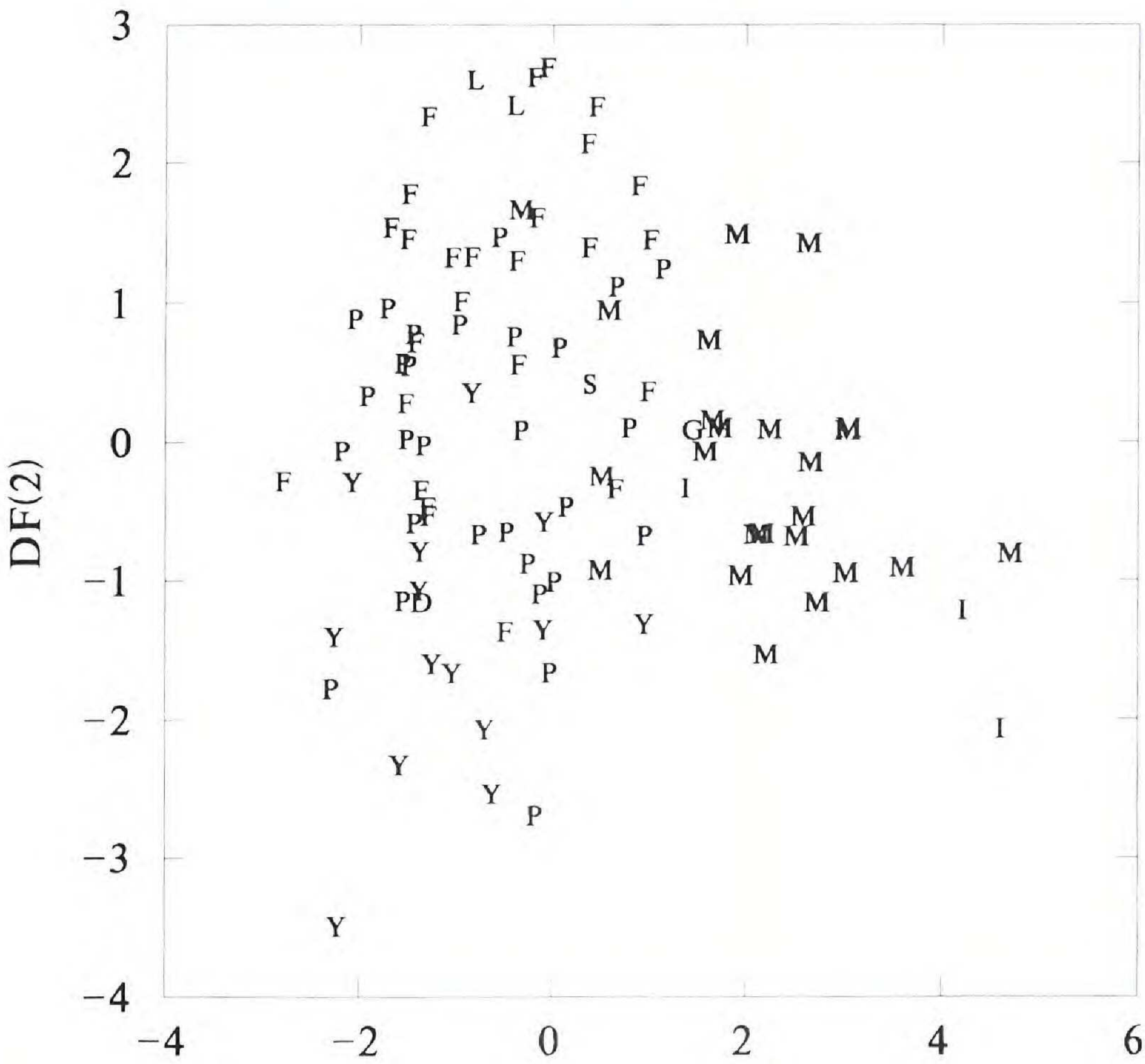

Figure 4. Bivariate plot of OTU's of the *Carex petricosa* group on discriminate functions 1 and 2. Letters identify taxa according to Table 2.

with an extreme range of 10–80 cm. The lack of any consistent morphological difference between *C. misandroides* and the other taxa in the group precludes the recognition of this as a distinct species. On the other hand the geographical isolation combined with a morphological feature which reliably classifies over 80% of individuals suggests that recognition at infraspecific rank is justified. The distribution of *Carex petricosa* in North America is given in Figure 5.

TAXONOMIC SUMMARY

1. **Carex petricosa** Dewey, Amer. J. Arts Sci 29: 246. 1836. Summits of Rocky mountains (probably west of Jasper, Alberta).

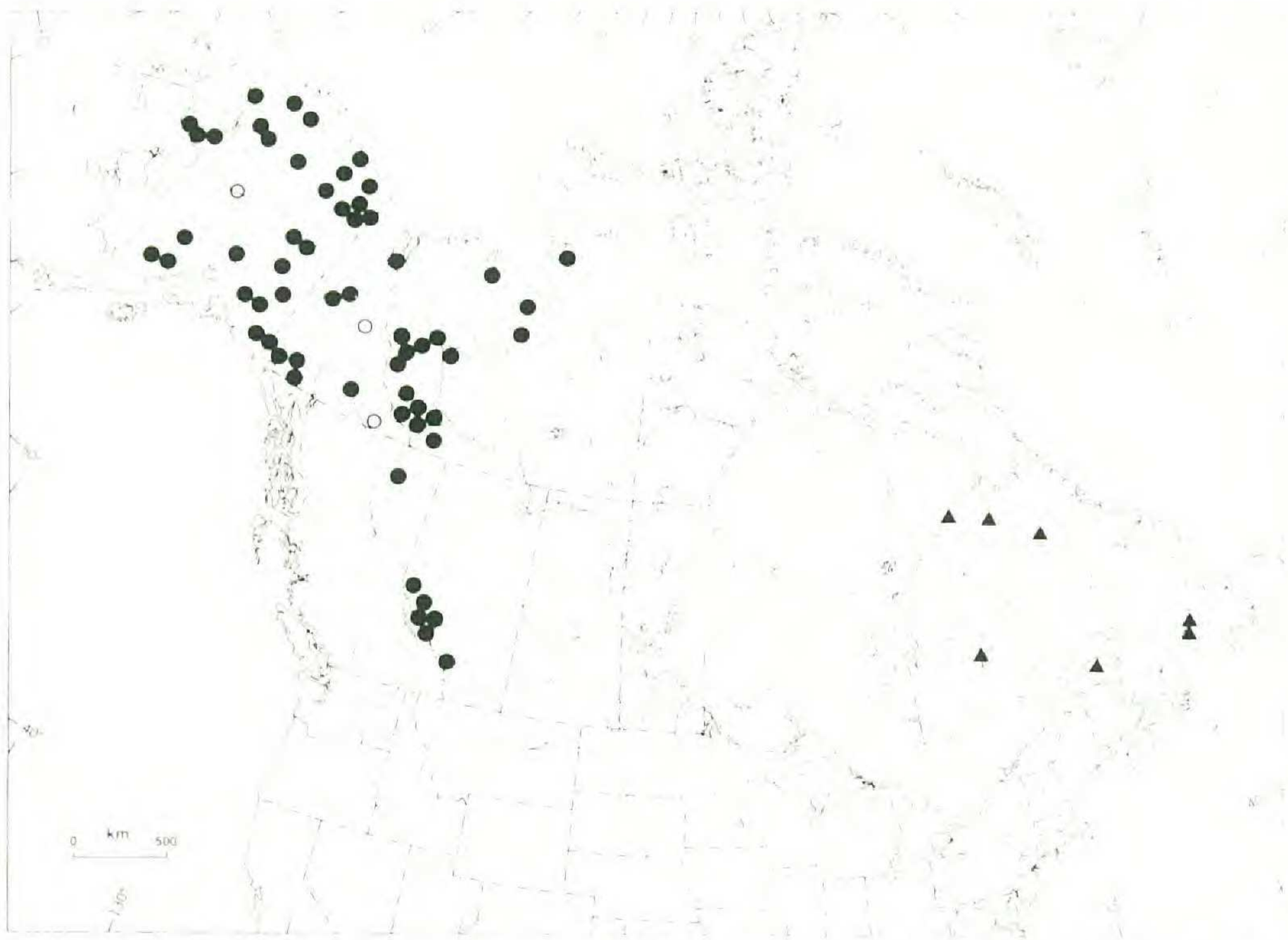

Figure 5. Distribution of *Carex petricosa* in North America. Circles = var. *petricosa*; triangles = var. *misandroides*. Solid symbols indicate specimens examined in this study; open symbols indicate literature records.

Drummond 283 (HOLOTYPE: Herb. Dewey, GH, photo CAN!, MT!, ISOTYPE: K, photo CAN!).

a. variety **petricosa**

Carex franklinii Boott in Hooker, Fl. bor.-am. 2: 217. 1839. Rocky mountains (near Jasper, Alberta). *Drummond 293* (HOLOTYPE: K, photo CAN!, MT!).

Carex distichflora Boivin, Naturaliste Canad. 75: 206. 1948. NORTHWEST TERRITORIES: Canol road, Mackenzie range, Sekwi river, mile 174E, pump station 5, 6 Sept. 1944. *Porsild and Breitung 11848* (HOLOTYPE: DAO!).

Carex mangursina Raymond, Canad. Field-Naturalist 66: 100. 1952. NORTHWEST TERRITORIES: Great Bear Lake, Harrison river, McTavish arm. 30 July 1948. *Steere et al. 3228* (HOLOTYPE: MT!).

Carex lepageana Raymond, Canad. Field-Naturalist 66: 101. 1952. ALASKA: Anvil Hill, Nome. 15 August 1948. *Lepage 24031* (HOLOTYPE: MT!).

Carex stenocarpa sensu Raymond, Canad. Field-Naturalist 66: 100. 1952. non Turcz. ex Besser.

b. variety **misandroides** (Fernald) Boivin, Phytologia 43(1): 83. 1979.

Carex misandroides Fernald, Rhodora 17: 158. 1915. NEWFOUNDLAND: Table Mountain, Port à Port Bay. *Fernald and St. John 10801* (HOLOTYPE: GH, photo CAN!). *Carex franklinii* var. *misandroides* (Fernald) Raymond, Canad. Field-Naturalist 66: 102. 1952.

Boivin first used this combination in 1967, but did not validly publish it until 1979 in Flora of the Prairie Provinces 4.

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