ANALYSIS OF THE COMPLETENESS OF VASCULAR PLANT RECORDS IN FLORIDA

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ABSTRACT

Using the species-area relationship formula $S=CA^z$, we predicted the species richness of vascular plants for each county in Florida. The predicted species richness value of each county was then compared to the documented species richness value for each county gathered from herbaria records. Results indicate that 67% of the Florida counties have documented species richness values that matched or exceeded predicted values. The remaining counties (33% of the Florida) lack adequate documentation of species richness and thereby constitute data-gaps in the state's floristic inventories.

KEY WORDS: biodiversity, Florida, herbarium, inventory, mapping, modeling, species area relationship, species richness, vascular plants

RESUMEN

Usando la fórmula de la relación especies-área $S=CA^z$, se predijo la riqueza en especies de plantas vasculares de todos los condados de Florida. El valor de riqueza de especies de los condados se comparó con el valor de riqueza documentado de cada condado obtenido de los registros de herbarios. Los resultados indican que el 67% de los condados de Florida tienen valores de riqueza de especies documentados que coinciden o exceden los valores pronosticados. Los restantes condados (33% de Florida) carecen de la documentación adecuada de riqueza de especies y por ello constituyen lagunas de datos en los inventarios florísticos del estado.

Williams and Lutterschmidt (2006) presented a herbarium assessment model that provides a mathematical and objective approach to identifying data gaps in documented species richness determined from a state's herbarium collections. The model (here coined *Collections Records Assessment Model* or *CRAM*) compares the documented species richness value for counties within a state (determined from a database of herbarium records) to the predicted species richness value (determined by the species area relationship formula). Results generated isolate a county by determining if its documented species richness value falls above or below predicted species richness. A county with documented species richness below the predicted value is considered under collected and constitutes a data gap in the state's records. Using *CRAM*, Williams and Lutterschmidt (2006) analyzed Texas and demonstrated that for much of the state's counties (88%) documented species richness values fell below predicted values. Given that documented species richness is a direct function of collections (Preston 1948; Williams & Lutterschmidt 2006), counties with species richness values below predicted richness are counties with little or no specimen collecting thus representing data-gaps in the state's herbaria.

A state requires two data sources to perform *CRAM*. The first data source is a database or Atlas of a substantial (if not entire) portion of a state's herbarium specimens. The database should be constructed in such a way that the number of species documented per county can be reported. Data source two requires that a state have a substantial number (15+) of published floristic inventories that represent a varying array of area size (from State level down to a few hectares). Information needed from each published inventory is the area of the study site and the number of species reported from that area. These values are necessary for determining the constants C and z used in the species area relationship formula $S=CA^z$. Species-area relationship is regarded as "one of community ecology's few laws (Schoener 1976)." The species-area relationship simply states that as area increases species richness increases (Brown & Lomolino 1998). The species area relationship can therefore be used to estimate or predict the number of species within a given area. In the formula S = species richness, A = Area, C = the number of species when area equals 1, this is defined by the intercept of the slope for known values (those gathered from the floristic inventories) and z = the rate of increase in species as area increases, this is defined by the slope of the known values (those gathered from the floristic inventories; MacArthur & Wilson 1967). After surveying the literature and state herbaria it was determined that Florida possessed substantial data in both sources. Consequently, we present an analysis of the documented floristic completeness for the state of Florida.

METHODS AND MATERIALS

Published checklists and floras for regions with defined boundaries within the state of Florida were identified (Table 1) using the FloraS of North America project (Qian et al. 2007). From each checklist the number of species was recorded and the geographic flora-coverage area (kilometers^2) was calculated. Both metrics were log transformed and entered into a database. The database was imported into SPSS 10.1 and linear regression was used to determine the relationship between species richness (dependent variable) and area (independent variable). From this analysis both the slope (z value) and the intercept (C value) for vascular plants in Florida were determined (Fig. 1).

To determine predicted species richness for each individual county in Florida the C and z constants were then applied to the Arrhenius log-log ($\log S = \log C + \log A^z$) model with A representing the area in square kilometers for each of the 67 counties (Table 2) in Florida.

We then accessed the Atlas of Florida Vascular Plants (Wunderlin & Hansen 2008) database and recorded the taxa richness reported from each county in Florida. Note that we reported here taxa richness rather than species richness. This is because: 1) Wunderlin and Hansen (2008) were thorough in their documentation of both species and their intra-specific taxa (both sub-species and varieties) and 2) it is the actual number of biological entities that we are concerned with rather than their systematic position. Whether a taxon is recognized as a species or a variety does not diminish the fact that it ecologically unique from other taxa and occupies space within the designated area under study.

RESULTS AND DISCUSSION

The constants z (0.17) and C (245) for vascular plants in Florida were determined using linear regression (Fig. 1) of geographical area and documented species richness values gathered from the 27 representative floristic inventories in Florida (Table 1). The determined value of z is within the accepted range of z values (0.12–0.17) for vascular plants within continents (MacArthur & Wilson 1967). The rather high z for Florida, in comparison to the entire range for terrestrial plants, is readily explained by the tropical physiognomy of the state. C indicates a species richness of 245 species for any given square-kilometer area in Florida. Using the obtained C and z values, we then predicted species richness for each of the 67 counties in Florida (Table 2).

A cubic regression analysis was used to compare documented ($r^2 = 0.165$) and predicted species richness ($r^2 = 0.999$) for each of the 67 counties in Florida (Fig. 2). Counties with documented species richness that approximate (here determined as within 95% of predicted richness) or exceed predicted species richness fall near, on or above the predicted regression line; counties that have an under representation of species richness fall well below the predicted regression line (Fig. 2). This cubic regression model allows curators and researchers to identify counties that are under collected/documented. Our results indicate that 22 (or 32.8%) of the 67 counties in Florida fall well below the predicted line and are, therefore, considered under collected counties (Table 2 and Fig. 3). The total area (38240 km^2) occupied by these under collected counties covers 26.5 % of Florida. Compared to the state of Texas, with only 29 out of the 254 counties well collected, the state of Florida is very strong in the documentation of vascular plant richness. It is suggested however, that effort be made to improve the collection and documentation of species richness for the under collected counties in Florida, specifically Baker, Glades, Hendry, Lafayette, Okeechobee, and Union Cos. (Table 2) which have documented less than 70% of the predicted species for their county.

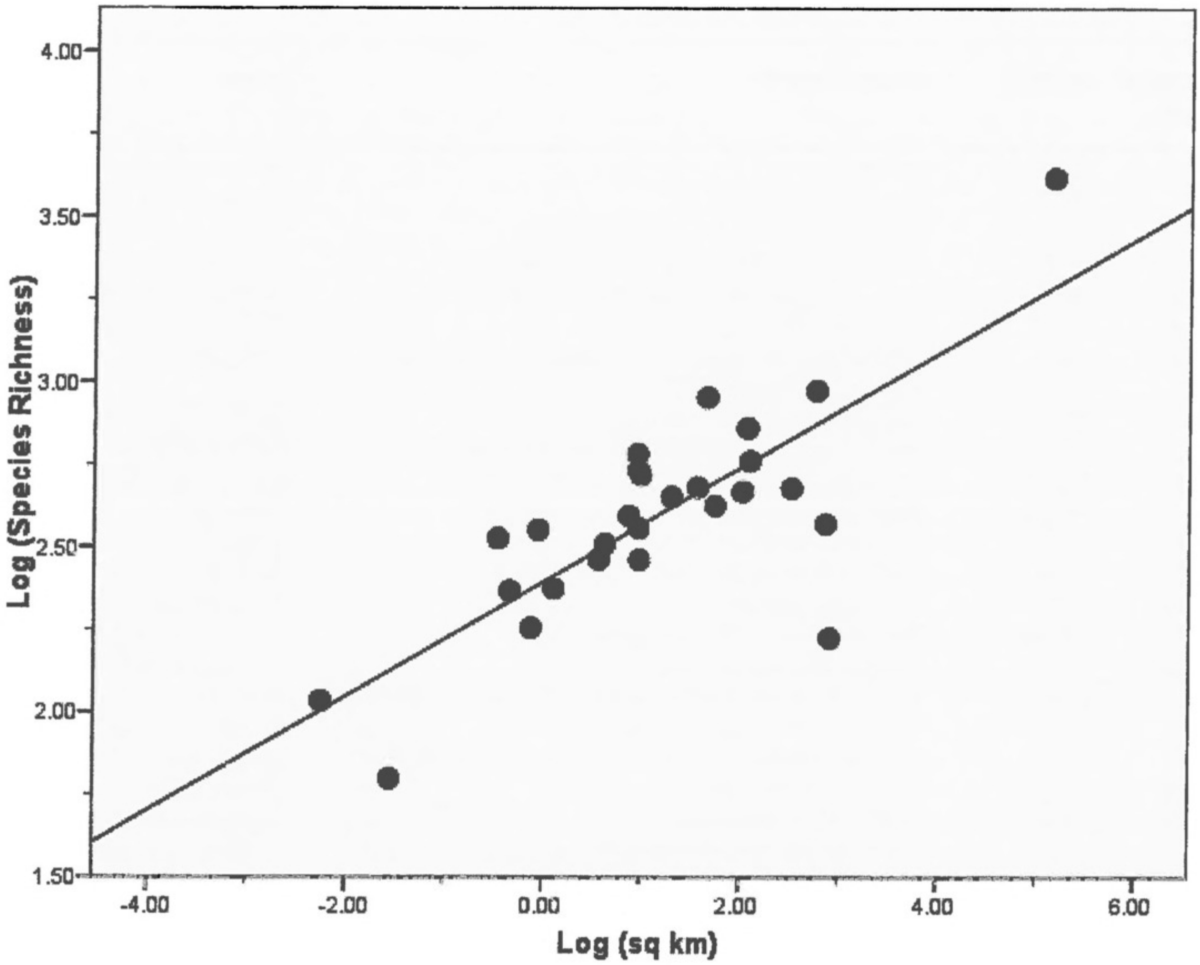

Fig. 1. Logarithmic relationship between species richness and geographic area. Dots = each of the 27 checklist and floras listed in Table 1 plotted for documented species richness and geographical area. Solid line = the regression between documented species richness and geographical area. The regression indicates a significant relationship between species richness and geographical area ($F = 39.737$, $df = 25$, $r^2 = 0.614$). Constants *C* and *z* were obtained from this analysis and used in the species-area relationship formula $S = CA^z$.

It is recognized that additional checklist for Florida probably exist, most likely in the form of unpublished government reports, and that those used (Table 1) for this study are only published representatives of the potential literature for Florida. Regardless, we feel that those used in this study represent well the degree of variation needed to determine credible *C* and *z* values. In particular the floras used represent an astonishing array of area size, ranging from the entire state with 144557 km² to a mere 0.01 km². In addition, when *C* is calculated using only 14 of the floras (selecting every other flora when arranged from largest to smallest starting with the entire state) the *C* value is 253, only an eight species difference from the 245 used for this analysis. Indeed, eight species can make a substantial difference when factoring in an increase in area, however when using predicted species richness values generated from a *C* value of 253 to determine the completeness of the Florida plant record, there is no substantial difference in the counties isolated as when using a *C* value of 245. We do accept that over time, and with it the consequent accumulation of additional data, the values presented in this study (Table 2) may and probably will change. We stress, however, that it is not our aim to present fixed species richness values per county, but rather to provide benchmark values that can be used in focusing collection/documentation effort.

Williams and Luttershmidt (2006) demonstrated that in Texas documented species richness values were in general greater in counties that had herbaria and lower in counties without herbaria. The implication is

TABLE 1. Published values of species richness for vascular plants and associated geographic area.

Number of Species	Area (km2)	Generalized Location	Citation
4144	144557.60	Florida State	Wunderlin & Hansen 2008
943	582.75	Merrit Island, Brevard Co.	Poppleton et al. 1977
899	46.54	Jonathan Dickinson State Park, Martin Co.	Roberts et al. 2006
726	116.81	Myakka River State Park, Sarasota and Manatee Cos.	Huffman & Judd 1998
604	9.06	Ichetucknee Springs, Suwannee and Colombia Cos.	Herring & Judd 1996
576	124.84	Waccasassa Bay, Levy Co.	Abbott & Judd 2000
540	9.25	O'Leno State Park and northeast River Rise State Preserve Alachua and Columbia Cos.	Tan & Judd 1995
523	9.79	Little Manatee, Hillsborough Co.	Myers & Wunderlin 2003
480	37.24	Timucuan ecological and historic preserve, Duval Co.	Zomlefer et al. 2007
477	326.34	Fakahatchee Strand State Preserve, Collier Co.	Austin et al. 1990
466	105.15	Bull Creek, Osceola Co.	Huck 1979
449	20.20	Cedar Key, Levy Co.	Amoroso & Judd 1995
422	56.20	Paynes Prairie, Alachua Co.	Easley & Judd 1990
393	7.43	Dog Island, Franklin Co.	Anderson & Alexander 1985
372	730.38	Biscayne National Park, Miami-Dade Co.	Stalter et al. 1999
360	9.32	Manatee Springs, Levy Co.	Gulledge & Judd 2002
356	0.88	Gold Head Branch Ravine and Adjacent Uplands, Clay Co.	White & Judd 1985
336	0.34	The Hammock, Dunedin, Pinellas Co.	Genelle & Fleming 1978
323	4.22	Gulf Islands National Seashore, Perdido Key, Escambia Co.	Looney et al. 1993
290	3.65	Fort DeSoto Park, Pinellas Co.	Thorne 1995
289	9.51	Little Talbot Island, Duval Co.	Easley & Judd 1993
237	1.27	Fort Matanzas National Monument, St. Johns Co.	Zomlefer et al. 2004
233	0.46	Blowing Rocks Preserve, Martin Co.	Richardson et al. 1992
180	0.75	Atlantic University Ecological Site, Broward Co.	Austin 1990
168	810.67	Ocala National Forest, Marion Co.	Mohlenbrock 1976
108	0.01	Turtle Mound, Volusia Co.	Norman 1976
63	0.03	Chicken Key, Miami-Dade Co.	Guala 1993

that botanists tend to concentrate their specimen collections in localities near their work or home base. The phenomena of collecting near biological stations was termed the "Collector's Syndrome" by Soberon et al. (1996) and later "The Botanist Effect" by Moerman and Estabrook (2006). Indeed, within Florida the counties with lower than expected species richness values are ones without herbaria (Fig. 3). It is acknowledged, however, that there are plenty of counties without herbaria that have documented species richness greater than predicted values (Fig. 3). Pautasso et al. (2007) suggest that species richness values are higher in some counties not because of the efforts of botanical collecting, but rather because humans tend to concentrate in areas with higher bio-diversity (more plant species = more humans = more botanist = herbaria). They demonstrated a positive correlation for all the counties in the Continental United States, showing that Human population increased with an increase in plant species richness. The question of whether botanist drive documented species richness or species richness drives human settlement is a "Chicken and Egg" argument that is better argued elsewhere. However based on our research we do believe that documented species richness is a product driven by the efforts of botanist and not vice versa.

This paper is one of many in the recent effort to develop models that predict species richness values for the vascular flora of the United States. The methods use a variety of techniques including GIS modeling (Iverson & Prasad 1998; Jarnevich et al. 2006) and species area relationship (SAR) (McNeill & Cody 1978; Buys et al. 1994; Williams & Lutterschmidt 2006; Qian et al. 2007). The aim in developing such models is to provide benchmark SR values that can be used for a variety of conservation efforts including assessing the completeness of museum collections (Williams & Lutterschmidt 2006; demonstrated here), determining

Table 2. List of the 67 counties in Florida, their documented taxa richness (generated from Wunderlin and Hansen 2008), predicted richness (generated from the formula $S=CA^z$), area and whether or not documented taxa richness exceeded predicted species richness. *= Counties with true documented values less than predicted values but falling within 95% error.

County	Documented taxa richness	Predicted species richness	Area (km. mi.)	Documented taxa greater than predicted richness?
Alachua	1547	943	2264	TRUE
Baker	583	880	1516	FALSE
Bay	998	921	1978	TRUE
Bradford	528	780	759	FALSE
Brevard	1174	968	2637	TRUE
Broward	1039	997	3122	TRUE
Calhoun	1070	875	1469	TRUE
Charlotte	772	906	1796	FALSE
Citrus	1137	879	1512	TRUE
Clay	985	884	1557	TRUE
Collier	1247	1090	5246	TRUE
Columbia	947	928	2064	TRUE
DeSoto	670	893	1651	FALSE
Dixie	735	908	1823	FALSE
Duval	1231	923	2004	TRUE
Escambia	1586	899	1715	TRUE
Flagler	777	851	1256	FALSE
Franklin	1531	869	1410	TRUE
Gadsden	1238	861	1337	TRUE
Gilchrist	609	804	904	FALSE
Glades	490	923	2004	FALSE
Gulf	761	871	1436	FALSE
Hamilton	579	860	1333	FALSE
Hardee	664	893	1651	FALSE
Hendry	527	989	2985	FALSE
Hernando	1218	849	1239	TRUE
Highlands	1095	970	2663	TRUE
Hillsborough	1608	973	2722	TRUE
Holmes	602	851	1250	FALSE
Indian River	742	857	1303	FALSE
Jackson	1460	950	2372	TRUE
Jefferson	935	883	1548	TRUE
Lafayette	444	868	1406	FALSE
Lake	1232	957	2469	TRUE
Lee	1275	929	2081	TRUE
Leon	1686	900	1727	TRUE
Levy	1236	984	2897	TRUE
Liberty	1345	935	2165	TRUE
Madison	642	905	1792	FALSE
Manatee	1120	916	1919	TRUE
Marion	1248	1044	4089	TRUE
Martin	995	872	1439	TRUE
Miami-Dade	1676	1083	5040	TRUE
Monroe	1135	964	2582	TRUE
Nassau	929	896	1688	TRUE
Okaloosa	1201	954	2423	TRUE
Okeechobee	563	923	2005	FALSE
Orange	1100	949	2350	TRUE
Osceola	837	1013	3424	FALSE
Palm Beach	1042	1085	5113	TRUE*

Table 2. continued

County	Documented taxa richness	Predicted species richness	Area (km. mi.)	Documented taxa greater than predicted richness?
Pasco	1117	917	1929	TRUE
Pinellas	1173	774	725	TRUE
Polk	1294	1076	4855	TRUE
Putnam	1029	912	1870	TRUE
Santa Rosa	1270	968	2634	TRUE
Sarasota	995	876	1480	TRUE
Seminole	887	787	798	TRUE
St. Johns	857	886	1577	TRUE*
St. Lucie	686	876	1483	FALSE
Sumter	925	869	1413	TRUE
Suwannee	606	904	1781	FALSE
Taylor	805	972	2699	FALSE
Union	458	754	622	FALSE
Volusia	1311	981	2857	TRUE
Wakulla	1262	885	1571	TRUE
Walton	1315	974	2739	TRUE
Washington	837	878	1502	TRUE*

the degree of invasiveness (Jarnevich et al. 2006), and determining the degree of sampling effort needed to complete a survey (Palmer et al. 2002). We believe that such models are important in directing future collecting, research and granting efforts, as well as laying the foundation for testing theoretical models.

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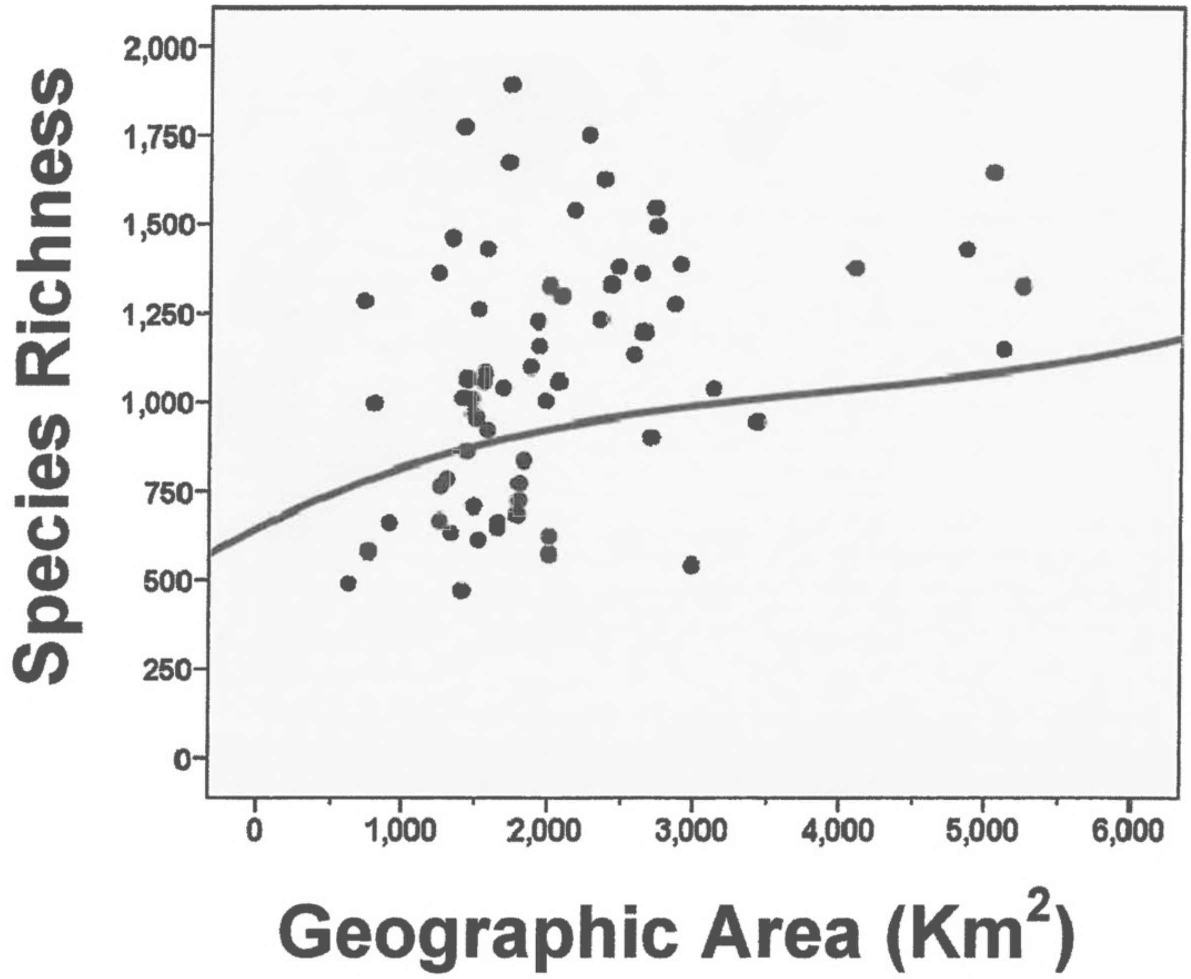

Fig. 2. Relationship between species richness and geographic area. Dots = each of the 67 counties in Florida plotted for documented taxa richness (y axis) and geographical area (x axis). Solid line = the cubic regression between predicted species richness and geographical area. Counties (dots) on or above the predicted species richness (line) indicate well collected counties that match or exceed predicted species richness.

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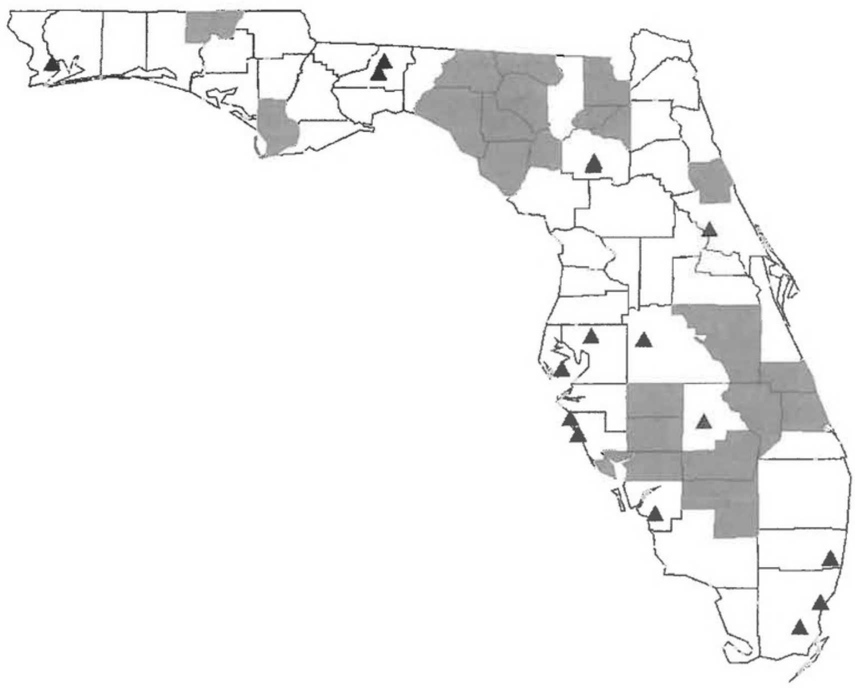

Fig. 3. Counties (shaded) where documented species richness is lower than predicted species richness. For the majority of counties in Florida documented species richness matches or exceeds predicted richness. Triangles represent the location of herbaria. FTU in Orange Co. was not included in this map as it is chiefly a Bryophyte collection.

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