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SOLIDAGO ALTISSIMA VAR. PLURICEPHLA (ASTERACEAE: ASTEREAE) IN AUSTRALIA, TONGA, AND HAWAII

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ABSTRACT

Herbarium collections of *Solidago* from Australia, Tonga, and Hawaii are reported here to be *Solidago altissima* L. var. *pluricephala* M.C. Johnston, which is previously unreported for these locations. Collections from K, MEL, and PERTH were included in a multivariate morphometric analysis comparing *S. altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea*. Also, a collection treated as *S. altissima* ssp. *altissima* from New Zealand was included in the analysis and confirmed to belong in the typical variety of the species. All specimens had densely hispid-strigose stems (sparsely to densely so proximally and densely so distally and in the inflorescence), lanceolate upper stem leaves with mostly entire margins and moderately to densely strigose abaxial main and prominent lateral veins. Specimens of var. *pluricephala* have secund conical inflorescences that are much longer than wide, while those of var. *altissima* tend to be nearly as wide as long.

Solidago altissima L. is native to North America and is a member of *S.* subsect. *Triplinerviae* (Torr. & A. Gray) Nesom (Semple & Cook 2006). The species includes plants with densely hispid-strigose stems (sparsely to densely so proximally and densely so distally and in the inflorescence), lanceolate upper stem leaves with mostly entire margins (lower and mid stem leaves are usually serrate) and moderately to densely strigose on the abaxial surface main and prominent lateral veins. Three varieties are recognized and differ in distribution, upper leaf shape, size and number of upper stem leaf serrations, and inflorescence shape (Semple et al. 2015). The typical race ssp./var. *altissima* is common to abundant in the northern half of the eastern deciduous forest region of North America. Variety *pluricephala* M.C. Johnston is native to the southeastern U.S. from Maryland to Florida west to Oklahoma and south Texas (Semple et al. 2015; not treated by Semple and Cook 2006 Flora North America). The subsp./var. *gilvocanescens* (Rydb.) Semple is native to the Great Plains prairies from Alberta to Manitoba south to northern Texas; it also occurs in scattered prairie habitats further east. Hexaploids of the species have been known to be invasive in south and eastern Asia and Oceania for many years though often reported as *S. canadensis* L. or under the synonym *S. canadensis* var. *scabra* (Muhl. ex Willd.) Torr. & Gray or as *S. altissima* (Li 1978; Iwatsuki 1995; Chen & Semple 2011, Sakata et al. 2015; Cheek and Semple 2016; Semple and Rao 2017; Australia's Virtual Herbarium 2017). The var. *altissima* was only recently confirmed to be adventive in Europe (Verloove et al. 2017); previous reports are likely for the diploid *S. canadensis* var. *hargeri* Fern. Only hexaploids of *S. altissima* have been reported from India (Sarkar et al. 1980; Bala and Gupta 2013; as *S. canadensis*), Japan (Huziwara, Y. 1962), and Taiwan (Peng & Hsu 1978). In North America, diploids and tetraploids occur in var. *gilvocanescens* with a few tetraploids and predominantly hexaploids being reported for var. *altissima* and var. *pluricephala* (Semple et al. 2015).

During a visit to Kew Herbarium (K; Thiers continuously updated) in late 2014, a number of Asian and Oceanian collections of what appeared to be either *S. chilensis* or *S. altissima* were examined among the general collections of *Solidago*. These were borrowed from K for more detailed

examination and scoring for comparison with specimens of the four species known to be invasives outside of North America: *S. altissima*, *S. candenisis*, *S. chilensis* (Lopez Laphitz and Semple 2015; Semple et al. 2017), and *S. gigantea* (Schlaepfer et al. 2008). Additional specimens of invasive *Solidago* were borrowed from MEL and PERTH to expand the sample of possible *S. altissima* plants from Australia and the second author provided data taken from greenhouse grown transplants of invasive species of *Solidago* from Australia to complete the sampling. The results of these new multivariate morphometric analyses and details on the specimens are present below.

MATERIALS AND METHODS

Herbarium specimens from BM, GH, F, K, LL, LP, MADS, MEL, MO, the J.K. Morton personal herbarium now deposited in TRT, MIN, NCU, NY, PERTH, TEX, USF, and WAT in MT were used in the multivariate analyses. A list of 14 vegetative and 16 floral traits scored was included in Semple et al. (2015) and is not repeated here. In total, 296 specimens of *S. altissima* (88 specimens included in Semple et al. 2015), *S. canadensis* (57 included in Semple et al. 2015), *S. chilensis* (89 specimens mostly included in Lopez Laphitz and Semple 2015), and *S. gigantea* Ait. (40 specimens, nearly all from Canada and the USA) were included in the analyses including the following:

S. altissima var *altissima*: **NEW ZEALAND**. Canterbury: NE of Christchurch, Harewood, 30 March 1968, *Healy 68/104* (K; dupl. CHR 231047; Figs. 1-2).

S. altissima var. *pluricephala*: **AUSTRALIA**: Queensland: Queensland: N of Kin Kin, Neusavale Rd., 26 Mar 2000, *Bean 16167* (MEL); Moreton, Ipswich, Bundamba Creek, Bergin's Hill Rd, 2 Apr 1993, *P.I. Forster PIF13192* (K; Figs. 3-4). South Australia: along River Torrens, Adelaide, 19 May 2015, greenhouse-grown transplant *Uesugi SAUT* (data from live plant, no voucher). Western Australia: Perth Station, May 1968, *Anon. s.n.* (PERTH). THAILAND. Bangkok, commonly cultivated, 7 Jul 1920, *Kerr s.n.* (K). TONGA. Tongatapu Is., Maufanga, 20 Apr 1959, *Soakai 622* (K; Figs. 5-6). USA. Hawaii: Oahu, Nu'Uanu Valley, Dowsett Tract, 10 Oct 1936, *Fosberg 13294* (K; dupl. US; Figs. 7-8).

S. altissima aff. var. *pluricephala*: **AUSTRALIA**. South Australia: Bray, Ackron Rd., 17 May 2015, greenhouse grown transplant, *Uesugi SAUA* (data from live plant, no voucher; identification tentative).

S. canadensis: **AUSTRALIA**. South Australia: Robe Rd., Greenways, 17 May 2015, greenhouse-grown transplant, *Uesugi SAUR* (data from live plant, no voucher).

All analyses were performed using SYSTAT v.10 (SPSS 2000). Two analysis were run to confirm the identification of *Anon. s.n.* (PERTH), *Bean 16167* (MEL), *Forster PIF13192* (K), *Fosberg 13294* (K), *Kerr s.n.* (K), *Healy 68/104* (K), *Soakai 622* (K), *Uesugi SAUT*, *Uesugi SAUR* and *Uesugi SAUA*. The first STEPWISE discriminant analysis included specimens of *S. altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea*. The second STEPWISE discriminant analysis was performed on 100 specimens of *S. altissima* (33 specimens of var. *altissima*; 29 specimens of var. *gilvocanescens*, and 38 specimens of var. *pluricephala*).

RESULTS AND DISCUSSION

Because some specimens were incomplete and lacked lower and mid stem portions of the shoot, only upper stem leaf traits were included. Ray floret ovary/fruit body length at anthesis and ray floret pappus length at anthesis were also not included due to high correlations with the disc floret traits.

In the STEPWISE discriminant analysis including 296 specimens in four species level a priori groups (*Solidago altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea*), the following ten traits were selected as useful in separating the four a priori groups in the analysis and are presented in order of decreasing F-to-remove values: number of upper leaf margin serrations (30.59), disc corolla length (21.28), outer phyllary length (21.31), number of disc florets (18.04), upper leaf width (13.91), disc

Figure 1. *Solidago altissima* var. *altissima* from New Zealand, *Healy 60_104* (K)

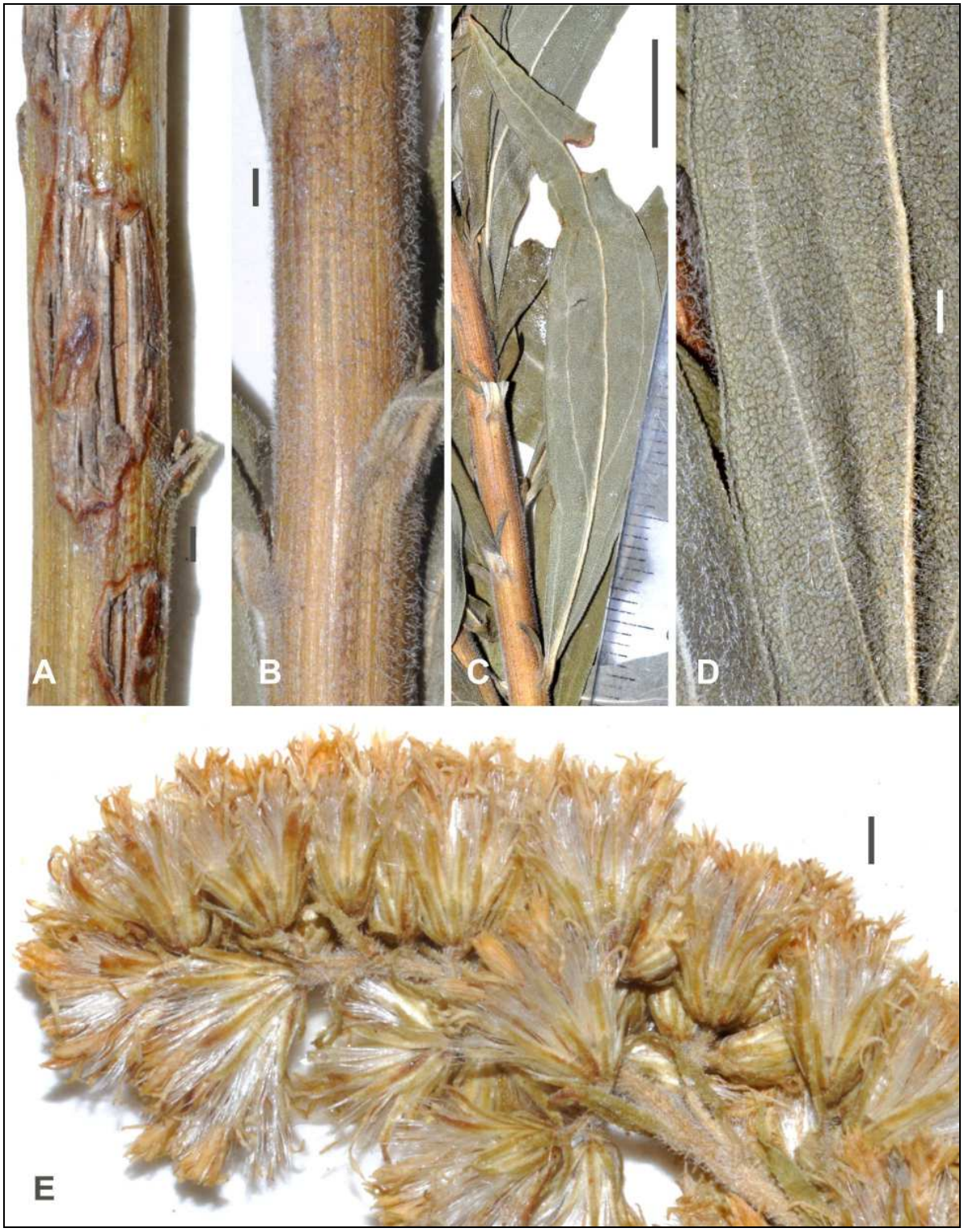

Figure 2. Details of *Solidago altissima* var. *altissima* from New Zealand, *Healy 60_104* (K). **A.** Lower stem. **B.** Mid stem. **C-D.** Upper mid stem leaf, abaxial surface. **E.** Heads. Scale bar = 1 mm in A, B, D and E; = 1 cm in C.

Figure 3. *Solidago altissima* var. *pluricephala* from eastern Australia, *Forster PIF13192* (K).

Figure 4. Details of *Solidago altissima* var. *pluricephala* from eastern Australia; *Forster PIF13291* (K). **A.** Mid stem. **B.** Upper stem. **C.** Mid stem leaf, abaxial surface. **D.** Upper stem leaf abaxial surface. **E.** Heads. Scale bars: = 1 mm in A, B and E; = 1 cm in C and D.

Figure 5. *Solidago altissima* var. *pluricephala* from Tonga, *Soakai 622* (K).

Figure 6. Details of *Solidago altissima* var. *pluricephala* from Tonga; *Soakai* 622 (K). **A.** Lower stem. **B.** Upper stem and leaf abaxial surface. **C.** Lower stem leaf, abaxial surface. **D.** Upper stem leaf, abaxial surface. **E.** Heads. Scale bars: = 1 mm in A, B and E; = 1 cm in C and D.

Figure 7. *Solidago altissima* var. *pluricephala* from Hawaii; *Fosberg 13294* (K).

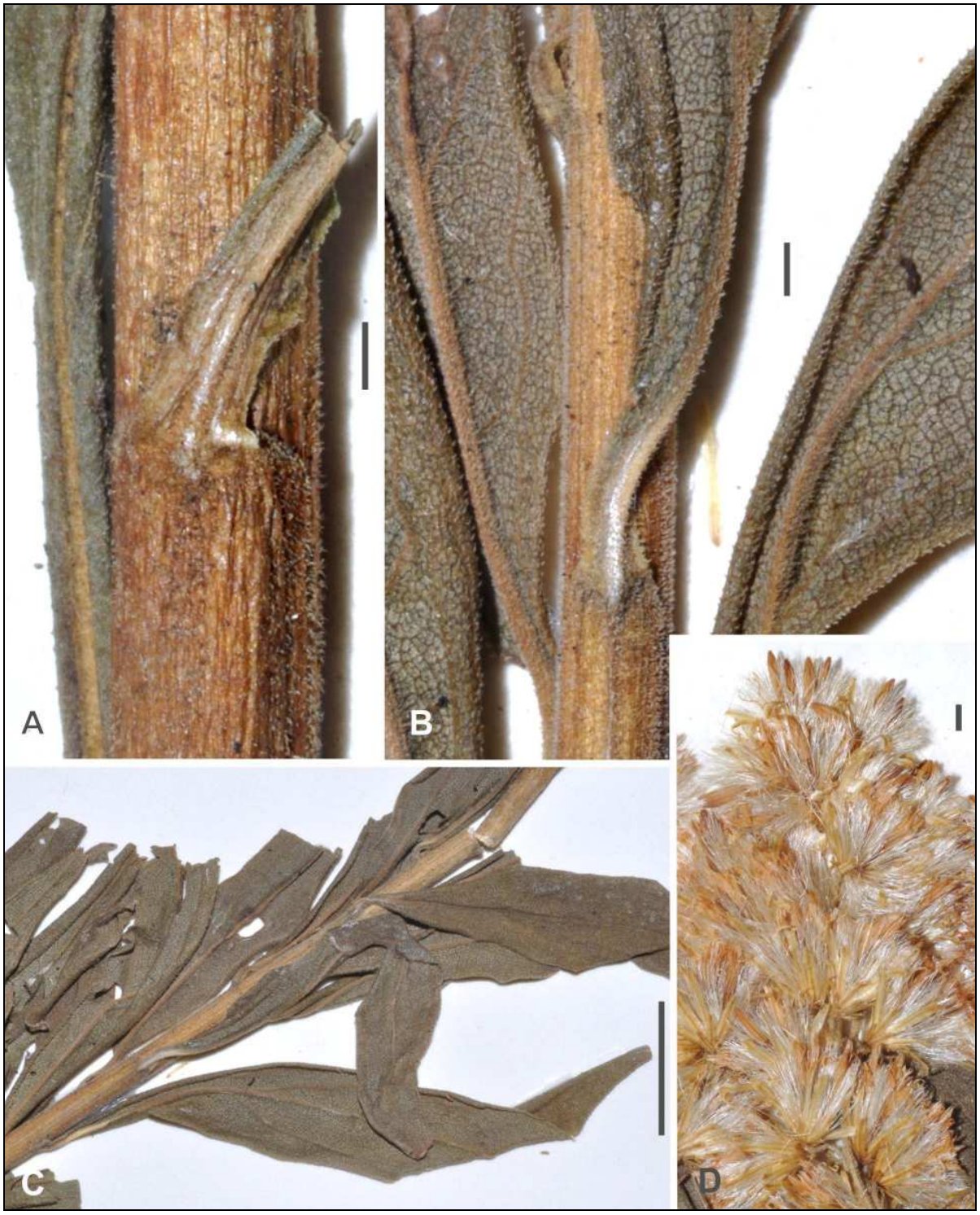

Figure 8. Details of *Solidago altissima* var. *pluricephala* from Hawaii; *Fosberg 13294* (K). **A.** Lower mid stem. **B.** Upper stem and abaxial leaf surfaces. **C.** Upper stem leaves. **D.** Heads. Scale bars: = 1 mm in A, B and D; = 1 cm in C.

Table 1. Between groups F-matrix for the four a priori groups analysis (df = 10 283).

Group	*altissima*	*canadensis*	*chilensis*
canadensis	31.180		
chilensis	74.882	86.564	
gigantea	38.706	33.039	57.985

Wilks' lambda = 0.0485 df = 10 3 292; Approx. F= 49.9922 df = 30 831 prob = 0.0000

corolla lobe length (11.24), upper leaf length (10.42), disc floret pappus length at anthesis (9.53), involucre height (9.98), and disc fruit body length at anthesis (8.95). 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 1. F-values based on Mahalanobis distances between group centroids indicated the largest separation was between *S canadensis* and *S. chilensis* (86.564), and the least separation was between *S. altissima* and *S. canadensis* (31.180).

In the Classificatory Discriminant Analysis, correct assignments of specimens for taxa ranged from 89% to 99%. The Classification matrix and Jackknife classification matrix are presented in Table 2. One hundred of the 110 specimens of the *S. altissima* a priori group (91%) were assigned a posterior to *S. altissima*: *Kerr s.n.* (K) from Thailand with 100% probability, *Soakai 622* (K) from Tonga with 99% probability, *Fosberg 13294* (K) from Hawaii with 99% probability, *Bean 16167* (MEL) from Australia with 99% probability, *Forster PIF13192* (K) from Australia with 95% probability, *Healy 68/104* (K) from New Zealand with 90% probability, *Uesugi SAUT* from Australia with 90% probability, and *Anon. s.n.* (PERTH) from Australia with 86% probability. Fifty-one of the 57 specimens of the *S. canadensis* a priori group (89%) were assigned a posteriori to *S. canadensis*: *Uesugi SAUR* with 48% probability (46% to *S. altissima* and 5% to *S. gigantea*). Thirty-eight of the 40 specimens of the *S. gigantea* a priori group (95%) were assigned a posteriori to *S. gigantea*. The greenhouse-grown *Uesugi SAUA* was assigned to *S. gigantea* with 99% probability and tentatively treated in that a priori group in the analyses. However, discussion about its assignment to *S. gigantea* resulted in reassigning it tentatively to *S. altissima* var. *pluriacephala* based on greenhouse observations. Australia's Virtual Herbarium (2017) lists no collections of *S. gigantea* from Australia. Additional details of the results are not presented here.

Table 2. Linear and jackknife classification matrices from the Classificatory Discriminant Analysis of four a priori groups; a posteriori placements to groups in rows.

Group	*altissima*	*canadensis*	*chilensis*	*gigantea*	% correct
altissima	100	7	1	2	91
canadensis	3	51	0	3	89
chilensis	1	0	88	0	99
gigantea	0	1	1	38	95
Totals	104	59	90	43	94

Jackknifed classification matrix

Group	*altissima*	*canadensis*	*chilensis*	*gigantea*	% correct
altissima	100	7	1	2	91
canadensis	6	48	0	3	84
chilensis	1	1	86	1	97
gigantea	1	1	3	35	88
Totals	108	57	90	41	91

Two dimensional plots of CAN1 versus CAN3 and CAN1 versus CAN2 canonical scores for 296 specimens of *Solidago altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea* are presented in Fig. 9. Eigenvalues on the first three axes were 3.625, 1.369 and 0.883.

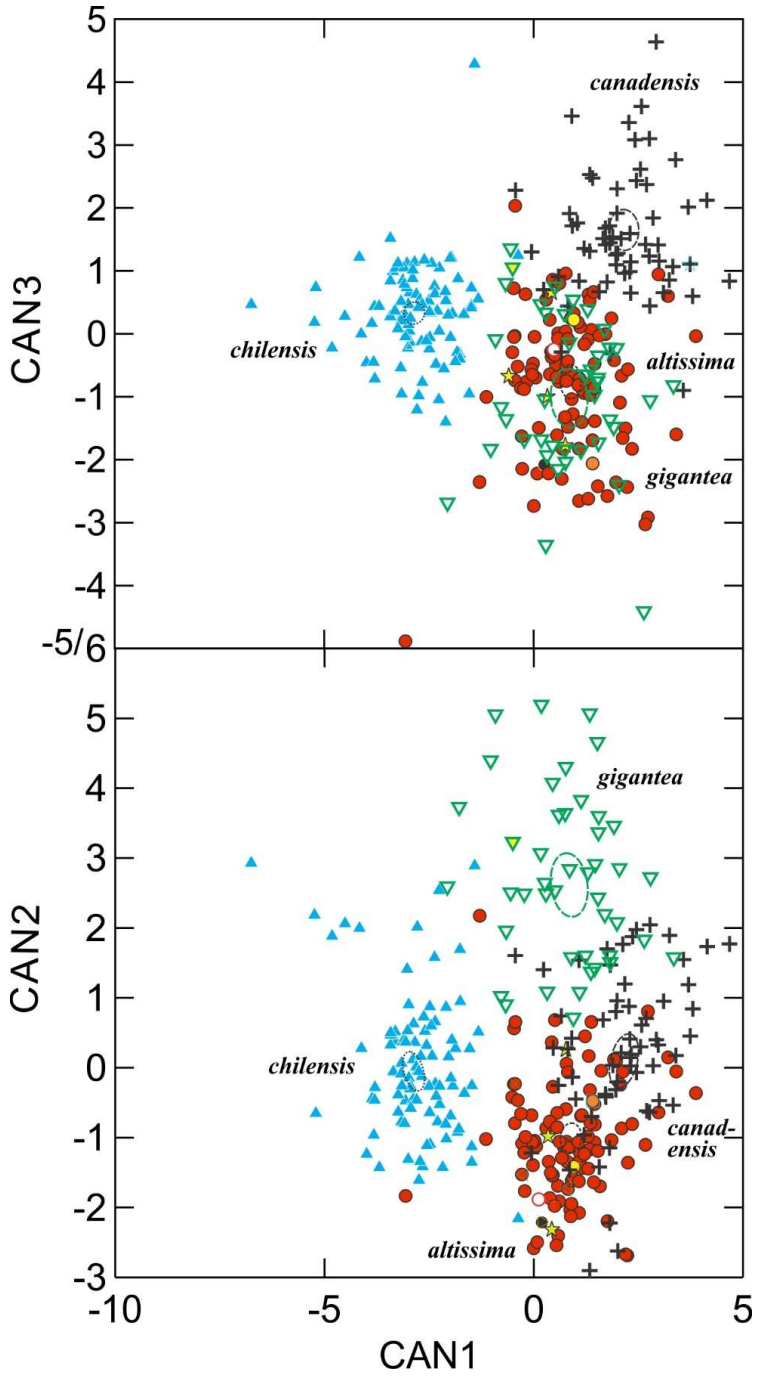

Figure 9. Plot of canonical scores (CAN1 vs CAN3 and CAN1 vs CAN2) for 296 specimens of adventive species of Solidago: *S. altissima* (red dots; from Australia - yellow stars; from New Zealand - yellow dot; from Tonga - orange dot; from Hawaii - white filled red circle; from Thailand - black dot), *S. canadensis* (black +s), *S. chilensis* (blue triangles), and *S. gigantea* (green inverted open triangles; from Australia - yellow filled green inverted triangle).

In the STEPWISE discriminant analysis of 100 specimens of three variety level a priori groups of *S. altissima* (var. *altissima*, var. *gilvocanescens* and var. *pluricephala*), the following seven traits were selected as best separating the groups and are listed in order of decreasing F-to-remove values: involucre height (30.96), disc corolla lobe length (9.05), number of disc florets (8.18), inner phyllary length (6.90), number of ray florets (5.99), outer phyllary length (4.99), and ray floret lamina width (4.21). 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 3. F-values based on Mahalanobis distances between group centroids indicated the largest separation was between var. *gilvocanescens* and var. *pluricephala* (17.151), and the least separation was between var. *altissima* and var. *pluricephala* (5.181).

Table 3. Between groups F-matrix for the three a priori groups analysis (df = 7 91).

Group	*altissima*	*gilvocanescens*
gilvocanescens	12.241	
pluricephala	5.181	17.151

Wilks' lambda = 0.3077 df = 7 2 97; Approx. F= 10.4372 df = 14 182 prob = 0.0000

In the Classificatory Discriminant Analysis of the three varietal level a priori groups (var. *altissima*, var. *gilvocanescens* and var. *pluricephala*), percents of correct a posterori assignment to the same a priori group were 93% for var. *gilvocanescens*, 76% for var. *pluricephala*, and 61% for var. *altissima*. The Classification matrix and Jackknife classification matrix are presented in Table 4. *Healy 68/104* (K) in the var. *altissima* a priori group was assigned a posteriori to var. *altissima* with 70% probability (29% to var. *pluricephala* and 1% to var. *gilvocanescens*). *Uesugi SAUT* (Australia) in the var. *altissima* a priori group was assigned a posteriori to var. *altissima* with 63% probability (31% to var. *pluricephala* and 6% to var. *gilvocanescens*). The following collections in the var. *pluricephala* a priori group were assigned to var. *pluricephala*: *Bean 16167* (MEL; Queensland, Australia) with 98% probability, *Fosberg 13294* (K; Hawaii) with 97% probability, *Kerr s.n.* (K; Thailand) with 96% probability, *Anon. s.n.* (PERTH; Western Australia, Australia) with 96% probability, *Soakai 622* (K; Tonga) with 94% probability, and *Forster PIF13192* (K; Queensland, Australia) 93% probability. Further details of the results are not presented.

Table 4. Linear and jackknife classification matrices from the Classificatory Discriminant Analysis of three varietal level a priori groups; a posteriori placements to groups in rows.

Group	*altissima*	*gilvocanescens*	*pluricephala*	% correct
altissima	16	5	12	48
gilvocanescens	3	26	0	90
pluricephala	9	2	27	71
Totals	28	33	39	69

Jackknifed classification matrix

Group	*altissima*	*gilvocanescens*	*pluricephala*	% correct
altissima	20	5	8	61
gilvocanescens	2	27	0	93
pluricephala	8	1	29	76
Totals	30	33	37	76

A two dimensional plot of CAN1 versus CAN2 canonical scores for 100 specimens of *S. altissima* var. *altissima*, *S. altissima* var. *gilvocanescens* and *S. altissima* var. *pluricephala* is presented in Fig. 10. Eigenvalues on the first two axes were 1.392 and 0.359.

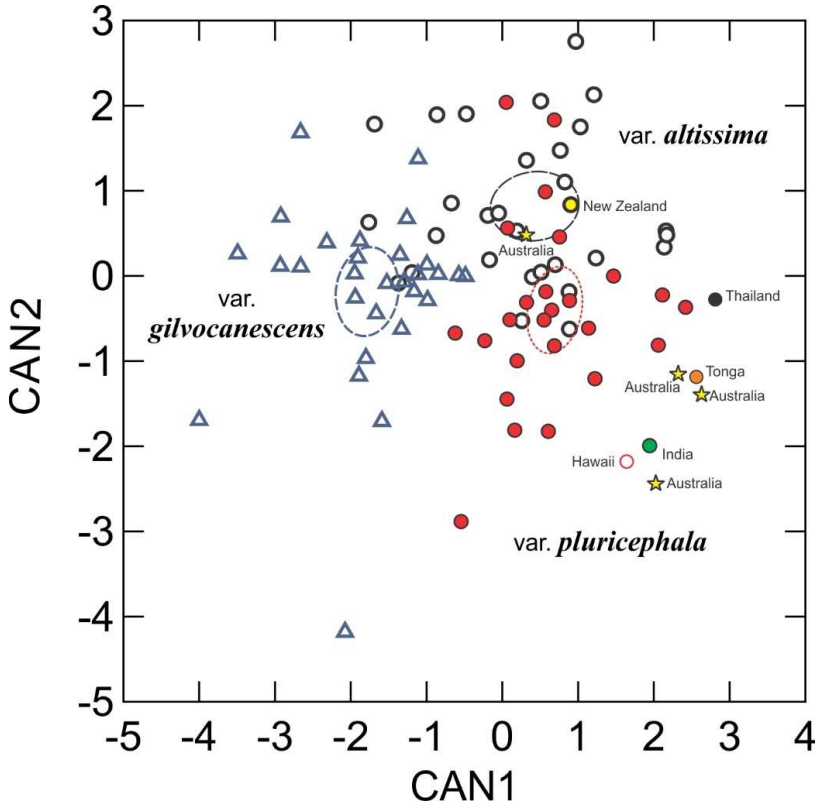

Figure 10. Plot of canonical scores (CAN1 vs CAN2) for 100 specimens of *Solidago altissima*: var. *altissima* (black circles; from New Zealand-yellow filled black circle), var. *gilvocanescens* (open blue triangles), and var. *pluricephala* (red dots; from Australia-yellow stars; from Tonga-orange dot; from Hawaii-white filled red circle; from Thailand-black dot; from India-green dot).

The results clearly show that *Solidago altissima* var. *pluricephala* occurs or did occur at one time as escaped cultivars or invasive adventives in the states of Queensland, South Australia, and Western Australia in Australia, Thailand, Tonga, and Oahu Is., Hawaii in the USA. *Solidago altissima* var. *altissima* is present in Australia and New Zealand. Semple et al. (2017) documented the presence of *S. chilensis* in Australia. The Australia's Virtual Herbarium (2017) listed 84 herbarium specimens of *S. altissima* collected in New South Wales, Queensland and Victoria, Australia. How many of these are *S. chilensis*, *S. altissima* var. *altissima*, and *S. altissima* var. *pluricephala* need to be determined.

Key to *Solidago* subsect. *Triplinerviae* taxa in Australia

All taxa in subsect. *Triplinerviae* have triple-nerved lower and middle and often upper stem leaves and have inflorescences that are generally very narrowly to broadly secund conical.

1. Lower stems hairless.

2. Middle and upper stem leaf margins serrate, inflorescence usually nearly as wide as tall.

3. Involucres 2.5–4 mm tall at flowering ..... **Solidago gigantea** (presence needs confirmation)
3. Involucres 1.7–2.5 mm tall at flowering ..... **Solidago canadensis var. canadensis**

2. Middle and upper stem leaf margins entire, inflorescence much narrower than tall **Solidago chilensis**

1. Lower stems moderately to densely hairy.

4. Involucres 1.7–2.5 mm tall at flowering; upper stem leaves serrate, moderately hairy on abaxial main veins ..... **Solidago canadensis var. hargeri**
4. Involucres 3.0–4.0 mm tall at flowering; upper stem leaves entire, densely hairy on abaxial main veins.

5. Infloresence about as wide as tall; upper stem leaves somewhat reduced in size compared to mid stem leaves ..... **Solidago altissima var. altissima**
5. Infloresence narrower to much narrower than tall; upper stem leaves much reduced in size compared to mid stem leaves ..... **Solidago altissima var. pluricephala**

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