From: Amoroso, Jame
To: Marshall, Michael E
Cc: Reid, Rebekah N; Mason, Suzanne; Robinson, Laura
Subject: RE: [External] HENA Drafts
Date: Thursday, March 1, 2018 10:33:07 AM
Attachments: image004.png
HENA_CURRENT CONDITIONS 2.22.18_NCNHP.docx
INFLUENCES ON VIABILITY_HENA 2.22.18_NCNHP.docx
Importance: High

Hi Mike,

I have attached the HENA drafts with NC NHP comments. We had some editorial comments and some content comments.
There is a lot to accomplish in a short period of time!

Thank you,
Jame

Jame Amoroso
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From: Marshall, Michael [mailto:michael_marshall@fws.gov]
Sent: Thursday, February 22, 2018 9:19 AM
To: Mason, Suzanne <suzanne.mason@ncdcr.gov>; Amoroso, Jame <jame.amoroso@ncdcr.gov>; Matt Estep <estepmc@appstate.edu>; Bassette, Tim <tpbassette@ncdot.gov>; Mark Endries <mark_endries@fws.gov>; Rebekah <rebekah_reid@fws.gov>; Drew Becker <drew_becker@fws.gov>; Stephanie DeMay <Stephanie.DeMay@ag.tamu.edu>
Subject: [External] HENA Drafts

Good morning Team!

Sorry for the delay, but here are the next two sections of the HENA SSA attached for your consideration and review, with appendices attached as well. These sections are Current Conditions and Influences on Viability. As you review and provide comments on these sections, we will be working on the Future Conditions section, which will be the final section of the SSA.

Please provide your edits and comments to these documents in track changes by **COB Friday March 2nd.**

Thanks you so much for your help and input on all of this. And, if at any time you have any questions, please feel free to contact me or Rebekah.

Take care and have a great weekend!

Mike

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Work Schedule 1st Week
Monday-Thursday --> In Office 7:30-4:30 CST

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NORTH CAROLINA
Natural Heritage Program
SCIENCE GUIDING CONSERVATION

NC DEPARTMENT OF NATURAL AND CULTURAL RESOURCES

CURRENT CONDITIONS

Below we assess current resilience, representation, and redundancy as they relate to population and habitat factors known to be important for species viability. Based off of recent reports (NCNHP 2016a; NCNHP 2016b), the species consists of 113 populations distributed across 12 counties in North Carolina and South Carolina. Recent genetic research suggests that dwarf-flowered heartleaf, as originally described, is found in the southern portion of its presumed range based on current EO locations, and the northern portion could be a currently undescribed species (Figure 1; Estep pers. Comm. 2018). The genetic analysis to support this is complete, but a review of the morphology is ongoing and a new species has not yet been described (Estep pers. Comm. 2018). For the purpose of this SSA, we assume all EO detections are *H. naniflora*, and represent the best currently available scientific data.

Commented [AJ1]: NHP records are not populations per se, but locations where the element occurs and aggregated based on general biological concepts and data management needs.

Commented [AJ2R1]: NatureServe definition for Population: A population is a geographically or otherwise distinct group of individuals of a particular species between which there is little demographic or genetic exchange (equivalent to the IUCN definition for a “subpopulation”). For animals, metapopulation structure may arise when habitat patches are separated by distances that the species is physically capable of traversing, but that exceed the distances most individuals move in their lifetime (that is, the patches support separate subpopulations or “demes”). If habitats are sufficiently close together that most individuals visit many patches in their lifetime, the individuals within and among the patches will tend to behave as a single continuous population.

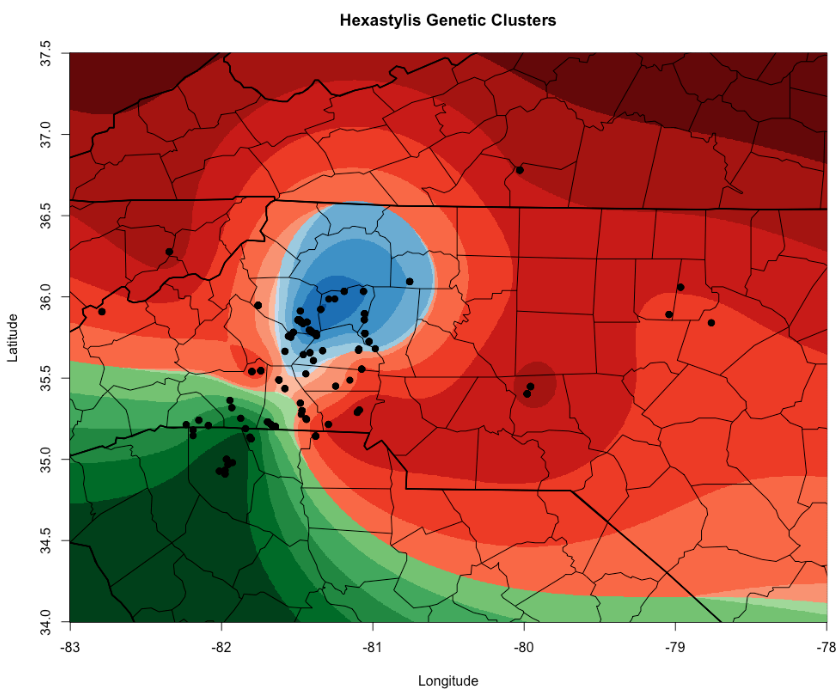

Figure 1-Recent genetic analyses detailing clustering of the genus Hexastylis. Green areas represent "true" *H. naniflora*; Blue represents a possible new species; Red represents other species in the genus (*H. minor, H. heterophylla*, etc.).

Current Population Resilience

Categorizing Resilience

For the purposes of this SSA, we use population size as the main driver of population resilience. The unit of measurement for population size in this species is a "clump" (rosette). As discussed previously, populations in North Carolina were delineated by NCNHP, whereas the Service defined populations in South Carolina. These delineations were based off of NatureServe criteria such as EO separation distance and intervening landscape matrix. EO data included a wide range of years since the species was last observed at a given location (1964-2017), so although recent reports suggest the species consists of 113 populations, some of that data is fairly outdated. For the purposes of this SSA, we only used EOs that were observed within the last 10 years (2007-2017). Based on that criteria, there are currently 68 populations distributed across the range of dwarf-flowered heartleaf, although this may be an underestimate as discussed in more detail in the habitat modelling section later.

To determine overall resilience for populations, we used EO viability ranks and expert opinion to bin population size classes into corresponding resilience categories. EO viability ranks for the species include excellent, good, fair, poor, extant, historical, and failed to find. The primary factor in determining these ranks is EO size (as quantified by number of clumps). Condition of habitat (vegetation community and structure) and landscape context (extent of suitable habitat and physical factors) are also incorporated secondarily. Appendix 1 shows the NCNHP EO rank specifications for dwarf-flowered heartleaf. The EO rank specifications suggest good-excellent viability for populations consisting of at least 500 individuals, given there is sufficient high quality habitat; fair viability for populations consisting of 100-500 individuals, depending on habitat conditions; poor viability for populations consisting of less than 100 individuals. Recent

Commented [MS3]: I agree with Jame that, though standard practice with regard to SSAs, it may be inappropriate to exclude older records. This equates to the assumption that those locations never have or are no longer able support the species. There are many EOs for this species that have persisted for decades, despite not having intervening surveys to confirm this and evidenced by the time elapsed between the first observation and the last observation. When you determined the number of populations, was the separation distance criteria reapplied as if these older than 10 year locations didn't exist on the landscape?

Commented [AJ4]: Why exclude outdated records from the model?

Commented [RL5]: Perhaps you should exclude data with low accuracy, rather than older data. There were status surveys conducted in 2005 that we did not get landowner permission to visit again in 2012-2016 and may be valuable data.

Commented [MS6]: I didn't see in the modelling section below where the issue of why this may be an underestimate was addressed.

reports (NCNHP 2016a; NCNHP 2016b) focus monitoring studies on populations with greater than 1,000 individuals, populations that are assumed to be very viable. Because we do not have habitat level information for every population we assessed, we synthesized all of the above population size information and created four resilience categories as follows:

- Very high—populations with >1,000 individuals; very high probability of persistence for 20-30 years at or above the current population size.
- High—populations with 500-1,000 individuals; moderate-high probability of persistence for 20-30 years at or above the current population size.
- Moderate—populations with 100-500 individuals; low probability of persistence for 20-30 years at or above the current population size.
- Low—populations with <100 individuals; low probability of persistence, and moderate-high probability of extirpation for 20-30 years at or above the current population size.

Occupancy and Abundance

There are 67 populations of dwarf-flowered heartleaf that have been observed within the last 10 years (Table 1), and resilience of these populations is as follows: 27 (very high); 5 (high); 20 (moderate); 15 (low). Table 2 shows the contribution of each resilience category as follows: 40% (very high); 7% (high); 30% (moderate); 22% (low). When looking at cumulative percentages of resilience, it is interesting to note that 78% of all of the populations are classified as moderate to very high resilience (Table 2).

Commented [MS7]: In the second paragraph of Categorizing Resilience section above, you state that there are 68 populations that have been observed in the last 10 years.

Table 1--Current populations of dwarf-flowered heartleaf and associated resilience across the species range.

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Site Name	State	County	Last Observed	Total plants	Resilience
Glade Creek, Alex County	North Carolina	Alexander	2017	>1000	very high
Catawba River: Hoyle Crk-Micol Crk	North Carolina	Burke	2013	>1000	very high
Island Creek Heath Bluff	North Carolina	Burke	2016	>1000	very high
Gunpowder Creek: South of Hudson	North Carolina	Caldwell	2012	>1000	very high
Peaked Top Rare Plant Site/Foothills Landfill	North Carolina	Caldwell	2014	>1000	very high
Jacob Fork West Corridor	North Carolina	Catawba	2012	>1000	very high
Murrays Mill/Upper Balls Creek NA	North Carolina	Catawba	2013	>1000	very high
NCDOT TIP: R-2824	North Carolina	Catawba	2015	>1000	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	North Carolina	Catawba	2013	>1000	very high

Cowpens NBF - Site 1	South Carolina	Cherokee	2016	>1000	very High
Cliffside Steam Station	North Carolina	Clev/Ruth	2016	>1000	very high
Broad River/Sandy Run NA	North Carolina	Cleveland	2012	>1000	very high
Broad River: Brushy Creek	North Carolina	Cleveland	2016	>1000	very high
Buffalo Creek: Kings Mountain Res	North Carolina	Cleveland	2016	>1000	very high
Buffalo Creek: Tributaries N and S of SR 2047	North Carolina	Cleveland	2012	>1000	very high
Rhyne Conservation Preserve	North Carolina	Lincoln	2016	>1000	very high
Mill Creek Forest and Seep	North Carolina	Polk	2016	>1000	very high
New Hope Springhead Swamp	North Carolina	Polk	2016	>1000	very high
Big Horse Creek Rare Plant Site	North Carolina	Rutherford	2015	>1000	very high
Broad River: Floyds Creek	North Carolina	Rutherford	2016	>1000	very high
Davenport Road/Mountain View Rare Plant Site	North Carolina	Rutherford	2016	>1000	very high
Facebook Site	North Carolina	Rutherford	2016	>1000	very high
Floyds Creek Tributray Rare Plant Site	North Carolina	Rutherford	2012	>1000	very high
New Bethel Rare Plant Site	North Carolina	Rutherford	2015	>1000	very high
Richardson Creek trib above Toms Lake	North Carolina	Rutherford	2016	>1000	very high
DNR Peters Creek Heritage Preserve	South Carolina	Spartanburg	2016	>1000	ver[illegible]
Taylor Blalock Res	South Carolina	Spartanburg	2016	>1000	ver[illegible]
Little Gunpowder Creek Rare Plant Site 1	North Carolina	Caldwell	2015	500-1000	high
Little Gunpowder Creek Rare Plant Site 2	North Carolina	Caldwell	2015	500-1000	high
Northern Catawba County	North Carolina	Catawba	2017	500-1000	high
Rock Barn Solar Farm	North Carolina	Catawba	2010-2011	500-1000	high
Buffalo Creek Rare Plant Site	North Carolina	Cleveland	2012	500-1000	high
Third Creek Rare Plant Site	North Carolina	Alexander	2010	100-500	moderate
Hickory Area	North Carolina	Burk/Cata/Cald	2016	100-500	moderate
Burke County - Drowning Creek UT	North Carolina	Burke	2017	100-500	moderate
Simms Hill/Little River Uplands	North Carolina	Burke	2015	100-500	moderate
Smith Cliff/Henry Fork River	North Carolina	Burke	2015	100-500	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	North Carolina	Catawba	2016	100-500	moderate
NCDOT TIP R-2824	North Carolina	Catawba	2015	100-500	moderate
South Fork Catawba River, Henry Fork	North Carolina	Catawba	2007	100-500	moderate
Broad River/Sandy Run NA	North Carolina	Cleveland	2012	100-500	moderate
Brushy Creek Headwaters	North Carolina	Cleveland	2014	100-500	moderate
First Broad River: Crooked Run Creek	North Carolina	Cleveland	2010	100-500	moderate
No Business Creek, Boyd Tract	North Carolina	Cleveland	2007	100-500	moderate
West Shelby Mesic Slope	North Carolina	Cleveland	2016	100-500	moderate
UT of Kings Mountain Res	North Carolina	Gaston	2012	100-500	moderate
Buffalo Shoals Creek	North Carolina	Iredell	2014	100-500	moderate
Cat Square Heartleaf Forest	North Carolina	Lincoln	2012	100-500	moderate
Collinsville (Hughes) Creek Slopes	North Carolina	Polk	2016	100-500	moderate
Fox Knoll Farm	North Carolina	Polk	2016	100-500	moderate
Forest City: Adj to Isothermal CC	North Carolina	Rutherford	2010	100-500	moderate
Jonas Road Rare Plant Site	North Carolina	Rutherford	2014	100-500	moderate
NCDOT TIP R-3603A	North Carolina	Alexander	2017	<100	low
South Mountains Pleasant Grove Uplands	North Carolina	Burke	2016	<100	low

Commented [MS8]: Should this be “very high” all lower case?

Gunpowder Creek	North Carolina	Caldwell	2012	<100	low
Killian Crossroads	North Carolina	Catawba	2010	<100	low
Pott Creek	North Carolina	Catawba	2012	<100	low
Beaverdam Crk at First Broad River	North Carolina	Cleveland	2011	<100	low
Buffalo Creek: Potts Creek	North Carolina	Cleveland	2012	<100	low
Buffalo Creek: Ravine	North Carolina	Cleveland	2007	<100	low
Hickory Creek - UT (Shelby High School)	North Carolina	Cleveland	2016	<100	low
Boulder Creek Subdivision - Jordan Road	South Carolina	Greenville	2016	<100	low
Gateway Elementary School	South Carolina	Greenville	2017	<100	low
Fanjoy Road Site	North Carolina	Iredell	2015	<100	low
Levan Family Farm	North Carolina	Iredell	2013	<100	low
Lincoln County, SR-1314	North Carolina	Lincoln	2014	<100	low
Northeast Lincolnton: UT Walker Branch	North Carolina	Lincoln	2009	<100	low

Table 2--Population resilience categories by county for dwarf-flowered heartleaf.

County	**Very High**	**High**	**Moderate**	**Low**	**Totals**
Alexander	1		1	1	3
Burk/Cata/Cald			1		1
Burke	2		3	1	6
Caldwell	2	2		1	5
Catawba	4	2	3	2	11
Cherokee	1				1
Clev/Ruth	1				1
Cleveland	4	1	5	4	14
Gaston			1		1
Greenville				2	2
Iredell			1	2	3
Lincoln	1		1	2	4
Polk	2		2		4
Rutherford	7		2		9
Spartanburg	2				2
Totals	**27**	**5**	**20**	**15**	**67**
% of total	*40*	*7*	*30*	*22*	*100*
Cumulative %	*40*	*48*	*78*	*100*	--

Commented [MS9]: Would it be possible to list the full name of the county instead of a shortened version so those not as familiar with them are clear as to which are being referred to? For example, someone might think there is both a Ruth County and a Rutherford County.

Population Trends

Although we lack an adequate past time series of abundance data for all populations to estimate growth rates or population trends, NCNHP conducted surveys of thirteen of the largest populations across the range of the species from 2012-2016. Table 3 shows the results of all of these surveys. Two populations show an increasing trend, nine show a stable trend, and two show a decreasing trend.

Table 3-Summary of population trends over 5 years of monitoring data for 13 of the largest populations of dwarf-flowered heartleaf across its range (from: NCNHP).

Trend	Survey	Site	2016 estimated number of plants (Rosettes)	2016 area occupied (Acres)
Increasing	NCNHP	Cliffside Steam Station (EO 276)	39,535	52
	NCNHP	Broad River: Floyds Creek, Long Branch (EO 177)	12,687	5.67
Stable	NCNHP	Island Creek Bluff/Love Lady Site (EO 029)	50,481	61.76
	NCNHP	Rhyne Preserve (EO 302)	19,873	22.43
	NCNHP	Mills Creek Forest and Seep (EO 023)	1,733	1.39
	NCNHP	New Hope Springhead Swamp (EO 125)	12,235	5.03
	NCNHP	Broad River: Henson's Creek, Brice, & Sandy Mush Outcrop (EO099)	106,940	83.39
	NCNHP	Broad River: Cleghorn Creek, US 221 (EO 176)	6,750	7.24
	NCNHP	Cowpens National Battlefield (SC EO 016, 017, 018)	2,823	6.05
	NCNHP	Peters Creek Preserve (SC EO 011)	3,306	8.98
	NCNHP	Blalock Reservoir (SC EO 007, 031)	3,505	7.59
Decreasing	NCNHP	Second Broad River (Forest City Industrial Complex) (EO 154)	2,576	4.74
	NCNHP	South Fork Catawba River: Jacob Fork, Camp Creek (EO 158)	123	0.09

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Habitat Factors: Slope, Aspect, Elevation, Soil, and Forest Type

A previous habitat suitability study attempted to quantify the habitat requirements for dwarf-flowered heartleaf. A model was created to predict habitat suitability, and based on the model results, the strongest habitat correlations were slope, aspect, soil type, elevation, and land use (Wagner 2015). With this model in mind, we used updated habitat data, as well as inclusion of updated EOs, to create a new habitat model to identify potential habitat throughout the species range. All source datasets and variables created are described in Appendix 2.

Source Data and Model Variables

Fifty three, 10-digit hydrologic units (HUC) comprise the analysis extent. In North Carolina, it includes all 10-digit HUC that fall within the boundaries of 8-digit HUC with known occurrence of *Hexastylis*. In South Carolina, we also included all 10-digit HUC that fell within the boundaries of 8-digit HUC with known occurrence of *Hexastylis*, but excluded the southern portions of the HUC-8 areas due to the boundaries being exceedingly large and far away from any known occurrences.

Commented [MS10]: Just for clarity, are you referring to H.naniflora or any Hexastylis?

Hexastylis naniflora element occurrence data was obtained from the North Carolina Natural Heritage Program and the South Carolina Heritage Trust Program. These data were in polygon format and digitized at a scale that accurately identified the boundaries of the individual population areas. Current populations of *Hexastylis naniflora* were identified by reviewing the last observed data in the database and excluding all populations that have not been observed in the last 10 years (2007). To represent these current population areas in Maxent, a raster cell center was retained for every 30 x 30 meter pixel that was situated within the current element occurrence data polygons.

Model Development

We used Maxent software (version 3.4.1) for species habitat modeling (Philips et al., 2018). An initial single model Maxent run was done to determine which variables could be excluded due to limited percent contribution to the model. Any variable that contributed less than 1% to the single model run results was excluded in the final model. The following variables were excluded: landcover diversity, SSURGO drainage class, SSURGO hydrologic group, aspect 9-class, aspect 5-class, slope, and maximum annual temperature.

Commented [MS11]: Though I am not a modeler and I realize this document is not a review of modelling attempts, it is unclear to as to why aspect and slope were excluded yet they were identified as strongly correlated in the Wagner (2015) model. Was this due to differences or limitations of the underlying data?

Commented [MS12]: It is not defined in the body of the document nor in Appendix 2 that SSURGO means Soil Survey Geographic Database.

For the final model a 10-run replicate Maxent model was created using cross-validation. For replicate models, the occurrence data is randomly split into a number of equal-sized groups called “folds”, and separate models are created leaving out each fold in turn. The individual model runs are then averaged together to derive the final model.

Results

Figure 2 shows the model output. The minimum cutoff value (to determine if an area is considered potential habitat for a species) of 0.406 was determined by using the average 10th percentile training presence. The 10th percentile training presence uses the suitability threshold associated with the presence record that occurs at the 10th percentile of presence records (Phillips 2018). This value excludes some of the outlier population areas in the Maxent predictions to focus on the typical habitat conditions for this species. The total area ranked greater than 0.406 in the Maxent model was just 6.39% of the total analysis area (Table 4).

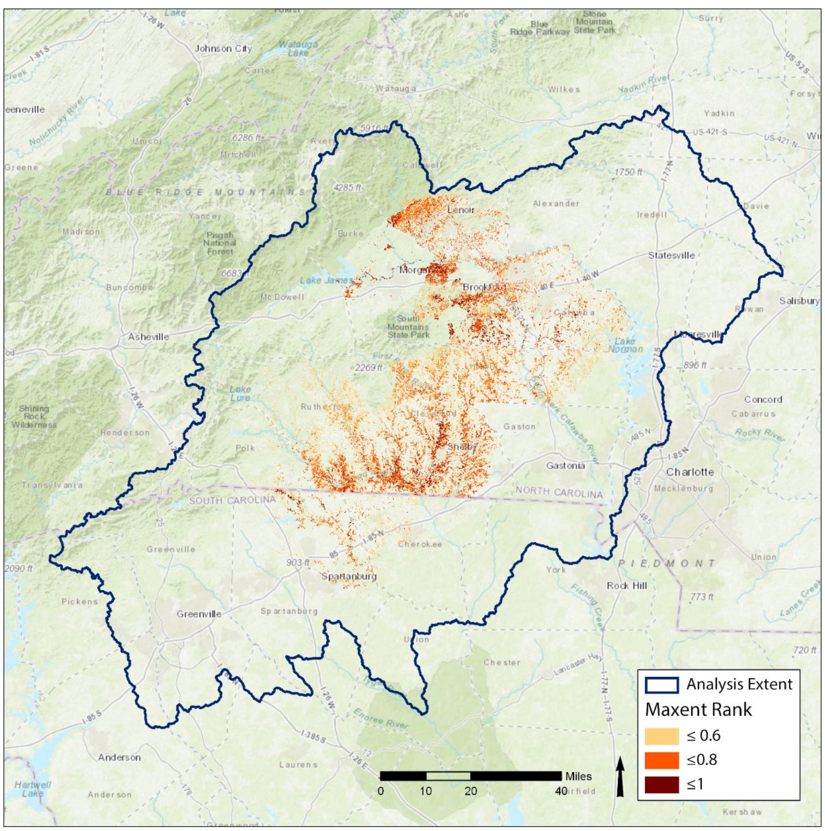

Figure 2-Maxent model output map

Commented [MS13]: There appears to be some issues with whichever input data sets were associated with counties – could you address this? For example, the density of ranked pixels appears to drop off on the north and west side of Gaston County. The same is true of the South Carolina border. The HUC's don't appear to follow the county boundaries in these areas. Is habitat being under-identified in these areas? Why?

Table 4-Area estimates of the Maxent model

Maxent Score	Acres	Square Miles	Percent of Total
0.406 and greater	321,262.37	501.97	6.39%
0.6 and greater	146,712.65	229.24	2.92%
0.8 and greater	22,677.96	35.43	0.45%

The average area-under-curve (AUC) score for the replicate Maxent model is 0.849. The AUC is calculated from the receiver operating characteristic (ROC) plot. This value has a range of 0 – 1 and may be interpreted as a single test statistic that assesses model performance, indicating the ability of the model to correctly classify the occurrence data used. The model performed well in its predictions, with a mean AUC of 0.849 (AUC value of 0.5 is no better than random; AUC<0.5 is worse than random; AUC>0.5 is greater predictive power than random; Baldwin 2009).

The Maxent output supplies estimates of the relative contributions of the environmental variables to the Maxent model (Table 5). SSURGO mukey is the top contributing variable. One hundred and thirty-five individual soil types are present within the polygon boundaries of the *Hexastylis naniflora* element occurrences. Many of these individual soil types are part of soil complexes and are separated by things such as percent slope, erosion, how stony/rocky, and amount of clay. The most common individual soil type was Meadowfield-Rhodhiss complex, 25 to 60 percent slopes, very stony (12.9% of total). However, collectively the Meadowfield soils only comprised 13.5% of all soils). The individual Pacolet soil types were very common and collectively comprise 36% of all soil types present. Woolwine soils were also collectively common, comprising 10% of all soils present.

Commented [MS14]: It would be helpful to define this as Map Unit Key here rather than having to refer to Appendix 2 prior to reading this section. Also, the percent contribution of the variables that are in Table 5 would be helpful to have inline with the text.

The minimum annual average temperature range in the analysis extent is 39 – 51 degrees Fahrenheit. The majority of the *Hexastylis naniflora* element occurrences (92%) are found at the

47 and 48 degrees. The average annual precipitation range in the analysis extent is 42 – 81 inches per year. The majority of the *Hexastylis naniflora* element occurrences (81%) are found in the 47 – 49 inches per year range.

Piedmont forested landcover habitats dominate the land area of the element occurrences. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier (52%), Southern Piedmont Mesic Forest (10%), Southern Piedmont Small Floodplain and Riparian Forest (3.6%), and Southern Piedmont Dry Oak-Pine Forest – Loblolly Pine Modifier (2.3%) collectively comprise 72% of the element occurrences area. Unfortunately, non-native habitats are also present. Evergreen Plantation or Managed Pine (8%), Harvested Forest – Grass/Forb Regeneration (7%), Developed, Open Space (5%), Pasture/Hay (2.5%) collectively comprise 22% of the total element occurrence area. The remaining 6 percent of element occurrence area is comprised of a mix of 14 other natural and disturbed landcover classes, but each at small percentages.

The landcover majority classification scheme reduces the total number of landcover classes present in the analysis extent from 23 to 12. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier is still the dominant landcover class (56%). However disturbed categories are increased in area (sum total of 35%). Evergreen plantation or managed pine (12%) and Pasture/Hay (12%) are the only other categories that have at least 10% or greater area. The increase in disturbed landcover area representation in the landcover majority layer suggests that many *Hexastylis naniflora* population areas are situated in areas impacted by disturbed landcover. This is likely due to urban encroachment and increasing fragmentation of habitats.

The landcover Hexastylis grouping reveals the amount of disturbance present in Hexastylis population areas. Landcover classes grouped as disturbed comprises 26% of the total area. Mixed forest (deciduous and evergreen) comprises 58%, hardwood forest 11%, and riparian 3.6%. Open water, evergreen and barren landcover groupings are all at less than 1% each.

Commented [MS15]: H. naniflora should be used consistently if that is the species being referred to.

Geomorphons revealed that the majority of *Hexastylis naniflora* element occurrence areas are situated in concave landforms. Geomorphon categories hollow (15%), valley (35%), and depression (17%) collectively comprise 67% of all *Hexastylis naniflora* population areas. Flat landforms comprise 22.5% of the area and convex landforms the remaining 10.5%.

Within the analysis extent, the range of elevation present is 335 – 5,265 feet. For *Hexastylis naniflora*, the prime elevation range is from 666 – 896 feet (54% of total element occurrence area). A lesser elevation range is present from 935 – 1,165 (35% of total element occurrence area).

Table 5-Percent contribution of the environmental variables

Environmental Variable	Percent Contribution
SSURGO mukey	23.3%
Minimum Annual Temperature	20.7%
Average Annual Precipitation	14.6%
Landcover	13%
Landcover Majority	9.5%
Landcover Hexastylis Grouping	7.3%
Geomorphons	6.4%
Elevation	5.2%

We performed an Analysis of Variance test to investigate the relationship between Maxent scores and current resilience of populations (Table 6). There are significant differences in the average Maxent scores between the four resilience categories (p = 0.01) and the mean Maxent score increases as population resilience increases for low to very high. It appears the model gives us some predictive ability regarding habitat quality, where higher Maxent scores, on average, result in higher population resilience.

Commented [MS16]: Was the purpose of the model to predict habitat quality or suitability? If the latter, how does it perform? And how is that performance compared to Wagner (2015), which was said to accurately predict suitability at a local scale 81% of the time? If it was quality then that should be stated in the introductory paragraphs.

Table 6-Results of the ANOVA investigating relationships between Maxent scores and current resilience groups for dwarf-flowered heartleaf.

Groups	*Count*	*Sum*	*Average*	*Variance*
low	13	5.240363	0.403105	0.124194
moderate	20	8.851696	0.442585	0.040139
high	4	2.292114	0.573028	0.039821
very high	27	16.66603	0.61726	0.020717

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.563333	3	0.187778	3.870253	0.01346	2.758078
Within Groups	2.911089	60	0.048518			
Total	3.474421	63				

Current Species Representation

Representation describes the ability of a species to adapt to changing environmental conditions. We lack genetic and ecological diversity data to characterize representation for dwarf-flowered heartleaf. In the absence of species-specific genetic and ecological diversity information, we typically evaluate representation based on the extent and variability of habitat characteristics across the geographical range. However, the dwarf-flowered heartleaf has a very limited range, and after consulting with experts, we decided delineating representative units was not appropriate for this species.

Current Species Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy for dwarf-flowered heartleaf is the total number and resilience of population segments and their distribution across the species range. As stated previously, there are 67 populations of dwarf-flowered heartleaf that have been observed within the last 10 years, and resilience of these populations is as follows: 27 (very high); 5 (high); 20 (moderate); 15 (low); 2 (unknown). The populations are spread across the range, although a majority occur in North Carolina. Although, there appears to be adequate redundancy within the range of dwarf-flowered heartleaf, the species range is very small, making it potentially vulnerable to catastrophic events. Thus, we classify redundancy as inherently low for the species.

Commented [MS17]: These total 69 not 67.

INFLUENCES ON VIABILITY

Hexastylis naniflora populations occur in rapidly growing urban areas with expanding suburbs of Charlotte, NC, to the east; Hickory, NC, to the north; and Greenville and Spartanburg, SC, to the south. At the time of listing, it was determined that the species was most threatened by habitat loss due to the conversion of land to residential, commercial, and industrial use in these areas. In addition to threats associated with residential, commercial, and industrial development, other documented threats include habitat loss from land conversion to agricultural use, timber harvest, hydrological alterations from the damming of ponds, impacts from grazing cattle, ORV damage, trampling from foot traffic, invasive species, highway or road improvements, and erosion or siltation (NCNHP 2016, Robinson and Padgett 2016). Climate change may exacerbate these risk factors through changes in temperature and precipitation.

Threats were assessed for populations monitored by NCNHP during 2012-2016 (Robinson and Padgett 2016), and EOs were reviewed for other documented threats to populations. Indirect or direct threats that were observed, inferred, or suspected to have an impact on populations were recorded and assigned a ranking based on their severity, scope, and immediacy from field observations. The rank for each threat factor determines the overall value for each threat observed at each population. No significant changes in threats within populations were noted from 2012-2016. Threats observed during these years included development, incompatible forestry practices, agriculture, trampling, invasive exotic species, sedimentation, erosion, and road construction.

Below, we summarize primary threats to the viability of dwarf-flowered heartleaf. Primary influences will be carried forward in our future projections in the next section.

Human Population Change

Increasing human populations drive development. With increases in population, there will be increasing conversion of open space to more impervious cover, with a subsequent increase in roads and other associated infrastructure. Increases in roads and impervious cover have the potential to lead to habitat loss and/or fragmentation, a primary risk factor for dwarf-flowered heartleaf. Tables 1-2 and Figures 1-2 show the estimated human population increases for North

Carolina and South Carolina counties within the range of the species. The most populous counties include Greenville and Spartanburg in South Carolina, and Catawba, Gaston and Iredell counties in North Carolina.

Table 1-Human population projections for North Carolina counties within the range of dwarf-flowered heartleaf. *Source: North Carolina OSBM, Standard Population Estimates.*

County	2018	2023	2028	2033	2037
Alexander	38609	39,244	39,686	39992	40169
Burke	90865	93,124	95,382	97644	99452
Caldwell	83919	86,723	88,689	91126	92870
Catawba	157424	159,799	162,175	164549	166447
Cleveland	98862	99,685	100,004	100128	100170
Gaston	221112	227,667	237,344	245276	252388
Iredell	179740	195,623	211,501	227383	240088
Lincoln	84494	91,034	96,865	103069	107858
Polk	21273	21,823	22,288	22681	22955
Rutherford	67880	68,154	68,283	68341	68368

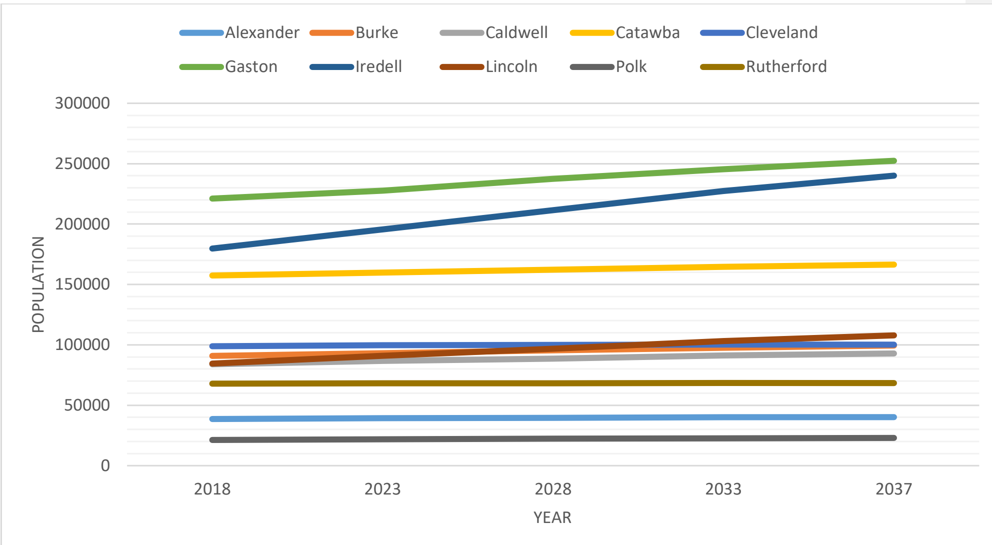

Figure 1- Human population projections for North Carolina counties within the range of dwarf-flowered heartleaf. *Source: North Carolina OSBM, Standard Population Estimates.*

Table 2- Human population projections for South Carolina counties within the range of dwarf-flowered heartleaf. *Source: U.S. Census Bureau, 2000 Census and 2007 Population Estimates. Population projections calculated by South Carolina Budget and Control Board, Office of Research and Statistics.*

County	2020	2025	2030	2035
Cherokee	61,760	64,760	67,350	70,170
Greenville	492,890	517,740	542,290	567,010
Spartanburg	310,220	323,550	336,810	350,110

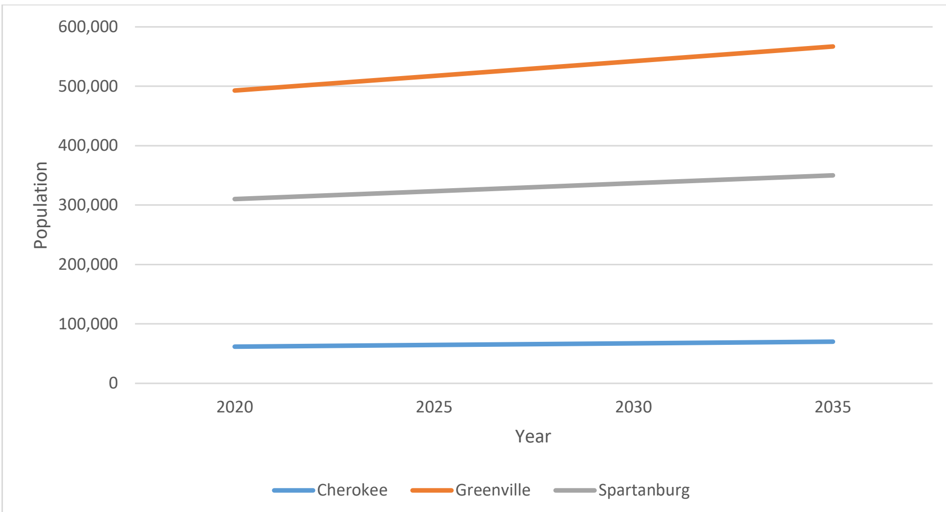

Figure 2- Human population projections for South Carolina counties within the range of dwarf-flowered heartleaf. *Source: U.S. Census Bureau, 2000 Census and 2007 Population Estimates. Population projections calculated by South Carolina Budget and Control Board, Office of Research and Statistics.*

Development

A large number of the known populations occur near expanding urban areas and are threatened by the residential, commercial, and industrial development associated with this growth. Populations occurring in more rural areas are threatened by habitat alteration or loss from land conversion to pasture or other agricultural uses, cattle grazing, intensive timber harvesting, residential construction, and construction of small ponds.

A 2011 review of existing NHP EOR data revealed that all or portions of 26 populations (24% of the total) had been directly or indirectly impacted through development projects or other causes such as trash disposal, expansion of residential lawns, cattle, or invasive exotics (NC NHP 2010; SCDNR 2010). Another 16 populations have been specifically reported to be threatened by one or more of these same sources. Therefore, threats have either occurred or are reasonably

Commented [MS1]: What was the total number of populations at that time? Was it 108 as indicated below?

Commented [MS2]: Should this be a different year as you begin by discussing a 2011 review but cite 2010 documents?

foreseeable within 42 of the 108 populations (corresponding to 39% of all known populations). Of these 42 populations, all or portions of 22 (50%) had been adversely impacted by activities requiring ESA Section 7 consultation with the USFWS. The fact that nearly 20% of all known populations had been subject to formal Section 7 consultation illustrates the threats faced by the species.

The most recurrent source of habitat destruction, and certainly the most common trigger for Section 7 consultations involving *H. naniflora* is road and bridge improvement projects. Ten of the 27 largest populations (containing more than 1,000 rosettes) have been the subject of Section 7 consultations between the USFWS and the NCDOT. Collectively, these projects have adversely impacted or are currently expected to impact some 22,135 rosettes. In most cases the Section 7 process has resulted in avoidance or minimization of adverse effects through relocation of plants and/or commitments of on-site protection to those plants remaining (post-construction) within NCDOT right-of-way (ROW).

Other forms of economic development have also resulted in the destruction or modification of habitats occupied by *H. naniflora*; in many cases, these activities have also required Section 7 consultations with the USFWS. Examples of these activities include the maintenance or expansion of hydroelectric and drinking water reservoirs, construction of an industrial development complex, and maintenance activities (in compliance with Federal Aviation Administration standards) at a regional airport. Collectively, these activities have involved the loss or relocation of several thousand rosette.

Blalock Reservoir in Spartanburg County, South Carolina was once estimated to contain the largest population of *H. naniflora*, with over 11,000 rosettes reported here in 1997 (JJ&G, 1998). This population was the subject of a section 7 consultation as a result of a proposal to raise the elevation of Blalock Reservoir, which provides water supply storage to Spartanburg County and the City of Spartanburg (USFWS, 2001). Approximately one-third of this population was directly threatened by inundation, and the Federal agency committed to the relocation of some 3,054 rosettes to remaining areas of occupied habitat around the reservoir. At the conclusion of formal section 7 consultation, the USFWS anticipated that as many as 6,619 rosettes (assuming

Commented [MS3]: The formatting of the citation has changed in this paragraph – throughout the rest of this document a comma is not used. This also happens below in the Climate Change section.

that all transplants survived) would be afforded protection through restrictive covenants placed on properties owned by the Spartanburg Water System (SWS) surrounding Blalock Reservoir. However, this population was last reported to contain a mere 1,400 rosettes (Newberry, 2006), and has twice since been impacted by encroachments from adjacent landowners (Newberry, 2009; Schneider, 2006, and JJ&G, 2006). Some of these apparent declines could be partially an artifact of incomplete survey effort, in that the exhaustive surveys which led to the 1997 estimate (of 11,000 rosettes) have never been repeated. However, it seems unlikely that plants occurring on privately owned shoreline not subject to restrictive covenants would be any more stable than those occurring on properties specifically protected and managed for the species (by SWS).

Invasive Species

Commented [MS4]: Could this be defined? Kalmia and Rhododendron noted in the paragraph below are not traditionally thought as invasive species but part of the native vegetation under which H.naniflora grows.

Several of the known populations of dwarf-flowered heartleaf occur on steep ravine slopes which also support stands of mixed hardwoods with an understory of mountain laurel (*Kalmia latifolia*) or *Rhododendron spp*. These stands are often very dense and reduce the amount of light reaching the dwarf-flowered heartleaf plants growing below. Under these conditions the plants often show reduced vigor and reduced flower and fruit production. Careful, selective logging or natural tree fall and limited understory removal would open up these populations to more light. Additional light, if not accompanied by increased siltation from the intensive soil disturbances associated with forest clear-cutting, probably would benefit these populations (Gaddy 1981).

Invasive exotic plant species are rampantly spreading throughout riparian corridors and ravines across the range of this species. Invasive exotics such as English Ivy (*Hedera helix*), Chinese privet (*Ligustrum* spp.), Japanese honeysuckle (*Lonicera japonica*) and Japanese Nepal grass (*Microstegium vimineum*) are known to threaten several populations; however, the scope and magnitude of this threat has not been comprehensively assessed. This threat requires active management in order to be successfully abated. At present, the majority of protected populations are secured against habitat conversion, but lack designated managers with the technical expertise and available resources (funding and personnel) to address this threat.

Climate Change

There is a growing concern that climate change may lead to increased frequency of severe storms and droughts (McLaughlin *et al.* 2002, p. 6074; Golladay *et al.* 2004, p. 504; Cook *et al.* 2004, p. 1015). Because typical habitats for this species include moist soils adjacent to creeks, streamheads, or along lakes and rivers, and plants have been observed to grow larger and have more frequent flowering in floodplains along rivers, lakes, and streams, specific effects of climate change to the dwarf-flowered heartleaf are likely related to changes in soil moisture associated with potential increases in drought.

Warming in the Southeast is expected to be greatest in the summer (NCCV 2016) which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to increased flooding events (IPCC 2013, p.7; NCCV 2016). Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan et al. 2010, p.7).

Despite the recognition of potential climate effects on ecosystem processes, there is uncertainty about what the exact climate future for the Southeastern US will be and how the ecosystems and species in this region will respond. Although climate change was not a listed factor leading to the original listing of the species, it should be recognized that the greatest threat from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats. As a result, impacts from rapid urbanization in the region might be exacerbated under even a mild to moderate climate future.

Regardless of a pessimistic, optimistic, or status quo climate future, the following systematic changes are expected to be realized to varying degrees in the Southeastern US (NCILT 2012, p.27; IPCC 2013, p.7):

- More frequent drought
- More extreme heat (resulting in increases in air and water temperatures, Figure 5-3)

- Increased heavy precipitation events (e.g., flooding)
- More intense storms (e.g., frequency of major hurricanes increases)
- Rising sea level and accompanying storm surge

In recent years, the Southeast has experienced moderate to severe droughts that many observers have implicated in population declines and poor transplant survivorship (NC NHP, 2010). A wildfire, presumably brought on or at least exacerbated by drought conditions, burned portions of one of the largest known populations in 2009 (Foothills Landfill in Caldwell County; Golder and Associates, 2009). Accelerated climate change is expected to increase the frequency and extent of drought conditions across the southeast (Karl, et al. 2009). The extent to which these climate changes will significantly affect populations of dwarf-flowered heartleaf is currently unknown.

Appendices 3a and 3b gives summary reports on historical and future predicted climate parameters from the USGS National Climate Change Viewer for both North Carolina and South Carolina. As discussed above, the trend for these States is as it is for the Southeast in general: more frequent drought, more extreme heat, and increased precipitation events. If these predictions hold true, dwarf-flowered heartleaf habitat would likely be impacted through increased evaporative rates and decreased soil moisture (Appendices 3a and 3b), increased potential for catastrophic wildfire events, as well as potential disruption of stream bank morphology through increased flooding events.

CURRENT CONDITIONS

Below we assess current resilience, representation, and redundancy as they relate to population and habitat factors known to be important for species viability. Based off of recent reports (NCNHP 2016a; NCNHP 2016b), the species consists of 113 populations distributed across 12 counties in North Carolina and South Carolina. Recent genetic research suggests that dwarf-flowered heartleaf, as originally described, is found in the southern portion of its presumed range based on current EO locations, and the northern portion could be a currently undescribed species (Figure 1; Estep pers. Comm. 2018). The genetic analysis to support this is complete, but a review of the morphology is ongoing and a new species has not yet been described (Estep pers. Comm. 2018). For the purpose of this SSA, we assume all EO detections are *H. naniflora*, and represent the best currently available scientific data.

Commented [AJ1]: NHP records are not populations per se, but locations where the element occurs and aggregated based on general biological concepts and data management needs.

Commented [AJ2R1]: NatureServe definition for Population: A population is a geographically or otherwise distinct group of individuals of a particular species between which there is little demographic or genetic exchange (equivalent to the IUCN definition for a "subpopulation"). For animals, metapopulation structure may arise when habitat patches are separated by distances that the species is physically capable of traversing, but that exceed the distances most individuals move in their lifetime (that is, the patches support separate subpopulations or "demes"). If habitats are sufficiently close together that most individuals visit many patches in their lifetime, the individuals within and among the patches will tend to behave as a single continuous population.

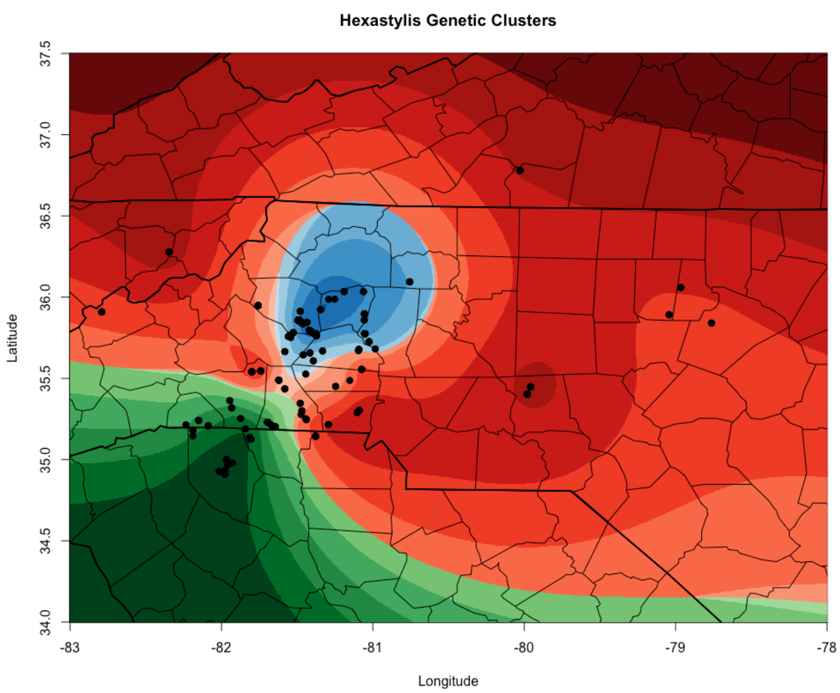

Figure 1-Recent genetic analyses detailing clustering of the genus Hexastylis. Green areas represent “true” *H. naniflora*; Blue represents a possible new species; Red represents other species in the genus (*H. minor, H. heterophylla*, etc.).

Current Population Resilience

Categorizing Resilience

For the purposes of this SSA, we use population size as the main driver of population resilience. The unit of measurement for population size in this species is a “clump” (rosette). As discussed previously, populations in North Carolina were delineated by NCNHP, whereas the Service defined populations in South Carolina. These delineations were based off of NatureServe criteria such as EO separation distance and intervening landscape matrix. EO data included a wide range of years since the species was last observed at a given location (1964-2017), so although recent reports suggest the species consists of 113 populations, some of that data is fairly outdated. For the purposes of this SSA, we only used EOs that were observed within the last 10 years (2007-2017). Based on that criteria, there are currently 68 populations distributed across the range of dwarf-flowered heartleaf, although this may be an underestimate as discussed in more detail in the habitat modelling section later.

To determine overall resilience for populations, we used EO viability ranks and expert opinion to bin population size classes into corresponding resilience categories. EO viability ranks for the species include excellent, good, fair, poor, extant, historical, and failed to find. The primary factor in determining these ranks is EO size (as quantified by number of clumps). Condition of habitat (vegetation community and structure) and landscape context (extent of suitable habitat and physical factors) are also incorporated secondarily. Appendix 1 shows the NCNHP EO rank specifications for dwarf-flowered heartleaf. The EO rank specifications suggest good-excellent viability for populations consisting of at least 500 individuals, given there is sufficient high quality habitat; fair viability for populations consisting of 100-500 individuals, depending on habitat conditions; poor viability for populations consisting of less than 100 individuals. Recent

Commented [MS3]: I agree with Jame that, though standard practice with regard to SSAs, it may be inappropriate to exclude older records. This equates to the assumption that those locations never have or are no longer able support the species. There are many EOs for this species that have persisted for decades, despite not having intervening surveys to confirm this and evidenced by the time elapsed between the first observation and the last observation. When you determined the number of populations, was the separation distance criteria reapplied as if these older than 10 year locations didn’t exist on the landscape?

Commented [AJ4]: Why exclude outdated records from the model?

Commented [RL5]: Perhaps you should exclude data with low accuracy, rather than older data. There were status surveys conducted in 2005 that we did not get landowner permission to visit again in 2012-2016 and may be valuable data.

Commented [MS6]: I didn’t see in the modelling section below where the issue of why this may be an underestimate was addressed.

reports (NCNHP 2016a; NCNHP 2016b) focus monitoring studies on populations with greater than 1,000 individuals, populations that are assumed to be very viable. Because we do not have habitat level information for every population we assessed, we synthesized all of the above population size information and created four resilience categories as follows:

- Very high—populations with >1,000 individuals; very high probability of persistence for 20-30 years at or above the current population size.
- High—populations with 500-1,000 individuals; moderate-high probability of persistence for 20-30 years at or above the current population size.
- Moderate—populations with 100-500 individuals; low probability of persistence for 20-30 years at or above the current population size.
- Low—populations with <100 individuals; low probability of persistence, and moderate-high probability of extirpation for 20-30 years at or above the current population size.

Occupancy and Abundance

There are 67 populations of dwarf-flowered heartleaf that have been observed within the last 10 years (Table 1), and resilience of these populations is as follows: 27 (very high); 5 (high); 20 (moderate); 15 (low). Table 2 shows the contribution of each resilience category as follows: 40% (very high); 7% (high); 30% (moderate); 22% (low). When looking at cumulative percentages of resilience, it is interesting to note that 78% of all of the populations are classified as moderate to very high resilience (Table 2).

Commented [MS7]: In the second paragraph of Categorizing Resilience section above, you state that there are 68 populations that have been observed in the last 10 years.

Table 1--Current populations of dwarf-flowered heartleaf and associated resilience across the species range.

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Site Name	State	County	Last Observed	Total plants	Resilience
Glade Creek, Alex County	North Carolina	Alexander	2017	>1000	very high
Catawba River: Hoyle Crk-Micol Crk	North Carolina	Burke	2013	>1000	very high
Island Creek Heath Bluff	North Carolina	Burke	2016	>1000	very high
Gunpowder Creek: South of Hudson	North Carolina	Caldwell	2012	>1000	very high
Peaked Top Rare Plant Site/Foothills Landfill	North Carolina	Caldwell	2014	>1000	very high
Jacob Fork West Corridor	North Carolina	Catawba	2012	>1000	very high
Murrays Mill/Upper Balls Creek NA	North Carolina	Catawba	2013	>1000	very high
NCDOT TIP: R-2824	North Carolina	Catawba	2015	>1000	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	North Carolina	Catawba	2013	>1000	very high

Cowpens NBF - Site 1	South Carolina	Cherokee	2016	>1000	very High
Cliffside Steam Station	North Carolina	Clev/Ruth	2016	>1000	very high
Broad River/Sandy Run NA	North Carolina	Cleveland	2012	>1000	very high
Broad River: Brushy Creek	North Carolina	Cleveland	2016	>1000	very high
Buffalo Creek: Kings Mountain Res	North Carolina	Cleveland	2016	>1000	very high
Buffalo Creek: Tributaries N and S of SR 2047	North Carolina	Cleveland	2012	>1000	very high
Rhyne Conservation Preserve	North Carolina	Lincoln	2016	>1000	very high
Mill Creek Forest and Seep	North Carolina	Polk	2016	>1000	very high
New Hope Springhead Swamp	North Carolina	Polk	2016	>1000	very high
Big Horse Creek Rare Plant Site	North Carolina	Rutherford	2015	>1000	very high
Broad River: Floyds Creek	North Carolina	Rutherford	2016	>1000	very high
Davenport Road/Mountain View Rare Plant Site	North Carolina	Rutherford	2016	>1000	very high
Facebook Site	North Carolina	Rutherford	2016	>1000	very high
Floyds Creek Tributray Rare Plant Site	North Carolina	Rutherford	2012	>1000	very high
New Bethel Rare Plant Site	North Carolina	Rutherford	2015	>1000	very high
Richardson Creek trib above Toms Lake	North Carolina	Rutherford	2016	>1000	very high
DNR Peters Creek Heritage Preserve	South Carolina	Spartanburg	2016	>1000	ver
Taylor Blalock Res	South Carolina	Spartanburg	2016	>1000	ver
Little Gunpowder Creek Rare Plant Site 1	North Carolina	Caldwell	2015	500-1000	high
Little Gunpowder Creek Rare Plant Site 2	North Carolina	Caldwell	2015	500-1000	high
Northern Catawba County	North Carolina	Catawba	2017	500-1000	high
Rock Barn Solar Farm	North Carolina	Catawba	2010-2011	500-1000	high
Buffalo Creek Rare Plant Site	North Carolina	Cleveland	2012	500-1000	high
Third Creek Rare Plant Site	North Carolina	Alexander	2010	100-500	moderate
Hickory Area	North Carolina	Burk/Cata/Cald	2016	100-500	moderate
Burke County - Drowning Creek UT	North Carolina	Burke	2017	100-500	moderate
Simms Hill/Little River Uplands	North Carolina	Burke	2015	100-500	moderate
Smith Cliff/Henry Fork River	North Carolina	Burke	2015	100-500	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	North Carolina	Catawba	2016	100-500	moderate
NCDOT TIP R-2824	North Carolina	Catawba	2015	100-500	moderate
South Fork Catawba River, Henry Fork	North Carolina	Catawba	2007	100-500	moderate
Broad River/Sandy Run NA	North Carolina	Cleveland	2012	100-500	moderate
Brushy Creek Headwaters	North Carolina	Cleveland	2014	100-500	moderate
First Broad River: Crooked Run Creek	North Carolina	Cleveland	2010	100-500	moderate
No Business Creek, Boyd Tract	North Carolina	Cleveland	2007	100-500	moderate
West Shelby Mesic Slope	North Carolina	Cleveland	2016	100-500	moderate
UT of Kings Mountain Res	North Carolina	Gaston	2012	100-500	moderate
Buffalo Shoals Creek	North Carolina	Iredell	2014	100-500	moderate
Cat Square Heartleaf Forest	North Carolina	Lincoln	2012	100-500	moderate
Collinsville (Hughes) Creek Slopes	North Carolina	Polk	2016	100-500	moderate
Fox Knoll Farm	North Carolina	Polk	2016	100-500	moderate
Forest City: Adj to Isothermal CC	North Carolina	Rutherford	2010	100-500	moderate
Jonas Road Rare Plant Site	North Carolina	Rutherford	2014	100-500	moderate
NCDOT TIP R-3603A	North Carolina	Alexander	2017	<100	low
South Mountains Pleasant Grove Uplands	North Carolina	Burke	2016	<100	low

Commented [MS8]: Should this be "very high" all lower case?

Gunpowder Creek	North Carolina	Caldwell	2012	<100	low
Killian Crossroads	North Carolina	Catawba	2010	<100	low
Pott Creek	North Carolina	Catawba	2012	<100	low
Beaverdam Crk at First Broad River	North Carolina	Cleveland	2011	<100	low
Buffalo Creek: Potts Creek	North Carolina	Cleveland	2012	<100	low
Buffalo Creek: Ravine	North Carolina	Cleveland	2007	<100	low
Hickory Creek - UT (Shelby High School)	North Carolina	Cleveland	2016	<100	low
Boulder Creek Subdivision - Jordan Road	South Carolina	Greenville	2016	<100	low
Gateway Elementary School	South Carolina	Greenville	2017	<100	low
Fanjoy Road Site	North Carolina	Iredell	2015	<100	low
Levan Family Farm	North Carolina	Iredell	2013	<100	low
Lincoln County, SR-1314	North Carolina	Lincoln	2014	<100	low
Northeast Lincolnton: UT Walker Branch	North Carolina	Lincoln	2009	<100	low

Table 2--Population resilience categories by county for dwarf-flowered heartleaf.

County	**Very High**	**High**	**Moderate**	**Low**	**Totals**
Alexander	1		1	1	3
Burk/Cata/Cald			1		1
Burke	2		3	1	6
Caldwell	2	2		1	5
Catawba	4	2	3	2	11
Cherokee	1				1
Clev/Ruth	1				1
Cleveland	4	1	5	4	14
Gaston			1		1
Greenville				2	2
Iredell			1	2	3
Lincoln	1		1	2	4
Polk	2		2		4
Rutherford	7		2		9
Spartanburg	2				2
Totals	**27**	**5**	**20**	**15**	**67**
% of total	*40*	*7*	*30*	*22*	*100*
Cumulative %	*40*	*48*	*78*	*100*	--

Commented [MS9]: Would it be possible to list the full name of the county instead of a shortened version so those not as familiar with them are clear as to which are being referred to? For example, someone might think there is both a Ruth County and a Rutherford County.

Population Trends

Although we lack an adequate past time series of abundance data for all populations to estimate growth rates or population trends, NCNHP conducted surveys of thirteen of the largest populations across the range of the species from 2012-2016. Table 3 shows the results of all of these surveys. Two populations show an increasing trend, nine show a stable trend, and two show a decreasing trend.

Table 3-Summary of population trends over 5 years of monitoring data for 13 of the largest populations of dwarf-flowered heartleaf across its range (from: NCNHP).

Trend	**Survey**	**Site**	**2016 estimated number of plants (Rosettes)**	**2016 area occupied (Acres)**
Increasing	NCNHP	Cliffside Steam Station (EO 276)	39,535	52
	NCNHP	Broad River: Floyds Creek, Long Branch (EO 177)	12,687	5.67
Stable	NCNHP	Island Creek Bluff/Love Lady Site (EO 029)	50,481	61.76
	NCNHP	Rhyne Preserve (EO 302)	19,873	22.43
	NCNHP	Mills Creek Forest and Seep (EO 023)	1,733	1.39
	NCNHP	New Hope Springhead Swamp (EO 125)	12,235	5.03
	NCNHP	Broad River: Henson's Creek, Brice, & Sandy Mush Outcrop (EO099)	106,940	83.39
	NCNHP	Broad River: Cleghorn Creek, US 221 (EO 176)	6,750	7.24
	NCNHP	Cowpens National Battlefield (SC EO 016, 017, 018)	2,823	6.05
	NCNHP	Peters Creek Preserve (SC EO 011)	3,306	8.98
	NCNHP	Blalock Reservoir (SC EO 007, 031)	3,505	7.59
Decreasing	NCNHP	Second Broad River (Forest City Industrial Complex) (EO 154)	2,576	4.74
	NCNHP	South Fork Catawba River: Jacob Fork, Camp Creek (EO 158)	123	0.09

Habitat Factors: Slope, Aspect, Elevation, Soil, and Forest Type

A previous habitat suitability study attempted to quantify the habitat requirements for dwarf-flowered heartleaf. A model was created to predict habitat suitability, and based on the model results, the strongest habitat correlations were slope, aspect, soil type, elevation, and land use (Wagner 2015). With this model in mind, we used updated habitat data, as well as inclusion of updated EOs, to create a new habitat model to identify potential habitat throughout the species range. All source datasets and variables created are described in Appendix 2.

Source Data and Model Variables

Fifty three, 10-digit hydrologic units (HUC) comprise the analysis extent. In North Carolina, it includes all 10-digit HUC that fall within the boundaries of 8-digit HUC with known occurrence of *Hexastylis*. In South Carolina, we also included all 10-digit HUC that fell within the boundaries of 8-digit HUC with known occurrence of *Hexastylis*, but excluded the southern portions of the HUC-8 areas due to the boundaries being exceedingly large and far away from any known occurrences.

Commented [MS10]: Just for clarity, are you referring to H.naniflora or any Hexastylis?

Hexastylis naniflora element occurrence data was obtained from the North Carolina Natural Heritage Program and the South Carolina Heritage Trust Program. These data were in polygon format and digitized at a scale that accurately identified the boundaries of the individual population areas. Current populations of *Hexastylis naniflora* were identified by reviewing the last observed data in the database and excluding all populations that have not been observed in the last 10 years (2007). To represent these current population areas in Maxent, a raster cell center was retained for every 30 x 30 meter pixel that was situated within the current element occurrence data polygons.

Model Development

We used Maxent software (version 3.4.1) for species habitat modeling (Philips et al., 2018). An initial single model Maxent run was done to determine which variables could be excluded due to limited percent contribution to the model. Any variable that contributed less than 1% to the single model run results was excluded in the final model. The following variables were excluded: landcover diversity, SSURGO drainage class, SSURGO hydrologic group, aspect 9-class, aspect 5-class, slope, and maximum annual temperature.

Commented [MS11]: Though I am not a modeler and I realize this document is not a review of modelling attempts, it is unclear to as to why aspect and slope were excluded yet they were identified as strongly correlated in the Wagner (2015) model. Was this due to differences or limitations of the underlying data?

Commented [MS12]: It is not defined in the body of the document nor in Appendix 2 that SSURGO means Soil Survey Geographic Database.

For the final model a 10-run replicate Maxent model was created using cross-validation. For replicate models, the occurrence data is randomly split into a number of equal-sized groups called “folds”, and separate models are created leaving out each fold in turn. The individual model runs are then averaged together to derive the final model.

Results

Figure 2 shows the model output. The minimum cutoff value (to determine if an area is considered potential habitat for a species) of 0.406 was determined by using the average 10th percentile training presence. The 10th percentile training presence uses the suitability threshold associated with the presence record that occurs at the 10th percentile of presence records (Phillips 2018). This value excludes some of the outlier population areas in the Maxent predictions to focus on the typical habitat conditions for this species. The total area ranked greater than 0.406 in the Maxent model was just 6.39% of the total analysis area (Table 4).

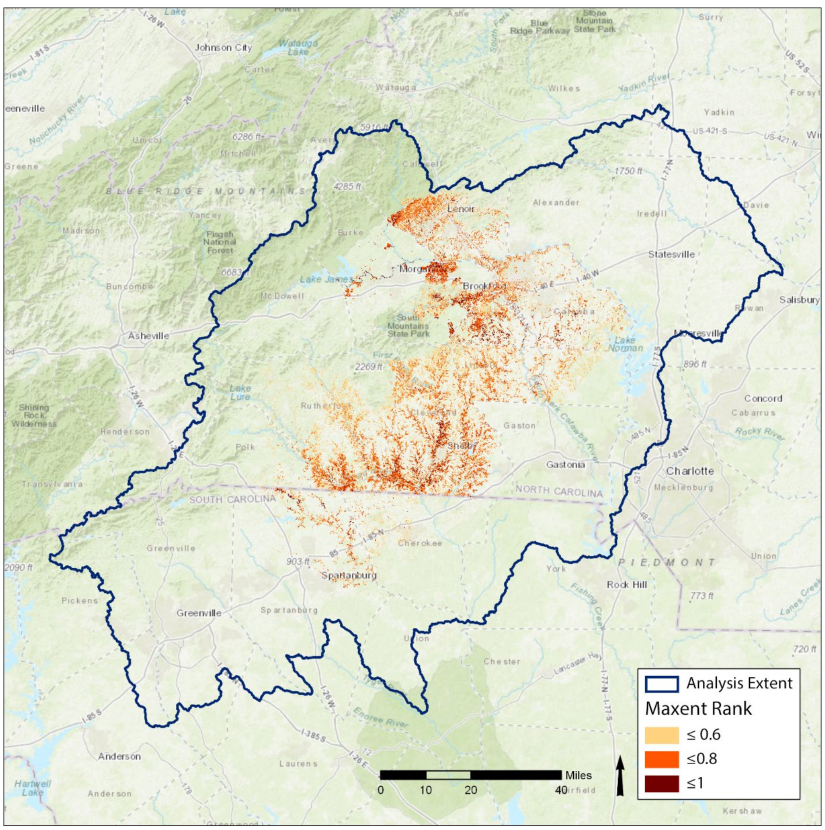

Figure 2-Maxent model output map

Commented [MS13]: There appears to be some issues with whichever input data sets were associated with counties – could you address this? For example, the density of ranked pixels appears to drop off on the north and west side of Gaston County. The same is true of the South Carolina border. The HUC's don't appear to follow the county boundaries in these areas. Is habitat being under-identified in these areas? Why?

Table 4-Area estimates of the Maxent model

Maxent Score	Acres	Square Miles	Percent of Total
0.406 and greater	321,262.37	501.97	6.39%
0.6 and greater	146,712.65	229.24	2.92%
0.8 and greater	22,677.96	35.43	0.45%

The average area-under-curve (AUC) score for the replicate Maxent model is 0.849. The AUC is calculated from the receiver operating characteristic (ROC) plot. This value has a range of 0 – 1 and may be interpreted as a single test statistic that assesses model performance, indicating the ability of the model to correctly classify the occurrence data used. The model performed well in its predictions, with a mean AUC of 0.849 (AUC value of 0.5 is no better than random; AUC<0.5 is worse than random; AUC>0.5 is greater predictive power than random; Baldwin 2009).

The Maxent output supplies estimates of the relative contributions of the environmental variables to the Maxent model (Table 5). SSURGO mukey is the top contributing variable. One hundred and thirty-five individual soil types are present within the polygon boundaries of the *Hexastylis naniflora* element occurrences. Many of these individual soil types are part of soil complexes and are separated by things such as percent slope, erosion, how stony/rocky, and amount of clay. The most common individual soil type was Meadowfield-Rhodhiss complex, 25 to 60 percent slopes, very stony (12.9% of total). However, collectively the Meadowfield soils only comprised 13.5% of all soils). The individual Pacolet soil types were very common and collectively comprise 36% of all soil types present. Woolwine soils were also collectively common, comprising 10% of all soils present.

Commented [MS14]: It would be helpful to define this as Map Unit Key here rather than having to refer to Appendix 2 prior to reading this section. Also, the percent contribution of the variables that are in Table 5 would be helpful to have inline with the text.

The minimum annual average temperature range in the analysis extent is 39 – 51 degrees Fahrenheit. The majority of the *Hexastylis naniflora* element occurrences (92%) are found at the

47 and 48 degrees. The average annual precipitation range in the analysis extent is 42 – 81 inches per year.   The majority of the *Hexastylis naniflora* element occurrences (81%) are found in the 47 – 49 inches per year range.

Piedmont forested landcover habitats dominate the land area of the element occurrences. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier (52%), Southern Piedmont Mesic Forest (10%), Southern Piedmont Small Floodplain and Riparian Forest (3.6%), and Southern Piedmont Dry Oak-Pine Forest – Loblolly Pine Modifier (2.3%) collectively comprise 72% of the element occurrences area. Unfortunately, non-native habitats are also present. Evergreen Plantation or Managed Pine (8%), Harvested Forest – Grass/Forb Regeneration (7%), Developed, Open Space (5%), Pasture/Hay (2.5%) collectively comprise 22% of the total element occurrence area. The remaining 6 percent of element occurrence area is comprised of a mix of 14 other natural and disturbed landcover classes, but each at small percentages.

The landcover majority classification scheme reduces the total number of landcover classes present in the analysis extent from 23 to 12. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier is still the dominant landcover class (56%). However disturbed categories are increased in area (sum total of 35%). Evergreen plantation or managed pine (12%) and Pasture/Hay (12%) are the only other categories that have at least 10% or greater area. The increase in disturbed landcover area representation in the landcover majority layer suggests that many *Hexastylis naniflora* population areas are situated in areas impacted by disturbed landcover. This is likely due to urban encroachment and increasing fragmentation of habitats.

The landcover Hexastylis grouping reveals the amount of disturbance present in Hexastylis population areas. Landcover classes grouped as disturbed comprises 26% of the total area. Mixed forest (deciduous and evergreen) comprises 58%, hardwood forest 11%, and riparian 3.6%. Open water, evergreen and barren landcover groupings are all at less than 1% each.

Commented [MS15]: H. naniflora should be used consistently if that is the species being referred to.

Geomorphons revealed that the majority of *Hexastylis naniflora* element occurrence areas are situated in concave landforms. Geomorphon categories hollow (15%), valley (35%), and depression (17%) collectively comprise 67% of all *Hexastylis naniflora* population areas. Flat landforms comprise 22.5% of the area and convex landforms the remaining 10.5%.

Within the analysis extent, the range of elevation present is 335 – 5,265 feet. For *Hexastylis naniflora*, the prime elevation range is from 666 – 896 feet (54% of total element occurrence area). A lesser elevation range is present from 935 – 1,165 (35% of total element occurrence area).

Table 5-Percent contribution of the environmental variables

Environmental Variable	Percent Contribution
SSURGO mukey	23.3%
Minimum Annual Temperature	20.7%
Average Annual Precipitation	14.6%
Landcover	13%
Landcover Majority	9.5%
Landcover Hexastylis Grouping	7.3%
Geomorphons	6.4%
Elevation	5.2%

We performed an Analysis of Variance test to investigate the relationship between Maxent scores and current resilience of populations (Table 6). There are significant differences in the average Maxent scores between the four resilience categories ($p = 0.01$) and the mean Maxent score increases as population resilience increases for low to very high. It appears the model gives us some predictive ability regarding habitat quality, where higher Maxent scores, on average, result in higher population resilience.

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Table 6-Results of the ANOVA investigating relationships between Maxent scores and current resilience groups for dwarf-flowered heartleaf.

Groups	*Count*	*Sum*	*Average*	*Variance*
low	13	5.240363	0.403105	0.124194
moderate	20	8.851696	0.442585	0.040139
high	4	2.292114	0.573028	0.039821
very high	27	16.66603	0.61726	0.020717

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.563333	3	0.187778	3.870253	0.01346	2.758078
Within Groups	2.911089	60	0.048518			
Total	3.474421	63				

Current Species Representation

Representation describes the ability of a species to adapt to changing environmental conditions. We lack genetic and ecological diversity data to characterize representation for dwarf-flowered heartleaf. In the absence of species-specific genetic and ecological diversity information, we typically evaluate representation based on the extent and variability of habitat characteristics across the geographical range. However, the dwarf-flowered heartleaf has a very limited range, and after consulting with experts, we decided delineating representative units was not appropriate for this species.

Current Species Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy for dwarf-flowered heartleaf is the total number and resilience of population segments and their distribution across the species range. As stated previously, there are 67 populations of dwarf-flowered heartleaf that have been observed within the last 10 years, and resilience of these populations is as follows: 27 (very high); 5 (high); 20 (moderate); 15 (low); 2 (unknown). The populations are spread across the range, although a majority occur in North Carolina. Although, there appears to be adequate redundancy within the range of dwarf-flowered heartleaf, the species range is very small, making it potentially vulnerable to catastrophic events. Thus, we classify redundancy as inherently low for the species.

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INFLUENCES ON VIABILITY

Hexastylis naniflora populations occur in rapidly growing urban areas with expanding suburbs of Charlotte, NC, to the east; Hickory, NC, to the north; and Greenville and Spartanburg, SC, to the south. At the time of listing, it was determined that the species was most threatened by habitat loss due to the conversion of land to residential, commercial, and industrial use in these areas. In addition to threats associated with residential, commercial, and industrial development, other documented threats include habitat loss from land conversion to agricultural use, timber harvest, hydrological alterations from the damming of ponds, impacts from grazing cattle, ORV damage, trampling from foot traffic, invasive species, highway or road improvements, and erosion or siltation (NCNHP 2016, Robinson and Padgett 2016). Climate change may exacerbate these risk factors through changes in temperature and precipitation.

Threats were assessed for populations monitored by NCNHP during 2012-2016 (Robinson and Padgett 2016), and EOs were reviewed for other documented threats to populations. Indirect or direct threats that were observed, inferred, or suspected to have an impact on populations were recorded and assigned a ranking based on their severity, scope, and immediacy from field observations. The rank for each threat factor determines the overall value for each threat observed at each population. No significant changes in threats within populations were noted from 2012-2016. Threats observed during these years included development, incompatible forestry practices, agriculture, trampling, invasive exotic species, sedimentation, erosion, and road construction.

Below, we summarize primary threats to the viability of dwarf-flowered heartleaf. Primary influences will be carried forward in our future projections in the next section.

Human Population Change

Increasing human populations drive development. With increases in population, there will be increasing conversion of open space to more impervious cover, with a subsequent increase in roads and other associated infrastructure. Increases in roads and impervious cover have the potential to lead to habitat loss and/or fragmentation, a primary risk factor for dwarf-flowered heartleaf. Tables 1-2 and Figures 1-2 show the estimated human population increases for North

Carolina and South Carolina counties within the range of the species. The most populous counties include Greenville and Spartanburg in South Carolina, and Catawba, Gaston and Iredell counties in North Carolina.

Table 1-Human population projections for North Carolina counties within the range of dwarf-flowered heartleaf. *Source: North Carolina OSBM, Standard Population Estimates.*

County	2018	2023	2028	2033	2037
Alexander	38609	39,244	39,686	39992	40169
Burke	90865	93,124	95,382	97644	99452
Caldwell	83919	86,723	88,689	91126	92870
Catawba	157424	159,799	162,175	164549	166447
Cleveland	98862	99,685	100,004	100128	100170
Gaston	221112	227,667	237,344	245276	252388
Iredell	179740	195,623	211,501	227383	240088
Lincoln	84494	91,034	96,865	103069	107858
Polk	21273	21,823	22,288	22681	22955
Rutherford	67880	68,154	68,283	68341	68368

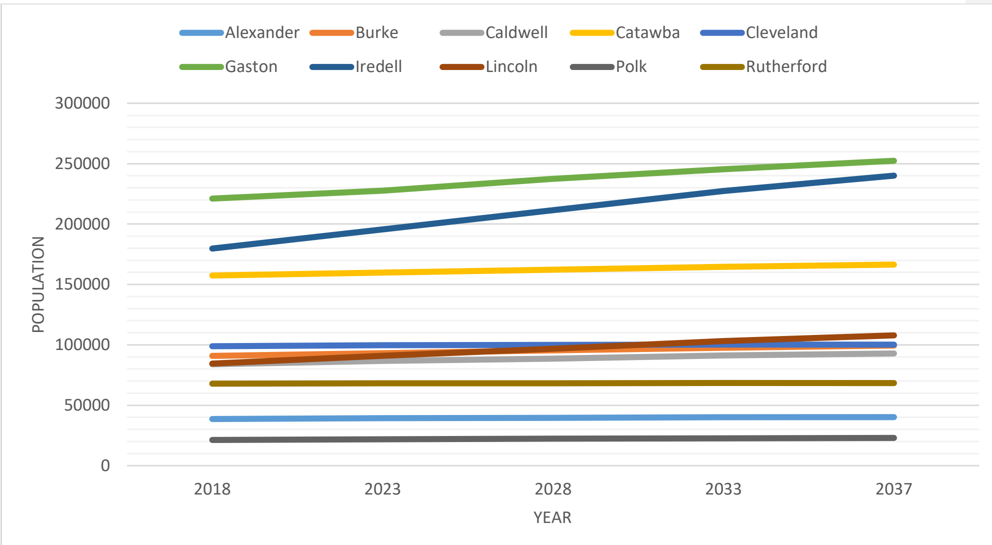

Figure 1- Human population projections for North Carolina counties within the range of dwarf-flowered heartleaf. *Source: North Carolina OSBM, Standard Population Estimates.*

Table 2- Human population projections for South Carolina counties within the range of dwarf-flowered heartleaf. *Source: U.S. Census Bureau, 2000 Census and 2007 Population Estimates. Population projections calculated by South Carolina Budget and Control Board, Office of Research and Statistics.*

County	2020	2025	2030	2035
Cherokee	61,760	64,760	67,350	70,170
Greenville	492,890	517,740	542,290	567,010
Spartanburg	310,220	323,550	336,810	350,110

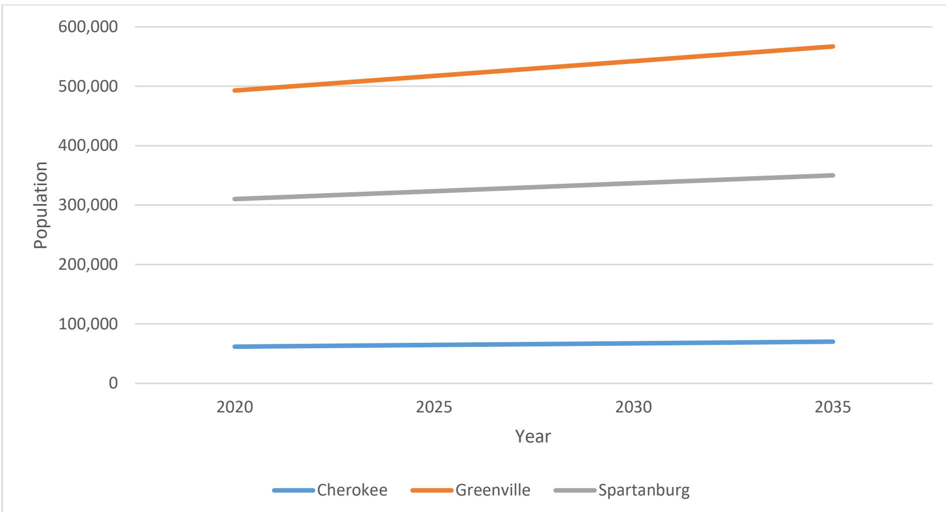

Figure 2- Human population projections for South Carolina counties within the range of dwarf-flowered heartleaf. *Source: U.S. Census Bureau, 2000 Census and 2007 Population Estimates. Population projections calculated by South Carolina Budget and Control Board, Office of Research and Statistics.*

Development

A large number of the known populations occur near expanding urban areas and are threatened by the residential, commercial, and industrial development associated with this growth. Populations occurring in more rural areas are threatened by habitat alteration or loss from land conversion to pasture or other agricultural uses, cattle grazing, intensive timber harvesting, residential construction, and construction of small ponds.

A 2011 review of existing NHP EOR data revealed that all or portions of 26 populations (24% of the total) had been directly or indirectly impacted through development projects or other causes such as trash disposal, expansion of residential lawns, cattle, or invasive exotics (NC NHP 2010; SCDNR 2010). Another 16 populations have been specifically reported to be threatened by one or more of these same sources. Therefore, threats have either occurred or are reasonably

Commented [MS1]: What was the total number of populations at that time? Was it 108 as indicated below?

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foreseeable within 42 of the 108 populations (corresponding to 39% of all known populations). Of these 42 populations, all or portions of 22 (50%) had been adversely impacted by activities requiring ESA Section 7 consultation with the USFWS. The fact that nearly 20% of all known populations had been subject to formal Section 7 consultation illustrates the threats faced by the species.

The most recurrent source of habitat destruction, and certainly the most common trigger for Section 7 consultations involving *H. naniflora* is road and bridge improvement projects. Ten of the 27 largest populations (containing more than 1,000 rosettes) have been the subject of Section 7 consultations between the USFWS and the NCDOT. Collectively, these projects have adversely impacted or are currently expected to impact some 22,135 rosettes. In most cases the Section 7 process has resulted in avoidance or minimization of adverse effects through relocation of plants and/or commitments of on-site protection to those plants remaining (post-construction) within NCDOT right-of-way (ROW).

Other forms of economic development have also resulted in the destruction or modification of habitats occupied by *H. naniflora*; in many cases, these activities have also required Section 7 consultations with the USFWS. Examples of these activities include the maintenance or expansion of hydroelectric and drinking water reservoirs, construction of an industrial development complex, and maintenance activities (in compliance with Federal Aviation Administration standards) at a regional airport. Collectively, these activities have involved the loss or relocation of several thousand rosette.

Blalock Reservoir in Spartanburg County, South Carolina was once estimated to contain the largest population of *H. naniflora*, with over 11,000 rosettes reported here in 1997 (JJ&G, 1998). This population was the subject of a section 7 consultation as a result of a proposal to raise the elevation of Blalock Reservoir, which provides water supply storage to Spartanburg County and the City of Spartanburg (USFWS, 2001). Approximately one-third of this population was directly threatened by inundation, and the Federal agency committed to the relocation of some 3,054 rosettes to remaining areas of occupied habitat around the reservoir. At the conclusion of formal section 7 consultation, the USFWS anticipated that as many as 6,619 rosettes (assuming

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that all transplants survived) would be afforded protection through restrictive covenants placed on properties owned by the Spartanburg Water System (SWS) surrounding Blalock Reservoir. However, this population was last reported to contain a mere 1,400 rosettes (Newberry, 2006), and has twice since been impacted by encroachments from adjacent landowners (Newberry, 2009; Schneider, 2006, and JJ&G, 2006). Some of these apparent declines could be partially an artifact of incomplete survey effort, in that the exhaustive surveys which led to the 1997 estimate (of 11,000 rosettes) have never been repeated. However, it seems unlikely that plants occurring on privately owned shoreline not subject to restrictive covenants would be any more stable than those occurring on properties specifically protected and managed for the species (by SWS).

Invasive Species

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Several of the known populations of dwarf-flowered heartleaf occur on steep ravine slopes which also support stands of mixed hardwoods with an understory of mountain laurel (*Kalmia latifolia*) or *Rhododendron spp*. These stands are often very dense and reduce the amount of light reaching the dwarf-flowered heartleaf plants growing below. Under these conditions the plants often show reduced vigor and reduced flower and fruit production. Careful, selective logging or natural tree fall and limited understory removal would open up these populations to more light. Additional light, if not accompanied by increased siltation from the intensive soil disturbances associated with forest clear-cutting, probably would benefit these populations (Gaddy 1981).

Invasive exotic plant species are rampantly spreading throughout riparian corridors and ravines across the range of this species. Invasive exotics such as English Ivy (*Hedera helix*), Chinese privet (*Ligustrum* spp.), Japanese honeysuckle (*Lonicera japonica*) and Japanese Nepal grass (*Microstegium vimineum*) are known to threaten several populations; however, the scope and magnitude of this threat has not been comprehensively assessed. This threat requires active management in order to be successfully abated. At present, the majority of protected populations are secured against habitat conversion, but lack designated managers with the technical expertise and available resources (funding and personnel) to address this threat.

Climate Change

There is a growing concern that climate change may lead to increased frequency of severe storms and droughts (McLaughlin *et al.* 2002, p. 6074; Golladay *et al.* 2004, p. 504; Cook *et al.* 2004, p. 1015). Because typical habitats for this species include moist soils adjacent to creeks, streamheads, or along lakes and rivers, and plants have been observed to grow larger and have more frequent flowering in floodplains along rivers, lakes, and streams, specific effects of climate change to the dwarf-flowered heartleaf are likely related to changes in soil moisture associated with potential increases in drought.

Warming in the Southeast is expected to be greatest in the summer (NCCV 2016) which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to increased flooding events (IPCC 2013, p.7; NCCV 2016). Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan et al. 2010, p.7).

Despite the recognition of potential climate effects on ecosystem processes, there is uncertainty about what the exact climate future for the Southeastern US will be and how the ecosystems and species in this region will respond. Although climate change was not a listed factor leading to the original listing of the species, it should be recognized that the greatest threat from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats. As a result, impacts from rapid urbanization in the region might be exacerbated under even a mild to moderate climate future.

Regardless of a pessimistic, optimistic, or status quo climate future, the following systematic changes are expected to be realized to varying degrees in the Southeastern US (NCILT 2012, p.27; IPCC 2013, p.7):

- More frequent drought
- More extreme heat (resulting in increases in air and water temperatures, Figure 5-3)

- Increased heavy precipitation events (e.g., flooding)
- More intense storms (e.g., frequency of major hurricanes increases)
- Rising sea level and accompanying storm surge

In recent years, the Southeast has experienced moderate to severe droughts that many observers have implicated in population declines and poor transplant survivorship (NC NHP, 2010). A wildfire, presumably brought on or at least exacerbated by drought conditions, burned portions of one of the largest known populations in 2009 (Foothills Landfill in Caldwell County; Golder and Associates, 2009). Accelerated climate change is expected to increase the frequency and extent of drought conditions across the southeast (Karl, et al. 2009). The extent to which these climate changes will significantly affect populations of dwarf-flowered heartleaf is currently unknown.

Appendices 3a and 3b gives summary reports on historical and future predicted climate parameters from the USGS National Climate Change Viewer for both North Carolina and South Carolina. As discussed above, the trend for these States is as it is for the Southeast in general: more frequent drought, more extreme heat, and increased precipitation events. If these predictions hold true, dwarf-flowered heartleaf habitat would likely be impacted through increased evaporative rates and decreased soil moisture (Appendices 3a and 3b), increased potential for catastrophic wildfire events, as well as potential disruption of stream bank morphology through increased flooding events.