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A RECENT COLLECTION OF *SOLIDAGO BUCKLEYI* (ASTERACEAE: ASTEREAE) IN ALABAMA AND A MULTIVARIATE MORPHOMETRIC COMPARISON OF *S. BUCKLEYI, S. PETIOLARIS* VAR. *PETIOLARIS,* AND *S. PORTERI*

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ABSTRACT

A collection of *Solidago buckleyi* was made in St. Clair Co., Alabama, in 2006: *Keener 4013* (UWAL, WAT). The WAT duplicate was included in a multivariate morphometric comparison of specimens of *S. buckleyi*, *S. petiolaris* var. *petiolaris*, and *S. porteri* and was placed a posteriori in *S. buckleyi* with 100% probability. This is the first confirmed collection of the species from Alabama since the original type material of the species was collected by S.B. Buckley in 1838. The collection represents a significant disjunction from the main area of distribution of the species in southern Missouri, adjacent Arkansas, and eastward though southern Illinois and adjacent Kentucky to extreme southwestern Indiana.

A goldenrod collection from Alabama was made and subsequently identified by Keener as *Solidago buckleyi* Torr. & A. Gray (St. Clair Co.: 2.0 air mi ENE of Ferguson Crossroad, Chandler Mountain, just W of Creel Chapel of Camp Sumatanga property, along NE facing bluff, 33.948293° N, 86.264177° W, 4 Nov 2007, *Keener 4013*; UWAL, WAT; Figs 1 and 2). The collection locality just under the bluff of the mountain is at the boundary of the Southwestern Appalachians and the Ridge and Valley Level III Ecoregions (Griffith et al 2001). It is also at a geologic boundary where Pottsville Formation sandstone along the rim of the mountain meets the Parkwood Formation shale just below the brow (Burchard & Andrews 1947). The soils weathered from Parkwood shale tends to be more alkaline than the soil from Pottsville sandstone above. As might be expected at a sharp geologic boundary, the assemblage of plants seemed to be a mixture of some odd associates including but not limited to *Rhus aromatica* and *Kalmia latifolia*. *Quercus montana* appeared to be one of the more dominant members of the canopy.

A duplicate of this collection was sent to Semple in 2016 for confirmation of identification following an email exchange regarding the specimen and possible alternative identifications, e.g. *S. porteri* Small if its lower stem and basal leaves are not present. The serrate mid stem leaves of *S. porteri* and *S. buckley* can be similar and both are very rare in Alabama. *Solidago buckleyi* is member of *Solidago* subsect. *Thyrsiflorae* A. Gray, which includes species that lack lower stem leaves at the time of flowering and phyllaries that are very sparsely to densely stipitate glandular and variously strigose. In comparison, *Solidago porteri* is a member of subsect. *Squarrosae* and has large petiolate basal stem leaves typical of the subsection and glabrous lower stems becoming sparsely to moderately strigose distally.

The original collection of S*olidago buckleyi* made in 1838 by S.B. Buckley came from "the interior" of Alabama based on a collection seen by Torrey and Gray. All other collections known for the species come from mainly Missouri, with some from northern Arkansas, southern Illinois, south-

Figure 1. *Solidago buckleyi* from St. Clair Co., Alabama: *B.R. Keener 4013* (WAT, unmounted).

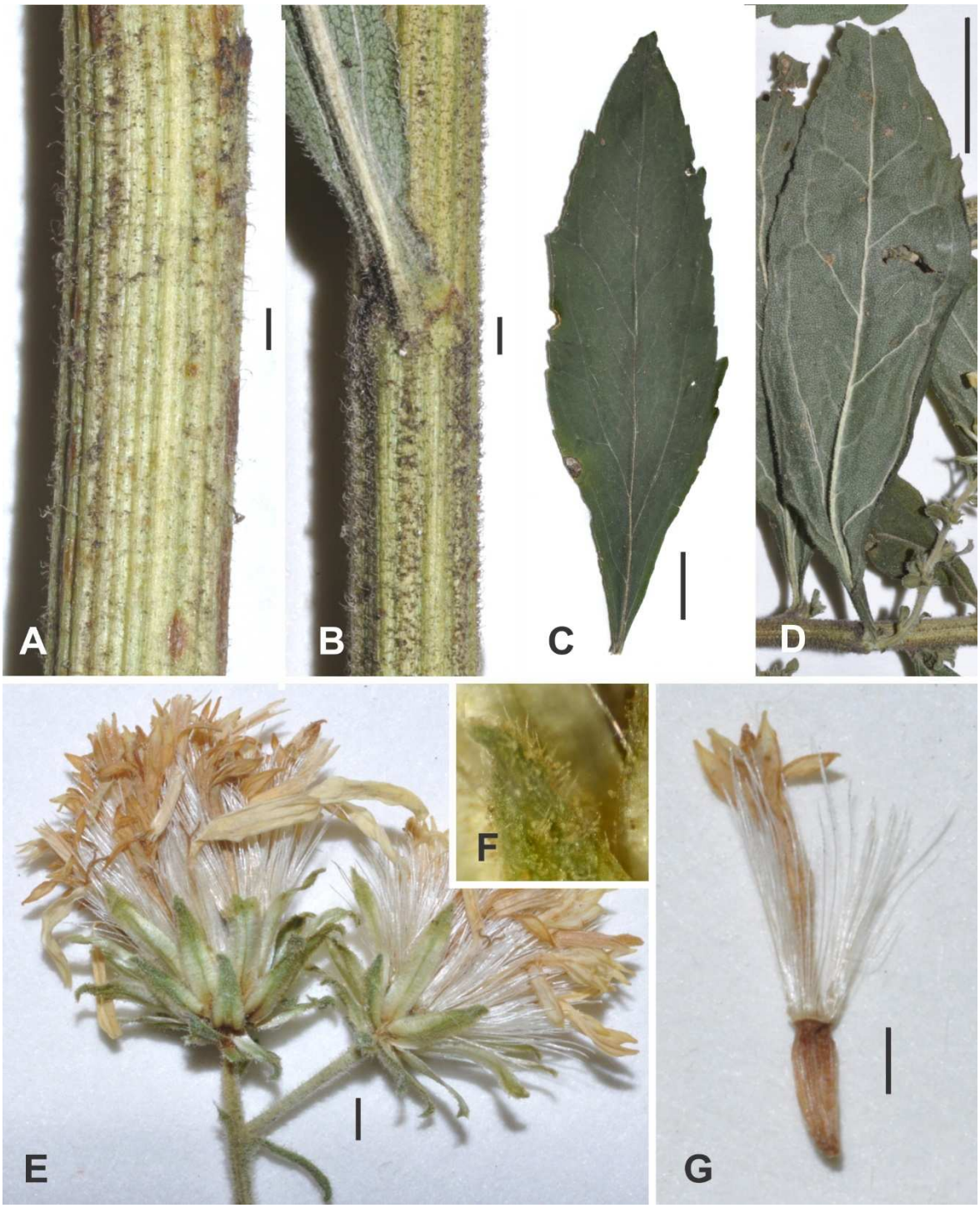

Figure 2. Details of morphology of *Solidago buckleyi* from Alabama: *Keener 4013* (WAT). **A**. Lower stem. **B.** Mid stem. **C.** Mid stem leaf , adaxial surface. **D.** Upper stem leaf in inflorescence, abaxial surface. **E.** Flowering heads. **F.** Mid series phyllary tip with stalked glands and strigose hairs**. G.** Developing cypsela with post anthesis disc corolla. Scale bar = 1 cm in C, D; = 1 mm in A, B, E, and G.

western Indiana, and western Kentucky (Semple & Cook 2006; Semple continuously updated). *Solidago buckleyi* has been recognized as a species separate from *S. petiolaris* Ait. by authors since it was first described, although difficulties in distinguishing it from *S. petiolaris* have often been noted

(Steyermark 1963; Cronquist 1968, 1980; Nesom 1993; Weakley 2015; Yatskievych 2006). Nesom (1990) discussed the history of the application of the name and provided a key to separate *S. petiolaris* and *S. buckleyi*.

Semple and Gandhi (2012) discussed the problems with typification of the name *Solidago buckleyi* and proposed a neotype for *S. buckleyi* (*E.J. Palmer 31579*, NY) because they believed that the single *S.B. Buckleyi s.n.* (NY) collection consisting of fragments was not the specimen on which Torrey and Gray (1942) had based their description and could not be the holotype. The only *Buckley s.n.* collection (NY ex Herb. LeRoy) consists of a few fragments and has the label data "Ala. 1838" and was included in a purchase of specimens to the NY herbarium 1896. Torrey and Gray must have had another source for the giving the location as "the interior" of Alabama and potentially a more complete shoot. If *Buckley s.n.* (NY ex Herb. LeRoy) is accepted as the holotype, then taxonomists are left with such an incomplete set of fragments typifying the species that application of the name is very ambiguous. The collection of *Keener 4013* (UWAL, WAT) provides a complete specimen from Alabama that can be used in a multivariate analysis and this is reported below. A manuscript on a multivariate study of all taxa in subsect. *Thyrsiflorae* is in preparation by the Semple Astereae Lab.

Multivariate analyses — materials and methods

In total, 52 specimens from GA, MO, NY, and WAT in MT (Thiers, continuously updated) were selected for inclusion in the analysis of the two species of subsect. *Thyrsiflorae* (18 specimens of *Solidago buckleyi* and 23 of *S. petiolaris* var. *petiolaris*) plus 11 *S. porteri* of subsect. *Squarrosae*. The 20 traits scored and included in the analysis are listed in Table 1. Only var. *petiolaris* occurs in Alabama (e.g., Nesom 2008) and is the sympatric taxon in subsect. *Thyrsiflorae* that can be very similar to *S. buckleyi*; specimens of var. *petiolaris* came from Alabama, Georgia, Florida, North Carolina, South Carolina, and Texas. Specimens of *S. porteri* from Alabama, Georgia, and Tennessee were included in the analysis because the mid and upper stem leaves can be similar in shape and serration traits to those of *S. buckleyi*. All the *S. porteri* specimens had large lower stem leaves present, while specimens of *S. buckley* and *S. petiolaris* were lacking basal stem leaves. All specimens of *S. petiolaris* have mid stem leaves with a distinctive short petiole (1-2 mm long) while mid stem leaves of *S. buckleyi* and *S. porteri* have tapering leaf bases and lack the distinct short petiole. *Keener 4013* (WAT) was included in the *S. buckleyi* a priori group in the analysis because it appeared to be most similar to *S. buckleyi* collections from elsewhere in the range and less so to *S. petiolaris* and *S. porteri* collections. Traits used to define a priori groups were not included in the analyses to avoid circular logic.

All analyses were performed using SYSTAT v.10 (SPSS 2000) following the methods of Semple et al. (2013, 2015).

Table 1. Traits scored for the multivariate analyses of 52 specimens of the taxa *Solidago buckleyi*, *S. petiolaris* var. *petiolaris*, and *S. porteri*.

Trait	Description
MLFLN	Mid stem leaf length
MLFWD	Mid stem leaf width at widest point
MLFWTOE	Length of mid stem from widest point to distal end of the leaf
MLFSER	Number of serrations along one side of the mid stem leaf margin
UPLFLN	Upper leaf length
UPLFWD	Upper leaf width at widest point
UPLFWTOE	Length of upper stem from widest point to distal end of the leaf
UPLFSER	Number of serrations along on side of the upper leaf margin

INVOLHT	Height of the involucre
RAYS	Number of ray florets in a head
OPHYLLN	Outer phyllary length
RAYLN	Length of the ray floret lamina
RAYWD	Width of the ray floret lamina
RACHLN	Length of the ray floret cypsela body at anthesis
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 at anthesis
DPAPLN	Length of longest disc floret pappus bristle

Multivariate analyses — results

In the STEPWISE discriminant analysis of three species-level a priori groups *Solidago buckleyi*, *S. petiolaris* (var. *petiolaris* only), and *S. porteri*, the following traits listed in order of decreasing F-to-remove values were selected (F-to-remove): mid leaf serrations (16.27), mid leaf length (14.52), ray floret pappus length (10.02), ray floret strap length (8.88), mid leaf width (5.80), upper leaf length (5.28), and disc floret lobe length (4.31). 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 using the characters listed above were between *Solidago buckleyi* and *S. petiolaris* and between *S. petiolaris* and *S. porteri* (16.090 and 15.193 respectively). The smallest separation was between *S. buckleyi* and *S. porteri* (8.809).

Table 2. Between groups F-matrix for the five a priori group analysis (df = 7, 43).

Group	***buckleyi***	***petiolaris***	***porteri***
buckleyi	0.000		
petiolaris	16.090	0.000	
porteri	8.809	15.193	0.000

Wilks' Lambda = 0.1016 df = 7 2 49
Approx. F= 13.1288 df = 14 86 prob = 0.0000

In the Classificatory Discriminant Analysis of the three a priori groups the percents of correct classification were 89% for *S. buckleyi*, and 100% for *S. petiolaris* and *S. porteri*. The Classification matrix and Jackknife classification matrix are presented in Table 3. Results for individual a priori taxa are presented in alphabetical order of species. (1) Sixteen of the 18 specimens of *S. buckleyi* were placed a posteriori in *S. buckleyi* (11 with 97-100% probability, two with 90-95% probability, one with 78% probability, and one with 39% probability and 35% and 26% probabilities to *S. petiolaris* and *S. porteri*, respectively). The Alabama collection of *S. buckleyi Keener 4013* WAT was placed a posteriori in *S. buckleyi* with 100% probability. Two specimens were placed in *S. petiolaris* with 94% probability and 51% probability (47% to *S. buckleyi*). (2) All 23 specimens of *S. petiolaris* were placed a posteriori in *S. petiolaris* (21 with 98-100% probability, one with 87%, and one with 59% probability to *S. petiolaris* and 23% and 18% probabilities to *S. buckleyi* and *S. porteri*, respectively). (3) All 11 specimens of *S. porteri* were placed a posteriori into *S. porteri* (seven with 98-100% probability, two with 89% probability, one with 81% probability, and one with 48%

probability to *S. porteri* and 41% and 11% probability to *S. petiolaris* and *S. buckleyi*, respectively). In the Jackknife classification there was a drop in mean correct placement from 96% to 87% correct a posteriori placement to a priori group.

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

Linear classification matrix

	buckleyi	***petiolaris***	***porteri***	% correct
buckleyi	16	2	0	89%
petiolaris	0	23	0	100%
porteri	0	0	11	100%
Total	16	25	11	96%

Jackknifed classification matrix

	buckleyi	***petiolaris***	***porteri***	% correct
buckleyi	13	4	1	72%
petiolaris	0	22	1	96%
porteri	0	1	10	91%
Total	13	27	12	87%

Two dimensional plots of scores of CAN1 versus CAN2 of *Solidago buckleyi*, *S. petiolaris* var. *petiolaris*, and *S. porteri* are presented in Figure 3. Eigen values on the first two axes were 3.055 and 1.427.

Discussion

The results very strongly support the conclusion that *Keener 4013* (WAT) was correctly identified as *Solidago buckleyi*. Overall the three species separate well on the characters selected by the analysis to maximize the Mahalanobis distances between the group centroids of the three species in N-dimensional hyperspace. There was a low level of incorrect assignment with weak to moderate probability of correct placement and an even lower level of a posteriori placement to another species. Two of the 18 specimens of *S. buckleyi* were placed into *S. petiolaris* a posteriori, which is a reflection of the difficulty noted in some floristic treatments that the two species can be rather similar. One of the specimens *Semple & Suripto 9917* (WAT) from Oregon Co., Missouri, had damage to the upper shoot resulting in limited head formation, but the lower and mid stem leaves had well-developed serrations and long tapering bases, and even the upper stem leaves had some serrations. Assignment to another species in the a posteriori classification analysis is likely the result of aberrant head traits due to the damage because the leaves are typical of *S. buckleyi*. Leaving the specimen out of the analysis because it was damaged would improve the results, but the reality is that herbarium specimens are sometime damaged and still need to be identified. Including them in an analysis gives taxonomists an indication of what technical traits are altered by damage besides those traits obviously effected by the damage. The second specimen of *S. buckleyi* assigned a posteriori to *S. petiolaris* was *Semple & Suripto 9878* (WAT) from Union Co., Illinois. Its lower mid stem leaves are large and broadly oblanceolate with a long tapering bases and large serrations on the upper margins; again typical of *S. buckleyi*. The inflorescence does not appear to be damaged and the upper stem leaves and those subtending lower inflorescence branches have serrations. It is not clear why this specimen was placed into *S. petiolaris* on technical traits with 94% probability to that species. Both collections were made in the same year so perhaps unknown environmental factors that year resulted in the development of atypical technical features. The one specimen of *S. porteri* assigned to that species a

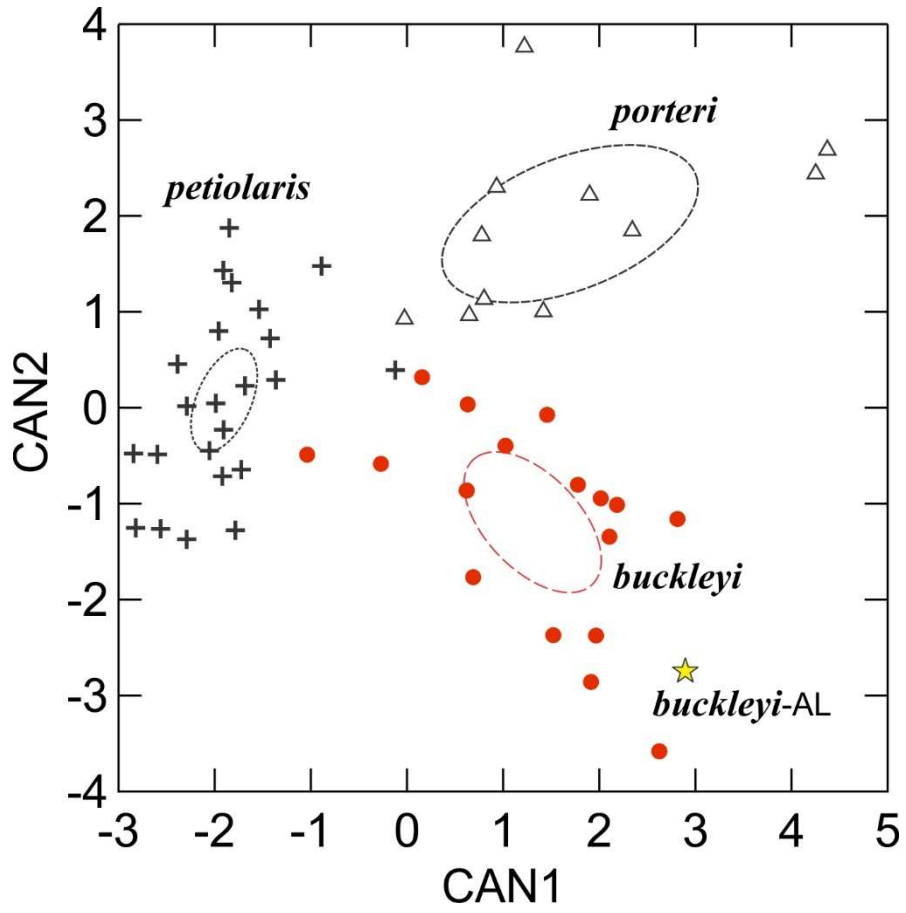

Figure 3. Plot of canonical variate scores (CAN1 and CAN2) of specimens of *Solidago buckleyi* (red dots), *S. petiolaris* (crosses) and *S. porteri* (open triangles). *Keener 4013* (WAT) from Alabama was included in the buckleyi a priori group in the multivariate analysis but is shown indicated by a star to emphasize its location in the diagram.

posteriori with low probability (46%) was *J. Semple & B. Semple 11190* (WAT) from Morgan Co., Alabama, the only known collection of the species from the state (Semple & Estes 2014). The specimen was hexaploid like the Tennessee population of *S. porteri*. The listing of 2*n* = 54 for *S. petiolaris* in Flora North America (Semple & Cook 2006) was based on this collection, which Semple and Estes (2014) noted was collected and identified in the field incorrectly as *S. petiolaris* var. *petiolaris*. The largest leaves on the plants are the lower stem leaves typical of *S. porteri* and all of subsect. *Squarrosae*. On technical traits it converges with those of *S. petiolaris*. In 2003 when the specimen was collected the first author of this paper was significantly lacking in knowledge of *S. porteri*. Now, the specimen can clearly be identified as *S. porteri* on all general features.

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LITERATURE CITED

Burchard, E.F. and T.G. Andrews. 1947. Iron ore outcrops of the Red Mountain formation in northeast Alabama. Alabama Geological Survey, Special Report 19.

Cronquist, A. 1968. *Solidago* L. Pp. 413-438, in H.A. Gleason (ed.). The New Britton and Brown Illustrated Flora of the Northeastern United States and Adjacent Canada. Hafner Pub. Co., New York.

Cronquist, A. 1980. Vascular Flora of the Southeastern United States. I. Asteraceae. Univ. North Carolina Press, Chapel Hill.

Griffith, G.E., J.M. Omernik, J.A. Comstock, G. Martin, A. Goddard, and V.J. Hulcher. 2001. Ecoregions of Alabama. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon.

Mohlenbrock, R.H. 1986. A Guide to the Vascular Flora of Illinois. Southern Illinois Univ. Press, Carbondale.

Nesom, G.L. 1990. Taxonomy of *Solidago petiolaris* (Astereae: Asteraceae) and related Mexican species. Phytologia 69: 445-456.

Nesom, G.L. 1993. Taxonomic infrastructure of *Solidago* and *Oligoneuron* (Asteraceae: Astereae) and comments on their phylogenetic position. Phytologia 75: 1–44.

Nesom, G.L. 2008. Taxonomic review of *Solidago petiolaris* and *S. wrightii* (Astereae: Asteraceae). Phytologia 90: 21–35.

Semple, J.C. 2015 (frequently updated and modified). Classification and Illustrations of Goldenrods. <https://uwaterloo.ca/astereae-lab/research/goldenrods/classification-and-illustrations>

Semple, J.C. and R.E. Cook. 2006. *Solidago* Linnaeus. Pp. 107–166, in Flora North America Editorial Committee (eds.). Flora of North America. Vol. 20. Asteraceae, Part 2. Astereae and Senecioneae. Oxford Univ. Press, New York.

Semple, J.C. and D. Estes. 2014. Discovery of *Solidago porteri* (Asteraceae: Astereae) in Alabama and Tennessee and a second population in Georgia. Phytoneuron 2014-45: 1–11.

Semple, J.C., H. Faheemuddin, Y.A. Chong, M.K. Sorour, J.A. Hood, I. Khamis, Y. Ma, and K. Kornobis. 2013. A multivariate morphometric study of the *Solidago canadensis / S. lepida* complex of *Solidago* subsect. *Triplinerviae*. I. Northeastern taxa (Asteraceae: Astereae). Phytoneuron 2013-58: 1–20.

Steyermark, J.A. 1963. Flora of Missouri. Iowa State Univ. Press, Ames.

Thiers, B. [continuously updated]. Index Herbariorum: A global directory of public herbaria and associated staff. Virtual Herbarium, New York Botanical Garden. <http://sciweb.nybg.org/science2/IndexHerbariorum.asp>

Weakley, A.S. 2015. Flora of the Southern and Mid-Atlantic States. Working draft of 21 May 2015. Univ. of North Carolina Herbarium (NCU), Chapel Hill. <http://www.herbarium.unc.edu/flora.htm>

Yatskievych, G. 2006. Steyermark's Flora of Missouri. Vol. 2. Missouri Bot Garden Press, St. Louis.