Morphometrics and species distribution modeling elucidates cryptic biodiversity in the Hawaiian *Coprosma foliosa* Complex (Rubiaceae)

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INTRODUCTION

Currently, there are 16 described taxa of *Coprosma* (Rubiaceae) in the Hawaiian Islands. The most recent taxonomic treatment including all taxa Hawaiian taxa was by Wagner et al. (1999). Many species were sunk into synonomy resulting in some taxa that are single island endemics, while others are found across many islands. In the case of *C. foliosa sensu lato*, this species was located across 5 of the 8 main islands. However, after many trips to the field and detailed herbarium investigation, it became clear that there are a number of taxa representing not yet described diversity (and some now synonomized) currently falling under the name *C. foliosa*. Moreover, it appears that these segregate taxa are potentially delimited by specific sets of morphologic characters as well as geographically, in which taxa are largely separated from each other by island and/or mountain range.

To more thoroughly investigate the taxa of the *C. foliosa* Complex, we embarked on an in depth morophmetric analysis from many herbarium specimens, field data collection and also utilized the development of niche models to better understand the suitable habitat of each taxon and test hypotheses of niche overlap.

Table 1. Key distinguishing characters for some taxa of the *C. foliosa* Complex

	Coprosma 'sp. Kaua'i'	*Coprosma* 'sp. Moloka'i'	*Coprosma cordicarpa*	*Coprosma* 'sp. O'ahu'
fruit calyx	minute	conspicuous 1-2 mm	conspicuous, 1.5 - 3.5 mm	minute
fruit shape	spherical	reniform or ovoid	cordate	ovoid
habit	multi stemmed liana	single stemmed tree	multi stemmed shrub	multi stemmed shrub
habitat	mesic forest	mesic-wet forest	dry forest	mesic-dry forest
leaf blade trichomes	moderately pilose	glabrous to sparsely pilose	glabrous to sparsely pilose	glabrous to sparsely pilose
leaf midrib trichomes	pilose to lanate	glabrous	puberulent	glabrous to sparsely pilose
location	Kaua'i	Moloka'i	East Maui	Waianae Mountains, O'ahu
fruit peduncle length	13-30 mm	3.4-7.1 mm	3-7(-13) mm	3 - 6 mm

METHODS

Field Work: Field observations were performed Feb-July 2016 to assess abundance and take field notes and digital photos. **Morphometrics:** All measurements were taken from dried herbarium specimens using calipers. **Niche Modeling:** Models were produced in MaxEnt using species presence data (GPS coodrdinates) and the 19 bioclimatic variables made available by WorldClim. The majority of the species presence data were collected with a Garmin eTrex GPS on multiple field excursions in 2016, with a few points taken from herbarium specimens (US). The bioclimatic variables were downloaded in a 30 x 30 degree tile with 30 second resolution (Zone 20). Each of the climate variable data layers were imported into ArcMap 10.2 and clipped to the extent of the Hawaiian islands. The output format of MaxEnt was set to logistic and was run with a 30% random test percentage.

KEY RESULTS

1. Morphometrics from this study confidently separate two taxa from the *C. foliosa* Complex, which effectively replace *C. foliosa s.s.* in their distribution. The two new taxa occur on Moloka'i (*C.* 'sp. Moloka'i') and Kaua'i (*C.* sp. Kaua'i') Islands.

2. Morphometric analyses suggest the potential of at least two additional segregate taxa from the *C. foliosa* Complex, but additional field work and herbarium material is needed to confirm their identity. These taxa occur on the island of Lana'i (*C.* 'sp. Lana'i') and in the Waianae and Northern Ko'olau Mountains of O'ahu (*C.* 'sp. O'ahu'). *Coprosma foliosa s.s.* therefore appears to be restricted to the central and southern Ko'olau Mountains of O'ahu only.

3. Generated niche models suggest both specialized and widespread distributions for the various segregate taxa. The models support the separation of the novel taxa based on geographic limitations and distinct morphological characters investigated (see key below).

Preliminary Key for the *C. foliosa* Complex

(modified from Cantley et al 2016)

1a Liana, sometimes appearing shrubby when young or not near adjacent tall vegetation .....**(2)**
1b Single stemmed tree or multi-stemmed shrub .....**(4)**
2a Single or few stemmed liana to 7.5 meters (20 feet) scrambling through understory vegetation towards open light patches, Lana'i.....***C.* 'sp. Lana'i'**
2b Multi-stemmed shrub-like liana to 10 meters (30 feet) in height often overtopping adjacent vegetation in a tangled mass of stems..... **(3)**
3a Leaves moderately pilose on primary to tertiary veins abaxially & adaxially, fruit on thin peduncle 13-30 mm long, Kaua'i.....***C.* 'sp. Kaua'i'**
3b leaves glabrous, female flowers and fruit on stout peduncle 1.5-15 mm long, Hawai'i Island..... .....***C. menziesii***
4a Single stemmed trees .....**(5)**
4b Multi-stemmed shrubs, sometimes single stemmed especially when young.....**(6)**
5a Tree to 20 feet in height, mature trees exceeding 40 feet in height and trunk dbh of greater than 12 inches, leaves lanceolate to ovate, fruit ovoid or often reniform due to two seed sizes, Moloka'i.....***C.* 'sp. Moloka'i'**
5b Tree to 20 feet in height, mature trees not known to exceed15 feet in height, (but found in poor degraded habitat and mature/long live individuals may not have been observed), leaves lanceo late to ovate, fruits ovoid, Ko'olau Mountains O'ahu.....***C. foliosa s.s.***
6a Fruit reddish-orange, ovoid, lacking a central constriction between the two seeds, apex not de pressed, calyx conspicuous or not.....**(7)**
6b Fruit reddish-orange to yellow, cordate (heart-shaped) with a central constriction between the two seeds, apex depressed, calyx conspicuous and persistent, leeward East Maui .....***C. cordicarpa***
7a Fruit reddish-orange to yellow, fruit calyx conspicuous and persistent and >1.5 mm long, East and West Maui.....***C. stephanocarpa***
7b Fruit reddish-orange to yellow, fruit calyx not present or sometimes minute (<1.5 mm).....**(8)**
8a Fruit with persistent connate calyx 1-2.5mm long with irregular teeth, Waianae Mountains .....***C.* 'sp. O'ahu'**
8b Fruit with callus tissue on apex, sometimes with minute calycine teeth, West Maui..... .....***C. stephanocarpa***

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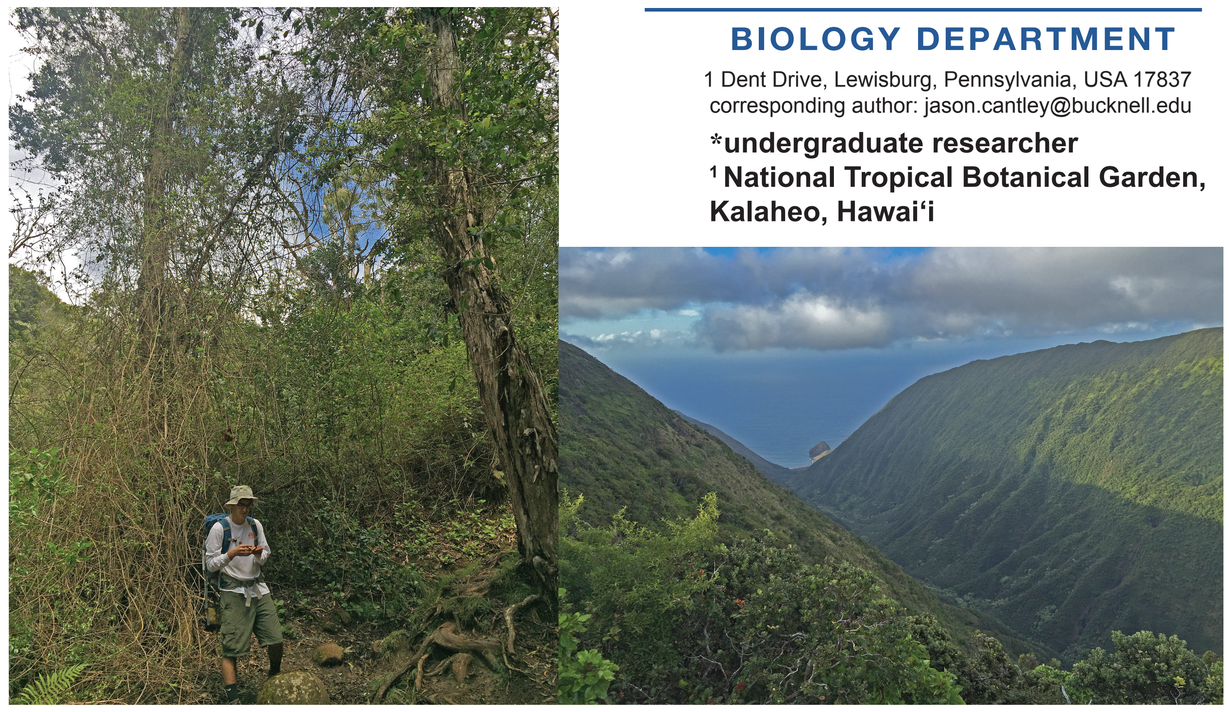


Fig 1. Left: Author NAD with the many-stemmed liana *C.* 'sp. Kaua'i'; Right: *Coprosma* 'sp. Moloka'i' at bottom left (lime green) overlooking Waikolu Valley, Moloka'i.

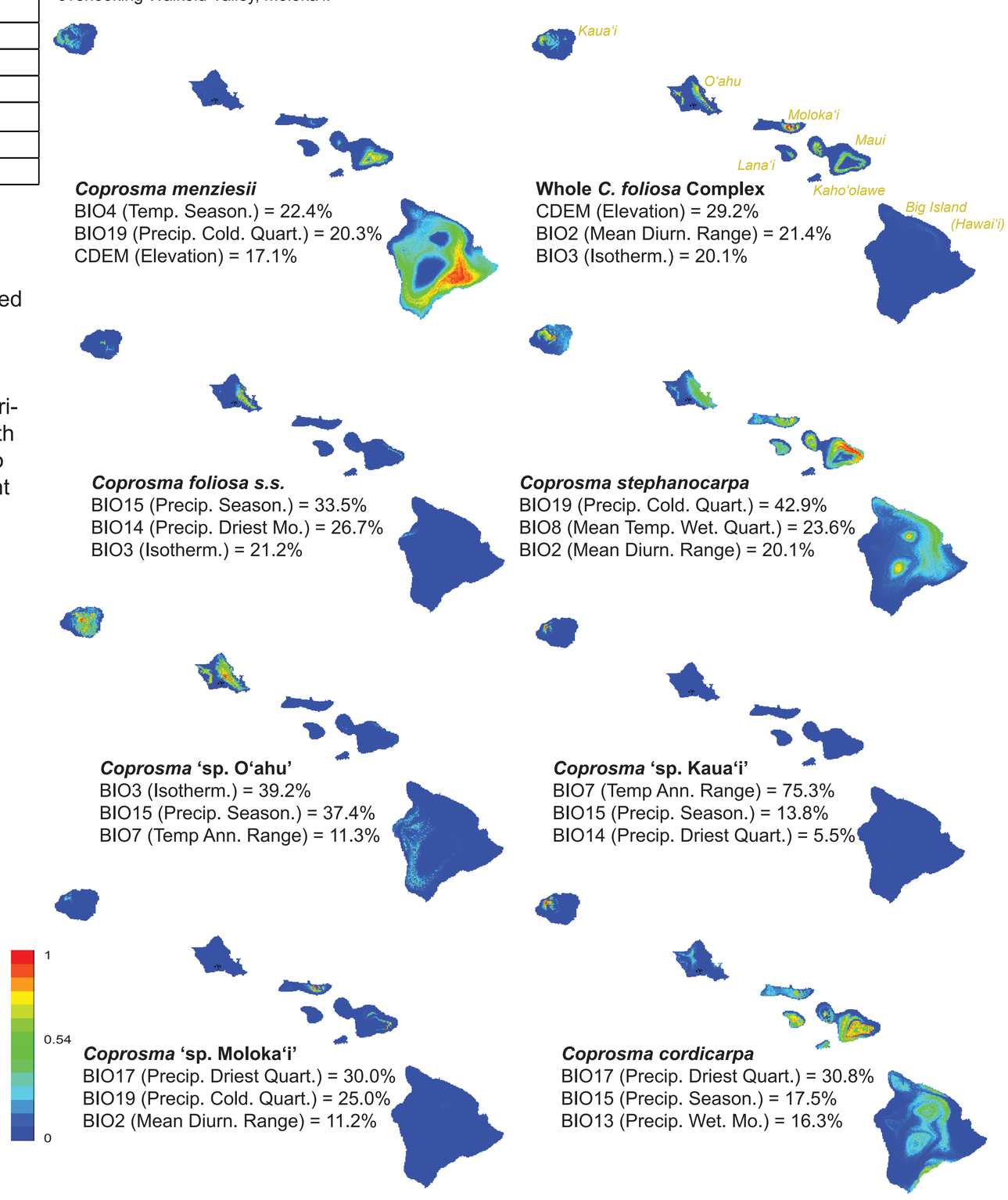


Fig 2. Visualizations of the MaxEnt niche models developed for each taxon of the *C. foliosa* Complex; warmer colors indicate potentially suitable habitat for each taxon. The model produced for the 'whole *C. foliosa* Complex' was the combination of all georeferneced points from the seven taxa of the complex plus a few points of *C.* 'sp Lana'i'. Too few localities are known to produce accurate models for *C.* 'sp Lana'i' and therefore was not included in this figure. Percent contribution of top environmental layers in development of models given under taxon name.

DISCUSSION

With the information from the models, in addition to geographic isolation, field observations, and morphometric data, we have reason to believe the segregation of taxa from this complex is warranted. There are several limitations and assumptions involved with niche modeling that must be considered when interpreting the models. With an extensive knowledge of the genus, and given these limitations and assumptions, we proceed with caution in our interpretations of these models.

In the cases of the *C.* 'sp. Moloka'i' and *C.* 'sp. Kaua'i' models, there was very little area with the appropriate predicted conditions necessary for their presence, perhaps suggesting they occupy a more specialized niche. Alternatively, the *C. menziesii, C. cordicarpa,* and *C. stephanocarpa* models had more widespread predicted niche, potentially hinting at a broad tolerance range or that some other variable outside of our model is more important to the distribution of these species. The niche model produced from all taxa of the Complex accurately reproduced the known locations for all taxa, except for *C. menziesii* that occurs on the Big Island only. For the various runs, different variables were important, but seasonality of precipitation and seasonality of temperature commonly were larger influences of model development. Hypothesis testingwith ENMtools, morphometric data collection, and population genetics will be explored as the next step in our analyses of the *C. foliosa* Complex.

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