CASTANEA 89(1): 1–11 February

Assessment of Macrolichen Diversity at Ordway-Swisher Biological Station in Northern Florida Contributes to the Scientific Mission of NEON

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ABSTRACT

The National Ecological Observatory Network (NEON) is gathering select ecological and taxonomic data across 81 sites in the United States and Puerto Rico. Lichens are one of the organismal groups that NEON has not yet assessed across these sites. Here we sampled lichens at Ordway-Swisher Biological Station (OSBS), a NEON site in north central Florida, to provide a baseline survey of the commonly encountered macrolichens (foliose, fruticose, and squamulose lichens). Macrolichens represent a subset of observable lichens and are more commonly surveyed than crustose lichens. Seventy-four species of macrolichens were collected, including 25 occurrences that constitute new records for Putnam County, Florida. The lichen diversity at OSBS comprised approximately 30% of the macrolichen diversity known from the entire state of Florida. Fifty-four taxa are common in the state of Florida, 12 infrequent across the state, and eight are considered rare. Macrolichens were the seventh most species-rich taxonomic groups at OSBS and more diverse than the NEON focal groups of mammals and fish. Lastly, we suggest a theoretical roadmap for how lichenologists could work together with NEON to include lichens in future datasets. We hope that biologists focused on other key organismal groups will sample in NEON sites so that NEON data can be leveraged appropriately in future cross-taxon studies of biodiversity at the continental scale.

Key words: biodiversity, ecology, macrolichens, National Ecological Observatory Network (NEON), taxonomic bias

INTRODUCTION

The National Ecological Observatory Network (NEON) is a set of 81 sites across the United States (including Puerto Rico) that aims to collect a standardized set of ecological and organismal data in terrestrial and aquatic ecosystems to address ecological, taxonomic, and large-scale scientific questions across time and space (NSF NEON 2022a). Ecological data includes carbon and nitrogen isotopes in the air and water, eddy flux, barometric pressure, and radiation flux (NSF NEON 2022). Organismal data includes aquatic algae, plants, mammals, mosquitoes, and ticks (NSF NEON 2022b). These data are deposited at Arizona State University and can be requested by scientists for research purposes.

While it is not feasible to survey organismal diversity for all living taxa across all NEON sites due to funding, storage logistics, and lack of taxonomic expertise, sampling additional taxa outside of NEON's core scope can contribute to the data that are publicly available from NEON sites. One example is fungi, which play an important role in ecological processes such as wood decay

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Received 14 July 2023; Accepted 19 February 2024

(Lustenhouwer et al. 2020), and nutrient transfer through mycorrhizae (Zak et al. 2019; Johnson and Gibson 2021). Fungi are indirectly sampled during ongoing NEON sampling as a byproduct in soil, water, and plant samples, but fruiting bodies (sexual reproductive structures of fungi) are not currently being sampled. Many fungi are hard to sample and/or identify due to their small size and/or lack or infrequent epigeous fruiting (Straatsma et al. 2001), but one group that are persistent year-round and amenable to intensive surveys are lichens. More than 20,000 lichen species have now been described (Lücking et al. 2017). Lichens are indicators of anthropological change such as pollution (Nash 2008) and climate change (Aptroot et al. 2016; Sancho et al. 2019), which are issues that NEON gathers data to study.

Recent surveys for lichens in Florida have yielded ecological insights and novel taxa. Lichen diversity and abundance were recently surveyed in hardwood bottoms, sand pine scrub, and longleaf pine forest in the Ocala National Forest, Florida (DeBolt et al. 2007). A total of 101 macrolichen taxa were collected and eight species were indicative of sand pine scrub and four species were indicative of hardwood bottoms. Another study observed that foliose and fruticose species were more common in north Florida, and crustose lichens were more common in south Florida (Rosentreter and DeBolt 2021). Finally, a single tree can yield ecological and taxonomic discoveries, suggesting that even small lichen inventories are important for building our understanding of lichen biodiversity. A single tree of *Quercus margarettae* Ashe ex Small supported multiple old growth-dependent lichen species (Rosentreter et al. 2020), and a single tree of *Q. pumila* Walter in south Florida supported 56 lichen species across 17 families (LaGreca et al. 2021).

The first taxonomic surveys of the lichens of Florida were conducted by William Wirt Calkins and John Wiegland Eckfeldt (Calkins 1886; Eckfeldt and Calkins 1887a; Eckfeldt and Calkins 1887b). Sixty-five years passed until the first monograph of the lichens of Florida was published, "The Cladoniae of Florida" (Evans 1952). The first comprehensive checklist of the macrolichens of Florida was published by Moore (Moore 1968), which documented 150 species across 25 genera. Even in recent years new macrolichens are still being described from Florida (Dal Forno et al. 2019; Lendemer and Allen 2020; Lücking et al. 2020). Despite these advances, there are still many regions of Florida that need further survey to establish baseline data. This includes Putnam County, where a NEON site is located within the Ordway-Swisher Biological Station (OSBS).

Ordway-Swisher Biological Station is owned and managed by the University of Florida. The Station contains 38 square km (Ordway-Swisher Biological Station 2023a) and is home to several different major habitat types, including sandhill, baygall, mesic hammock, scrubby flatwoods, and pine plantation (Ordway-Swisher Biological Station 2023b). To enhance the organismal knowledge of the Ordway-Swisher Biological Station (OSBS) and the NEON biodiversity initiative, we surveyed OSBS for macrolichens. We qualitatively assessed the habitat preferences of the lichen species we encountered, and we assessed the OSBS's lichen diversity in comparison to published surveys and data from the Consortium of North American Lichen Herbaria (CNALH). Here we show how a small, focused survey of a particular biotic group can help to inform ecological and taxonomic knowledge of a NEON site and allow for biodiversity comparisons to other sites, regions, and organismal groups. The main goals of this work were: 1) assess how well a survey of a NEON site could capture macrolichen diversity at the county and state levels, 2) compare diversity of taxonomic groups within OSBS, and 3) examine trends in habitat preference of the lichen species at OSBS.

MATERIALS AND METHODS

Collection and Identification

Six collection trips were made to OSBS in Spring 2018. Additional specimens were opportunistically collected at OSBS from 2014–2022 as part of ongoing research to study fungal diversity at OSBS. Macrolichen specimens were collected opportunistically with an emphasis on collecting one specimen per species of the most common taxa. Macrolichens were defined as foliose, fruticose, and squamulose species (Ascomycota lichens) or minutely filamentous species (Basidiomycota lichens). Taxonomy follows Esslinger (2021). Only macrolichens identified to species complex are presented here and were used in our analyses. Specimens were identified with a Zeiss Stemi 2000 dissecting scope and a Zeiss Axio Image A2 compound microscope (Carl Zeiss Microscopy, White Plains, New York). Identification keys that were used for this work include Brodo et al. (2001) and Rosentreter et al. (2022). Standard spot tests, K (10% potassium hydroxide), C (unscented bleach), and PD (paraphenylenediamine), were used to aid identification (Brodo et al. 2001). Specimens were photographed in the lab with a Canon EOS Rebel T3i with an 18–55mm lens (Tokyo, Japan). Specimens and images were deposited at FLAS-L (lichens) museum collection at the University of Florida. Specimen data were uploaded onto the Consortium of North American Lichen Herbaria (CNALH). A photo guide to the lichen species will be placed on the OSBS website after upgrades are made to the site.

Abundance

For each macrolichen species, we assessed the abundance at the state level. Species were rated as rare, infrequent, or common using the methodology from McCune et al. (2019) and species data from Rosentreter and DeBolt (2021).

Habitat Assessment

To better understand the ecology of the lichens, we recorded the habitat based on visual observations and photographs obtained during collecting. The GPS coordinates of collecting locations was also overlaid on a vegetation map of the OSBS. Habitat type was determined by a combination of our visual observations and the GPS locations of collection sites. The OSBS map uses vegetation types from the Florida Natural Area Inventory (FNAI), a publication of standardized definitions of the habitats of Florida (Florida Natural Areas Inventory 2010). This provided the first opportunity to explore how FNAI vegetation categorizations might work for interpreting lichen diversity.

Ordway-Swisher Macrolichen Diversity Comparisons

To estimate macrolichen diversity within Putnam County, we queried the CNALH, using “United States, Florida, Putnam County” on 15 December 2022 and downloaded the data. Data from OSBS (this study) and microlichens were removed. Taxonomic synonyms were removed, and four additional taxa (*Cladonia* sp, *Cladonia stellaris* (Opiz) Pouzar & Vězda, *Usnea hirta* (L.) Weber ex F.H. Wigg., *Usnea subcomosa* Vain.) were omitted because they were not found in the state or could not be identified to species. Lastly, we assessed the similarity of macrolichen diversity between OSBS, Putnam County, and the State of Florida. We used a list of Florida macrolichens (Kaminsky, unpublished) and compared the percentage similarity of macrolichens identified to species between the three locations (e.g. OSBS vs. Putnam Co. vs. State of Florida). Specimens identified only to the genus level were excluded from this analysis.

Comparisons of Organismal Diversity within OSBS

To assess taxonomic biases in diversity estimates at NEON, we compared the data on fungi and lichens at OSBS to the data from other organisms that NEON actively monitors or surveys from various University of Florida research groups. Data from the taxonomic groups surveyed in OSBS were gathered from the OSBS website (Ordway-Swisher Biological Station 2023c) and compiled with lichen and fungi data from our lab. Data on non-lichenized fungi of OSBS was gathered from a biodiversity inventory and DNA barcoding project on fleshy fungi of OSBS conducted by Kaminsky and Smith (2018).

RESULTS

Overview

A total of 88 collections of macrolichens were made comprising 74 species. Of these, 85 were identified to species and three to species complex (Table 1). Twenty-five macrolichens were new county records. At the state level, the abundance of the species found at OSBS were: 54 common, 12 infrequent, and eight rare.

Table 1. Macrolichen checklist listing habitat data and abundance of the species at the state level. Seventy-four species were collected. Thirty-four species were collected from sandhill, followed by 28 from mesic hammocks. Habitat type follows the Florida Natural Area Inventory. Twenty-five species were first new collections in Putnam County. The abundance of each species at the state level was 54 common, 12 infrequent, eight rare. Abundance ratings are C=common, I=infrequent, and R=rare.

Catalog Number	Scientific Name	Habitat	New to Putnam County	Abundance in Florida
FLAS L13417	*Bulbothrix confoederata* (W.L. Culb.)	sandhill		C
FLAS L13393	*Bulbothrix isidiza* (Nyl.) Hale	sandhill		C
FLAS L13395	*Bulbothrix scortella* (Nyl.) Hale	successional hardwood forest		C
FLAS L13371	*Canoparmelia caroliniana* (Nyl.) Elix & Hale	mesic hammock		C
FLAS L13339	*Canoparmelia cryptochlorophaea* (Hale) Elix & Hale	sandhill		C
FLAS L13419	*Cladonia didyma* (Fée) Vainio	mesic hammock	yes	C
FLAS L13349	*Cladonia evansii* Abbayes	sandhill		C
FLAS L13411	*Cladonia hypoxantha* Tuck.	sandhill	yes	I
FLAS L13350; FLAS L13392; FLAS L13410	*Cladonia leporina* Fr.	sandhill		C
FLAS L13412	*Cladonia parasitica* (Hoffm.) Hoffm.	sandhill		I
FLAS L13421	*Cladonia peziziformis* (With.) J.R. Laundon	sandhill		C
FLAS L13351	*Cladonia prostrata* A. Evans	sandhill		C
FLAS L13394	*Cladonia rappii* A. Evans	sandhill		C
FLAS L13433	*Cladonia subcariosa* Nyl. (Ahti 2000)	sandhill	yes	C
FLAS L13434	*Cladonia subradiata* (Vainio) Sandst.	mesic hammock		C
FLAS L13352	*Cladonia subtenuis* (Abbayes) Mattick	sandhill		C
FLAS L13416	*Coccocarpia palmicola* (Sprengel) Arv. & D.J. Galloway	sandhill		C
FLAS L14518	*Cyphellostereum jamesianum* Dal Forno & Kaminsky	sandhill	yes	R
FLAS L13275	*Dictyonema lawreyi* Dal Forno, Kaminsky & Lücking	mesic hammock	yes	R
FLAS L13335	*Dirinaria aegialita* (Afz.) B.J. Moore	sandhill	yes	C
FLAS L13390	*Dirinaria applanata* (Fée) D.D. Awasthi	successional hardwood forest	yes	I
FLAS L13375	*Dirinaria picta* (Sw.) Clem. & Shear	mesic hammock		C
FLAS L13385	*Emmanuelia lobulifera* (B. Moore) Ant. Simon & Goffinet	mesic hammock	yes	I
FLAS L13336	*Enchylium* cf *conglomeratum* (Hoffm.) Otálora, P.M. Jørg. & Wedin	mesic hammock	yes	R
FLAS L13347	*Heterodermia albicans* (Pers.) Swinscow & Krog	sandhill		C
FLAS L13430	*Heterodermia crocea* R.C. Harris	successional hardwood forest		C
FLAS L13422	*Heterodermia granulifera* (Ach.) W.L. Culb.	successional hardwood forest	yes	R

Table 1. continued

Catalog Number	Scientific Name	Habitat	New to Putnam County	Abundance in Florida
FLAS L13354; FLAS L13418	*Heterodermia obscurata* (Nyl.) Trevisan	successional hardwood forest; mesic hammock		C
FLAS L13348	*Heterodermia pseudospeciosa* (Kurok.) W.L. Culb.	sandhill	yes	R
FLAS L13372	*Hyperphyscia pyrithrocardia* (Müll. Arg.) Moberg & Aptroot	mesic hammock	yes	R
FLAS L13346	*Hypotrachyna horrescens* (Taylor) Krog & Swinscow	sandhill		C
FLAS L13374	*Hypotrachyna livida* (Taylor) Hale	successional hardwood forest		C
FLAS L13402	*Hypotrachyna minarum* (Vainio) Krog & Swinscow	mesic hammock		C
FLAS L13431	*Hypotrachyna osseoalba* (Vainio) Park & Hale	successional hardwood forest		C
FLAS L13356	*Hypotrachyna spumosa* (Asahina) Krog & Swinscow	sandhill		I
FLAS L13409	*Leptogium austroamericanum* (Malme) C.W. Dodge	mesic hammock		C
FLAS L13355	*Leptogium cyanescens* (Ach.) Körb.	successional hardwood forest		I
FLAS L13427	*Leptogium floridanum* Sierk	mesic hammock	yes	C
FLAS L13377	*Leptogium isidiosellum* (Riddle) Sierk	successional hardwood forest		I
FLAS L13397	*Leptogium marginellum* (Sw.) Gray	successional hardwood forest		C
FLAS L14556	*Leptogium millegranum* Sierk	mesic hammock	yes	R
FLAS L14549	*Leptogium sessile* Vain.	basin swamp, successional hardwood forest, [not recorded]	yes	R
FLAS L13389	*Parmelinella amazonica* (Nyl.) A.S. Rodrigues, A.P. Lorenz & Canêz	abandoned field/pasture		C
FLAS L13342	*Parmelinella salacinifera* (Hale) Marcelli & Benatti	sandhill		C
FLAS L13373; FLAS L13426	*Parmeliopsis subambigua* Gyelnik	mesic hammock; sandhill	yes	C
FLAS L13399	*Parmotrema crinitum* (Ach.) M. Choisy	mesic hammock		C
FLAS L13379	*Parmotrema dilatatum* (Vainio) Hale	sandhill		C
FLAS L13380; FLAS L13382	*Parmotrema gardneri* C.W. Dodge) Sérus.	successional hardwood forest; sandhill		C
FLAS L13407	*Parmotrema hypoleucinum* (J. Steiner) Hale	sandhill		C
FLAS L13406	*Parmotrema perforatum* (Jacq.) A. Massal.	successional hardwood forest		C
FLAS L13388; FLAS L13404	*Parmotrema rampoddense* (Nyl.) Hale	successional hardwood forest		C
FLAS L13340; FLAS L13401	*Parmotrema reticulatum* (Taylor) M. Choisy	sandhill; mesic hammock		C
FLAS L13338	*Parmotrema subisidiosum* (Müll. Arg.) Hale	sandhill		C

Table 1. continued

Catalog Number	Scientific Name	Habitat	New to Putnam County	Abundance in Florida
FLAS L13381	*Parmotrema submarginale* (Michaux) DePriest & B. Hale	mesic hammock		C
FLAS L13391	*Parmotrema tinctorum* (Delise ex Nyl.)	sandhill		C
FLAS L13337	*Parmotrema xanthinum* (Müll. Arg.)	abandoned field/pasture	yes	I
FLAS L13383	*Phyllopsora* cf *parvifolia* (Pers.) Müll. Arg.	successional hardwood forest	yes	C
FLAS L13384	*Phyllopsora pyxinoides* (Nyl.) Kistenich, Timdal, Bendiksby & S. Ekman	mesic hammock		C
FLAS L13376	*Physcia americana* G. Merr.	successional hardwood forest	yes	C
FLAS L13343; FLAS L13428	*Physcia atrostriata* Moberg	sandhill; mesic hammock		C
FLAS L13357	*Physcia sorediosa* (Vainio) Lynge	mesic hammock	yes	C
FLAS L13378	*Pseudoparmelia uleana* (Müll. Arg.) Elix & T.H. Nash	sandhill		C
FLAS L13400	*Punctelia rudecta* (Ach.) Krog	mesic hammock	yes	C
FLAS L13408	*Pyxine caesiopruinosa* (Nyl.) Imshaug	mesic hammock		C
FLAS L13405	*Pyxine eschweileri* (Tuck.) Vainio	mesic hammock		C
FLAS L13341	*Pyxine subcinerea* Stirton	sandhill; successional hardwood forest	yes	I
FLAS L13425	*Ramalina paludosa* B.J. Moore	mesic hammock		C
FLAS L13420	*Ramalina stenospora* Müll. Arg.	mesic hammock	yes	C
FLAS L13334	*Sticta* cf *weigelii* (Ach.) Vain.	mesic hammock		I
FLAS L13344	Usnea ceratina Ach.	sandhill	yes	I
FLAS L13429	*Usnea mutabilis* Stirton	mesic hammock		C
FLAS L14560	*Usnea rubicunda* Stirton	sandhill	yes	C
FLAS L13386; FLAS L13413	*Usnea strigosa* (Ach.) Eaton	mesic hammock; sandhill		C
FLAS L13345; FLAS L13415	*Usnea subscabrosa* Nyl. ex Motyka	sandhill		I

Habitat

Two species were collected from abandoned pasture, one from basin swamp, 28 from mesic hammock, 34 from sandhill, and 17 from successional hardwood forest. There was more species diversity of *Cladonia* and *Parmotrema* in the sandhill habitat while the genus *Leptogium* was more species-rich in mesic hammocks and basin swamps. Several species were collected from multiple different habitats, suggesting that lichen diversity and distribution does not strictly follow the FNAI plant communities.

Macrolichen Diversity at the County and State Level

There were 81 macrolichen species recorded from Putnam County outside of our collections from OSBS. There were 48 species that were shared between our dataset from OSBS and the previous records from the rest of Putnam County. Our survey increased macrolichen diversity in Putnam County from 81 to 106 species. Florida has records of 245 macrolichen species according to unpublished data assembled by Kaminsky. The OSBS contains 30% of the macrolichens known from Florida while Putnam County contains 43% of the macrolichens known from Florida.

Comparisons of Taxonomic Diversity among Different Organismal Groups at OSBS

Diversity data were available for twelve different organismal groups from OSBS (Table 2). The macrolichens ranked as the seventh most diverse group at OSBS. Compared to NEON focal taxa, macrolichen diversity is lower than plants and beetles, but higher than mammals, fish, and gastropods.

DISCUSSION

The macrolichen survey of OSBS found 30% of all previously known Florida macrolichens within the reserve, despite the relatively small amount of sampling at a site that is only 38 km^2 (9,500 acres). This result implies that small surveys can capture a good snapshot of macrolichen diversity and are useful to document some rare species. Our results indicate that with limited sampling, many of the common macrolichen species could be found and a baseline of diversity could be established. We estimate that a more intensive survey would likely reveal additional macrolichen species that are present but uncommon at OSBS.

The habitat data suggest that habitat delineations in the FNAI might be helpful for identifying broad associations between lichens and particular habitats, but that lichens are not necessarily restricted to particular FNAI habitats. Since some of the lichens we surveyed were found in several different habitats, it would not be necessary to visit all habitats to sample macrolichens. Macrolichen species were most likely found in multiple FNAI habitats because the dominant tree species are similar among some FNAI habitats and some habitats often border one another (DeBolt et al. 2007).

Sampling at OSBS yielded several rare and/or undercollected taxa with only limited sampling effort. For example, *Cladonia hypoxantha* is a subtropical species that occurs only sporadically in Florida (Ahti 2000) but was found once at OSBS in sandhill. *Heterodermia granulifera,* a small lobed species that has granular isidia, is a very rare species in the southeast United States (Lendemer 2009), but was nonetheless found at OSBS in successional hardwood forest. In addition, multiple undescribed macrolichen species were collected and will be treated in future papers. We also noted that some areas of OSBS are seasonally inundated and can therefore be challenging to sample for lichens and other organisms. For example, we suspect that further sampling within the basin swamps would yield additional macrolichen taxa that were not yet detected in this survey.

Lichen diversity in OSBS was high compared to what is known for several other organismal groups, such as mammals and fish. Even with our moderate survey, we detected significantly more macrolichen species (74 species) than the known number of mammal species (37 species) at OSBS. It is well established that the diversity, distribution and conservation of larger, more “charismatic” organisms such as mammals are disproportionately surveyed (Clark and May 2002; Donaldson et al. 2017) and data on birds are prolific in part because of successful campaigns to generate data with the help of citizen scientists (Devictor et al. 2010; Petersen et al. 2021). If microlichens at OSBS were surveyed, there would be at least 100 additional lichen species and in that case lichens would be considered more species-rich than beetles, ants, and birds. One major hurdle to studying smaller, inconspicuous, and taxonomically-challenging organisms is that these organisms do not attract nearly as much attention from the general public as large, showy animals (Allen et al. 2019; Wang et al. 2021).

NEON is not directly studying lichens but studies like this one could complement other datasets that NEON collects. For example, at least two bird species use lichens to make nests in Florida (Graves and Dal Forno 2018) and moths in Psychidae also collect lichens to include in their protective cases (Miranda-González et al. 2023). There are at least three different arthropod species that mimic lichens, suggesting that they regularly interact with lichens in their natural habitats (Krombein 1963; Gerson 1973). Arthropods such as Lepidopterans also eat lichens (Wagner et al. 2008; Scott Chialvo et al. 2018; Palting and Moore 2022). Lichen fruiting bodies or DNA may also be present in litterfall, soil, or wood samples. Lichen surveys could also provide baseline data for future research to see how lichen diversity changes after natural events (such as hurricanes or fires) or manmade events (such as climate change, logging or air pollution).

Table 2. Species richness among sampled organismal groups at Ordway-Swisher Biological Station. Macrolichens were the seventh most species-rich group. NEON sampled plants, beetles, mammals, fishes, and gastropods (aquatic only). Data for non-lichenized fungi is based from work by Kaminsky & Smith (2018).

Taxonomic Group	Number of Species
Plants	700+
Lepidoptera	488
non-lichenized fungi	587
Birds	149
Ants	101
Beetles	84
Macrolichens	74
Reptiles	45
Mammals	37
Grasshoppers	31
Amphibians	27
Fishes	26
Gastropods	8

For lichens to be incorporated into NEON datasets, it will take a partnership between NEON and lichenologists to build datasets for NEON sites as both parties are limited in time and personnel. A new workflow would be needed to efficiently collect and identify lichens. One possibility is that NEON personnel could voucher specimens and send them to a consortium of lichen specialists. Another possibility is an iNaturalist workflow where NEON employees take photos with geolocation data, and experts identify specimens. With iNaturalist, it might be hard to identify collections to species, but a baseline of lichen diversity to genus or species complex would nonetheless enrich the understanding of abundance and biodiversity of lichens at NEON sites and help with additional studies.

The National Ecological Observatory Network is generating a dataset that scientists will be able to use for decades to come. While it is not possible for NEON to collect data about every organismal group, any data collected for study on these groups that are excluded from the current sampling could benefit future studies. Here we showed that with moderate effort we were able to document and identify many of the common lichens at the OSBS NEON site. We also showed here that the current NEON sampling exhibits some taxonomic biases and does not necessarily sample the most diverse organismal groups. We hope that this study encourages researchers to think about how datasets of non-focal taxa in NEON's sampling scheme can be sampled in NEON sites to further enhance knowledge of these sites.

ACKNOWLEDGMENTS

We thank IFAS Research Dean John Davis for additional support of the lichen inventory project. We also thank Lucas Majure and Alan Franck from the Florida Museum of Natural History for collection support and David Borland for assistance in the field. This work was supported by the USDA National Institute of Food and Agriculture, McIntire-Stennis project FLA-PLP-006168 (MES), U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project 1001991 (MES) and Ordway-Swisher Jumpstart Funding from the Institute for Food and Agricultural Sciences at University of Florida. Lastly, we thank reviewers for feedback and manuscript suggestions. Participation of M.E. Smith was also supported by the U.S. National Science foundation grant DEB-2106130.

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