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A MULTIVARIATE MORPHOMETRIC STUDY OF THE *CHRYSOPSIS SCABRELLA* COMPLEX IN PENINSULA FLORIDA (ASTERACEAE: ASTEREAE)

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ABSTRACT

The *Chrysopsis scabrella* complex includes four diploid species of goldenasters native to peninsular Florida: *C. delaneyi, C. floridana, C. highlandsensis,* and *C. scabrella*. These Florida goldenasters are yellow, daisy-like, short-lived, herbaceous perennials with glandular involucres and fruits without reddish-brown ridges. As part of the work towards revising the treatment of the genus, the degree of morphological differences among the two more recently described species *C. highlandsensis* and *C. delaneyi* and the two long-recognized species *C. scabrella*, and *C. floridana* were investigated using discriminant analysis. A data matrix of 38 vegetative and floristic characters scored on 111 individuals was constructed. Discriminant analysis provided statistically significant support for recognizing four distinct taxa. Discriminating characters were determined using STEPWISE discriminant analysis. Classification discriminant analysis provided strong support for recognizing each species level *a priori* group. The a *posteriori* assignment probabilities of each specimen to the four *a priori* groups were determined in a classificatory discriminant analysis and indicated that most specimens were correctly assigned to their respective a priori groups with very high probability. In addition, variation between central ridge and Atlantic ridge populations of *C. delaneyi* was examined and found not to warrant taxonomic recognition. The complex includes a number of individuals with atypical traits occurring in isolated portions of the ranges of the four species.

Chrysopsis (Nutt.) Ell., nom.cons., is a genus of goldenasters endemic to the southeastern USA, particularly Florida (Semple 2006a). The genus is restricted to those North American goldenasters bearing flagelliform hairs with bases of one to usually several large cells (Semple et al. 1980; Semple 1981). *Chrysopsis* includes species with a triple or double pappus: a short secondary outer whorl, a primary outer whorl of mid to long, tapering, non-clavate bristles (sometimes reduced or absent) and a primary inner whorl of long, clavate bristles (Semple 2006 b). Semple (1981) monographed *Chrysopsis* as consisting of 10 species including *C. pilosa* Nutt. and included several important differences in the treatment of the genus following Semple (1977) and Semple et al. (1980). Prior to 1980, *Chrysopsis* often included species of the grass-leaf goldenaster genus *Pityopsis* Nutt., species of *Heterotheca* sect. *Phyllotheca*, and a species of rayless aster (e.g. Cronquist 1968). *Chrysopsis* was treated as consisting of 11 species native to southeastern USA, with species defined on sets of characteristics — chromosome number, leaf indument, glandularity, phyllary shape and cypsela traits receiving the greatest weighting (Semple 2006c). *Chrysopsis pilosa* was transferred to *Bradburia* (Semple 1996) and included in the Flora North America treatment of that genus of two annual species (Semple 2006c).

For many years Kris DeLaney had been aware of a number of unusual populations of *Chrysopsis* on the Florida east coast and central peninsula areas. One group of populations occurred in the central Florida peninsula. These had woolly stems and leaves and glandular involucres and peduncles and were treated as *C. highlandsensis* DeLaney & Wunderlin (2002). A second group of populations are endemic to the Lake Wales Ridge, southern Atlantic Coastal Ridge and Orange County upland and were included in *C. delaneyi* Wunderlin & Semple (DeLaney et al. 2003). This group of populations was treated as *Chrysopsis delaneyi* in honor of Kris DeLaney, who discovered it and researched the distribution and morphological variation for over a decade (DeLaney et al. 2003). Semple (1981) had included specimens of both new species in *C. scabrella* Torr. & Gray.

As part of the work preparing the treatment of the genus for Flora North America, the degree of morphological similarity among the two new species *C. delaneyi* (Fig. 1*)* and *C. highlandsensis* (Fig. 2) and the two long-recognized species *C. scabrella* (Fig. 3) and rare *C. floridana* Small (Fig. 4) were investigated using multivariate morphometric analyses. In addition, the Lake Wales and Atlantic Ridge populations of *C. delaneyi* were examined to determine how similar the two populations are to each other. The nomenclature followed in this paper is that accepted at the end of the study and followed in Semple (2006a).

Materials and Methods

Specimens included in this morphometric study were selected from herbarium collections borrowed from University of South Florida Herbarium (USF) and New York Botanical Gardens (NY) or collections held in the University of Waterloo Herbarium (WAT). One hundred and eleven specimens were included in the multivariate analyses: 29 *Chrysopsis delaneyi*, 10 *C. floridana*, 10 *C. highlandsensis*, and 62 *C. scabrella*. These specimens were chosen based on provenance and the suitability of their stage of development from a sample size of approximately 160 plant collections.

Measurements were made on plants that were at the same stage of development (anthesis) and on structures in the same position on the plant. Numerous morphological characteristics were considered for the analyses; 38 characters ultimately were scored for each individual plant (Appendix 1). All listed characters were used in the multivariate analysis unless they had a Pearson correlation number greater than r= |0.7|. Only one trait of highly correlated pairs was included to minimize the potential biasing of results by including traits that were really the consequence of pleiotrophic effects of a single gene. In addition, characteristics were excluded if a significant number of plants were missing the particular trait; e.g. basal stem leaf traits.

SYSTAT 10.0 (SPSS Inc, 2000) was used for all statistical and canonical analyses of the data. Specimens were assigned to four *a priori* species level groups. Membership in *a priori* groups was based on gland height and hair height. This was determined through observations and literature. Consequently, these characters were not included in the discriminant analysis. STEPWISE discriminant analysis was used to select a subset of ten characteristics which maximized the differences between the *a priori* groups. These characters were then used to perform a discriminant analysis. Classificatory discriminant analysis was used to classify individuals *a posteriori* into *a priori* groups.

If a specimen was misclassified, the results indicated which species it should be in based on the traits included. The specimen was examined more closely to determine whether it was misclassified *a priori* or simply an odd specimen. Correct classification and Geisser assignment probabilities indicate the strength of group membership. Jackknife classification was performed as a cross-validation of the classificatory analysis, as it is a more stringent analysis and uses different characteristics than the classification

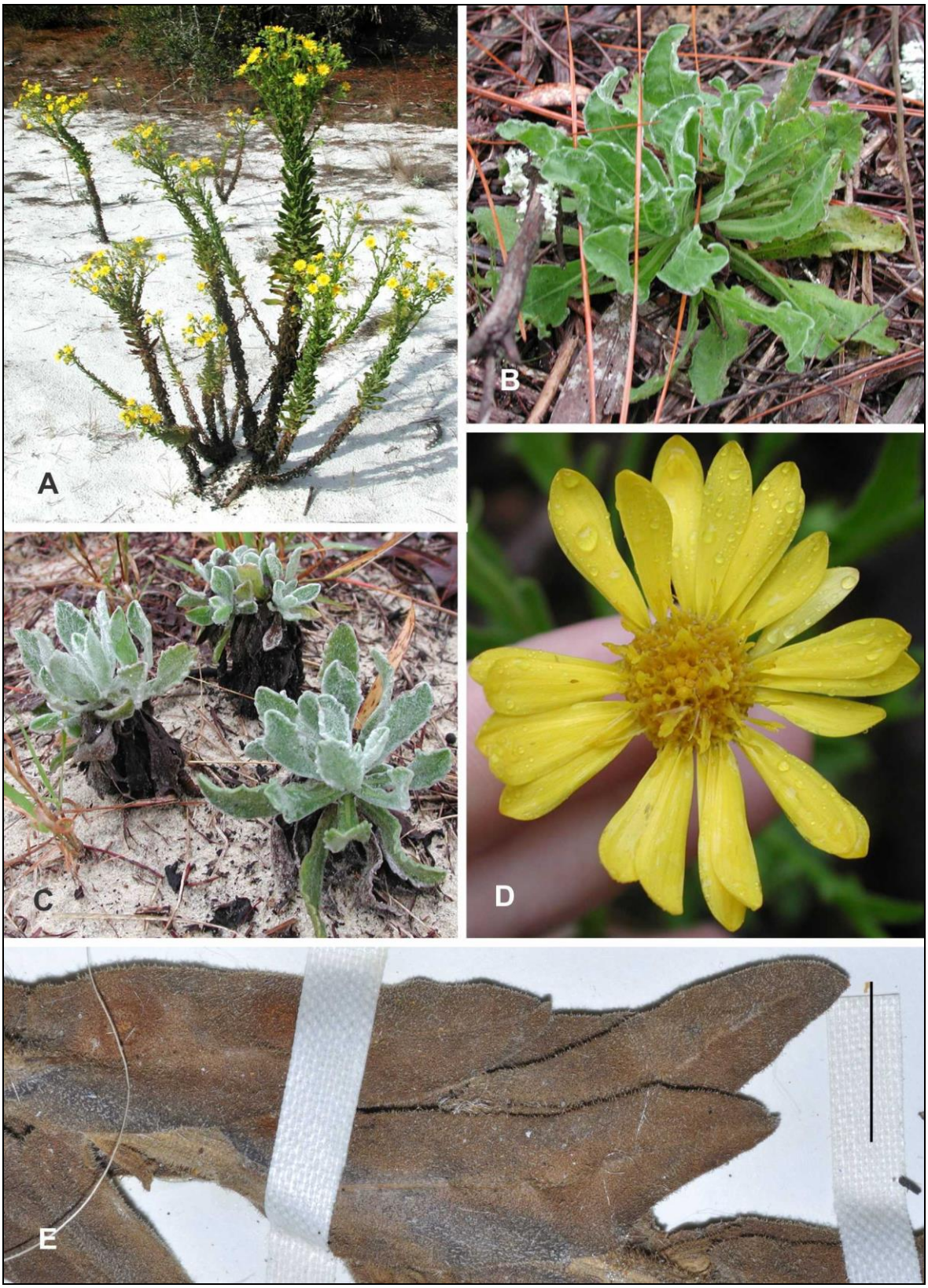

Figure 1. *Chrysopsis delaneyi*. **A.** Habit, Brevard Co., *Semple, Wunderlin, & Delaney 11144*, **B.** Glandular rosette, Lake Co. **C.** Wooly rosettes, Polk Co. **D.** Florets, Polk Co. **E.** Mid stem leaves, *Godfrey 75780* WAT. Scale bar = 1 cm in E.

Figure 2. *Chrysopsis highlandsensis*. **A.** Erect habit, Highlands Co., *Semple, Wunderlin & Delaney 10899*. **B**. Moderately wooly mid stem leaves, Highlands Co., *Semple, Wunderland, & Delaney 10899*. **C.** Decumbent-ascending habit, Polk Co., *Semple, Wunderlin & Delaney 10897*. **D.** Inflorescence, Highlands Co., *Semple, Wunderlin & Delaney 10899*.

Figure 3. *Chrysopsis scabrella*. **A.** Habit, Orange Co., *Semple & Wunderlin 2547*. **B.** Mid stem and leaf, Charlotte Co., *Semple, Wunderlin, Walker, Delaney, & Cochrane 10901*. **C.** Wooly rosettes (after recent rain), Hillsborough Co., *Semple & Wunderlin & 2490*. **D.** Heads, Charlotte Co., *Semple, Wunderlin, Walker, Delaney, & Cochrane 10901*.

Canonical discriminant analysis is a dimension-reducing technique that was used to assist in the visualization of the results of the stepwise discriminant analysis. Canonical variable scores are the linear combination of the variables that best discriminate among the groups. Canonical scores may reveal significant differences between *a priori* groups, when none of the variables can do so independently. These scores are then plotted against each other to give a better visualization of the results of the discriminant analysis.

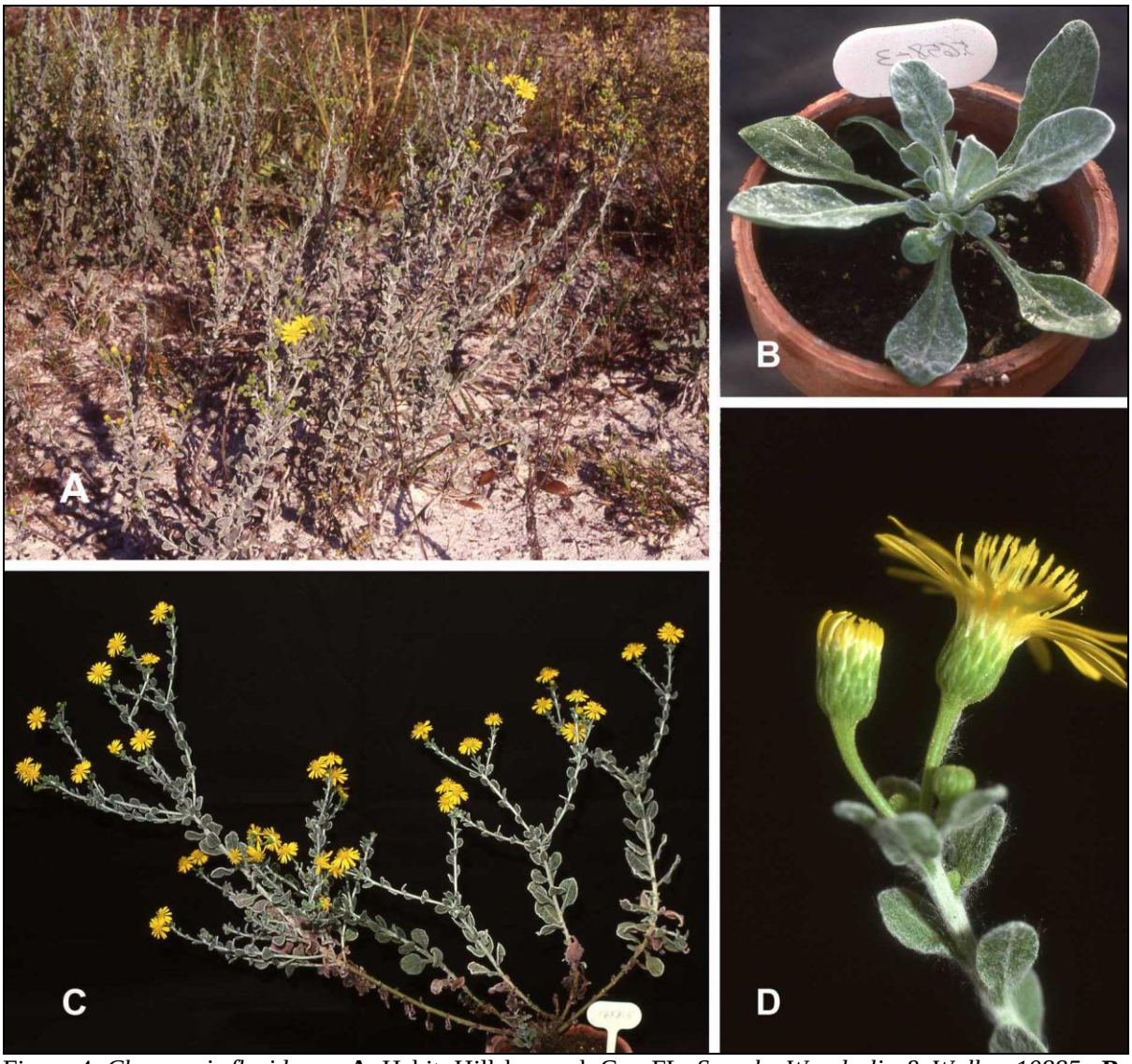

Figure 4. *Chrysopsis floridana*. **A.** Habit, Hillsborough Co., FL, *Semple, Wunderlin & Walker 10885*. **B.** Seedling rosette cultivated at WAT from fruit off Wunderlin 5658 USF. **C.** Greenhouse grown flowering plant cultivated *from Wunderlin 5658* USF**. D.** Wooly upper stem leaves and stipitate glandular heads cultivated from *Wunderlin 5658* USF.

Results

Four species level a priori groups were analyzed: *Chrysopsis delaneyi*, *C. floridana, C. highlandsensis*, and *C. scabrella.* Gland height (GLNDHT) and hair height (HAIRHT) were used to distinguish between the four *a priori* groups (Figs. 5-6; Table 1). Geographic location and elevation are also useful in assigning group membership but were not used in this study. GLNDHT and HAIRHT were not included in subsequent discriminant analyses.

The lack of overlap in gland height was particularly useful in distinguishing between *Chrysopsis delaneyi* and *C. scabrella* (Fig. 5), but not for discriminating between *C. floridana* and *C. highlandsensis* as they both have short small glands. The mean gland height (GLNDHT) for *C. delaneyi* was 0.5±0.14 mm, whereas the mean for *C. scabrella* was 0.16 ± 0.07 mm. *Chrysopsis. highlandsensis* had a few, small glands and *C. floridana* had very few, small glands on the leaves.

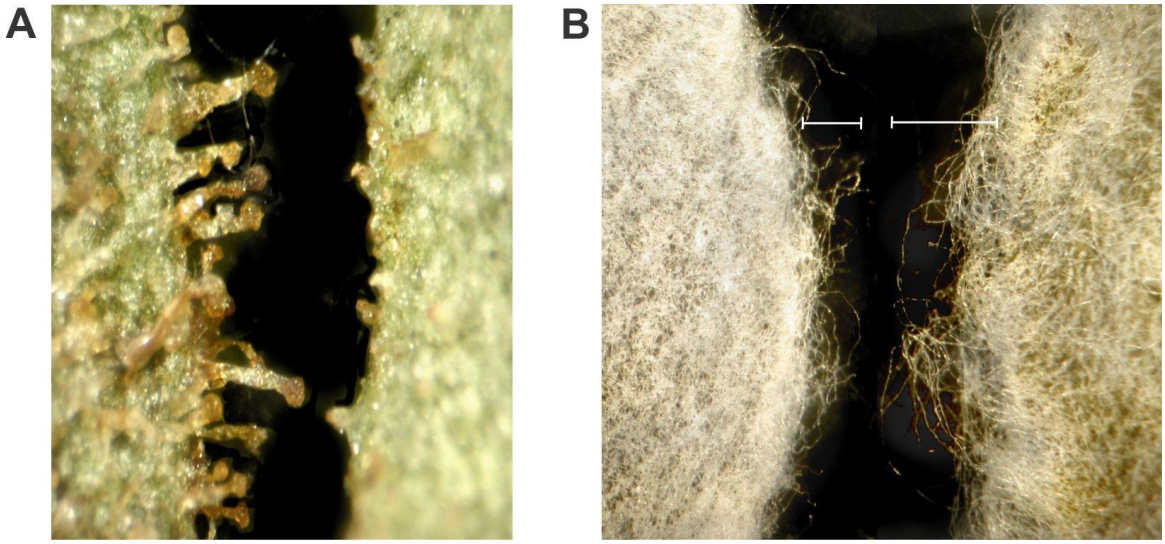

Figure 5. Leaf induments of *Chrysopsis*. **A.** Gland Height of *Chyrsopsis. delaneyi* (left) and *C. scabrella* (right). **B.** Hair matt height (white bars) of *C. floridana* (left) and *C. highlandsensis* (right).

Table 1. Means (mm) ± standard deviation and ranges (shown in parenthesis) for the characters used to define the *a priori* groups for *C. delaneyi, C. floridana, C. highlandsensis, and C. scabrella* (mm). (GLNDHT = gland height, HAIRHT = hair matt height)

Character	***C. delaneyi*** (N=18)	***C. floridana*** (N=10)	***C. highlandsensis*** (N=10)	***C. scabrella*** (N=19)
GLNDHT	0.53 ± 0.17	0.1 ± 0.0	0.126 ± 0.05	0.20 ± 0.09
	(0.30 - 1.0)	(0.1 - 0.1)	(0.1 - 0.3)	(0.1 - 0.4)
HAIRHT	0.0 ± 0.0	0.41 ± 0.11	1.11 ± 0.21	0.0 ± 0.0
	(0.0 - 0.0)	(0.3 - 0.6)	(0.9 - 1.5)	(0.0 - 0.0)

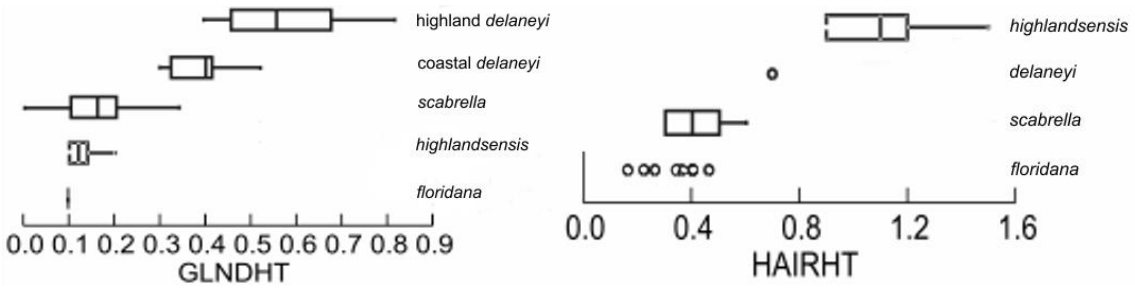

Figure 6. Box Plots of gland height (GLNDHT) and hair height (HAIRHT) for samples of *Chrysopsis delaneyi, C. floridana, C. highlandsensis*, and *C. scabrella*.

The difference in hair matt height was useful in distinguishing between *Chrysopsis highlandsensis* and *C. floridana.* As noted in the Methods, HAIRHT was determined by measuring the height of the hair matt on mid-stem leaf margins. This was a measure of how oppressed the hairs were, not how long the hairs were. As seen in Fig. 6, the hair matt of *C. highlandsensis* stands much higher off the leaf than the more tightly matted hairs of *C. floridana.* There is no overlap in hair height ranges between the two species. The mean for *C. floridana* was 0.41 ± 0.11 mm while that of *C. highlandsensis* was 1.11 ± 0.21 mm. In *C. delaneyi* and *C. scabrella,* mid-stem leaf hair height

was near zero on average due to the absence of the wooly indument, except for the rare plant in which the hairs continued to be produced on leaves well up the stem. Consequently, non-pubescent leaved specimens with a gland height greater than 0.3 mm were classified *a priori* as *C. delaneyi*, and those specimens with a gland height below 0.3 mm were treated as *C. scabrella* in the discriminant analyses. Those specimen's with loosely matted hair were assigned to *C. highlandsensis*, and those with more tightly matted hair were assigned to *C. floridana* in the discriminant analyses.

Cluster Analysis

The results of a cluster analysis using just hair and gland traits for 57 individuals of *Chrysopsis delaneyi*, *C. floridana*, *C. highlandsensis*, and *C. scabrella* is presented in Figure 7. Most specimens of each species grouped together with one or two individuals in each species coming out generally near but not included in the main cluster of specimens of each species. All but one specimen of *C. delaneyi* and *C. scabrella* came out in one main branch and all specimens of *C. floridana* and *C. highlandsensis* came out in the second main branch.

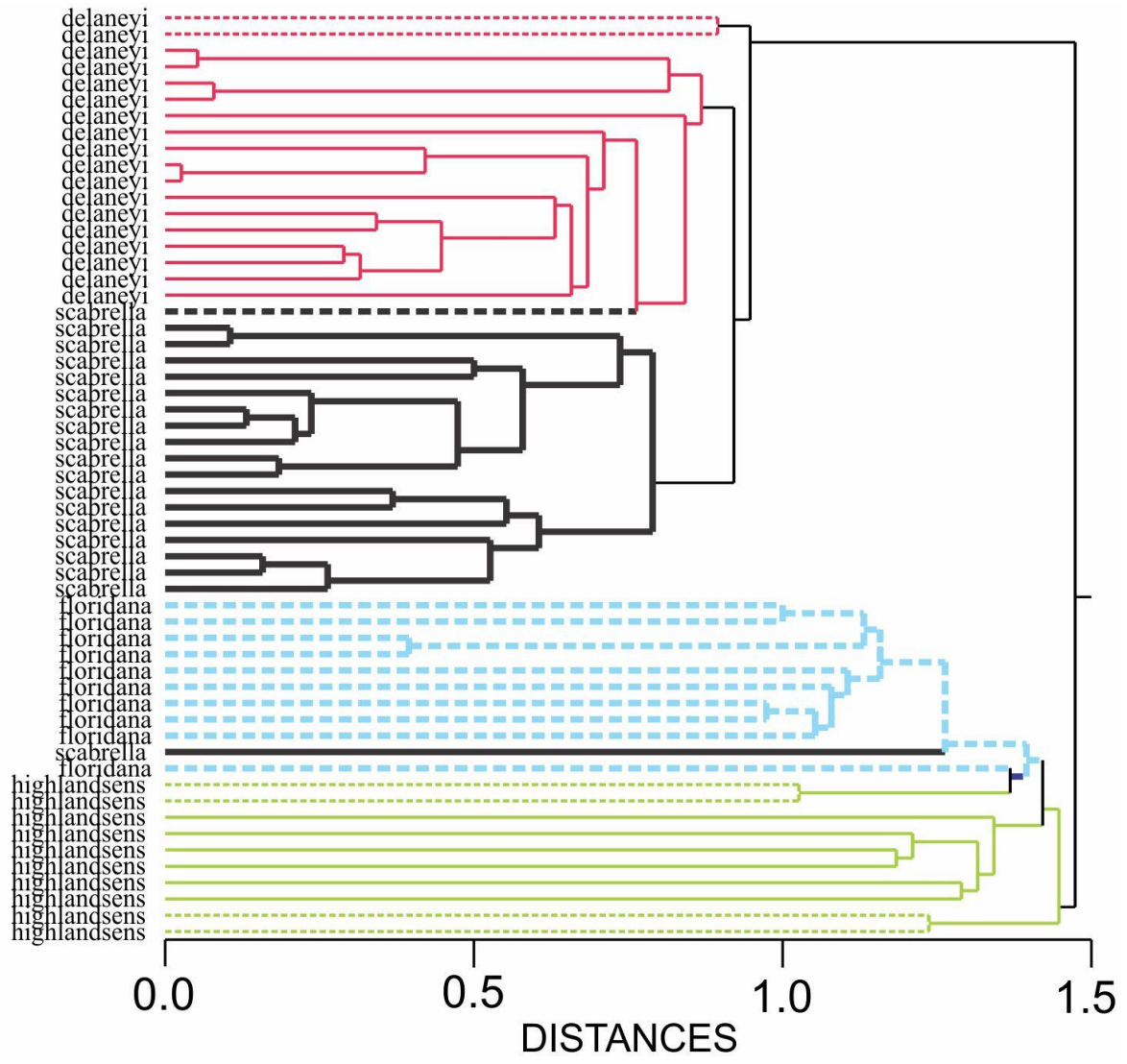

Figure 7. Cluster analysis of 57 individuals of *Chrysopsis delaneyi* (red lines), *C. floridana* (blue lines), *C. highlandsensis* (green lines), and *C. scabrella* (thick black lines) using only hair and gland traits.

SYSTAT discriminant analysis of four species level a priori groups

In the STEPWISE discriminant analysis, 4 characteristics were selected as statistically useful in separating the four species (*Chrysopsis delaneyi*, *C. floridana*, *C. highlandsensis*, and *C. scabrella*) listed in decreasing F-to-remove values discriminated among the four *a priori* groups: leaf hair length (117.76), number of disc florets (7.95), mid stem leaf length (9.84), and upper stem leaf width (2.68). Table 2 presents the between group F-matrix values. 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 3. The largest degree of separation was between *C. highlandsensis* and *C. delaneyi* (90.281), while the smallest degree of separation was between *C. delaneyi* and *C. scabrella* (14.733).

Table 2. Between-groups F-matrix for the four species level a priori groups analysis (df = 4 47).

	delaneyi	***floridana***	***highlandsensis***
floridana	55.270		
highlandsensis	112.712	23.423	
scabrella	12.327	34.524	95.748

Wilks' lambda = 0.0216 df = 4 3 50; Approx. F= 33.67038 df = 121 124 prob = 0.0000

In the Classificatory Discriminant Analysis of 54 specimens of *Chrysopsis delaneyi*, *C. floridana*, *C. highlandsensis*, and *C. scabrella*, the percents of correct a posterori assignment to the same a priori group varied from 100% to 76% with 100% for *C. floridana* with all 10 specimens assigned a posteriori to *C. floridana* with 100% probability. Nine of the 10 specimens of *C. highlandsensis* (90%) were assigned a posteriori to *C. highlandsensis*: 8 specimens with 100% probability and 1 specimen with 63% probability. One specimen of *C. highlandsensis* (*Semple, Wunderlin, Walker, Delaney & Cochrane 10899*) was assigned a posteriori to *C. floridana* with 92% probability; in the field the collectors all agreed it was a specimen of *C. highlandsensis*. Fifteen of the 17 specimens of *C. scabrella* (88%) were assigned a posteriori to *C. highlandsensis*: 1 specimen with 100% probability, 10 specimens with 90-99% probability, 1 specimen with 87% probability, 1 specimen with 73% probability, and 1 specimen with 59% probability. Two specimens of *S. scabrella* were assigned a posteriori to other species: 1 specimen with 100% probability to *S. floridana* (*Hansen 6844* USF from Charlotte Co., FL has moderately wool mid stem leaves and glandular upper stem leaves typical for *C. scabrella*); and 1 specimen with 74% probability to *C. delaneyi* (*Correll 52862* xx from Volusia Co., FL; only the basal rosette leaves are wooly while even the lower stem leaves are short glandular but gland height was 0.34 mm which is at the high end for *C. scabrella* and into the lower end of the range of gland height for *C. delaneyi*; R.P. Wunderlin annotated the specimen as *C. scabrella* in 2003 and the authors of this paper did so in 2005). Thirteen of the 17 specimens of *C. delaneyi* (76%) were assigned a posteriori to *C. delaneyi*: 6 specimens with 100% probability, 2 specimens with 99% and 97% probabilities, 1 specimen with 87% probability, 1 specimen with 77% probability, 1 specimen with 66% probability, and 1 specimen with 54% probability. Four specimens of *C. delaneyi* were assigned a posteriori to *C. scabrella* with 88% probability (Orange Co., FL; *Taylor s.n.* USF; gland height 0.3 mm), 69% probability (Polk Co., FL, *Delaney 4081* USF; gland height 0.5 mm), 68% probability (Polk Co., FL, *Delaney* 4091 USF; gland height 0.4 mm), and 52% probability (Indian River Co., FL, *Delaney 5119* WAT; gland height 0.4 mm).

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

Classification matrix

	delaneyi	*floridana*	*highlandsensis*	*scabrella*	% correct
delaneyi	12	0	0	4	**76**
floridana	0	10	0	0	**100**
highlandsensis	0	1	9	0	**90**
scabrella	1	1	0	15	**88**
Total	14	12	9	19	**87**

Jackknifed classification matrix

	delaneyi	*floridana*	*highlandsensis*	*scabrella*	% correct
delaneyi	12	0	0	5	**71**
floridana	0	10	0	0	**100**
highlandsensis	0	2	8	0	**80**
scabrella	1	1	0	15	**88**
Total	13	13	8	20	**83**

The first versus second and first versus third canonical scores for 57 specimens of *Chrysopsis delaneyi, C. floridana, C. highlandsensis,* and *C. scabrella* are plotted in Fig. 8. The Eigenvalues for the three conical axes were 7.558, 1.2191, and 0.431.

Comparison of Atlantic Ridge and Central Ridge *C. delaneyi* with *C. scabrella*

In a discriminant analysis, each of the *Chrysopsis delaneyi* specimens was assigned to one of the two *a priori* groups based on geography and compared to the specimens of *C. scabrella.* The data on *C. delaneyi* and *C. scabrella* used in the previous study were examined in a three *a priori* group analysis. The two allopatric sets of populations of *C. delaneyi* were split into coastal ridge and central highland *a priori* groups based on gland height. The central ridge *C. delaneyi* had a higher average gland height than the Atlantic ridge subset (Fig. 6).

Ten characteristics were found to be useful in separating the three *a* priori groups: GLNDHPED, MSERAT, MLWTOE, GLNDHPHY, RFLOR, DLOBL, HEADWD, RACHL, RSTPL, HEADHT. In the classificatory discriminant analysis each of the specimens was assigned to one of the *a* priori groups *a posteriori*. Only 64% of the Atlantic Ridge *C. delaneyi* were assigned to their *a priori* group, while 100% each for central ridge *C. delaneyi* and *C. scabrella* were assigned to their *a* priori groups. In the jackknife analysis, the assignment rates dropped: 55% for the Atlantic ridge *C. delaneyi* 94% for central ridge *C.* delaneyi, and 100% for *C. scabrella.* Giesser assignment probabilities were generally low. The F-statistics and probabilities revealed that the two *a priori* groups of *C. delaneyi* were not significantly different from each other.

Discussion

The results of the discriminant analysis indicate that there is strong support for recognizing *Chrysopis delaneyi, C. floridana, C. highlandsensis,* and *C. scabrella* as separate species. The four species discriminant analysis indicated that the majority of species had high probabilities that they were correctly assigned a priori. The results also indicated that there were some specimens that could be assigned to a different species a posteriori when one trait significantly dominated the a posteriori placement. The ranges of height of stipitate glands occurring on stems and leaves overlapped at the very high end for *S. scabrella* with the very low end for *S. delaneyi*, but the majority of specimens in the two species differed significantly on this trait. Other traits on such specimens indicated that the a priori placement was likely correct. Of the four species one would rarely misidentify *C. scabrella* or *C. delaneyi* as *C. highlandsensis* or *C. floridana*. The misidentification would more often occur between *C. highlandsensis* and *C. floridana* and between *C. delaneyi* and *C. scabrella*.

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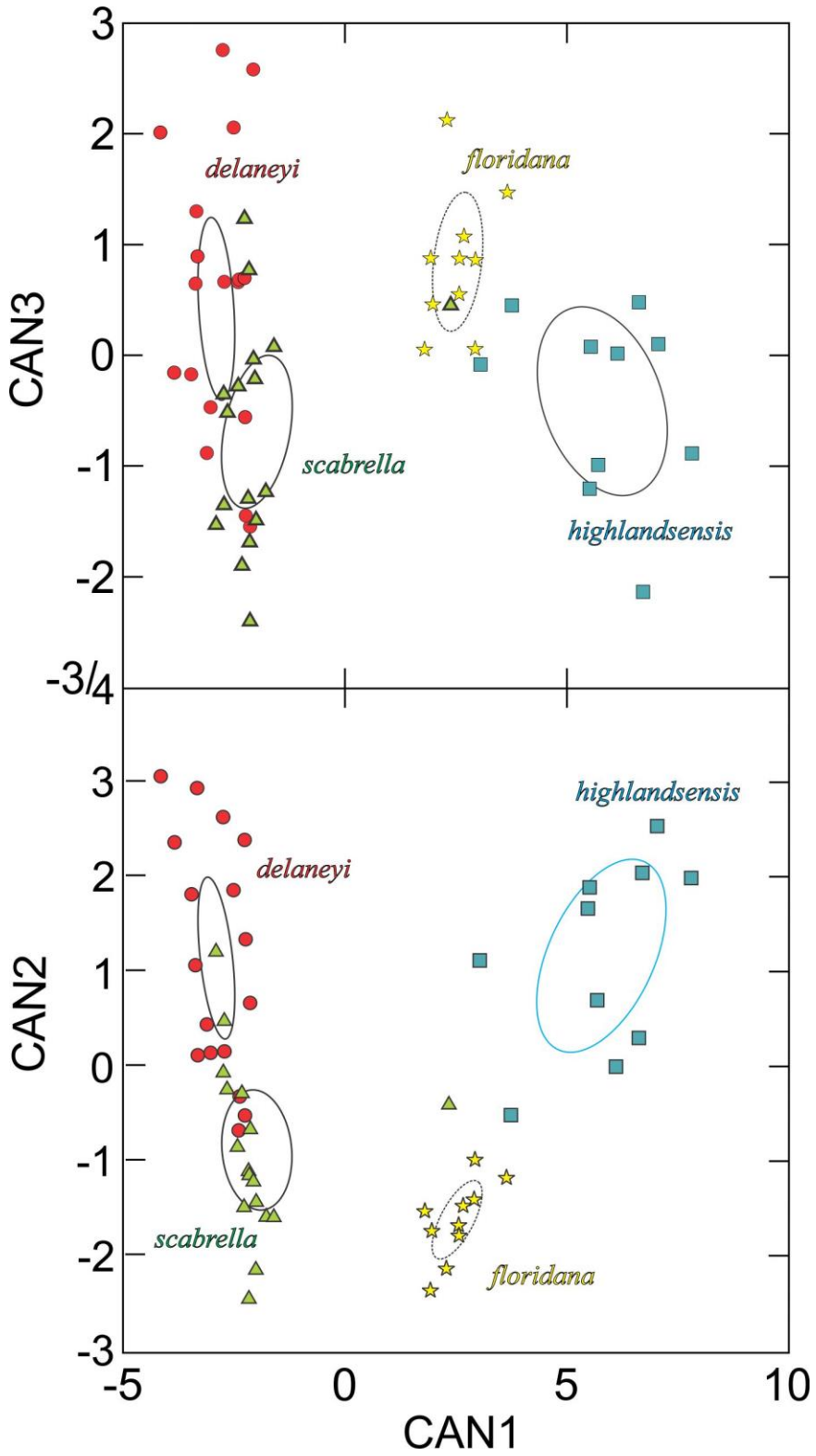

Figure 8. Two dimensional plots of CAN1 versus CAN2 and CAN1 versus CAN3 scores for 57 specimens of four a priori species groups of the *Chrysopsis*: *C. delaneyi* (red dots), *C. floridana* (yellow stars), *C. highlandsensis* (blue squares), and *C. scabrella* (green triangles).

Appendix 1. Characters scored for 111 individuals of *Chrysopsis delaneyi*, *C. floridana*, *C. highlandsensis*, and *C. scabrella*.

GLNDHT	Gland height on leaf margins (mm)
GLNDHTPHY	Gland height on phyllaries (mm)
HAIRHT*	Hair matt height on leaf margins (mm)
HAIRL	Hair length (mm)
STEMHT	Stem height (mm)
BLLENG	Basal leaf length (mm)
BLWID	Basal leaf width (mm)
BLWTOE	Basal leaf length measured from widest point to the apex (mm)
BSERAT	Basal leaf Serrations
LLLENG*	Lower stem leaf length (mm)
LLWID	Lower stem leaf width (mm)
LLWTOE	Lower stem leaf length from widest point to the apex (mm)
LSERAT	Number of lower leaf serrations
MLLENG	Mid stem leaf length (mm)
MLWID	Mid stem leaf width (mm)
MLWTOE*	Mid stem leaf length from widest point to the apex (mm)
MSERAT	Number of mid stem leaf serrations
ULLENG*	Upper stem leaf length (mm)
ULWID	Upper stem leaf width (mm)
ULWTOE*	Upper stem leaf length from widest point to the apex (mm)
HPIFLOR	Number of heads per inflorescence
INVOLHT	Involucre height (mm)
HEADWD	Head width (mm)
OPHLENG	Outer phyllary length (mm)
RFLOR#	Number of ray florets
RSTPL	Ray strap length (mm)
RSTPW	Ray strap width (mm)
RACBL	Ray achene body length at anthesis (mm)
RACHL	Ray achene length including pappus (mm)
DFLOR#	Number of Disc Florets
DCORL	Disc corolla length (mm)
DLOBL*	Disc corolla lobe length (mm)
DACBL*	Disc achene body length (mm)
DPAPL	Disc pappus length (mm)

Note: Traits marked with an * were not included in further analysis as they correlated strongly with another trait.