

**MULTIVARIATE MORPHOMETRIC CONFIRMATION
OF *SOLIDAGO CHILENSIS* (ASTERACEAE: ASTEREAE)
IN AUSTRALIA**

JOHN C. SEMPLE

Department of Biology
University of Waterloo
Waterloo, Ontario, Canada N2L 3G1
jcsemp@uwaterloo.ca

RITA LOPEZ LAPHITZ

INIBIOMA-CONICET
Quintral 1250 (8400) S.C. de Bariloche
Río Negro, Argentina

AKANE UESUGI

School of Biological Sciences
Monash University
Clayton, Melbourne, Victoria, Australia

SKYE C. COFFEY

Western Australian Herbarium (PERTH)
Department of Parks and Wildlife
Kensington, Western Australia, Australia

NEVILLE G. WALSH

Royal Botanic Gardens and National Herbarium of Victoria
Melbourne, Victoria, Australia

ABSTRACT

Collections of adventive *Solidago* from the states of Western Australia, South Australia, and Victoria in Australia are reported here to be *S. chilensis* Meyen. The species is not currently listed as present in Australia. Four collections were scored and included in a multivariate morphometric analysis comparing *S. altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea* known to be adventive in Eurasia and Oceania. Additional Australian herbarium specimens not included in the analysis with glabrous lower and mid stems, glabrous linear lanceolate upper stem leaves with ciliate entire margins, and secund conical inflorescences that are much longer than wide have been determined as *S. chilensis*.

Solidago chilensis Meyen is native to South America and is a member of *S.* subsect. *Triplinerviae* (Torr. & A. Gray) Nesom (Lopez Laphitz 2009; Lopez Laphitz & Semple 2015). The species includes plants with densely very short canescent stems to plants with glabrous stems from base to into the inflorescence. The glabrous-stemmed morphs are most common in Argentina and occur as the only morph present in the La Plata to Buenos Aires region (Lopez Laphitz 2009); similar plants have been introduced into the West Indies and Madeira Island, Portugal (Conçalves Silva et al. 2009). The species is not listed as present in Australia (Australia's Virtual Herbarium 2017).

During a visit to Kew Herbarium (K; Thiers, continuously updated) in November of 2014 a specimen from Western Australia *Keighery 8049* (K; Figs. 1-2; AUSTRALIA. Western Australia: 16 km S of Perth, Jandokot, Nicholson Rd, 5 Mar 1986) was examined and thought to be either *Solidago altissima* L. var. *pluricephala* M.C. Johnst. or *S. chilensis* based on upper leaf traits and inflorescence shape. The specimen was subsequently borrowed for detailed study in the laboratory in Waterloo, Canada, and traits scored for inclusion of the specimen in a multivariate morphometric analysis of



Figure 1. *Solidago chilensis* from Jandakot south of Perth, Australia; Keighery 8049 (K).



Figure 2. Details of *Solidago chilensis* from Australia, *Keighery 8049* (K). A. Upper mid stem. B. Upper stem at base of inflorescence. C. Upper stem leaves. D. Upper stem leaf, adaxial surface and ciliate margin. E. Heads. Scale bars: = 1 mm in A, B, D and E; = 1 cm in C.

similar plants. The specimen had upper stems and leaves that were glabrous or very sparsely strigose in the inflorescence which is consistent with many specimens of *S. chilensis*, but not for specimens of *S. altissima*, which is known to occur in Australia (Australia's Virtual Herbarium 2017). Additional *Solidago* specimens were borrowed from MEL and PERTH and A. Uesugi recorded data from transplanted individuals under greenhouse cultivation resulting in three additional putative *S. chilensis* collections being scored for inclusion in the multivariate analyses: *Walsh 5179* (MEL; AUSTRALIA. Victoria: Gippsland Plain, Melbourne suburb, Glen Iris, eastern bank of Gardiners Creek, 30 Mar 2000; Fig. 3), *A. Uesugi SAHV* (cult. Greenhouse, Monash University-Clayton original from AUSTRALIA. South Australia: Hope Valley, 18 May 2015), and *A. Uesugi SAPR* (cult. Greenhouse, Monash University – Clayton, originally from AUSTRALIA. South Australia: Adelaide, Player Reserve, 19 May 2015). Semple et al. (2017) noted the presence of *S. altissima* var. *pluricephala* in Australia and from several other locations in Asia, Oceania, and Hawaii. *Solidago altissima* has densely hairy stems from the base to the apex, although robust plants with thick lower stems may lose hairs as the stem grows.

MATERIALS AND METHODS

Herbarium specimens of *Solidago altissima*, *S. canadensis*, *S. chilensis*, and *S. gigantea* 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.

All analyses were performed using SYSTAT v.10 (SPSS 2000). Two analysis were run to confirm the identification of *Keighery 8049* (K), *Walsh 5179* (MEL), and *Uesugi SAHV* and *Uesugi SAPR* as *S. chilensis*. A STEPWISE discriminant analysis was performed on 121 specimens of *S. chilensis* (85), *S. mexicana* (19) and *S. sempervirens* (17) to confirm that *Walsh 5179* (MEL) was not *S. mexicana* or *S. sempervirens*. A second STEPWISE discriminant analysis was performed on 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) to confirm that *Keighery 8049* (K), *Walsh 5179* (MEL), and *Uesugi SAHV* and *Uesugi SAPR* were *S. chilensis*.

RESULTS AND DISCUSSION

Because *Keighery 8049* (K) was 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 first STEPWISE discriminant analysis including *S. chilensis*, *S. mexicana* and *S. sempervirens*, *Keighery 8049* (K), *Walsh 5179* (MEL), and *Uesugi SAHV* and *Uesugi SAPR* were all placed a posteriori into *S. chilensis* with 98-100% probability. The following five traits were selected as best separating the taxa and are listed in order of decreasing F-to-remove values: number of ray florets (74.84), upper leaf length (23.44), ray floret lamina length (21.72), number of disc florets (20.48), and involucre height (7.22). Further details of the analysis are not presented. *Walsh 5179* (MEL) was first identified as *S. aff. canadensis* on the original label, then annotated in 2000 from a duplicate by C. Taylor (Southeastern Oklahoma State University) as *S. sempervirens*, but was assigned a posteriori in this study to *S. chilensis* with 100% probability. At the time of performing the analysis, *Walsh 5179* (MEL) was one of 19 specimens listed under *S. sempervirens* on Australia's Virtual Herbarium: all from a narrow zone running from well north of Melbourne, to the Bass Coast south of Melbourne, Victoria. Superficially, *Walsh 5179* (MEL) looks similar to specimens of *S. sempervirens*, but on technical leaf and floret traits is clearly not that species; e.g. the mid stem leaves



Figure 3. *Solidago chilensis* from Glen Iris, Melbourne, Australia; Walsh 5179 (MEL).



Figure 4. *Solidago chilensis*, greenhouse-grown plant from south of greater Melbourne, Australia; *Akane Uesugi* plant SAU4 (not included in study).

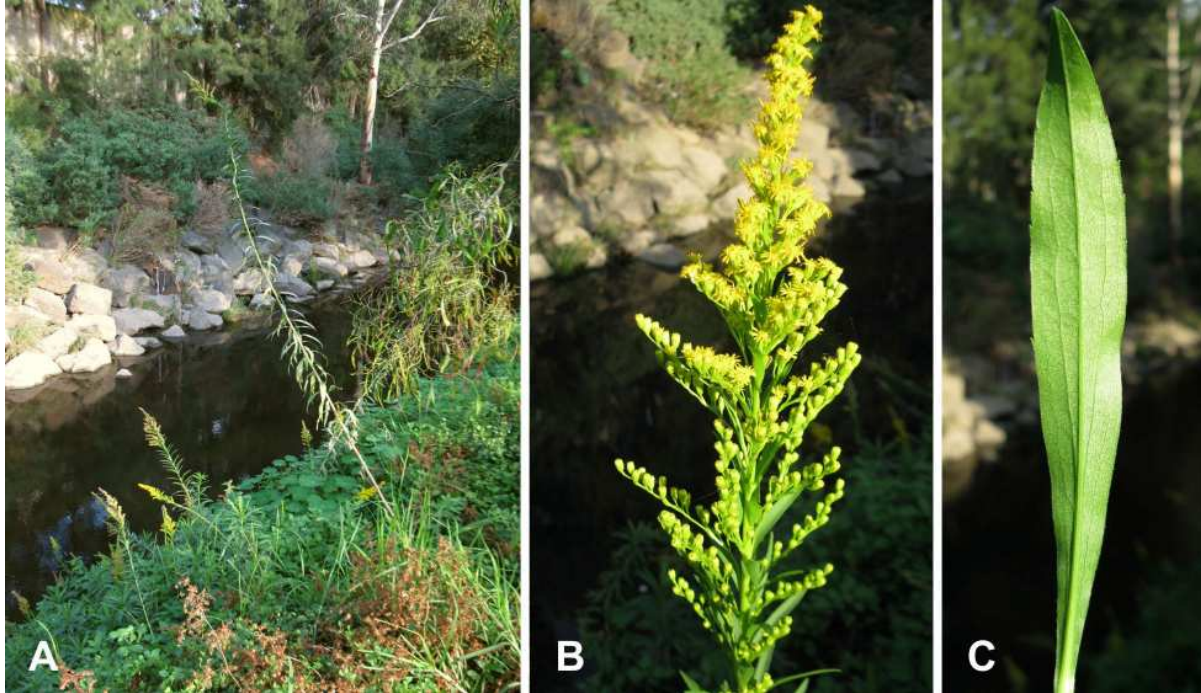


Figure 5. *Solidago chilensis* in Glen Iris, Melbourne, Victoria, Australia, population near Walsh 7159 (MEL). A. Habitat. B. Inflorescence. C. Stem leaf. Digital photographs by N.G. Walsh.

are triple-nerved. Subsequent to submission of this publication, all of the other 18 specimens had been redetermined by N.G. Walsh to *S. chilensis*. There are no specimens at MEL or other Australian herbaria that document the presence of *S. sempervirens* in Australia.

In the second 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 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 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 were 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. Eighty-eight of the 89 specimens of the *Solidago chilensis* a priori group were assigned a posteriori to *S. chilensis*: Keighery 8049 (K) with 100% probability, Walsh 5179 (MEL) with 98% probability, Uesugi SAHV with 95% probability, and Uesugi SAPR with 68% probability (30% to *S. altissima* and 2% to *S. gigantea*; this was a greenhouse grown specimen). Additional details of the results are not presented here.

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

Group	<i>altissima</i>	<i>canadensis</i>	<i>chilensis</i>
<i>canadensis</i>	31.180		
<i>chilensis</i>	74.882	86.564	
<i>gigantea</i>	38.706	33.039	57.985

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

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

Jackknifed classification matrix

Group	<i>altissima</i>	<i>canadensis</i>	<i>chilensis</i>	<i>gigantea</i>	% correct
<i>altissima</i>	100	7	1	2	91
<i>canadensis</i>	6	48	0	3	84
<i>chilensis</i>	1	1	86	1	97
<i>gigantea</i>	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. 5. Eigenvalues on the first three axes were 3.625, 1.369 and 0.883.

Additional collections of *S. chilensis* examined. AUSTRALIA. Victoria: Balwyn North, brow of the S bank of Koonung Creek, adjacent to the NE corner of the Boroondara Tennis Centre car park, 19 Apr 2005, *Lorimer 1886a* (MEL); Echuca Village, Mitchell Road, 29 Mar 2004, *Caldwell s.n.*, (MEL); Inverloch, south side of Esplanade, opposite intersection with Nautilus Rd., 16 Mar 2008, *Stajsic 4498* (BRI, MEL, NSW); Inverloch, foreshore, 20 Mar 2006, *Hibbert s.n.* (MEL). **Western Australia:** Bayswater, Baigup Wetlands, 3 Mar 1999, *Keighery 15665* (PERTH); Bayswater, NW bank of Swan River at Garratt Rd Bridge, 6 Mar 1995, *Lepschi & Lally 1755* (AD, CANB, PERTH), W end of Garret Rd Bridge, 3 Jul 2001, *Davis 9816* (PERTH); Brookton Hwy, 0.5 km from Croyden Rd, s.d., *Lloyd s.n.* (PERTH); Canning Vale, Randford Rd., 500 m E of Nicholson Rd, s.d., *Lloyd s.n.* (PERTH); ca 14 km SSE of Capel on road to Donnybrook, 3 May 1996, *Lepschi & Lally BJL 2592* (AD, CANB, PERTH, US); Esperance, 4 Mar 1999, *Turley 5/399* (PERTH); Dempster St, vacant lot, 4 Apr 1987, *Keighery & Alford 1307* (PERTH); Lake Richmond Nature Reserve, NE side, 100 m from Safety Bay Rd, 20 Apr 2001, *Bellman 6* (PERTH); Wembley Downs, near junction of Weaponess Road and Empire Ave, 29 Mar 2000, *Davis 9153A* (PERTH).

Almost certainly, additional collections of *S. chilensis* are included among the 196 specimens of *Solidago* listed on Australia's Virtual Herbarium (2017).

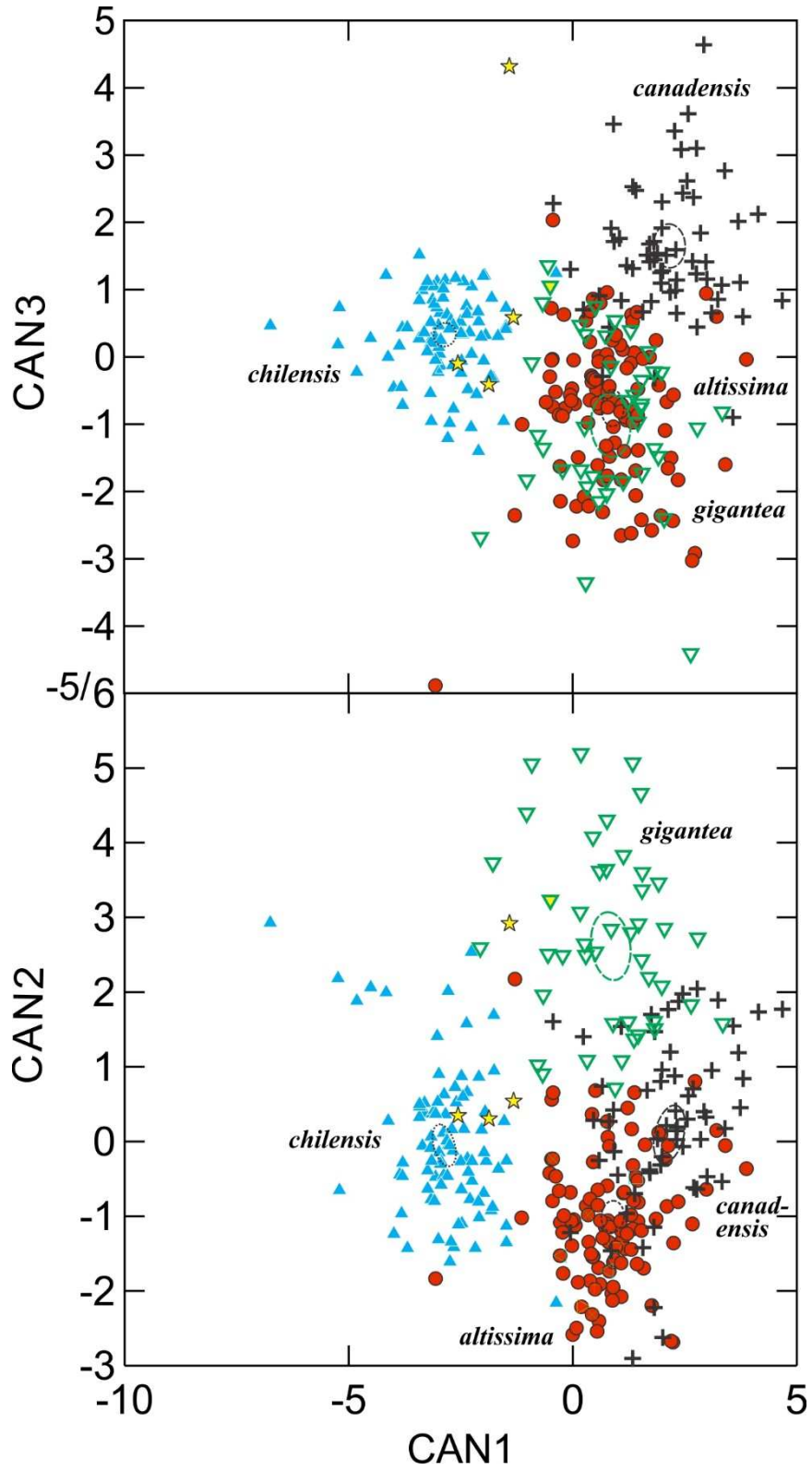


Figure 4. Plot of canonical scores (CAN1 vs CAN3 and CAN1 vs CAN2) for 296 specimens of adventive species of *Solidago*: *S. altissima* (red dots), *S. canadensis* (black +s), *S. chilensis* (blue triangles; Australian adventives-yellow stars), and *S. gigantea* (green inverted open triangles).

Detailed description of *Solidago chilensis* based on all collections included in the analyses

(modified from Lopez Laphitz and Semple 2015; means in bold face)

Herbaceous perennials from short to long rhizomes; stems 7–**105**–200 cm, erect, glabrate proximally, glabrate to densely canescent distally, hairs 0.05–0.3 mm. Leaves with the proximal ones oblanceolate, twisted, nearly always withering well before flowering; mid-stem leaves usually persisting, in most cases the biggest, sessile, blades linear to oblanceolate, 13–**61**–130 × 2–**6.7**–32 mm, with 0–2–12 serrations, 3(5)-nerved from shortly above base, abaxial and adaxial faces glabrous or sparsely strigose; distal leaves linear-lanceolate, smaller than proximal, 10–**37**–80 × 1–**4**–27 mm, with 0–**0.5**–10 serrations; inflorescence leaves linear to lanceolate, 4.4–45 × 0.5–18 mm with 0–5 serrations. Heads 20 to 200 plus; in secund lax to dense conical paniculiform arrays, 5–**13.8**–32 × 1–**7.9**–35 cm, branches spreading recurved, secund; involucre campanulate, 3.5–**4.4**–5.5 m high; phyllaries in 3 or 4 series, those of outer series ovate, 1.1–2.7 × 0.3–1.6 mm, with inner phyllaries oblanceolate, 0.29–5.1 × 0.3–1 mm, 1 to 3 nerves. Ray florets 7–**14**–21; laminae yellow, 0.4–**2.9**–3.1 × 0.1–**0.5**–1.2 mm; disk florets 2–**9**–30; corollas 2.4–**3.8**–4.9 mm, lobes 0.12–**1.1**–3.9 mm. Fruit: cypselae body, 0.6–**0.8**–1.5 at anthesis, to 3.3 mm at maturity, sparsely to densely strigose; longest pappus bristles 1.9–**3.5**–5.1 mm. Chromosome count 2n = 18.

ACKNOWLEDGEMENTS

This research was supported by Natural Sciences and Engineering Research Council Discovery Grants to JCS. Kew Herbarium is thanked for assistance during my visit in November 2014 and for the loan of specimens of *Solidago*. Kevin Thiele of the Western Australian Herbarium (PERTH) is thanked for his assistance in obtaining a digital image of *Lepschi & Lally 1755* (PERTH) and for making observations on stem pubescence features of the actual specimen. Pina Milne at MEL is thanked for her assistance with collections of *Solidago* at the National Herbarium of Victoria. Joan Venn (WAT) is thanked for her curatorial assistance in Waterloo. Andrew Lam assisted in recording location data on specimens of *Solidago* subsect. *Triplinerviae*. The following students are thanked for collecting morphological data on species of subsect. *Triplinerviae*: Sofia Bzovsky, Y. Alex Chong, Haris Faheemuddin, Imram Khamis, Katherine Kornobis, Hammad Rahman, and Marian Sorour.

LITERATURE CITED

- Australia's Virtual Herbarium. 2017. *Solidago*. <avh.ala.org.au> Accessed 13 April 2017.
- Conçalves Silva, J.J., J.C. Semple, R. Lopez Laphitz, and M. Menezes de Sequeira. 2009. First record of La Plata River Goldenrod *Solidago chilensis* Meyen (Asteraceae), in the Island of Madeira (Portugal). Bol. Mus. Mun. Funchal 58: 32–36.
- Lopez Laphitz, R. 2009. The genus *Solidago* L. (Astereae, Asteraceae) in South America and related taxa in North America. M.Sc. Dissertation. Univ. of Waterloo, Waterloo, Ontario.
- Lopez Laphitz, R. and J.C. Semple. 2015. A multivariate morphometric analysis of the *Solidago chilensis* complex in South America and related taxa in North America (Asteraceae: Astereae). Ann. Missouri Bot. Garden 100: 423–441.
- Semple, J.C. and A. Uesugi. 2017. *Solidago altissima* var. *pluricephala* (Asteraceae: Astereae) in Australia, Tonga, and Hawaii. Phytoneuron 2017-40: 1–16.
- Semple, J.C., H. Rahman, S. Bzovsky, M.K. Sorour, K. Kornobis, R. Lopez Laphitz, and L. Tong. 2015. A multivariate morphometric study of the *Solidago altissima* complex and *S. canadensis* (Asteraceae: Astereae). Phytoneuron 2015-10: 1–31.
- SPSS. 2000. SYSTAT version 10 for Windows. SPSS Inc., Chicago. Illinois.
- Thiers, B. [continuously updated]. Index Herbariorum: A global directory of public herbaria and associated staff. Virtual Herbarium, New York Botanical Garden, Bronx. <<http://sciweb.nybg.org/science2/IndexHerbariorum.asp>>