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TYPIFICATION OF *SOLIDAGO CHAPMANII* (ASTERACEAE: ASTEREAE) AND A MULTIVARIATE MORPHOMETRIC COMPARISON WITH *S. DRUMMONDII, S. FISTULOSA, S. ODORA* AND *S. RUGOSA*

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ABSTRACT

A lectotype is designated for *Solidago chapmanii* (*Chapman s.n.*, GH). The species is compared with *S. drummondii*, *S. fistulosa*, *S. odora*, and *S. rugosa* using multivariate morphometric methods. *Solidago chapmanii* is found to be statistically distinct from its two most similar relatives in ser. *Odorae* and more distinct compared with the species in ser. *Venosae* and ser. *Drummondiana*.

Solidago chapmanii Torr. & A. Gray is a goldenrod species native to Peninsula Florida. It is a member of *Solidago* subsect. *Venosae* (G. Don in Loudon) Nesom and was treated as *S. odora* Ait. subsp. *chapmanii* (Torr. & Gray) Semple in the Flora of North America (Semple & Cook 2006). Small (1903) separated *S. chapmanii* (Figs. 1-2) from *S.odora* (Fig. 3) by the latter having stem pubescence in lines and leaf blades that were 6–7 times longer than wide versus the former having more evenly distributed stem pubescence and leaf blades that were 2–5 times as long as wide. Cronquist (1980) treated the species as *S. odora* var. *chapmanii* (Torr. & A. Gray) Cronq. and distinguished it from the typical var. *odora* on the basis of stem pubescence traits and leaf shape. *Solidago odora* has stems with hairs confined to decurrent lines running down from the upper leaf bases and it has leaves that are (4–)5–11 times as long as wide; leaves are strongly anise-scented when crushed. In contrast, *S. chapmanii* has stems that are evenly pubescent with sometimes a glabrous to glabrate zone below the leaf bases; leaves may lack the anise-scent when crushed or be only faintly scented.

Semple and Cook (2006) placed *Solidago odora* with subsp. *chapmanii* into ser. *Odorae* (Mackenzie) Semple of subsect. *Venosae*. Semple (2015, continuously updated) included *S. chapmanii*, *S. odora*, and *S. fistulosa* Ait. (Fig. 4) in ser. *Odorae*. Series *Venosae* includes *S. delicatula* Small, *S. latissimifolia*, *S. rugosa* Mill., (Fig. 5) and *S. ulmifolia* Muhl. A more detailed multivariate analysis of ser. *Venosae* is in preparation. *Solidago drummondii* Torr. & A. Gray (Fig. 6) was placed in ser. *Drummondiana* Semple of subsect. *Venosae* by Semple (2003), Semple and Cook (2006), and Semple (2015, continuously updated).

Typification

Solidago chapmanii A. Gray, Proc. Amer. Acad. Arts 16: 80. 1880. *Solidago odora* Ait. var. *chapmanii* (A. Gray) Cronq., Brittonia 29: 224. 1977. *Solidago odora* Ait. subsp. *chapmanii* (A. Gray) Semple, Sida 20: 1611. 2003. **LECTOTYPE** (designated here): **Florida**. "Pine barrens," *Chapman s.n.* (GH!, shoot on left; possible isolectotype: NY!).

The *Chapman s.n.* (GH) specimen is not annotated by A. Gray as "sp. nov." It does, however, bear Chapman's label as “Solidago odora. Our pine woods form, Fla.,” which was noted by A. Gray in the protologue. The specimen also bears A. Gray’s "SYN. FL. N. AMER." label and his handwritten identification on the small label as “*S. chapmanii.*” The lectotype is selected because it apparently is the collection referred to in the protologue, especially as Gray named the species for the collector.

Figure 1. Lectotype of *Solidago chapmanii* A. Gray, *Chapman s.n.* (GH). The two shoots are apparently from the same gathering but should this prove not to be the case, the left shoot is the formal designate.

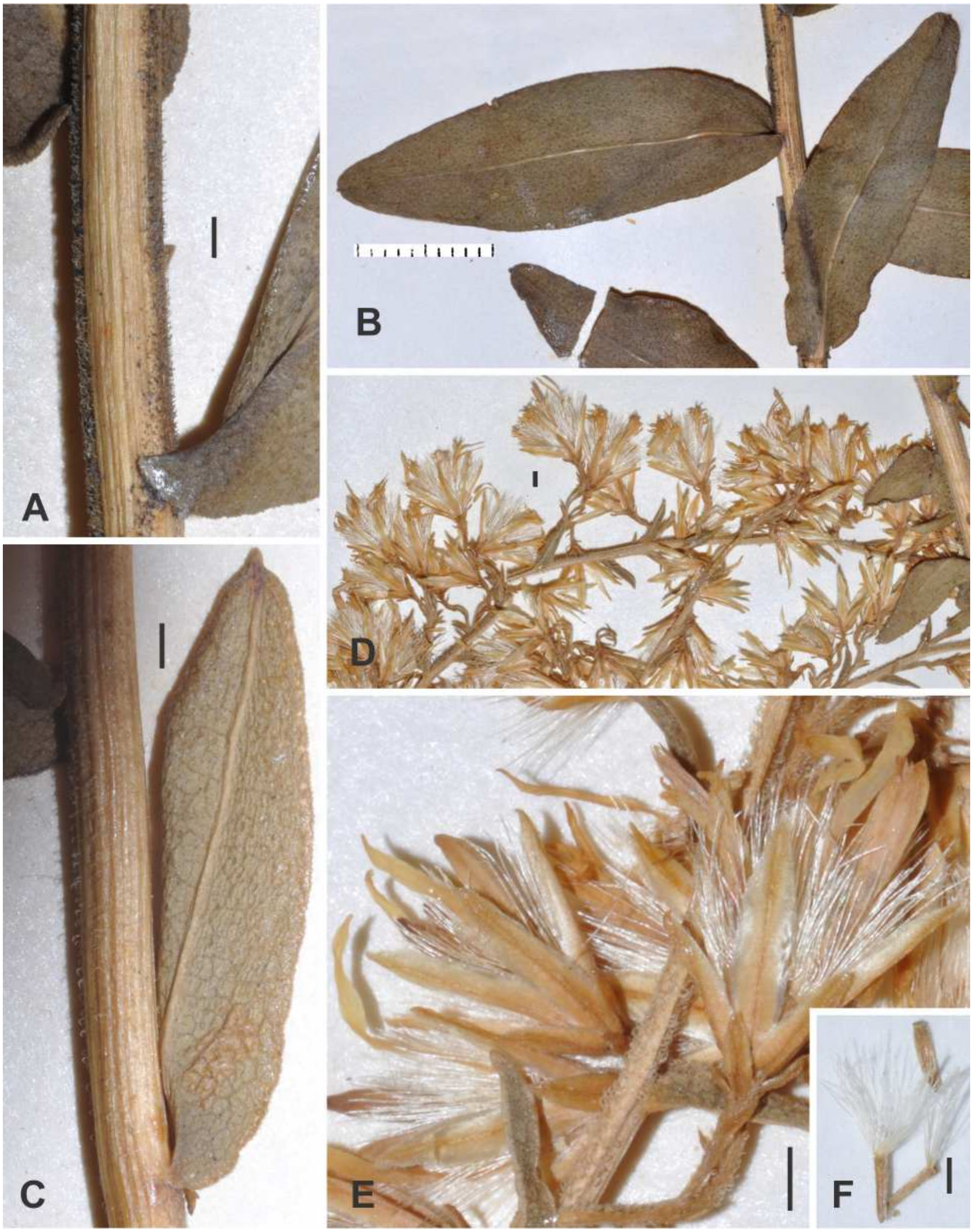

Figure 2. Details of lectotype of *Solidago chapmanii*.

Figure 3. Morphology of *Solidago odora*. **A.** Habit, South Carolina, *Semple 11669*. **B-C**. Tennessee, *Semple 11864*. **B.** Upper stem leaves. **C.** Heads and peduncular bracts.

Figure 4. *Solidago fistulosa*. **A.** Habit, Delaware. **B-C.** Florida, *Semple 11734.* **B.** Habit of large and small shoots. **C.** Upper stem leaves. **D.** Upper stem leaves, Delaware. **E.** Heads, Maryland, *Semple & Suripto 9751* (WAT); scale bar = 1 mm.

Figure 5. Morphology of *Solidago rugosa*. **A.** Habit, var. *rugosa*, Québec, *Semple & Semple 11447*. **B.** Stem leaf, var. *rugosa*, Ontario. **C.** Stem and leaves, var. *aspera*, Delaware, *Semple & Ringius 7641*. **C.** Upper stem leaves. **D.** Upper stem leaves, var. *celtidifolia*, Louisiana, *Semple & Suripto 10086* (WAT); scale bar = 1 cm. **E.** Inflorescence, var. *cronquistiana*, North Carolina, *Semple & Suripto 9666*. **F.** Stem, var. *sphagnophila*, Connecticut, *Semple & Suripto 9182*.

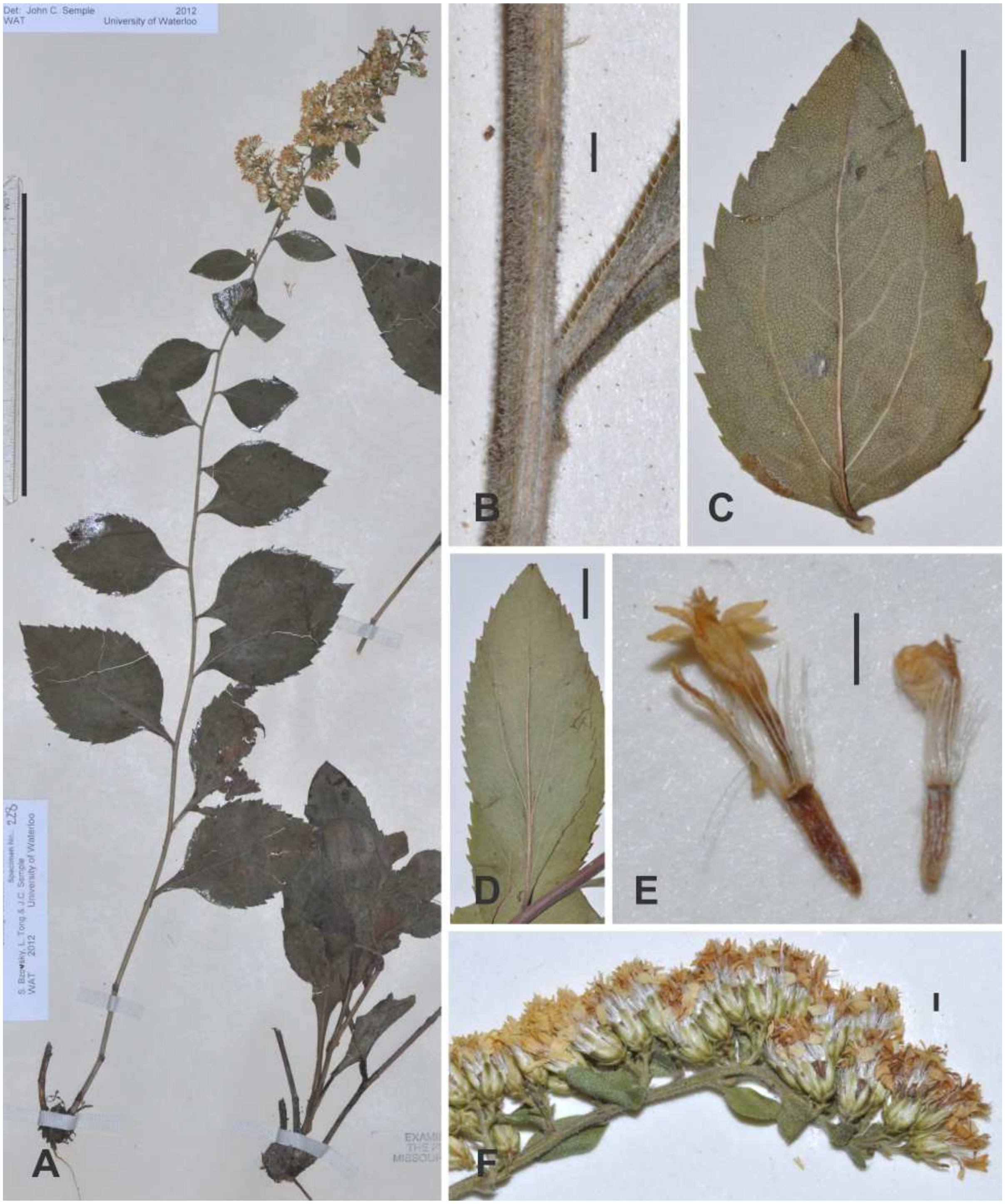

Figure 6. Morphology of Solidago drummondii. **A-B.** *Steyermark 15707* (MO). **A.** Shoot. **B.** Lower stem. **C.** Lower stem leaf, *Palmer 19447* (MO). D. Mid stem leaf, *Steyermark 26057* (MO). **E.** Disc and ray florets, *Palmer 19447* (MO). **F.** Upper portion of inflorescence, Missouri, *Rowan 1179* (MO). All collections from Missouri; scale bar = 10 cm in **A**: =1 cm in **C**, **D**; = 1 mm in **B**, **E**, **F**.

A possible duplicate of the lectotype is *Chapman s.n.* (NY ex Columbia College Herbarum!), which has a handwritten Herb. Chapman label with "Solidago odora Ait. S. fl.! Florida" on the label and annotations “Solidago Chapmanii A. Gray K.M”{acKenzie} and S. Chapmanii, A. Gray.” It is not known whether Gray saw the specimen before publishing the protologue of *Solidago chapmanii*.

Other specimens were candidates for the lectotype. Two are syntypes: **Florida**. Levy Co.: Nov 1877, *Dr. Garber s.n.* (GH-2 sheets!). Both GH specimens are marked ‘Solidago chapmanii n.sp.’ by A. Gray. A sheet of *Solidago chapmanii* (PH 01081724, online digital image! barcode 27138) with two shoots has a large "SYN. FL. N. AMER." label with the following in Gray’s script: “This is my S. Chapmanii {(} S. odora Chapm. in part) Where did these specimens come from? Dr. Garber got it. A.G.” The PH specimen may be a duplicate of the two at GH.

Multivariate analyses — materials and methods

In total, 63 specimens from MO, USF, and WAT in MT (Thiers, continuously updated) were selected for inclusion in the analysis of the three species of ser. *Odorae (18 Solidago chapmanii*, 10 *S. fistulosa* and 10 *S. odora*) plus 11 *S. drummondii* of ser. *Drummondiana* and a selected sample of 14 diploid individuals of *S. rugosa* of ser. *Venosae*. Only diploids were included because only diploids have been reported in ser. *Odorae* (Semple & Cook 2006) and comparisons with other species would be influenced by the including polyploids in samples of *Solidago rugosa*. All traits scored are listed in Table 1.

Table 1. Traits scored for the multivariate analyses of 49 specimens of four species of *Solidago* subsect. *Venosae*.

Trait	Description
MLLN	Mid leaf length
MLWD	Mid leaf width at widest point
MLSER	Number of serrations along on side of the mid leaf margin
UPLN	Upper leaf length
UPWD	Upper leaf width at widest point
UPSER	Number of serrations along on side of the upper leaf margin
INVOLHT	Height of the involucre
RAYS	Number of ray florets in a head
RAYLN	Length of the ray floret lamina
RAYWD	Width of the ray floret lamina
RACHLN	Length of the ray floret cypsela body
RPAPLN	Length of the longest ray floret pappus bristle
DISCS	Number of disc florets in a head
DCORLN	Length of the disc floret corolla including lobes
DLOBLN	Length of the disc floret corolla lobes
DACHLN	Length of the disc floret cypsela body
DPAPLN	Length of longest disc floret pappus bristle

Traits used to define a priori groups were not included in the analyses to avoid circular logic. Differences in general inflorescence shape and branching characteristics, lower stem pubescence density, and leaf pubescence density were used to define a priori groups along with geographic location.

All analyses were performed using SYSTAT v.10 (SPSS 2000) following the methods of Semple et al. (2013, 2015). Three separate discriminant analyses were performed. The first was performed on five a priori species-level groups and included all 49 specimens assigned to one of the a priori groups. In the first analysis MLSER, UPLN, UPWD, UPSER, RACHLN, RPAPLN, and DACHLN were not included because these traits were not scored on *Solidago rugosa* specimens, whose data came from a different unpublished study of ser. *Venosae*. A second analysis was performed on four a priori species groups including the 49 specimens of *S. chapmanii*, *S. drummondii*, *S. fistulosa*, and *S. odora*. A third analysis was performed on three a priori species groups of just the 38 specimens of *Solidago chapmanii*, *S. fistulosa*, and *S. odora*. The second and third analyses included all traits scored and listed in Table 1.

Five taxa analysis

In the STEPWISE discriminant analysis of five species-level a priori groups *Solidago chapmanii*, *S. drummondii*, *S. fistulosa*, *S. rugosa* and *S. odora*, the following traits listed in order of decreasing F-to-remove values were selected (F-to-remove): mid leaf width (37.57), number of ray florets (30.35), disc floret pappus length (20.01), mid leaf length (12.52), disc floret corolla length (6.69), and ray floret strap length (4.05). Wilks's lambda, Pillai's trace, and Lawley-Hotelling trace tests of the null hypothesis that all groups were the samples of one group had probabilities of p = 0.000 that the null hypothesis was true. The F-matrix for the discriminant analysis is presented in Table 2. F-values based on Mahalanobis distances between group centroids indicate the largest separations were between *Solidago drummondii* and *S. odora*, *S. chapmanii* and *S. fistulosa* (57.011, 54.668 and 50.980 respectively). The smallest separation was between *S. chapmanii* and *S. odora* (6.856).

Table 2. Between groups F-matrix for the five a priori group analysis (df = 8, 51).

Group	***chapmanii***	***drummondii***	***fistulosa***	***odora***	***rugosa***
chapmanii	0.000				
drummondii	46.124	0.000			
fistulosa	6.741	39.221	0.000		
odora	6.468	48.253	14.912	0.000	
rugosa	30.497	16.628	18.118	36.908	0.000

Wilks' lambda
Lambda = 0.0069 df = 8 4 58
Approx. F= 16.8343 df = 32 189 prob = 0.0000

In the Classificatory Discriminant Analysis of the five species-level a priori groups the percents of correct classification ranged from 70-100% with a mean value of 92%. The Classification matrix and Jackknife classification matrix are presented in Table 3. Results for individual a priori taxa are presented in decreasing order of percent correct. (1) 3 species had 100% a posteriori placement of specimens to their respective a priori group: 10 specimens of *Solidago odora* (9 with 91-100% probability and 1 with 70% probability), and the 14 specimens of *S. rugosa* (12 with 97-100% probability, 1 with 94% probability, and 1 with 51% probability to *S. rugosa* and 49% probability to *S. drummondii*). (2) For *S. chapmanii*, 89% correct a posteriori placement of specimens (10 with 89-100% probability and 3 with 79%, 77%, and 69% probabilities); 1 specimen was placed a posteriori in *S. odora* with 84% probability. (3) For *S. fistulosa*, 70% correct a posteriori placement of specimens (7 with 98-100% probability); 3 specimens with assigned a posteriori to *S. chapmanii* with 82%, 76%, and 63% probability. In the Jackknife classification there was only a small drop in mean correct placement to 87% correct a posteriori placement to a priori group.

Two dimensional plots of scores of CAN1 versus CAN2 and CAN1 versus CAN3 of *Solidago chapmanii*, *S. drummondii*, *S. fistulosa*, *S. odora*, and *S. rugosa* are presented in Figure 7. Eigen values on the first four axes were 10.483, 3.038, 0.951, and 0.131.

Table 3. Linear and jackknife classification matrices from the Classificatory Discriminant Analysis of five a priori groups; a posteriori placements to groups in rows.

Linear classification matrix

	chapmanii	***drummondii***	***fistulosa***	***odora***	***rugosa***	% correct
chapmanii	16	0	0	2	0	89%
drummondii	0	11	0	0	0	100%
fistulosa	3	0	7	0	0	70%
odora	0	0	0	10	0	100%
rugosa	0	0	0	0	0	100%
Total	19	11	7	12	14	92%

Jackknifed classification matrix

	chapmanii	***drummondii***	***fistulosa***	***odora***	***rugosa***	**% correct**
chapmanii	16	0	0	2	0	89%
drummondii	0	11	0	0	0	100%
fistulosa	3	0	7	0	0	70%
odora	1	0	0	9	0	90%
rugosa	1	1	0	0	12	86%
Total	21	12	7	11	12	87%

Four taxa analysis

In the STEPWISE discriminant analysis of the four species-level a priori groups *Solidago chapmanii*, *S. drummondii*, *S. fistulosa*, and *S. odora*, the following traits listed in order of decreasing F-to-remove values were selected (F-to-remove): mid leaf width (23.38), mid leaf length (22.43), number of mid leaf margin serrations (18.15), disc floret pappus length (13.29), number of ray florets (6.80), ray floret strap length (5.77), and involucre height (5.26). Wilks's lambda, Pillai's trace, and Lawley-Hotelling trace tests of the null hypothesis that all groups were the samples of one group had probabilities of p = 0.000 that the null hypothesis was true. The F-matrix for the discriminant analysis is presented in Table 4.

Table 4. Between groups F-matrix for the four a priori group analysis (df = 7, 39).

Group	***chapmanii***	***drummondii***	***fistulosa***
drummondii	46.124	0.000	
fistulosa	6.741	39.221	0.000
odora	6.468	48.253	14.912

Wilks' lambda
Lambda = 0.0049, df = 7 3 45
Approx. F = 28.6915, df = 21 112 prob. = 0.0000

In the Classificatory Discriminant Analysis of the four species-level a priori groups the percents of correct classification ranged from 90-100% with a mean value of 98%. The Classification matrix and Jackknife classification matrix are presented in Table 5. Results for individual a priori taxa are presented in decreasing order of percent correct. (1) 3 species had 100% a posteriori placement of specimens to their respective a priori group: 18 specimens of *Solidago chapmanii* (16 with 97-100% probability, 1 with 63% probability to *S. chapmanii* and 37% to *S. odora*, and 1 with 55% to *S. chapmanii* and 45% to *S. odora*), 11 specimens of *S. drummondii* with 100% probability, and 10 specimens of *S. odora* with 92-100% probability. (2) For *S. fistulosa*, 90% correct a posteriori placement of specimens to *S. fistulosa* (6 with 100% probability, 3 with 94%, 96%, and 97% probabilities); 1 specimen was placed a posteriori in *S. chapmanii* with 54% probability (44% probability in *S. fistulosa*).

Table 5. Linear and jackknife classification matrices from the Classificatory Discriminant Analysis of five a priori groups; a posteriori placements to groups in rows.

Linear classification matrix

	chapmanii	***drummondii***	***fistulosa***	***odora***	% correct
chapmanii	18	0	0	0	100%
drummondii	0	11	0	0	100%
fistulosa	1	0	9	0	90%
odora	0	0	0	10	100%
Total	19	11	9	10	98%

Jackknifed classification matrix

	chapmanii	***drummondii***	***fistulosa***	***odora***	**% correct**
chapmanii	16	0	0	2	89%
drummondii	0	11	0	0	100%
fistulosa	2	0	8	0	80%
odora	0	0	0	10	100%
Total	18	11	8	12	92%

Two dimensional plots of scores of CAN1 versus CAN 2 and CAN1 versus CAN3 of *Solidago chapmanii, S. drummondii, S. fistulosa,* and *S. odora* are presented in Figure 8. Eigen values on the first three axes were 27.299, 2.489, and 1.072.

Three taxa analysis

In the STEPWISE discriminant analysis with the three species level a priori groups *Solidago chapmanii*, *S. fistulosa*, and *S. odora*, the following traits listed in order of decreasing F-to-remove values were selected (F-to-remove): number of mid leaf serrations (52.33), mid leaf length (43.95), mid leaf width (15.98), ray floret strap length (11.24),), disc floret pappus length (10.14), and ray floret ovary length at anthesis (6.85). Wilks's lambda, Pillai's trace, and Lawley-Hotelling trace tests of the null hypothesis that all groups were the samples of one group had probabilities of p = 0.000 that the null hypothesis was true. The F-matrix for the discriminant analysis is presented in Table 6.

Table 6. Between groups F-matrix for the three a priori group analysis (df = 6 30).

Group	***chapmanii***	***fistulosa***
fistulosa	43.188	
odora	14.808	55.261

Wilks' lambda
Lambda = 0.0234, df = 6 2 35
Approx. F= 27.6849, df = 12 60 prob = 0.0000

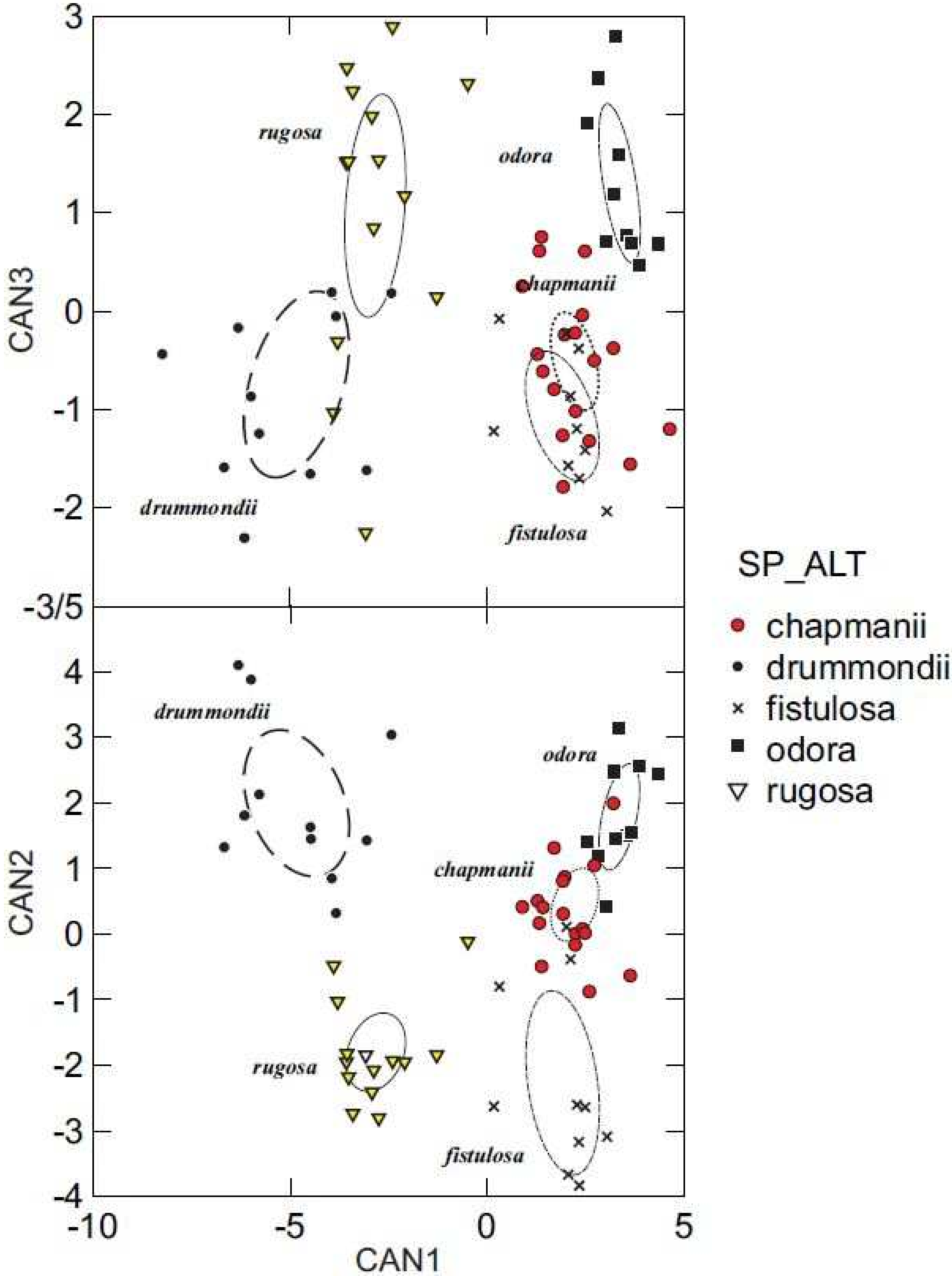

Figure 7. Two dimensional plots of canonical scores CAN1 versus CAN2 and CAN1 versus CAN3 for specimens of *Solidago chapmanii*, *S. drummondii*, *S. fistulosa*, *S. odora*, and *S. rugosa*.

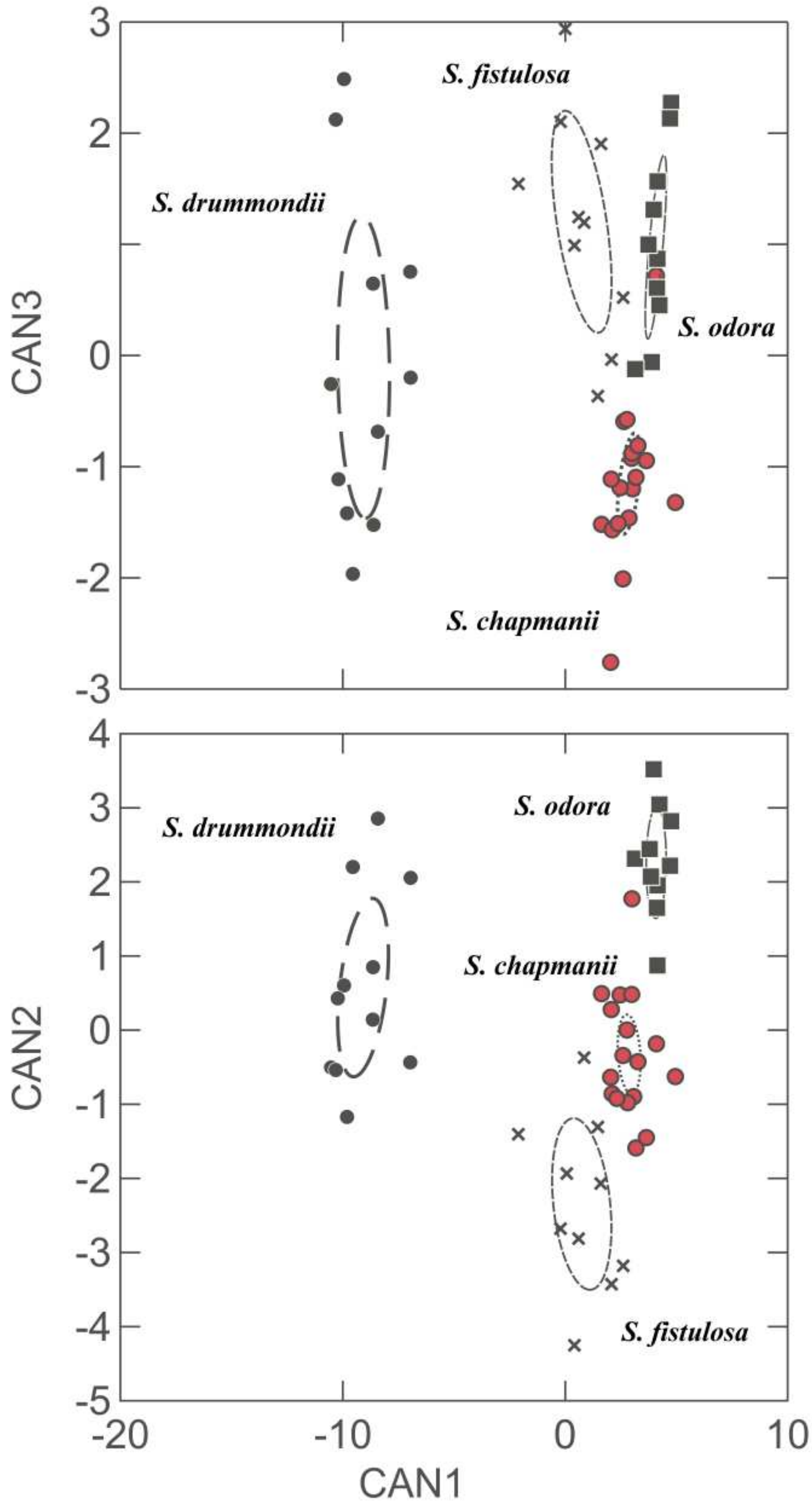

Figure 8. Two dimensional plots of canonical scores CAN1 versus CAN2 and CAN1 versus CAN3 for specimens of *Solidago chapmanii*, *S. drummondii, S. fistulosa*, and *S. odora*.

In the Classificatory Discriminant Analysis of the three species-level a priori groups the percents of correct classification ranged from 90-100% with a mean value of 97%. The Classification matrix and Jackknife classification matrix are presented in Table 7. Results for individual a priori taxa are presented in decreasing order of percent correct. (1) 3 species had 100% a posteriori placement of specimens to their respective a priori group: 18 specimens of *Solidago chapmanii* (16 with 97-100% probability, 1 with 63% probability to *S. chapmanii* and 37% to *S. odora*, and 1 with 55% to *S. chapmanii* and 45% to *S. odora*), 11 specimens of *S. drummondii* with 100% probability, and 10 specimens of *S. odora* with 92-100% probability. (2) For *S. fistulosa*, 90% correct a posteriori placement of specimens to *S. fistulosa* (6 with 100% probability, 3 with 94%, 96% and 97% probabilities); 1 specimen was placed a posteriori in *S. chapmanii* with 54% probability (44% probability in *S. fistulosa*).

Table 7. Linear and jackknife classification matrices from the Classificatory Discriminant Analysis of three priori groups.

Linear classification matrix

	chapmanii	***fistulosa***	***odora***	**% correct**
chapmanii	17	0	1	94%
fistulosa	0	10	0	100%
odora	0	0	10	100%
Total	19	9	10	97%

Jackknifed classification matrix

	chapmanii	***fistulosa***	***odora***	**% correct**
chapmanii	17	0	1	94%
fistulosa	0	10	0	100%
odora	0	0	10	100%
Total	17	10	11	97%

A two dimensional plots of scores of CAN1 versus CAN 2 of specimens of *Solidago chapmanii*, *S. fistulosa*, and *S. odora* are presented in Figure 9. Eigen values on the first two axes were 12.630 and 2.839.

Discussion

The results support the recognition of the following five species: *Solidago chapmanii*, *S. drummondii*, *S. fistulosa*, *S. odora,* and *S. rugosa*. *Solidago drummondii* is the most distinct species with its broad lower leaves with multiple prominent veins, with *Solidago rugosa* being nearly as distinct with its often strongly rugose leaves. This is demonstrated as well in the two species being separated from each other and the other three species on the first and second canonical axes in Figure 1 based on additional technical traits. This is not surprising as the two species are in ser. *Drummondii* and ser. *Venosae* of subsect. *Venosae* in Semple and Cook (2006). With a few exceptions, specimens of *S. chapmanii*, *S. fistulosa* and *S. odora* of ser. *Odorae* are also strongly separated in the multivariate analyses with overall high correct a posteriori placements with high probabilities in their respective species groups.

Although *Solidago chapmanii* has been treated at an infraspecific rank within *S. odora*, the two groups of specimens included in the analysis were well-supported as distinct with the misclassification of specimens occurring between *S. fistulosa* and *S. chapmanii* as well as at a low level between *S. chapmanii* and *S. odora*. Gray's 1880 original decision to treat *S. chapmanii* as a species (also regarded as distinct in a few subsequent treatments, e.g., Small 1933, Nesom 1993, Weakley 2015) turns out to be more strongly supported than later decisions to treat the taxon as a variety or subspecies within *S. odora* (e.g., Cronquist 1977; Semple 2003; Semple & Cook 2006)). DeCronquistification of *Solidago* continues.

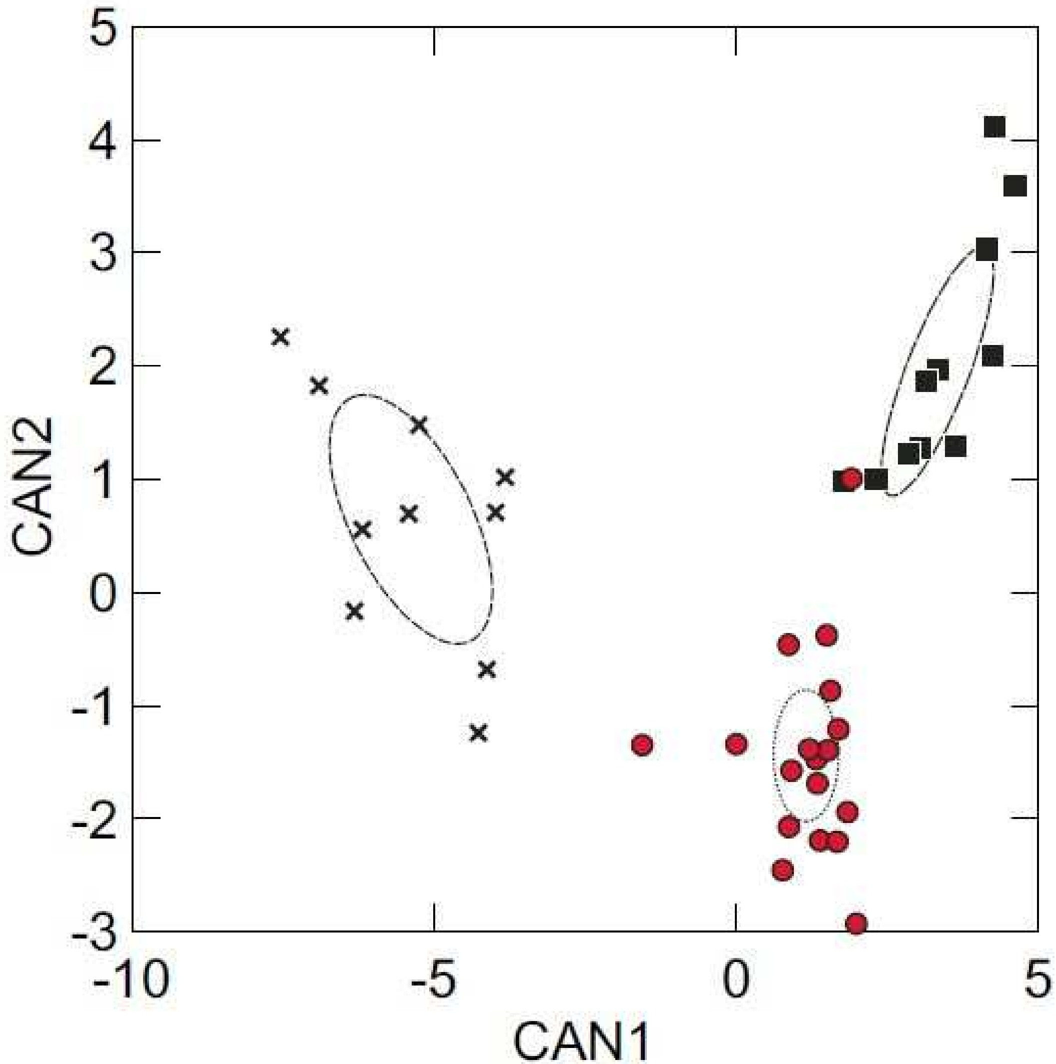

Figure 9. Two dimensional plot of canonical scores CAN1 versus CAN2 for specimens of *Solidago chapmanii*, *S. fistulosa*, and *S. odora*.

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