Species Status Assessment for Dwarf-flowered Heartleaf (*Hexastylis naniflora*)

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Version 2.0
May 2019

EXECUTIVE SUMMARY

The dwarf-flowered heartleaf (*Hexastylis naniflora*), a perennial member of the birthwort family, is known from 119 populations in North and South Carolina. It is threatened by habitat loss due to the conversion of land to residential, commercial, industrial, and agricultural use, timber harvest, hydrological alterations from damming of ponds, cattle grazing, ORV damage, trampling, invasive species, highway and road improvements, and erosion or siltation. To evaluate the biological status of dwarf-flowered heartleaf currently and into the future, we consider the species' viability as characterized by resiliency, redundancy, and representation (i.e., 3Rs). Dwarf-flowered heartleaf needs multiple resilient populations across its range to maintain its persistence into the future and to avoid extinction. Given the relatively high number of populations across each scenario analyzed, redundancy remains similar to current conditions. Redundancy within the range of dwarf-flowered heartleaf appears to be adequate which would allow the species to withstand the impacts of localized short-term catastrophic disturbances; however, the species range is relatively small, making it potentially vulnerable to long-term catastrophic events, such as climate change. Dwarf-flowered heartleaf has a limited range and representative units were not defined for the species; however, the scenarios analyzed do not predict declines in species representation.

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Chapter 1: INTRODUCTION

The dwarf-flowered heartleaf (*Hexastylis naniflora*) is a plant endemic to the upper Piedmont region of western North Carolina and upstate South Carolina. It has been listed as threatened under the Endangered Species Act of 1973, as amended (Act), since 1989 (FR 54 14964-14967). The Species Status Assessment (SSA) framework (USFWS 2016, entire) summarizes the information compiled and reviewed by the US Fish and Wildlife Service (Service), incorporating the best available scientific and commercial data, to conduct an in-depth review of the species' biology and threats, evaluate its biological status, and assess the resources and conditions needed to maintain long-term viability. The SSA supports all functions of the Endangered Species Program from listing to consultations to recovery. The SSA is intended to inform regulatory and policy decision, but has been developed independently from any such decision.

A recovery plan for the species was never completed; however, over the last 29 years, the Service has worked closely with partners to make significant progress toward recovery of the species. The Service initiated this SSA to aid in determining the appropriateness of reclassifying the species. Should the species not be reclassified, the SSA will inform the development of a recovery plan. Importantly, the SSA does not result in a decision by the Service on whether this species should be proposed for reclassification under the Act. Instead, this SSA provides a review of the available information strictly related to the biological status of the dwarf-flowered heartleaf.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in its natural habitat over time. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire).

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.
- **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).
- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

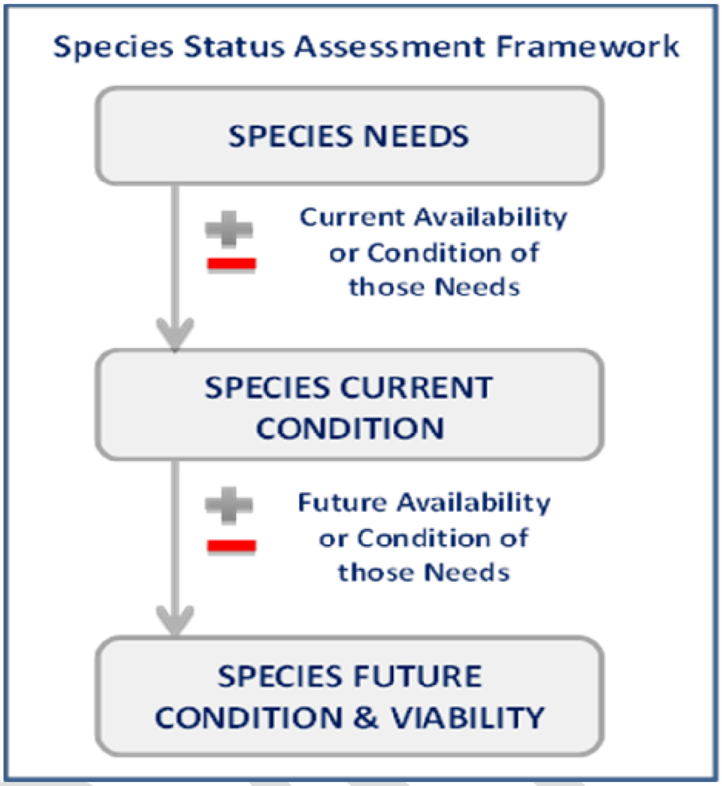


Figure 1.1. Species Status Assessment Framework

To evaluate the biological status of the dwarf-flowered heartleaf, both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA provides a thorough assessment of biology and natural history, and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

This document is a compilation of the best available scientific and commercial information, and includes: (1) biology and species needs, (2) current conditions, (3) influences on viability, and (4) future conditions.

Chapter 2: SPECIES BIOLOGY

In this chapter, we provide basic biological information about the dwarf-flowered heartleaf (*Hexastylis naniflora*), including its taxonomic history, species description, distribution, life history traits, and habitat characteristics. We then use this information to outline the resource needs of dwarf-flowered heartleaf.

Taxonomy and Species Description

Dwarf-flowered heartleaf is a rare, low growing herbaceous plant in the birthwort family (Aristolochiaceae). The species was described by Blomquist (1957) in his revision of the North American members of the genus *Hexastylis*. The dwarf-flowered heartleaf has been recognized as part of the Virginica group, and this group was further subdivided into three subgroups or complexes: Virginica, Shuttleworthii, and Heterophylla (Blomquist 1957; Whittemore and Gaddy 1997). Three species have been recognized in the Heterophylla complex, *Hexastylis naniflora, H. heterophylla* and *H. minor*, and field biologist have generally recognized that considerable morphological overlap occurs (Murrell et al. 2007). One concern regarding this complex is the inability to distinguish between species without access to fresh flowers. Even with fresh flowers, Blomquist (1957) and Gaddy (1987) still recognized considerable overlap in flower morphology making species delineation difficult.

Murell et al. 2007, conducted a comparative genetic analysis using Inter Simple Sequence Repeats, and were unable to separate *H. naniflora* from the other members within the complex. However, based on biogeographical, ecological, molecular, morphological, as well as micromorphological work, their results show that *H. naniflora* is a well-defined species.

Although there has been considerable disagreement on the generic distinctiveness of *Hexastylis* and *Asarum* (Barringer 1993 and Kelly 1997, 1998, 2001), a recent phylogeny estimate using chloroplast genes supports that *Hexastylis* is a monophyletic clade and should be recognized as a genus (Niedenberger 2010). Additionally, most North American publications recognize *Hexastylis* at the generic level (Flora of North America 1997, Weakley 2015).

The Service is not aware of any proposed changes in taxonomy that would affect the continued legal status of *H. naniflora* under the Act. However, within the range of *H. naniflora* there are populations which fall outside of the range of published values for key floral characteristics, overlapping with values described for *H. heterophylla* or *H. minor* (Figure 2.1; Weakley 2010; Murrell et al. 2007; Gaddy 1987). These geographic areas of overlap in key characters have been the focus of recent genetic analyses (Murrell et al. 2007; Renninger 2010; Murrell 2015).

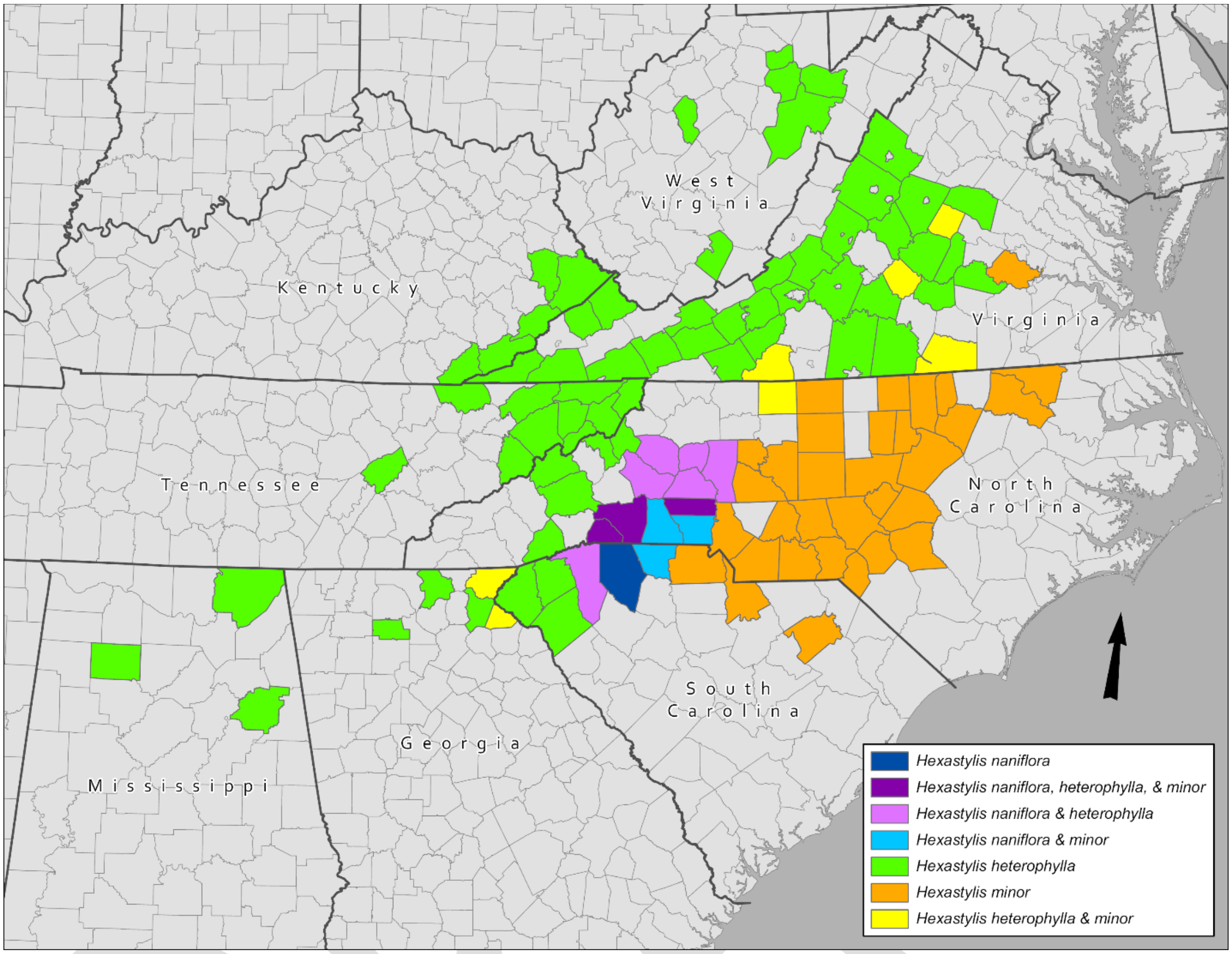


Figure 2.1. Distribution map showing county records for the three species in the Heterophylla complex. Data was gathered from herbarium specimens, element occurrence records and field studies. *Based on Murrell et al. 2007.*

The most outstanding characteristic of this species is the small flowers, which are one of the smallest of any *Hexastylis* species in North America (Blomquist 1957). The plant's heart shaped leaves are dark green in color, evergreen, and leathery, and are supported by long thin petioles from a subsurface rhizome. The shape of the leaf blades, their pattern of variegation, and the ridged reticulation inside the calyx-tube, place this species inside the Virginica group. It differs from all the other members of this group, aside from the small flowers, in having no flare in the calyx-tube. Maximum height rarely exceeds 15 centimeters (cm). The jug-shaped flowers are usually beige to dark brown in color and appear from mid-March to early June. They are small and inconspicuous and are found near the base of the petioles. The fruit matures from mid-May to early July (Blomquist 1957, Gaddy 1980, 1981). Characteristics that distinguish it from other *Hexastylis* species are found in floral structures and pollen characters (Gaddy 1987, Padgett 2004, Niedenberger 2010). *H. naniflora* has a smaller calyx tube orifice, which is typically 5mm or less (sometimes up to 7mm) and the ovary is half-inferior, rather than superior (Blomquist 1957, Gaddy 1987, Padgett 2004, HDR 2005). Pollen surface features have also been shown to be an effective character to identify *H. naniflora*, as it has a microporate surface and, unlike any other *Hexastylis* species, lacks gemmae entirely (Padgett 2004, Niedenberger 2010).

Distribution

Although dwarf-flowered heartleaf is restricted in range, it is not as rare as once thought (USFWS 2010, NCNHP 2016). When dwarf-flowered heartleaf was federally listed in 1989, the listing rule described 24 extant "populations" (and one extirpated population) distributed across eight counties in the upper Piedmont of North and South Carolina. Since 1989, the range has expanded to include five additional counties in North Carolina. In North Carolina, it is found in Alexander, Burke, Caldwell, Catawba, Cleveland, Gaston, Iredell, Lincoln, Polk, and Rutherford Counties. In South Carolina, it is in Cherokee, Greenville, and Spartanburg Counties. As of 2018, the distribution of this species consisted of 119 populations distributed across 13 counties in these two states (Figure 2.2).

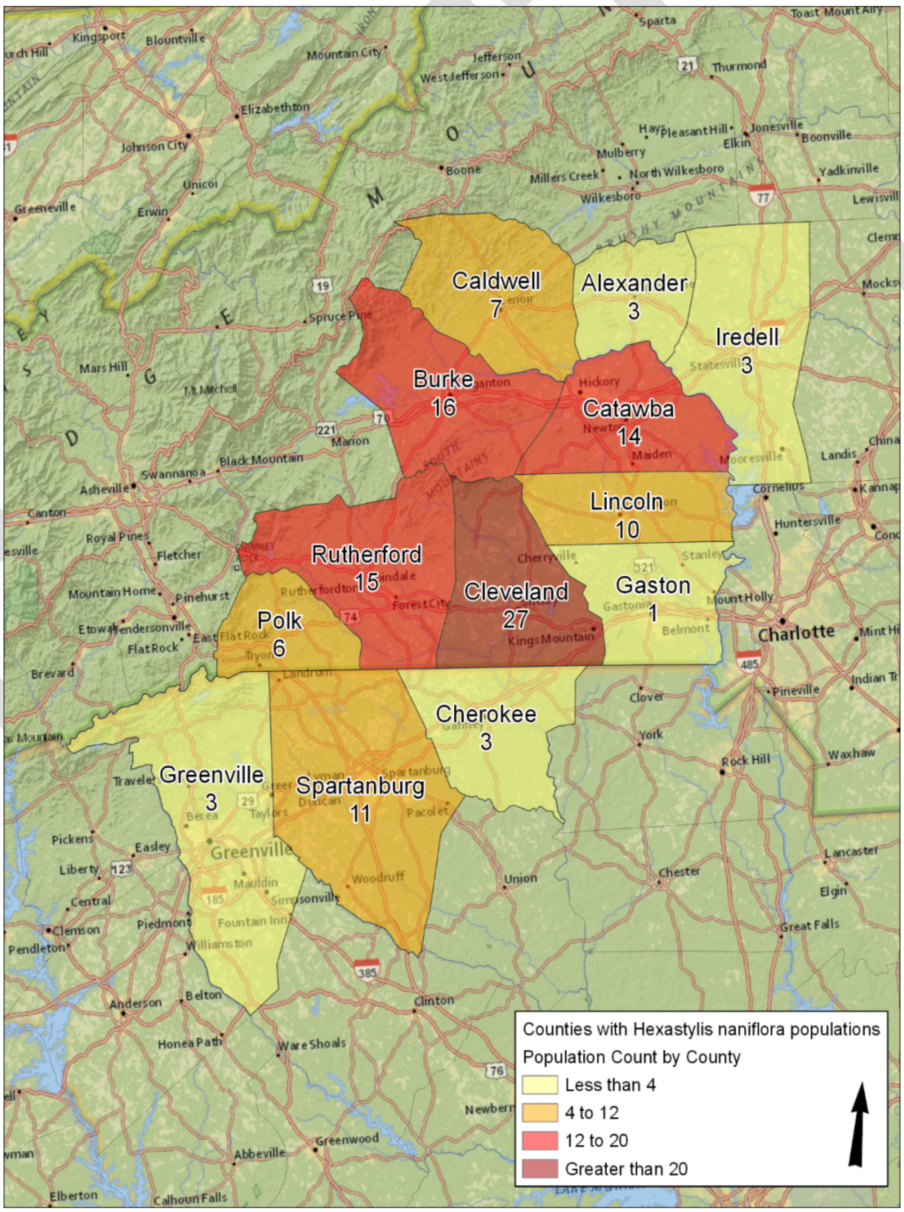


Figure 2.2. Current county distribution for dwarf-flowered heartleaf, with associated number of known populations within each county.

Many of those working with *Hexastylis naniflora* have used the terms "sub site", "site", "location", "occurrence" (often, but not always, in reference to Natural Heritage Program Element Occurrence (EO) records), "subpopulation" and "population" interchangeably. Others have aggregated smaller sites into populations according to subjective criteria which have never been explicitly defined. This generates discrepancies among sources with respect to the abundance and distribution of the species, resulting in data usually not comparable from one source to the next. We describe how the numerous small, site-specific locations containing *H. naniflora* have been aggregated into proxies for 119 biological populations for purposes of this review, using mapping standards devised by NatureServe and its network of Natural Heritage Programs, in Chapter 3 of this report.

Life History

Demographics

The Service is aware of a single effort to collect demographic-level data (survivorship and recruitment of tagged individuals) for dwarf-flowered heartleaf. Surveys occurred during the 1990-1991 field seasons, within a portion of the Peters Creek population in Spartanburg County, SC (Newberry 1993). This study demonstrated a 96.1% survival rate over these two consecutive seasons, with 50% of the mortality occurring in plants located at the highest position on the forested slope (away from the adjacent floodplain). Mortality was highest in small plants bearing fewer than four leaves. Plant size was variable, with the largest plant bearing 45 leaves and 33 flowers, and growing in the floodplain. In general, plants in the floodplain were larger than plants on adjacent slopes. The percentage of flowering plants averaged 70%, with the highest frequency of flowering occurring among plants in the floodplain (USFWS 2010).

Pollination and Dispersal

The pollination of *Hexastylis* has not been well studied but the genus was thought to be pollinated by insects including flies, wasps, and thrips (Otte 1977). Additionally, Lengyel et al. (2010) described how, within the family Aristolochiaeae, more than 50% of the plant lineage is myrmecochorous (seed dispersal by ants). This supports Gaddy's work (1986), which found three species within the Heterophylla complex (*Hexastylis naniflora, H. heterophylla, and H. minor*), which employ myrmecochory as a method for seed dispersal.

Ants appear to be a primary dispersal agent for the dwarf-flowered heartleaf (Gaddy 1986; Jones et al. 2014). All diaspores of *H. naniflora* presented to ants (*Aphaenogaster rudis*) were quickly removed (Gaddy 1986). This is not to say that they are not occasionally, or even frequently, dispersed and/or pollinated by other means. Jones et al. (2014) suggests the pollination mechanism is facultative, benefiting from more than one method of pollination/fertilization. Ants were the pollinators in a controlled experiment, and their data supports that when outside molesting forces/pollinators (biotic and abiotic) were limited by their caging procedure, the efficiency of pollination decreased by almost 50%, however, caged flowers did produce seeds, indicating pollination occurred via some alternative method.

Habitat

Dwarf-flowered heartleaf appears to have a restricted range due to its habitat requirements. The habitat is limited in size and scope due to a multitude of factors including soil type, moisture availability, and slope aspect (Wagner 2013). This unique combination of factors limits not only the range of dwarf-flowered heartleaf, but also the size of a given population. With the limited range and size in populations, questions arise regarding gene flow among populations. How much is occurring and how often does it occur? It is due, in part, to narrow habitat requirements that conservation measures have been implemented for the protection of the species.

Dwarf-flowered heartleaf occurs on piedmont uplands on acidic sandy-loam soils that are very deep and moderately permeable (Gaddy 1981, 1987). Typical habitats for this species include mesic to dry bluffs, slopes, or ravines in deciduous forests that are frequently associated with *Kalmia latifolia* (Padgett 2004, Weakley 2015, USFWS 2015), or moist soils adjacent to creeks, streamheads, or along lakes and rivers. Plants have been observed to grow larger and have more frequent flowering in floodplains along rivers, lakes, and streams (Newberry 1993). Wagner (2013) conducted a habitat suitability study to quantify the habitat requirements for dwarf-flowered heartleaf, which may be used for helping identify the species when not in flower (relative to other *Hexastylis* species habitat preferences), find new populations, or identify suitable sites for transplants.

Soils

The species appears to be restricted to Pacolet sandy loam, Madison gravelly sandy loam, and Musella fine sandy loam soils (Gaddy 1981,1987). The species grows in acidic soils along bluffs and adjacent slopes, in boggy areas next to streams and creekheads, and along the slopes of nearby hillsides and ravines (Gaddy 1980, 1981). It is primarily found inhabiting north- to northwest-facing slopes, bluffs, and ravines in close proximity to creeks or streams. Within these areas exists the soil type required for *Hexastylis naniflora* to grow. It grows primarily on well-drained, sandy, acidic soils, and will not grow in heavy clay (Gaddy 1981).

The results of soil samples analyzed at the Clemson Soil Lab suggest that major differences in soil chemistry requirements exist between the species in the Heterophylla complex (Murrell et al. 2007). Statistical analysis of the soil samples showed that many of the basic elements were significantly different among the three species. Those significant differences occurred in phosphorous (P), potassium (K), magnesium (Mg), zinc (Zn), manganese (Mn), sodium (Na), and cation exchange capacity (CEC). Slightly significant differences were seen in buffer pH and acidity.

Soil chemistry showed marked differences between the species in the complex (Murrell et al. 2007). The results indicated that soil chemistry is very different between *H. naniflora* and *H. minor* localities. The results also show that *H. heterophylla* and *H. naniflora* are found in soils where the chemistry is more similar, but still showed significant differences. It would appear that differentiation in soil types could be used as a proxy for species delineation. The soil analysis also indicates that soils must be considered when trying to select sites for relocation of imperiled populations of *H. naniflora*.

Thirteen population sites in North and South Carolina were examined using the Carolina Vegetation Survey (CVS) method to compare species richness between the three species of the Heterophylla complex (Murrell et al. 2007). The analysis did not show statistically significant differences among the three species in the complex. However, *H. naniflora* appears to have an association with three oak species that is lacking in the other two species in the complex. There are a number of oak species (*Quercus coccinea*, *Q. prinus* (*Q. montana*), and *Q. velutina*), that tend to co-occur with only *H. naniflora*, but are not present with the other two species in the complex. This may be the result of some microbial need or specific soil nutrient required for those species to occur in the same habitat.

Fire

There are little data on the response to fire by *Hexastylis naniflora*, however, prescribed burns have been conducted within the population at Cowpens National Battlefield in Cherokee County, SC. Preliminary data at this site and recent annual monitoring data of this population support the theory that moderate controlled burns do not negatively affect this population (Walker et al. 2009). Additionally, a dormant season wildfire did not show evidence of negative impacts to a population in Caldwell County (USFWS 2010). Fire suppression could be a hazard to *H. naniflora* by allowing fire intolerant, nonnative and invasive plants to thrive, as well as the accumulation of thick duff or leaf litter that may shade low growing species (Wagner 2013).

Genetics

Analyses on ecology, morphology, soil chemistry, pollen, and molecular genetics have been evaluated for *Hexastylis naniflora* to determine the boundaries within the Heterophylla complex, which consists of *H. heterophylla*, *H. minor*, and *H. naniflora* (Murrell 2015, Wagner 2013, Niedenburger 2010, USFWS 2010, Murrell et al. 2007, Padgett 2004). These analyses support the continued recognition of these taxa as well-defined, discrete species. Scanning electron microscopy (SEM) consistently distinguished *H. naniflora* from other members of the Heterophylla complex based on pollen microscopy. Principal Components Analysis of floral characters and soil chemistry also consistently distinguished *H. naniflora* from *H. minor* and *H. heterophylla*. However, efforts to obtain consistently distinct banding patterns using Inter Simple Sequence Repeats (ISSRs) were unsuccessful at distinguishing *H. naniflora* from other members of this complex (Murrell et al. 2007). These results were based upon an extremely small sample size (n=10 *H. naniflora* individuals), and therefore warrant further investigation.

Field observations demonstrate that there are some populations of dwarf-flowered heartleaf with morphological characteristics that do not fit within the range of published values for key traits, overlapping with values for *H. heterophylla* or *H. minor* (Gaddy 1987, Murrell et al. 2007, USFWS 2010, Weakley 2015). These populations were the focus of a genetic analysis conducted at Appalachian State University (ASU) through funding provided by the NC Department of Transportation (NCDOT) (Murrell 2015). In some populations, floral characteristics are highly variable, suggesting the potential for hybridization or individuals with highly variable flower size and shape (Murrell 2015). Additionally, no vegetative characters were previously known to consistently distinguish *H. naniflora* from other close relatives. Given the difficulties with field identification of the species, particularly when not in flower, this study sought to develop a microsatellite library of molecular markers to resolve variation in populations of dwarf-flowered heartleaf and apply the markers to populations with highly variable characters, as identified by NCDOT biologists. The morphological and micromorphological information from those variable populations were compared to molecular results with morphological, micromophological, and distributional data to determine genetic structure, biological boundaries, and placement of putative hybrids or intermediate populations of *H. naniflora* (Murrell 2015).

The preliminary findings of this study suggest populations in the southern range of dwarf-flowered heartleaf exhibit a more uniform genetic pattern, with some possible hybridization with *H. minor*. Populations in the northern part of the range appear to have hybridized with both *H. heterophylla* and *H. minor*, although there are still individuals with "pure" *H. naniflora* genotypes in the northern range (Murrell 2015). It is critical to note that although these data provide anecdotal evidence of hybridization within the Heterophylla complex, intraspecific variation may be caused by forces other than hybridization, such as convergent morphological evolution (Dobzhansky 1937), or the species is in the process of speciation and this study shows a case of incomplete speciation (Murrell 2015), and/or other environmental factors are at play (Wagner 2013). On May 11, 2016, a meeting was held with the Service, NC Natural Heritage Program (NCNHP), NCDOT, and ASU to discuss the status of *H. naniflora* and the current work being conducted among the agencies (Amoroso 2016). Based on discussions during this meeting, the results of this study reported by ASU to NCDOT in 2015 are preliminary. Dr. Matt Estep (ASU) provided additional preliminary results to NCNHP in May 2016, showing which populations were sampled, sample size, and percent of samples that show evidence of hybridization, and hybridizing with which species. ASU continues to work towards a more definitive explanation of the variation in the Heterophylla complex (Murrell 2015, Amoroso 2016).

Chapter 3: SPECIES NEEDS

For the purpose of this report, we define viability as the ability of the species to sustain wild populations over time. Species with greater numbers (redundancy) of healthy populations (resiliency), encompassing a broad array of ecological and genetic diversity in a spatial arrangement that maintains adequate gene flow (representation), are more likely to be viable. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

Delineating Populations

As stated in the Service's five-year review, many of those working with dwarf-flowered heartleaf have used the terms "sub site," "site," "location," "occurrence" (often, but not always, in reference to Natural Heritage Program EO records), and "population" interchangeably, while others have aggregated sites into populations according to subjective criteria which have never been explicitly defined. This has generated considerable discrepancies among sources with respect to the number of known populations within a given area (or across the species' range), to the extent that numbers are not comparable from one source to the next. The past tendency to treat each location as a separate population also artificially inflated the actual number of populations known.

The Natural Heritage Programs collect information on occurrences of rare plants, animals, natural communities, and animal assemblages. Collectively, these are referred to as "elements of natural diversity" or simply as "elements." Locations of these elements are referred to as EO records. In recent years, NatureServe and its member Natural Heritage Programs have devised mapping standards to balance the need for fine-scale, highly site-specific EO records (required for monitoring and management) with the need to aggregate these records in meaningful units of conservation interest that may approximate biological populations (NatureServe 2002). Since the Service does not maintain its own database of known locations of *Hexastylis naniflora*, it regards the Natural Heritage Program databases as the best repository for this information (USFWS 2010).

We delineate populations for the purposes of this SSA according to the NatureServe (2002) convention. Separation distances are a key component to delineating populations from EO records. For the dwarf-flowered heartleaf, we used the EO Data Standard which provides a default separation distance of 1 km (~0.62 miles) for plant and animal elements that lack EO specifications, noting that situations involving dispersal barriers could involve even shorter distances. While gene flow declines over distance at different rates for different elements, the minimum default EO separation distance of 1 km has been accepted by the NatureServe network as the most suitable round-number metric-system approximation broadly applicable to many (but not all) situations. This results in several dwarf-flowered heartleaf populations being stand-alone EOs, as well as many populations being aggregates of several EOs.

Population Resiliency

For the dwarf-flowered heartleaf to maintain viability, its populations or some portion thereof must be resilient. Stochastic factors that have the potential to affect dwarf-flowered heartleaf include impacts to its habitat, particularly human development pressures, but also climate change and presence of invasive species. Other factors that influence the resiliency of dwarf-flowered heartleaf populations include abundance within populations, and habitat factors such as soil type, aspect, elevation, and land use. Influencing those factors are elements of dwarf-flowered heartleaf ecology that determine whether populations can grow to maximize habitat occupancy, thereby increasing resiliency of populations. These factors and habitat elements are discussed below (Figure 3.1).

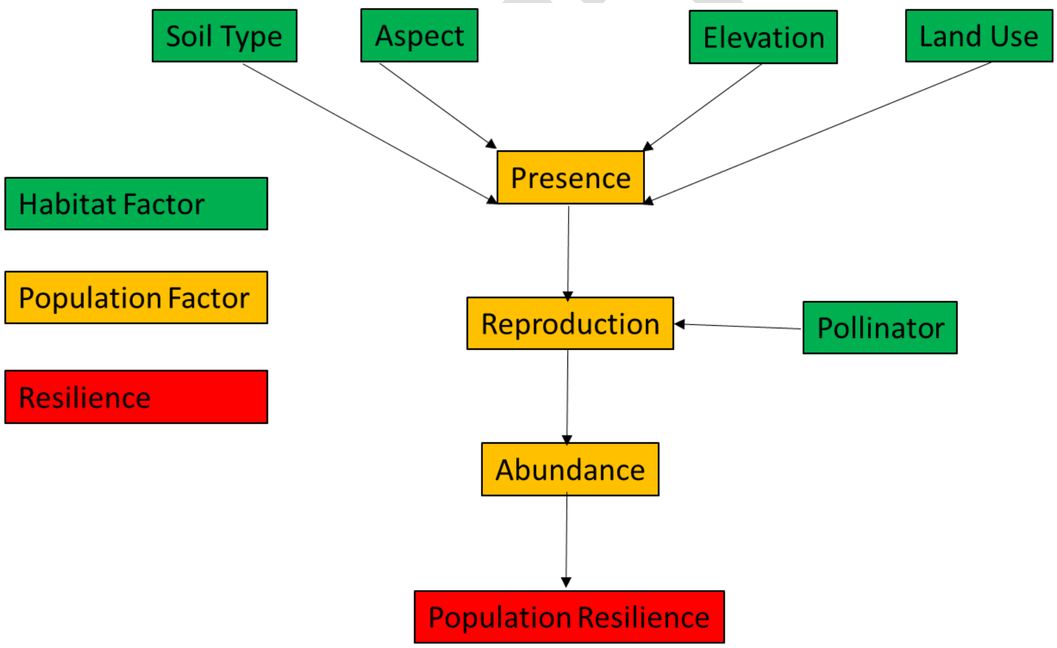


Figure 3.1. Conceptual diagram describing population and habitat factors influencing population resilience for dwarf-flowered heartleaf.

Habitat Factors: Soil Type, Aspect, Elevation, and Land Use

A previous habitat suitability study attempted to quantify the habitat requirements for dwarf-flowered heartleaf (Wagner 2013). With this model in mind, and the input of species experts as to important habitat factors for the species, 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 3.

<u>Source Data and Model Variables</u>

Fifty-three, 10-digit hydrologic units (HUC) comprise the analysis extent (Figure 3.2). In North Carolina, it includes all 10-digit HUC that fall within the boundaries of 8-digit HUC with known occurrence of *Hexastylis naniflora*. In South Carolina, we also included all 10-digit HUC that fell within the boundaries of 8-digit HUC with known occurrence of *H. naniflora*, but excluded the southern portions of the HUC-8 areas due to the boundaries being exceedingly large and far away from any known occurrences.

H. naniflora EO data was obtained from the North Carolina Natural Heritage Program (NCNHP) and the South Carolina Heritage Trust Program (SCDNR). Current populations of *H. naniflora* were identified by reviewing the last observed data in the database and excluding all populations that have not been observed since 2005. 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 EO data polygons.

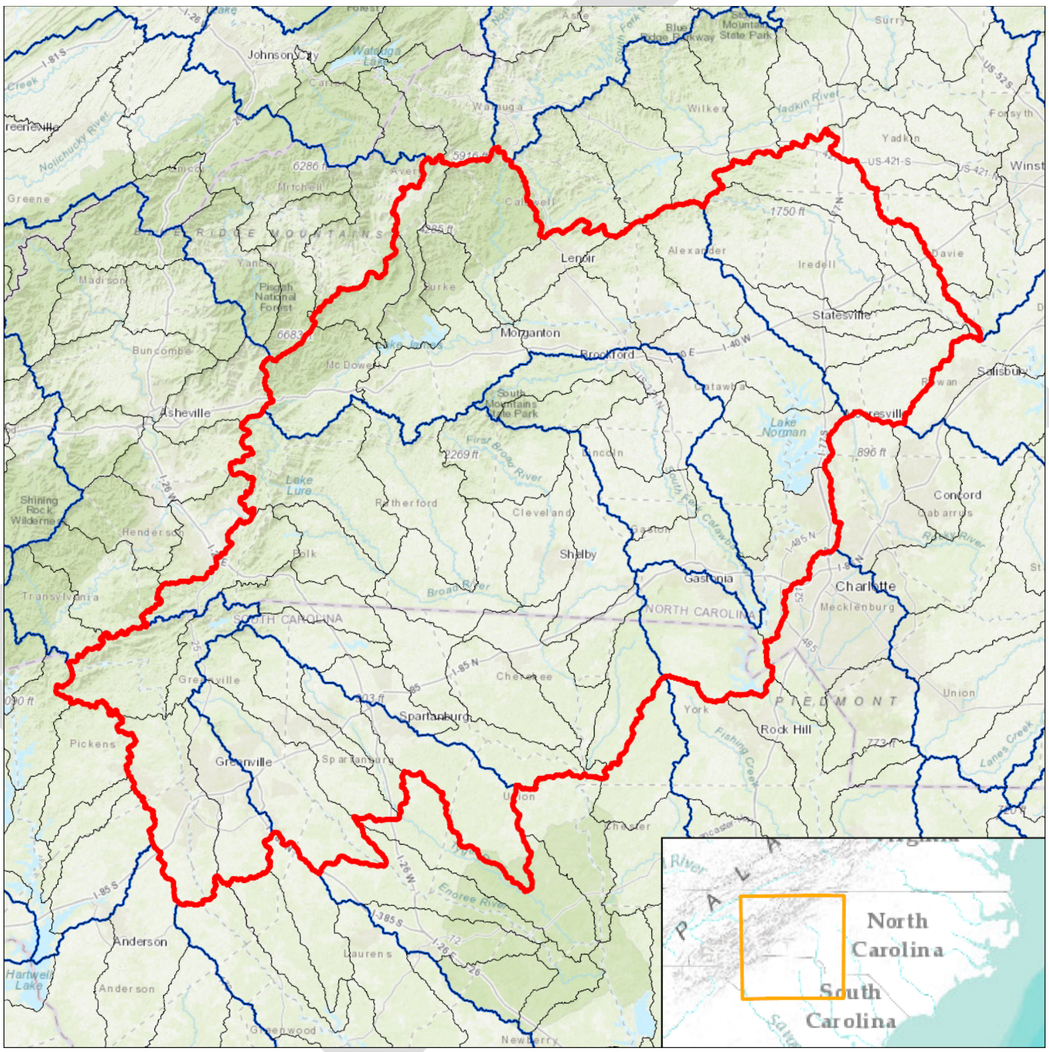


Figure 3.2. Analysis extent of the habitat model for *Hexastylis naniflora.* Red line indicates Maxent analysis extent, blue lines are 8-digit HUC boundaries, black lines are 10-digit HUC boundaries.

<u>Model Development</u>

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 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, canopy height, Soil Survey Geographic Database (SSURGO) drainage class, SSURGO hydrologic group, aspect 9-class, aspect 5-class, slope, solar radiation, and maximum annual temperature. It is interesting to note that a previous habitat modelling effort (Wagner 2013) included slope aspect, whereas the Maxent model excluded this variable. This does not mean the variable is not an important component of dwarf-flowered heartleaf habitat, but rather did not significantly improve the model. Also, landform data was included, and perhaps landform, which includes components of aspect and slope combined is a more meaningful variable than aspect or slope independently.

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 3.3 shows the model output. The minimum cutoff value (to determine if an area is considered potential habitat for a species) of 0.39 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 0.39 in the Maxent model was just 6% of the total analysis area (Table 3.1).

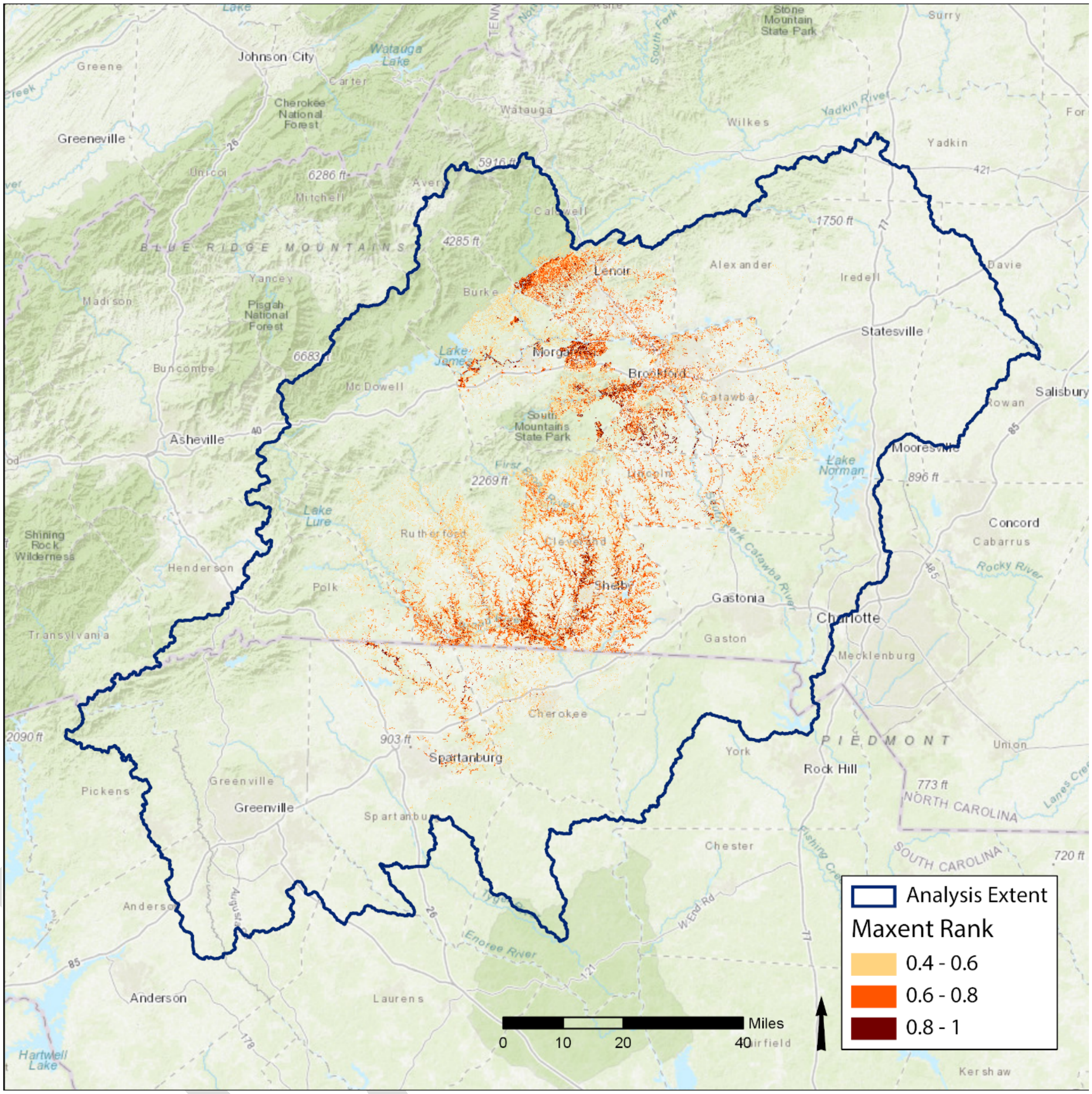


Figure 3.3. Maxent model output map

Table 3.1. Area estimates of the Maxent model

Maxent Score	Acres	Square Miles	Percent of Total
0.39 and greater	302,834.13	473.18	6.02%
0.6 and greater	128,273.52	200.43	2.55%
0.8 and greater	22,115.97	34.56	0.44%

The average area-under-curve (AUC) score for the replicate Maxent model is 0.86. 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 EO data used. The model performed well in its predictions, with a mean AUC of 0.86 (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 3.2). SSURGO map unit key (i.e. soil class) is the top contributing variable. One hundred and thirty-five individual soil types are present within the polygon boundaries of the *H. naniflora* EOs. 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 (14.1% of total). However, collectively the Meadowfield soils only comprised 14.3% of all soils. The individual Pacolet soil types were very common and collectively comprise 36% of all soil types present. Woolwine, Rion, and Fairview soils were also collectively common, comprising 10.4%, 9.7%, and 8.8% of all soils present respectively.

Table 3.2. Percent contribution of the environmental variables

Environmental Variable	Percent Contribution
SSURGO map unit key	23.5%
Minimum Annual Temperature	17.8%
Average Annual Precipitation	15.7%
Landcover	12.9%
Landcover Majority	12.0%
Landcover Hexastylis Grouping	5.4%
Geomorphons	4.9%
Elevation	4.6%
Canopy Cover	3.2%

The minimum annual average temperature range in the analysis extent is 39 – 51 degrees Fahrenheit. The majority of the *H. naniflora* EOs (89%) are found at 47 and 48 degrees. The average annual precipitation range in the analysis extent is 42 – 81 inches per year. The majority of the *H. naniflora* EOs (82%) are found in the 47 – 49 inches per year range.

Piedmont forested landcover habitats dominate the land area of the EOs. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier (53%), Southern Piedmont Mesic Forest (9%), Southern Piedmont Dry Oak-Pine Forest (5.2%), Southern Piedmont Small Floodplain and Riparian Forest (4.4%), and collectively comprise 71% of the EO area. Evergreen Plantation or Managed Pine (9%), Harvested Forest (7.2%), Developed, Open Space (5%), Pasture/Hay (2.1%) collectively comprise 22% of the total EO area. The remaining 6 percent of EO 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 11. Southern Piedmont Dry Oak-Pine Forest – Hardwood Modifier is still the dominant landcover class (58%). 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 either many *H. naniflora* population areas are situated in areas impacted by disturbed landcover, or that the majority of surveys have taken place in disturbed areas because of required surveys due to development.

The landcover *H. naniflora* grouping reveals the amount of disturbance present in *H. naniflora* population areas. Landcover classes grouped as disturbed comprises 27% of the total area. Mixed forest (deciduous and evergreen) comprises 58%, pasture/hay 12%, and hardwood forest 2%. Open water, evergreen and barren landcover groupings are all at less than 1% each.

Geomorphons revealed that the majority of *H. naniflora* EO areas are situated in concave landforms. Geomorphon categories hollow (13%), valley (46%), and depression (10%) collectively comprise 69% of all *H. naniflora* population areas. Flat landforms comprise 15.5% of the area and convex landforms the remaining 15.5%.

Within the analysis extent, the range of elevation present is 335 – 5,265 feet. For *H. naniflora*, the prime elevation range is from 666 – 908 feet (53% of total EO area). A lesser elevation range is present from 935 – 1,184 (37% of total EO area).

Canopy cover for the *H. naniflora* populations are dominated by Tree Cover 70-80% (20.2%) and Tree Cover 80-90% (63.9%). The rest of the canopy cover categories are 2% or less.

We performed a Kruskal-Wallis 1-way non-parametric Analysis of Variance (ANOVA) to investigate the relationship between Maxent scores and current resilience of populations (Table 3.3). There are significant differences in the average Maxent scores between the four resilience categories ($p = 0.04$) and the mean Maxent score increases as population resilience increases from low to very high. The model gives us some predictive ability regarding habitat suitability where higher Maxent scores, on average, result in higher population resilience. The model indicates that larger, more resilient populations occur in habitat that scored higher.

Table 3.3 Results of the Kruskal-Wallis 1-way non-parametric ANOVA investigating relationships between Maxent scores and current resilience groups for dwarf-flowered heartleaf.

Groups	*Count*	*Mean Rank*
low	13	30.7
moderate	25	30.7
high	5	42.8
very high	28	45.7

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	4375.7	4	1093.92	2.65	0.0404
Within Groups	28036.3	68	412.30		
Total	32412.0	72			

Reproduction and Presence of Pollinators

The pollination of *Hexastylis* has not been well studied but the genus is thought to be pollinated by insects including flies, wasps, and thrips (Otte 1977). Additionally, Lengyel et al. (2010) described how, within the family Aristolochiaeae, more than 50% of the plant lineage is myrmecochorous (seed dispersal via ants). This supports Gaddy's work (1986), which found three species within the Heterophylla complex (*H. heterophylla, H. naniflora, and H. minor*), which employ myrmecochory as a method for seed dispersal.

Because the flower for this species is often partially or completely covered with soil and leaf litter, possibly inhibiting pollinator activity (Gonzalez 1972), there is still uncertainty of the pollination mechanism for dwarf-flowered heartleaf. Otte (1977) suggests that a variety of possible pollinators reside in this leaf litter, however, the calyx opening is considered to be far too small for efficient pollinating (Gaddy 1981). There are, however, invertebrates within this proposed size limit that could theoretically act as pollinators. It is possible the species employs self-pollination, with or without a vector, or that cross-pollination occurs by a number of invertebrates. Jones et al. (2014) investigated pollination of dwarf-flowered heartleaf under a manipulative experimental design, and found that while insects may play a significant role in pollination, even without them, flowers managed to produce a partial seed set. Although flowers managed to produce seeds in the absence of insect pollinators, the efficiency of pollination decreased by almost 50%. Also, even if successful pollination occurs in the absence of insect vectors, the dispersal of plants amongst populations would be limited, and could result in decreased resilience due to genetic concerns such as limited gene flow and issues associated with potential inbreeding depression.

Abundance

The influence of stochastic variation in demographic (reproductive and mortality) rates is much higher for small populations than large ones. Stochastic variation in demographic rates causes small populations to fluctuate randomly in size. In general, the smaller the population, the greater the probability that fluctuations will lead to extinction. There are also genetic concerns with small populations, including reduced availability of compatible mates, genetic drift, and inbreeding depression. Small populations of dwarf-flowered heartleaf have low resilience, leaving them particularly vulnerable to stochastic events.

As of 2016, the combined databases of the NCNHP and SCDNR contain 239 EO records for *H. naniflora* (NCNHP 2016, SCDNR 2016). These EO records depict roughly 113 locations which are sufficiently geographically distinct to be regarded as proxies for populations of the species (See

Delineating Populations). Thus, the total number of populations has increased more than four-fold (from 24 to 113) since the species was listed in 1989.

At this time, the largest known populations have been monitored by NCNHP and NCDOT. The estimates for entire populations are based on a consistent monitoring methodology developed by NCDOT, the Service, and NCNHP with monitoring plots representing roughly 10% of a population. Populations were delineated to get a more accurate boundary and size of the area occupied. All rosettes were counted annually in each monitoring plot to estimate an extrapolated population size, based on the number and density in the plots. As a result of these efforts, better estimates of population sizes for the largest known populations are available, compared to when the last five-year review was completed in 2010 (Robinson and Padgett 2016).

The 113 EO records have been estimated to contain anywhere from a single rosette to over 100,000 rosettes. Appendix 1 was created by NCNHP (2016) to replicate the same format and population data as Table B2 of the most recent Service five-year review of *H. naniflora* (USFWS 2010), for comparison of changes since 2010, and summarizes the largest occurrences of *H. naniflora*, with the size of the population based on the number of rosettes it was last estimated to contain. The number of populations estimated to contain over 1,000 rosettes is 26. This is approximately 23% of the total known populations and many of these populations contain well over 1,000 individuals.

There are, however, 13 populations (12% of all known) that are simply known to be extant, with no available estimate of population size (NCNHP 2016, SCDNR 2016). If the most recent population estimates for each EO record are compiled across years of observation, the 113 populations could conservatively be estimated to contain a collective total of more than 300,000 rosettes (NCNHP 2016, SCDNR 2016).

<u>Population Trends</u>

Although abundance is critical in assessing the resilience of dwarf-flowered heartleaf, trends in population growth can also be informative. Long-term growth trends are typically defined as the degree of change in population size over 200 years, whereas short-term growth is typically measured as that degree of change over a 10 year period. We lack a robust data set to assess trends at either of these time scales. However, from 2012-2016, NCNHP conducted systematic annual surveys of thirteen of the largest populations across the range.

Based on the results of the five-year monitoring efforts completed in 2016, nine out of 13 populations remain stable during the five years of data collection (Robinson and Padgett 2016). The largest known population, Broad River: Henson's Creek, Brice, & Sandy Mush Outcrop in Rutherford County, NC, is estimated to have over 100,000 rosettes (Robinson and Padgett 2016). This large population consists of many scattered subpopulations on private property; two of the subpopulations are protected as a Registered Heritage Area, although Registry is a non-binding agreement with landowners that can be cancelled at any time (NCNHP 2018).

Two of the 13 populations increased in numbers from 2012-2016: Cliffside Steam Station and Broad River: Floyds Creek, Long Branch. The Cliffside Steam Station is protected with a voluntary agreement with Duke Energy and was estimated to contain over 39,000 rosettes in 2016.

The Broad River: Floyds Creek, Long Branch population is not at all protected, but was last estimated to consist of over 12,000 individuals in 2016 (Robinson and Padgett 2016).

Based on the results of recent surveys and a review of all known populations of *H. naniflora*, the overall trend over approximately 30 years is estimated to be declining 10-30%. This is estimated by a combination of documented declines of some populations, while many others appear to be remaining relatively stable, and some have increased.

Chapter 4: 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 on recent data and reports (Robinson and Padgett 2016; Robinson 2016), the species consists of 119 populations distributed across 13 counties in North and South Carolina. Populations are composed of both multiple EOs and stand-alone EO records. Recent genetic research discussed in Chapter 2, 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 4.1; 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 *Hexastylis naniflora*, and represent the best currently available scientific data.

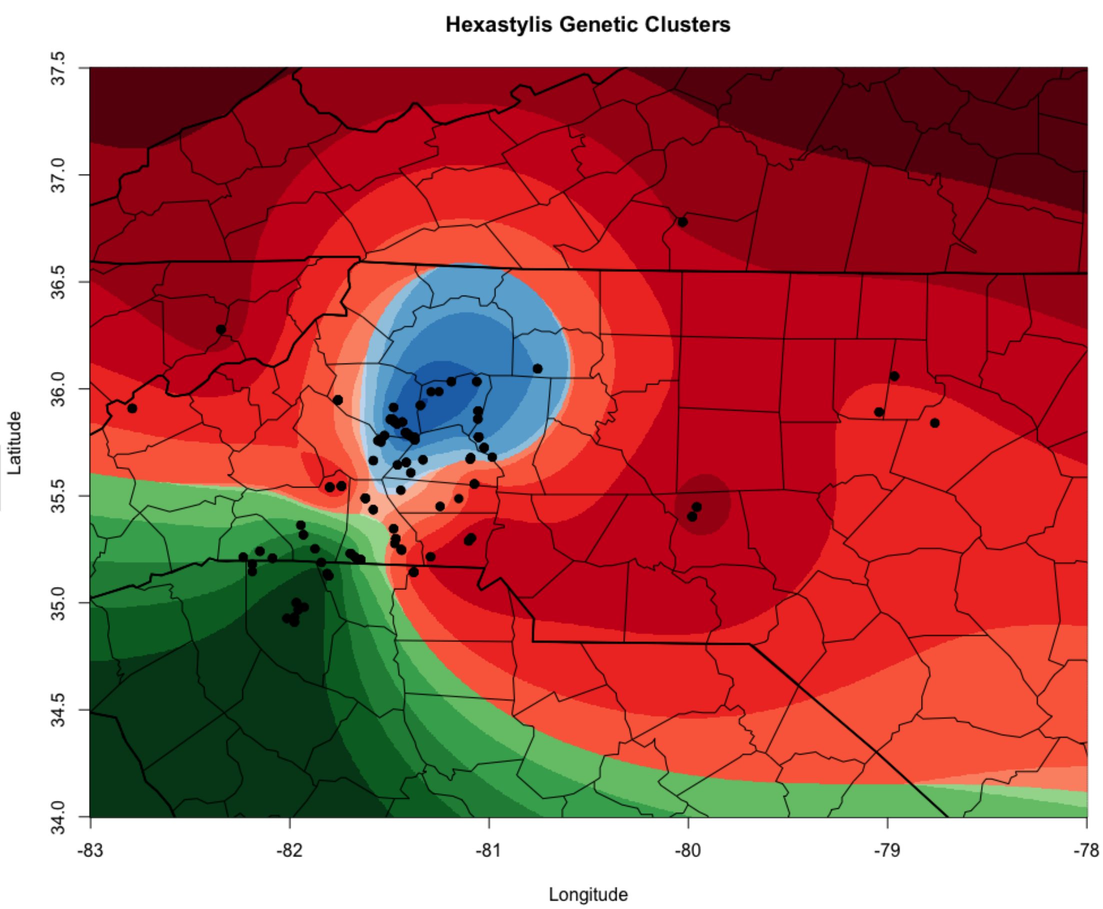


Figure 4.1. Recent genetic analyses detailing clustering of the genus *Hexastylis*. Black dots represent GIS locations of individual plants included in the genetic analysis. Green areas represent "true" *H. naniflora*; Blue represents a possible new species; Red represents other species in the genus (*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 data and reports suggest the species consists of 119 populations, some of that data is fairly outdated. For the purposes of this SSA, we only used EOs that were observed since 2005. We did this for several reasons. First, we did not want to go back too far and assume a population was still present. Second, we wanted to be consistent in what we considered "current" for both categorizing resilience and use in the habitat model. Also, experts concurred that records as old as 12 years are still likely to persist. Finally, there was a natural break in the data at the year 2005, coinciding with the year the last five-year review was initiated, where the number of EOs dropped off significantly in the years 2004 and earlier. It is important to note that many of the populations that we excluded from our analysis may still persist on the landscape. In fact, many EOs for this species have persisted for decades, despite not having intervening surveys to confirm their persistence.

Based on the criteria (excluding EOs prior to 2005), there are currently 78 populations distributed across the range of dwarf-flowered heartleaf, although this may be an underestimate as discussed above.

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 2 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 reports (Robinson 2016; Robinson and Padgett 2016) focus monitoring studies on populations with greater than 1,000 individuals (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 for 20-30 years at or above the current population size, and moderate-high probability of extirpation.

Occupancy and Abundance

There are 78 populations of dwarf-flowered heartleaf that have been observed since 2005 (Table 4.1), and resilience of these populations is as follows: 28 (very high); 5 (high); 26 (moderate); 19 (low). Table 4.2 shows the contribution of each resilience category as follows: 36% (very high); 7% (high); 34% (moderate); 23% (low). When looking at cumulative percentages of resilience, it is interesting to note that 77% of all of the populations are classified as moderate to very high resilience (Table 4.2).

Table 4.1. Current populations of dwarf-flowered heartleaf and associated resilience across the species range. Abundance and last observation date based on Natural Heritage Program data (2018).

Site Name	State	County	Last Observed	Total plants	Resilience
Glade Creek, Alex County	NC	Alexander	2017	>1000	very high
Catawba River: Hoyle Crk-Micol Crk	NC	Burke	2013	>1000	very high
Island Creek Heath Bluff	NC	Burke	2016	>1000	very high
Gunpowder Creek: South of Hudson	NC	Caldwell	2012	>1000	very high
Peaked Top Rare Plant Site/Foothills Landfill	NC	Caldwell	2014	>1000	very high
Jacob Fork West Corridor	NC	Catawba	2012	>1000	very high
Murrays Mill/Upper Balls Creek NA	NC	Catawba	2013	>1000	very high
NCDOT TIP: R-2824	NC	Catawba	2015	>1000	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	NC	Catawba	2013	>1000	very high
Cowpens NBF - Site 1	SC	Cherokee	2016	>1000	very high
Cliffside Steam Station	NC	Cleveland/Rutherford	2016	>1000	very high
Broad River/Sandy Run NA	NC	Cleveland	2012	>1000	very high
Broad River: Brushy Creek	NC	Cleveland	2016	>1000	very high
Buffalo Creek: Kings Mountain Res	NC	Cleveland	2016	>1000	very high
Buffalo Creek: Tributaries N and S of SR 2047	NC	Cleveland	2012	>1000	very high
Rhyne Conservation Preserve	NC	Lincoln	2016	>1000	very high
Mill Creek Forest and Seep	NC	Polk	2016	>1000	very high

Site Name	State	County	Last Observed	Total plants	Resilience
New Hope Springhead Swamp	NC	Polk	2016	>1000	very high
Big Horse Creek Rare Plant Site	NC	Rutherford	2015	>1000	very high
Broad River: Floyds Creek	NC	Rutherford	2016	>1000	very high
Davenport Road/Mountain View Rare Plant Site	NC	Rutherford	2016	>1000	very high
Facebook Site	NC	Rutherford	2016	>1000	very high
Floyds Creek Tributray Rare Plant Site	NC	Rutherford	2012	>1000	very high
New Bethel Rare Plant Site	NC	Rutherford	2015	>1000	very high
Richardson Creek trib above Toms Lake	NC	Rutherford	2016	>1000	very high
DNR Peters Creek Heritage Preserve	SC	Spartanburg	2016	>1000	very high
Taylor Blalock Res	SC	Spartanburg	2016	>1000	very high
Leepers Creek Heartleaf Site	NC	Lincoln	2006	>1000	very high
Little Gunpowder Creek Rare Plant Site 1	NC	Caldwell	2015	500-1000	high
Little Gunpowder Creek Rare Plant Site 2	NC	Caldwell	2015	500-1000	high
Northern Catawba County	NC	Catawba	2017	500-1000	high
Rock Barn Solar Farm	NC	Catawba	2010-2011	500-1000	high
Buffalo Creek Rare Plant Site	NC	Cleveland	2012	500-1000	high
Third Creek Rare Plant Site	NC	Alexander	2010	100-500	moderate
Hickory Area	NC	Burke/Catawba/ Caldwell	2016	100-500	moderate
Burke County - Drowning Creek UT	NC	Burke	2017	100-500	moderate
Simms Hill/Little River Uplands	NC	Burke	2015	100-500	moderate
Smith Cliff/Henry Fork River	NC	Burke	2015	100-500	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	NC	Catawba	2016	100-500	moderate
NCDOT TIP R-2824	NC	Catawba	2015	100-500	moderate
South Fork Catawba River, Henry Fork	NC	Catawba	2007	100-500	moderate
Broad River/Sandy Run NA	NC	Cleveland	2012	100-500	moderate
Brushy Creek Headwaters	NC	Cleveland	2014	100-500	moderate

Site Name	State	County	Last Observed	Total plants	Resilience
First Broad River: Crooked Run Creek	NC	Cleveland	2010	100-500	moderate
No Business Creek, Boyd Tract	NC	Cleveland	2007	100-500	moderate
West Shelby Mesic Slope	NC	Cleveland	2016	100-500	moderate
UT of Kings Mountain Res	NC	Gaston	2012	100-500	moderate
Buffalo Shoals Creek	NC	Iredell	2014	100-500	moderate
Cat Square Heartleaf Forest	NC	Lincoln	2012	100-500	moderate
Collinsville (Hughes) Creek Slopes	NC	Polk	2016	100-500	moderate
Fox Knoll Farm	NC	Polk	2016	100-500	moderate
Forest City: Adj to Isothermal CC	NC	Rutherford	2010	100-500	moderate
Jonas Road Rare Plant Site	NC	Rutherford	2014	100-500	moderate
Knob Creek NA	NC	Cleveland	2005	100-500	moderate
Buffalo Creek	NC	Cleveland	2005	100-500	moderate
Kross Keys NA	NC	Polk	2005	100-500	moderate
Catawba River: North Fork Mountain Creek	NC	Catawba	2005	100-500	moderate
Catawba River: Lake James	NC	Burke	2006	100-500	moderate
Hogpen Branch Transplant Site	NC	Rutherford	2005	100-500	moderate
NCDOT TIP R-3603A	NC	Alexander	2017	<100	low
South Mountains Pleasant Grove Uplands	NC	Burke	2016	<100	low
Gunpowder Creek	NC	Caldwell	2012	<100	low
Killian Crossroads	NC	Catawba	2010	<100	low
Pott Creek	NC	Catawba	2012	<100	low
Beaverdam Crk at First Broad River	NC	Cleveland	2011	<100	low
Buffalo Creek: Potts Creek	NC	Cleveland	2012	<100	low
Buffalo Creek: Ravine	NC	Cleveland	2007	<100	low
Hickory Creek - UT (Shelby High School)	NC	Cleveland	2016	<100	low
Boulder Creek Subdivision - Jordan Road	SC	Greenville	2016	<100	low
Gateway Elementary School	SC	Greenville	2017	<100	low
Fanjoy Road Site	NC	Iredell	2015	<100	low
Levan Family Farm	NC	Iredell	2013	<100	low
Lincoln County, SR-1314	NC	Lincoln	2014	<100	low
Northeast Lincolnton: UT Walker Branch	NC	Lincoln	2009	<100	low

Site Name	State	County	Last Observed	Total plants	Resilience
Sandy Spring Church Springhead Swamp	NC	Polk	2005	<100	low
First Broad River: Hickory Creek	NC	Cleveland	2006	<100	low
Smith Cliff/Henry Fork River	NC	Burke	2005	<100	low
First Broad River: Beaverdam Creek Tribs	NC	Cleveland	2006	<100	low

Table 4.2. Population resilience categories by county for dwarf-flowered heartleaf.

County	Very High	High	Moderate	Low	Totals
Alexander	1		1	1	3
Burke/Catawba/Caldwell			1		1
Burke	2		4	2	8
Caldwell	2	2		1	5
Catawba	4	2	4	2	12
Cherokee	1				1
Cleveland/Rutherford	1				1
Cleveland	4	1	7	6	18
Gaston			1		1
Greenville				2	2
Iredell			1	2	3
Lincoln	2		1	2	5
Polk	2		3	1	6
Rutherford	7		3		10
Spartanburg	2				2
Totals	**28**	**5**	**26**	**19**	**78**
% of total	*36*	*7*	*34*	*23*	*100*
Cumulative %	*40*	*43*	*77*	*100*	--

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 13 of the largest populations across the range of the species from 2012-2016. Table 4.3 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 4.3. Summary of population trends over 5 years of monitoring data for 13 of the largest populations of dwarf-flowered heartleaf across its range (Robinson and Padgett 2016).

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

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

For the dwarf-flowered heartleaf to maintain viability, the species also needs to exhibit some degree of redundancy. Species-level redundancy reflects the ability of a species to withstand catastrophic events, and is best achieved by having multiple, widely distributed populations relative to the spatial occurrence of catastrophic events. Redundancy for dwarf-flowered heartleaf is the total number and resilience of population segments and their distribution across the species range.

An important question when investigating redundancy for dwarf-flowered heartleaf is, "what exactly is a catastrophe?" We consider a catastrophe to be any population-level disturbance with the potential to negatively influence population resiliency outside of normal environmental and demographic stochasticity. Disturbances often act quickly, like hurricanes, and often with devastating effects, however, they can also occur over long periods of time. A disturbance that occurs as a relatively discrete event in time is referred to as a "pulse" disturbance, while more gradual or cumulative pressures on a system are referred to as "press" disturbance. Both types of disturbances are part of the natural variability of dwarf-flowered heartleaf ecological systems, and must be considered when assessing redundancy. While there is certainly a variety of potential pulse disturbances for the species (timber harvest, hydrological alterations, road and right-of-way construction), the primary potential catastrophic disturbances are press disturbances from long term climate change, which have great potential to affect ecosystem processes and communities by altering the underlying abiotic conditions (DeWan et al. 2010).

As stated previously, there are 78 populations of dwarf-flowered heartleaf that have been observed since 2005 (Table 4.1), and resilience of these populations is as follows: 28 (very high); 5 (high); 26 (moderate); 19 (low). The populations are spread across the range, although a majority occurs in North Carolina. Although, there appears to be adequate redundancy within the range of dwarf-flowered heartleaf to withstand the impacts of localized press catastrophic disturbances, the species range is very small, making it potentially vulnerable to long-term catastrophic events, such as climate change.

Chapter 5: 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, 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 5.1-5.2 and Figures 5.1-5.2 show the estimated human population increases for North 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 in North Carolina.

Table 5.1. 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	38,609	39,244	39,686	39,992	40,169
Burke	90,865	93,124	95,382	97,644	99,452
Caldwell	83,919	86,723	88,689	91,126	92,870
Catawba	157,424	159,799	162,175	164,549	166,447
Cleveland	98,862	99,685	100,004	100,128	100,170
Gaston	221,112	227,667	237,344	245,276	252,388
Iredell	179,740	195,623	211,501	227,383	240,088
Lincoln	84,494	91,034	96,865	103,069	107,858
Polk	21,273	21,823	22,288	22,681	22,955
Rutherford	67,880	68,154	68,283	68,341	68,368

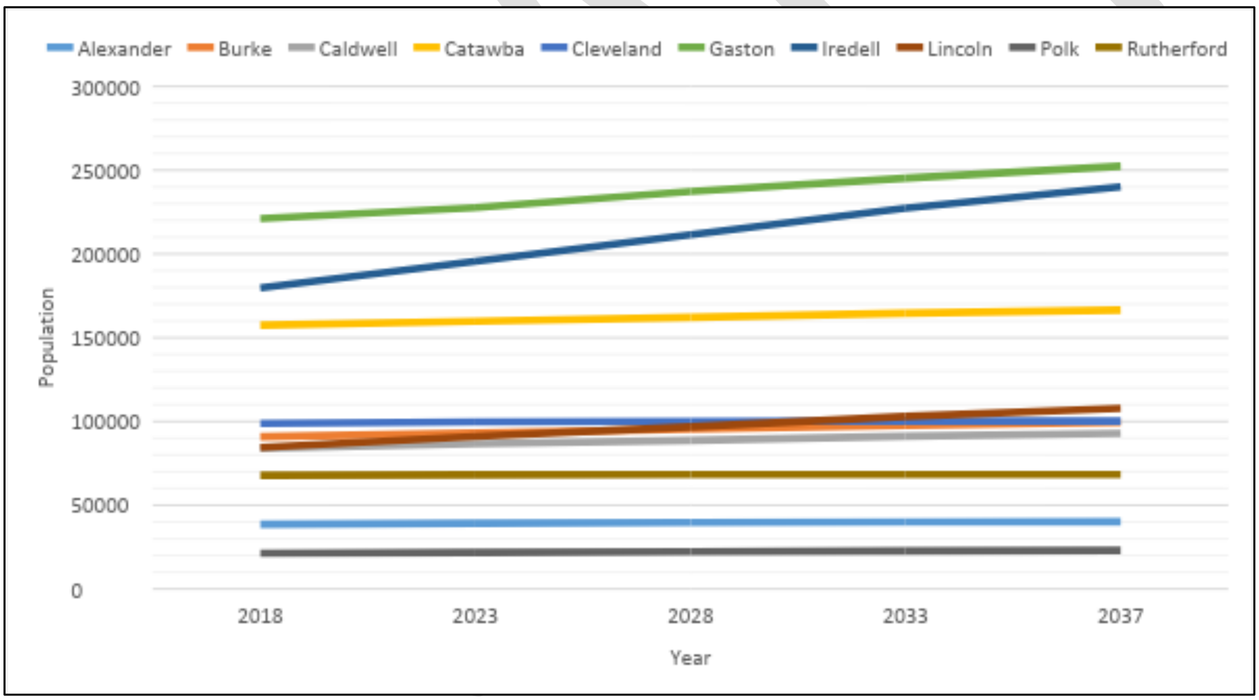


Figure 5.1. Human population projections for North Carolina counties within the range of dwarf-flowered heartleaf. *Source: North Carolina OSBM, Standard Population Estimates.*

Table 5.2. 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

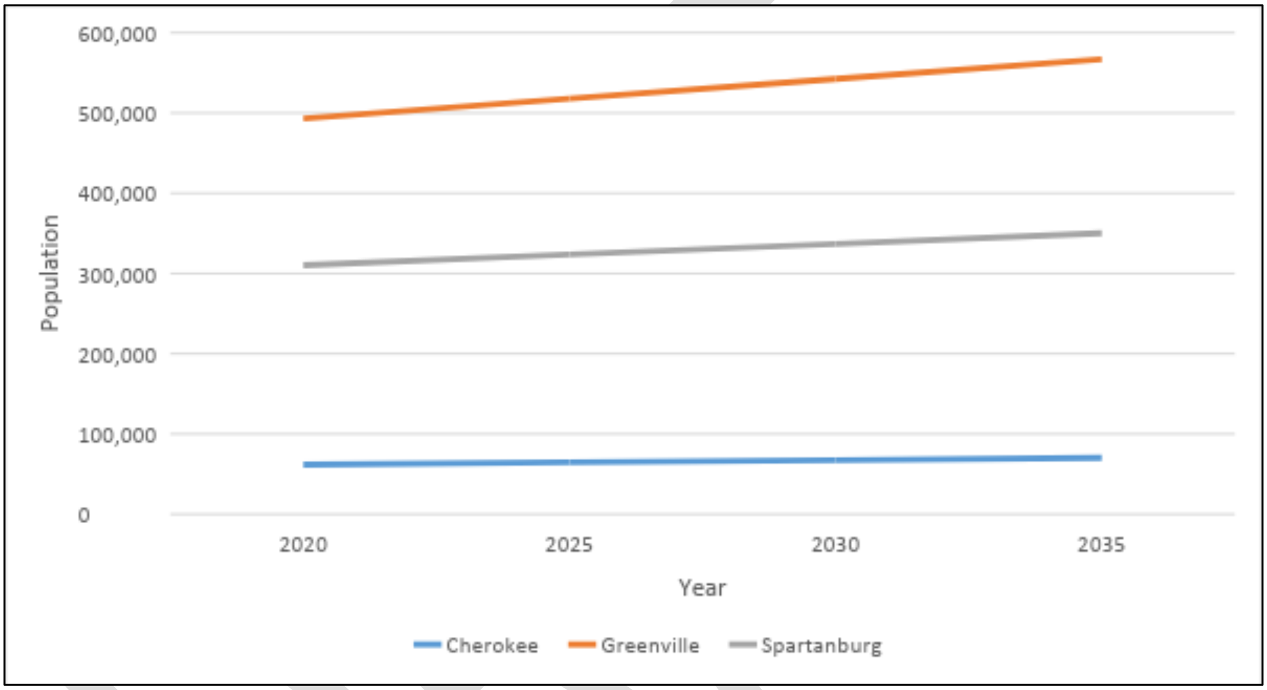


Figure 5.2. Human population projections for South Carolina counties within the range of dwarf-flowered heartleaf. *Source: U.S. Census Bureau, 2000 Census and 2007 Population Estimates. Population projections calculated by South Carolina Budget and Control Board, Office of Research and Statistics.*

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 2010 review of existing NHP EO 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 (NCNHP 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 foreseeable within 42 populations (corresponding to 37% 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 Service. The fact that nearly 20% of all known populations had been subject to formal Section 7 consultation illustrates the threats faced by the species.

In the same 2010 review, the most recurrent source of habitat destruction, and certainly the most common trigger for Section 7 consultations involving *Hexastylis 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 Service 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 Service. 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 rosettes.

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 Service anticipated that as many as 6,619 rosettes (assuming 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 and Woody Encroachment

Several populations of dwarf-flowered heartleaf occur on steep ravine slopes with stands of mixed hardwoods and 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 occur across the range of this species. Plants such as English Ivy, Chinese privet, Japanese honeysuckle and Japanese stiltgrass are known at several sites which contain dwarf-flowered heartleaf. Invasive, exotic species were identified as a threat at eight of 10 North Carolina populations monitored by NCNHP (Robinson and Padgett 2016, pp. 17-19). The eight populations include four stand-alone EOs and four parent EOs with 19 sub-EOs. Of the four stand-alone EOs, one has an invasive threat rank of B (moderate to severe, imminent threat for a significant portion (20-60%) of the population, occurrences, or area), two have a rank of F (low severity threat for most or significant proportion of population, occurrences, or area), and one has a rank of G (low severity threat for a small proportion of population, occurrences, or area). Of the 19 sub-EOs, nine have invasive, exotic species identified as a threat. Of the nine sub-EOs, one has an invasive threat rank of A (moderate to severe, imminent threat for most (>60%) of population, occurrences, or area), four have a rank of B (moderate to severe, imminent threat for a significant portion (20-60%) of the population, occurrences, or area), two have a rank of E (moderate to severe threat for small proportion of population, occurrences, or area), and two have a rank of G (low severity threat for a small proportion of population, occurrences, or area). The one stand-alone and five sub-EOs with the highest threat ranks (A and B) are located in three populations. Based on the most recent monitoring data, one is increasing, one is stable, and one is decreasing (Robinson and Padgett 2016, p.11).

Invasive exotic species were identified as a threat at all (three) South Carolina populations monitored by NCNHP and all sites had an invasive threat rank of F (low severity threat for most or significant proportion of population, occurrences, or area) (Robinson and Padgett 2016, pp. 20). Based on the most recent monitoring data, all populations are stable (Robinson and Padgett 2016, p.11).

This data indicates that dwarf-flowered heartleaf populations can persist and increase in the presence of exotic invasive species. Despite the long-term presence of invasive, exotic plants, from 2012 to 2016 there were no significant changes in the threats facing the plant (NCNHP 2016, p. 8).

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 (Newberry 1993), 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 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 (IPCC 2013):

- More frequent drought
- More extreme heat (resulting in increases in air and water temperatures)
- 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 (NCNHP 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), and although moderate controlled burns do not negatively affect this population (Walker et al. 2009), severe wildfires could have negative effects. 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 4a and 4b gives summary reports on historical and future predicted climate parameters from the USGS National Climate Change Viewer for both North and South Carolina. As discussed above, the trend for these States is consistent with the general trend in the Southeast: 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 4a and 4b), increased potential for catastrophic wildfire events, as well as potential disruption of stream bank morphology through increased flooding events. Our habitat model indicates a preferred temperature and precipitation range, indicating that the species would be sensitive to a changing climate.

Chapter 6: FUTURE CONDITION

Future Considerations

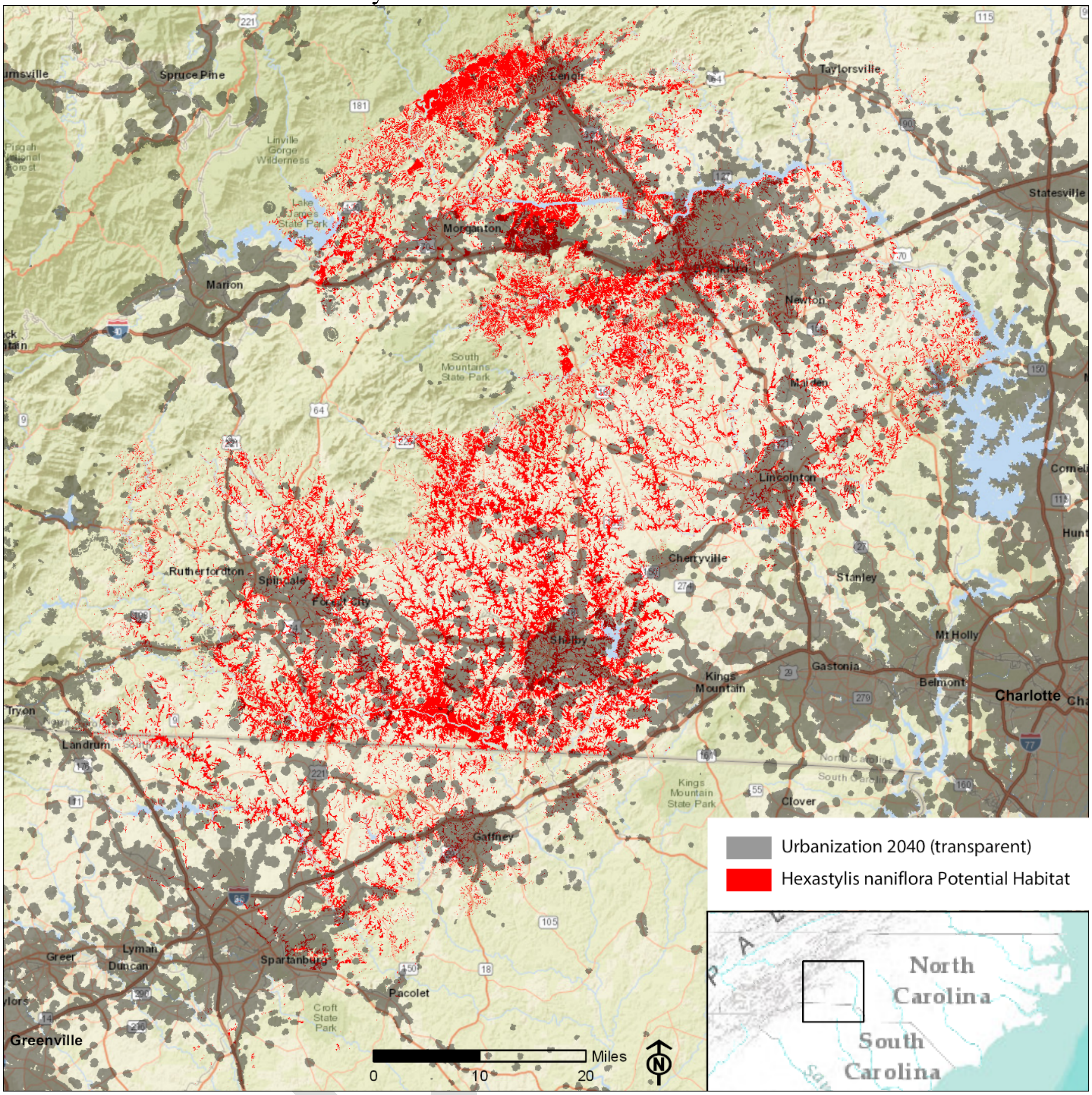
Our analysis of the past, current, and future influences on what the dwarf-flowered heartleaf needs for long term viability revealed that there are several influences that pose risks to future viability of the species. These risks are primarily related to habitat changes from development and long term climate change. We use projections of urban development to assess potential habitat loss and fragmentation. We also considered how climate change may exacerbate the impacts of development in a qualitative fashion using a narrative approach.

Because the actual impacts of urbanization are unknown, we use three scenarios, projected out to the year 2040, to capture the uncertainty related to the potential impacts to each population's resiliency: Status Quo, Targeted Conservation, and High Development. Results of future projections within each scenario are focused on current populations and potential habitat identified by the Maxent model as described below. Based on the life span of the species, expert input, development as the key risk factor brought forward, uncertainty about future conditions, and lack of knowledge about where additional populations may persist on the landscape, we chose to project populations out to the year 2040 under each scenario, but no further.

In constructing our scenarios, we considered two main influences by which species viability projections could be affected: location of additional populations (positive influence) and habitat loss and fragmentation due to urban development (negative influence). Habitat quantity can be negatively impacted by development or land use change (particularly on private lands) or positively impacted by land acquisition, restoration, and/or introductions into unoccupied sites that already have suitable habitat.

We use the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) models to determine areas predicted to be urbanized by 2040 (Figure 6.1). SLEUTH is a cellular automata model that applies transition rules to the states of a gridded series of cells, and in this case the transition is that from undeveloped to developed land cover, otherwise known as urbanization, and has been successfully applied worldwide over the last 15 years to simulate land use change (Clarke 1995).

Figure 6.1. Results of the SLEUTH model with *Hexastylis naniflora* potential habitat predicted by the MAXENT model overlaid.



The SLEUTH model predictions are broken down by probabilities of urbanization, ranging from 0-100%. We chose 80% probability as our cutoff, as this cutoff has been used by USGS and other SSAs, and this threshold represents a highly likely outlook for urbanization of the landscape. To forecast viability using urban development projections, we assessed the following:

- % increase in projected development (SLEUTH probability of urbanization >80%) within current populations
- % increase in projected development (SLEUTH probability of urbanization >80%) within areas delineated as potential habitat by the Maxent habitat model

There is no data available on the exact relationships between urbanization and the impacts to dwarf-flowered heartleaf. We do know that several current populations are located in areas with surrounding urban landscapes. We also know that urban development has led to extirpation of populations in the past through loss of habitat. Because of this uncertainty, we attempted to capture unknowns in two ways. First, our scenarios reflect a range of potential impacts from urban development. Also, we used two thresholds for % increase in urban development to capture potential deleterious effects: 25% and 50%. Our assumptions were that very small increases in development are unlikely to negatively impact populations; development increase of at least 25% of the area of current populations was likely to have some negative impacts; development increase of at least 50% was likely to have significant impacts to populations. We also assume that populations currently on protected lands are likely to see smaller impacts from urbanization compared to those that are not protected, but protection status (perpetuity vs non-perpetuity) matters. For example, Registered Heritage Areas are non-binding agreements with a land owner, and if the land changes ownership, or the owner decides not to continue with the agreement, then the Registry is no longer valid. Appendix 5 shows the protection status of each delineated population which helped to inform our assessment of resilience under each scenario.

We also assessed potential positive effects by integrating the potential location or rediscovery of additional populations throughout the range into two of our scenarios: Targeted Conservation and Status Quo. We believe this is appropriate for several reasons. First, location of new EOs is common; many of the populations we consider for Current Conditions include detections that have occurred within the last few years. Second, we did not include many older detections (i.e. only included detections since 2005), although many of those detections are likely to persist. Dwarf-flowered heartleaf is a long-lived perennial, and several EOs have been revisited after more than 10 years and the species was present. For example, one such EO was first observed in 1957 and next observed in 2001. It seems as long as suitable habitat is still present, it is reasonable to assume that the species is still there. Finally, there is plenty of predicted suitable habitat present within older EOs based on the Maxent model predictions that were not included as current populations due to the relatively long time since last observation.

The first step in identifying additional areas where dwarf-flowered heartleaf is likely to be found in the future, was to identify EOs from populations that were last observed prior to 2005 (i.e. our cut-off for current populations). Although our focus is on older EOs, where dwarf-flowered heartleaf is likely to persist into the future, we also included current EOs (2005-current) in our analysis because we were interested in how the older EOs compared to those known to be persisting on the landscape since 2005. Also, by including older EOs that are within current delineated populations, we can investigate whether current populations might be predicted to contain more plants than the most recent abundance estimate. For example, many of our current populations consist of multiple EOs, and we only considered EOs that were detected from 2005-current. If these older EOs within current populations that were not included in our Current Condition assessment are found to be likely to persist, then it is possible we underestimated the resilience of that population.

Once these older EOs were identified, we created a 1,000-meter buffer around the population and calculated a number of useful metrics including resilience category based on the last known abundance estimate, Maxent habitat model metrics, and the results of the SLEUTH model to further refine a list of potential sites where the species would likely be found to persist within our 20-25 year projection window. Resilience categories were assessed using last known abundance in the same way as populations assessed in the Current Conditions section (i.e. low = less than 100 individuals; moderate = 100-500 individuals; high = 500-1000 individuals; very high = greater than 1,000 individuals). We assessed two habitat metrics for these older EOs: average Maxent score and % Maxent classified as 0.8-1.0 score. Average Maxent score indicates habitat suitability, where in general, the higher the score, the better the habitat, and was calculated by taking the mean Maxent score of all potential habitat within the 1,000-meter buffer. The % Maxent classified as 0.8-1.0 represents the percentage of all potential habitat within the 1,000-meter buffer that falls within the highest suitability habitat class. Together, these two habitat metrics give general estimates of habitat quantity and quality. Finally, we calculated the total percentage of the 1,000-meter buffer around each EO that is projected to be urbanized in the year 2040, which helps capture the primary risk factor of development when assessing the areas where dwarf-flowered heartleaf is likely to persist. Table 6.1 (North Carolina) and 6.2 (South Carolina) show all of the EOs we considered and the corresponding metrics associated with resilience categories, urban development, and habitat scores.

Table 6.1. North Carolina raw data for metrics assessed to investigate potential sites where dwarf-flowered heartleaf was historically found and is likely to persist. Resilience categories are based on last known abundance estimates as follows: 1 = low; 2 = moderate; 3 = high; 4 = very high. MAXENT Average Mean refers to the mean Maxent score of all potential habitat. % Maxent classified as 0.8-1.0 represents the percentage of all potential habitat that falls within the highest habitat class. % Urban Development refers to the percentage of the 1,000-meter buffer around the EO that is projected to be urbanized in the year 2040.

EO not part of a current population
EO included as part of a current population
EO is a part of a current population but last detection was prior to 2005
Eliminated/not scored

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
1	2	34	1	3
2				
3	2	22	0	10
4	2	22	0	7
5	2	21	0	0
6				
8	1	27	0	6
9	3	44	4	0
10	4	33	2	0
11				
12	4	54	10	0

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
13	1	31	1	30
14	2	61	16	7
15				
16	4	18	0	47
17	1	50	13	0
18	1	36	8	2
19				
20	2	22	1	88
21	2	34	4	54
23	4	15	0	8
25	1	47	15	30
27				
28	2	43	12	29
29	4	43	8	30
30	4	27	2	74
31	4	30	3	86
32	2	34	2	47
33	2	33	3	0
34	1	49	13	63
35	1	42	10	23
36	1	19	0	12
37	4	41	6	17
38	2	14	0	46
39	1	19	0	11
40	2	37	2	32
44	4	20	0	59
45	1	27	5	13
46	3	42	6	6
47	1	28	1	96
48	1	14	0	12
49	4	61	14	5
50				
51	4	52	11	18
52	2	46	4	0
53	1	35	4	24
54	1	35	1	10
55	4	30	0	0
56	2	40	2	6
57	2	21	0	80

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
58	1	42	5	0
59	2	11	0	49
60	1	25	0	2
61	3	41	0	0
62	2	34	0	0
63	1	27	0	6
64	2	39	9	11
69	2	46	11	19
70	2	38	1	0
71	2	30	2	0
72	2	52	14	0
73	4	60	17	1
74	3	65	14	4
75	4	47	6	9
76	4	42	4	10
77	3	31	1	27
79	2	39	1	0
80	1	43	4	15
83	2	17	0	11
84	2	13	0	1
85	2	42	4	5
87				
89	2	13	2	0
90	2	28	2	0
91	1	49	5	0
92	2	15	0	30
106	4	39	4	38
107	1	14	0	40
113	4	46	4	7
114				
115	2	37	3	26
118	3	42	0	9
121	2	41	5	0
122	1	12	0	39
124	1	12	0	9
125	4	15	0	41
130	2	17	0	24
149	4	64	17	3
151	2	16	0	27

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
154	4	30	1	22
157	2	20	0	0
158	3	36	7	5
159	4	62	24	60
160	3	62	24	32
161	4	64	28	30
162	1	32	2	58
163	2	15	0	56
164	3	18	0	52
165	1	13	0	56
166	1	14	0	40
167	4	30	0	20
168	4	19	0	34
169	1	30	0	12
170	2	17	0	40
172	1	39	3	7
173	2	30	1	48
174	1	42	4	16
175				
180	2	21	1	0
181	4	29	2	0
182	4	45	4	0
183	2	15	0	5
184	4	19	0	19
187	2	20	1	35
188	2	24	0	53
189	1	25	0	14
190				
191	2	34	2	0
192	2	35	3	0
193	2	36	7	6
194	4	51	14	18
195	1	21	0	96
196	1	23	4	67
197	4	35	8	38
198	2	32	6	25
199	2	29	5	43
200	1	26	2	87
201	1	39	4	63

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
202	4	35	4	85
203	1	43	4	49
204				
205	2	43	1	49
206	1	37	3	66
207	2	33	2	85
208	1	32	1	67
209	2	33	2	94
210				
212	1	37	3	85
213	1	36	4	72
219	1	32	1	4
222	2	23	3	7
223				
224	1	22	3	17
225	2	24	2	12
227	4	55	2	5
229	2	28	0	21
230	1	54	15	13
231	1	41	7	0
233	4	53	12	14
235	2	50	8	6
236	2	62	14	5
237	2	67	16	5
238	4	51	15	0
239	2	63	14	5
240	1	57	18	0
241	2	62	16	3
242	1	53	9	0
246	1	62	13	4
249	4	47	5	0
250	4	45	4	0
251	4	43	4	0
254	2	54	18	6
255				
256	2	54	15	13
258	3	19	0	51
259	4	25	0	0
262	4	29	2	50

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
263				
264				
265				
266				
267	2	29	1	0
268	1	33	2	0
269	2	49	17	0
270	1	46	18	1
271	1	26	7	0
272	1	33	0	71
273	2	28	2	0
274	2	50	8	0
275	2	12	0	0
276	4	42	5	21
277				
278				
279	1	32	4	89
280	2	64	30	30
281	1	64	31	36
282	1	64	31	51
283	1	65	34	59
284	1	64	35	45
286				
287	2	15	0	35
291	2	21	1	84
292	2	14	0	83
293	1	8	0	16
294	2	36	4	61
296	2	3	0	5
297				
298	2	16	0	1
299	1	12	0	0
300	1	9	0	18
303	2	31	0	0
304	2	31	0	0
305	1	30	2	0
306	1	4	0	53
308	2	15	0	3
309	1	5	0	0

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
310	4	58	26	35
311	2	15	0	0
312	4	17	0	57
313				
314				
315	1	36	4	61
317	1	15	0	53
318	2	34	4	52
319	4	43	4	10
320	4	41	6	98
321				

Min	1	3	0	0
Max	4	67	35	98

Table 6.2. South Carolina raw data for metrics assessed to investigate potential sites where dwarf-flowered heartleaf was historically found and is likely to persist. Resilience categories are based on last known abundance estimates as follows: 1 = low; 2 = moderate; 3 = high; 4 = very high. MAXENT Average Mean refers to the mean Maxent score of all potential habitat. % Maxent classified as 0.8-1.0 represents the percentage of all potential habitat that falls within the highest habitat class. % Urban Development refers to the percentage of the 1,000-meter buffer around the EO that is projected to be urbanized in the year 2040.

EO not part of a current population
EO included as part of a current population
EO is a part of a current population but last detection was prior to 2005
Eliminated/not scored

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
1	2	21	0	0
2	2	1	0	4
3				
4	1	13	0	10
5	2	0	0	64
6	1	0	0	36
7	4	27	0	35
8	2	0	0	14
9				
10				
11	4	14	0	52
12				
13	1	7	0	100

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
14	4	14	0	43
15	1	0	0	4
16	4	22	0	38
17	4	22	0	33
18	3	19	0	52
19	1	12	0	65
20	2	5	0	100
21	3	5	0	90
22	1	0	0	0
23				
24	1	4	0	3
25	1	14	0	48
26	4	12	0	65
27	4	18	1	40
28	4	19	1	49
29				
30	2	7	0	88
31	4	0	0	0
32	2	7	0	93
33	2	2	0	20
34	1	31	3	1
35	1	23	1	53
36	2	6	0	0
37	1	24	2	0
38	4	5	0	37
39	1	6	0	1
40	2	6	0	20
41	1	11	0	87
42	2	3	0	6
43	1	23	0	43
44				
45				
46	1	10	0	96
47				
48				
49	3	8	0	70
50	2	5	0	54
51	1	0	0	35
52	3	0	0	0

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
53	2	10	0	66
54	2	9	0	91
55	1	4	0	99
56	2	14	0	96
57	3	15	0	38
59	2	4	0	17
60	4	17	1	12

Min	1	0	0	0
Max	4	31	3	100

Next, we implemented a set of ranking rules using the data from Tables 6.1 and 6.2 to further assess which EOs had a higher likelihood of persistence on the landscape. We used additive weighting methodology to quantify and implement our ranking rules. Because the metrics of interest vary in data type (i.e. categorical vs continuous) and range of values (i.e. not all continuous variables have the same maximum and minimum), our first step was to normalize all of the data on a scale of 0-100. Normalization allows for aggregation of criteria with numerical and comparable data. We decided to analyze North and South Carolina data separately because the Maxent model predicts habitat differently across state lines due to differences in soil classification. We weighted each variable according to our opinion of the level of contribution each variable had to the probability of persistence of that particular EO. This resulted in abundance having the highest weight (100%), with habitat (as calculated by average Maxent score) and urbanization given relatively similar weighting (80%). The results of the normalization procedure and weighting can be found in Tables 6.3 and 6.4.

Table 6.3. Normalized scores for North Carolina EOs and category weights.

EO not part of a current population
EO included as part of a current population
EO is a part of a current population but last detection was prior to 2005
Eliminated/not scored

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
1	33	49	3	97
2				
3	33	30	0	90
4	33	29	0	93
5	33	28	1	100
6				
8	0	37	0	94
9	67	65	11	100

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
10	100	46	6	100
11				
12	100	80	28	100
13	0	43	2	69
14	33	90	44	93
15				
16	100	23	0	52
17	0	73	37	100
18	0	52	22	98
19				
20	33	30	3	11
21	33	48	12	45
23	100	19	0	92
25	0	68	42	69
27				
28	33	62	33	71
29	100	63	22	69
30	100	38	5	24
31	100	43	8	12
32	33	48	5	52
33	33	47	8	100
34	0	73	37	35
35	0	60	29	77
36	0	25	0	88
37	100	60	17	82
38	33	17	0	53
39	0	24	0	89
40	33	54	7	67
44	100	26	1	40
45	0	37	14	86
46	67	60	18	94
47	0	39	2	2
48	0	17	0	88
49	100	91	39	95
50				
51	100	77	31	82
52	33	68	11	100
53	0	50	11	76
54	0	49	1	90

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
55	100	43	0	100
56	33	58	7	94
57	33	28	0	19
58	0	60	15	100
59	33	12	0	50
60	0	34	1	98
61	67	59	1	100
62	33	49	0	100
63	0	38	0	94
64	33	56	24	88
69	33	67	31	80
70	33	55	3	100
71	33	42	5	100
72	33	77	41	100
73	100	89	48	99
74	67	97	41	95
75	100	69	16	91
76	100	61	11	89
77	67	43	2	72
79	33	56	4	100
80	0	62	11	85
83	33	22	0	89
84	33	15	0	99
85	33	61	10	95
87				
89	33	15	5	100
90	33	38	5	100
91	0	71	13	100
92	33	18	0	70
106	100	56	10	61
107	0	16	0	59
113	100	68	11	93
114				
115	33	53	8	74
118	67	61	1	91
121	33	59	13	100
122	0	14	0	60
124	0	13	0	91
125	100	19	0	58

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
130	33	22	0	76
149	100	95	49	97
151	33	20	0	72
154	100	41	2	78
157	33	26	0	100
158	67	51	20	95
159	100	92	69	39
160	67	92	69	68
161	100	95	79	69
162	0	45	7	41
163	33	18	0	43
164	67	24	0	47
165	0	16	0	43
166	0	16	0	59
167	100	41	0	79
168	100	25	0	65
169	0	42	0	88
170	33	22	0	60
172	0	56	8	93
173	33	42	3	52
174	0	62	12	84
175				
180	33	28	2	100
181	100	41	6	100
182	100	66	12	100
183	33	18	1	95
184	100	24	0	81
187	33	27	2	64
188	33	33	0	46
189	0	33	1	86
190				
191	33	48	7	100
192	33	49	10	100
193	33	51	19	94
194	100	75	40	81
195	0	28	0	3
196	0	30	10	32
197	100	50	24	61
198	33	45	18	74

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
199	33	41	14	56
200	0	35	6	11
201	0	56	11	36
202	100	49	11	13
203	0	62	11	50
204				
205	33	62	4	50
206	0	52	8	33
207	33	47	4	14
208	0	45	4	32
209	33	46	5	4
210				
212	0	53	9	14
213	0	52	11	27
219	0	45	2	96
222	33	31	9	92
223				
224	0	29	8	83
225	33	32	6	88
227	100	81	7	95
229	33	39	0	79
230	0	80	44	87
231	0	59	20	100
233	100	79	34	86
235	33	74	22	94
236	33	93	41	95
237	33	100	46	95
238	100	74	41	100
239	33	94	40	94
240	0	85	51	100
241	33	93	47	97
242	0	78	27	100
246	0	93	38	95
249	100	68	13	100
250	100	65	12	100
251	100	62	11	100
254	33	80	51	93
255				
256	33	80	44	87

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
258	67	25	0	48
259	100	34	0	100
262	100	41	6	49
263				
264				
265				
266				
267	33	41	3	100
268	0	46	7	100
269	33	72	49	100
270	0	67	52	99
271	0	35	19	100
272	0	47	0	28
273	33	39	7	100
274	33	73	23	100
275	33	14	0	100
276	100	61	14	79
277				
278				
279	0	46	11	9
280	33	95	85	70
281	0	95	88	64
282	0	96	88	48
283	0	97	95	40
284	0	95	100	54
286				
287	33	18	0	64
291	33	28	4	14
292	33	16	0	16
293	0	7	0	84
294	33	52	11	38
296	33	0	0	95
297				
298	33	20	0	99
299	0	13	0	100
300	0	9	0	82
303	33	44	1	100
304	33	43	0	100
305	0	42	5	100

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
306	0	1	0	46
308	33	18	0	97
309	0	3	0	100
310	100	86	75	64
311	33	19	0	100
312	100	22	0	42
313				
314				
315	0	51	10	38
317	0	19	0	46
318	33	48	12	47
319	100	63	12	89
320	100	60	17	0
321				

Weights			
100	60	20	80

Table 6.4. Normalized scores for South Carolina EOs and category weights.

EO not part of a current population

EO included as part of a current population

EO is a part of a current population but last detection was prior to 2005

Eliminated/not scored

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
1	33	67	14	100
2	33	2	0	96
3				
4	0	42	3	90
5	33	0	0	36
6	0	0	0	64
7	100	87	2	65
8	33	0	0	86
9				
10				
11	100	43	0	48
12				
13	0	23	0	0
14	100	43	0	57
15	0	0	0	96

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
16	100	72	1	62
17	100	70	1	67
18	67	62	0	48
19	0	37	0	35
20	33	16	0	0
21	67	15	0	10
22	0	1	0	100
23				
24	0	13	0	97
25	0	44	0	52
26	100	40	0	35
27	100	56	18	60
28	100	60	28	51
29				
30	33	22	0	12
31	100	0	0	100
32	33	23	0	7
33	33	5	0	80
34	0	100	100	99
35	0	75	34	47
36	33	18	0	100
37	0	78	66	100
38	100	16	0	63
39	0	19	0	99
40	33	18	0	80
41	0	36	0	13
42	33	10	0	94
43	0	72	0	57
44				
45				
46	0	32	0	4
47				
48				
49	67	27	0	30
50	33	16	0	46
51	0	1	0	65
52	67	0	0	100
53	33	33	0	34
54	33	29	0	9

EO_Code	Resilience Category	Average Maxent Score	% Maxent classified as 0.8-1.0	% Urban Development
55	0	13	0	1
56	33	43	0	4
57	67	47	8	62
59	33	13	0	83
60	100	53	21	88
Weights				
	100	60	20	80

To determine a final rank for likelihood of persistence, we calculated a weighted sum for each EO. We then converted the weighted sum to a final rank value that ranged from 0-100. Finally, we determined the top 10% or 90th percentile, and top 25% or 75th percentile ranking for EOs in each state. Table 6.5 summarizes the final ranks and top 10% and 25% for North and South Carolina. We will include the top 10% in the Status Quo scenario, and the top 25% in the Targeted Conservation scenario.

Table 6.5. Final rank scores for EOs in North and South Carolina. Dark green represents the top 10% of scores, and light green includes the top 25% of scores.

EO not part of a current population
EO included as part of a current population
EO is a part of a current population but last detection was prior to 2005
Eliminated/not scored

South Carolina	
EO_Code	**Final Score**
60	79
7	79
17	75
16	74
27	71
28	70
31	69
14	66
11	63
38	62
34	61
1	60
26	59
52	56
57	56
18	55
37	54
36	48
42	44
2	43
40	42
59	41
49	41
8	39
33	39
4	37
39	35
35	34
43	34
24	33
21	32
22	31
53	31
50	31

North Carolina	
EO_Code	**Final Score**
149	94
73	93
49	92
12	90
238	90
161	88
227	87
249	86
233	86
182	85
250	85
251	84
194	84
51	84
310	84
75	84
113	84
319	81
76	81
74	81
10	80
181	79
55	79
37	79
276	78
259	77
159	77
29	76
160	73
167	72
9	72
154	72
23	71
106	71

South Carolina	
EO_Code	Final Score
15	30
25	26
56	24
5	24
54	22
30	22
32	20
51	20
6	20
19	19
20	17
41	12
46	8
13	5
55	3
3	0
9	0
10	0
12	0
23	0
29	0
44	0
45	0
47	0
48	0

North Carolina	
EO_Code	Final Score
197	71
61	70
46	70
184	69
237	69
158	68
118	68
241	68
239	67
236	66
14	66
72	64
168	64
254	64
269	64
262	64
280	63
274	62
256	62
125	61
235	60
52	60
16	60
121	58
77	58
85	57
79	57
44	57
70	57
312	56
192	56
56	56
69	55
33	55
30	55
191	55
193	55
64	55
62	55

North Carolina	
EO_Code	Final Score
202	55
240	54
1	54
303	54
246	54
71	54
320	54
304	54
267	53
273	53
90	53
31	53
28	51
242	51
17	51
5	50
180	50
270	50
157	50
222	49
230	49
115	48
281	48
91	48
4	48
298	48
311	48
225	48
198	47
89	47
3	47
84	47
308	47
275	47
183	46
40	46
284	46
258	46
231	46

North Carolina	
EO_Code	EO_Code
229	46
58	46
164	46
83	45
282	44
18	44
205	43
172	42
296	42
283	42
268	42
80	41
130	41
174	41
305	41
199	41
271	40
25	40
32	40
219	40
35	40
151	40
54	39
318	39
187	39
173	39
92	39
21	39
60	38
63	38
8	38
294	37
169	37
287	37
170	36
45	36
53	36
188	34
189	34

North Carolina	
EO_Code	EO_Code
299	34
38	33
224	33
39	33
36	33
13	32
309	31
124	31
59	31
48	31
34	30
203	30
163	30
207	28
293	27
300	27
57	25
209	25
201	25
315	24
291	24
162	23
20	23
206	23
107	22
166	22
122	22
292	21
213	21
208	20
272	20
317	19
196	18
212	17
165	17
306	14
279	14
200	12
47	10

North Carolina	
EO_Code	EO_Code
195	7
2	0
6	0
11	0
15	0
19	0
27	0
50	0
87	0
114	0
175	0
190	0
204	0
210	0
223	0
255	0
263	0
264	0
265	0
266	0
277	0
278	0
286	0
297	0
313	0
314	0
321	0

Below we describe how we integrated potential positive and negative influences across the scenarios. We can assume there is some tipping point at which an area becomes so urbanized it is unsuitable for dwarf-flowered heartleaf, but we don't know exactly what that tipping point is. Similarly, we can assume additional populations are likely to be found or rediscovered across the range, but there is no clear way to predict the exact number or location of these populations. Although there is great uncertainty associated with how the species will be influenced by these factors, the three scenarios are intended to capture the range of this uncertainty. Note, changes in climate have potential to exacerbate the effects of urbanization, but these effects are not likely to occur within our projection window (e.g. 2040).

Status Quo Scenario

Under the Status Quo scenario, we assume a few populations will be identified as persisting throughout the range, and that there will be a range of impacts from urbanization that are related to the percent increase in urban development and whether a population is protected or not. We assessed population resilience under the following assumptions:

- Two populations are identified as persisting based on Maxent model metrics, last known abundance category, and total predicted urbanization from SLEUTH modelling. Six additional EOs within currently delineated populations not included in our Current Conditions analysis are predicted to persist based on the same metrics.
- Potential impacts of urban development based on SLEUTH Model projections focused on current delineated populations:
    - Protected areas
        - Protected in perpetuity—no negative impacts from urbanization
        - Voluntary protection/non-perpetuity—population drops 1 resilience rank if % increase in urbanization exceeds >50% threshold
    - Non-protected—population drops 1 resilience rank if % increase in urbanization exceeds >25% threshold; population drops 2 resilience ranks if % increase in urbanization exceeds >50% threshold

High Development Scenario

Under the High Development scenario, we assume no additional populations will be identified as persisting throughout the range, and that impacts from urbanization are relatively high, and are also affected by whether a population is protected or not. We assessed population resilience under the following assumptions:

- No populations are identified as persisting
- Potential impacts of urban development based on SLEUTH Model projections focused on current delineated populations:
    - Protected areas
        - Protected in perpetuity— population drops 1 resilience rank if % increase in urbanization exceeds >50% threshold
        - Voluntary protection/non-perpetuity— population drops 1 resilience rank if % increase in urbanization exceeds >25% threshold; population drops 2 resilience ranks if % increase in urbanization exceeds >50% threshold
    - Non-protected—population drops 1 resilience rank if % increase in urbanization exceeds >25% threshold; population drops 2 resilience ranks if % increase in urbanization exceeds >50% threshold; extirpation of populations if % increase in urbanization exceeds >90% threshold.

Targeted Conservation Scenario

Under the Targeted Conservation scenario, we assume it is likely several additional populations (i.e. more than Status Quo scenario) will be identified as persisting throughout the range. The range of impacts from urbanization are the same as the Status Quo scenario. We assessed population resilience under the following assumptions:

- Six populations are identified as persisting based on Maxent model metrics, last known abundance category, and total predicted urbanization from SLEUTH modelling. Six additional EOs within currently delineated populations not included in our Current Conditions analysis are predicted to persist based on the same metrics.
- Potential impacts of urban development based on SLEUTH Model projections focused on current delineated populations:
    - Protected areas
        - Protected in perpetuity—no impacts from urbanization
        - Voluntary protection/non-perpetuity—population drops 1 resilience rank if % increase in urbanization exceeds >50% threshold
    - Non-protected—population drops 1 resilience rank if % increase in urbanization exceeds >25% threshold; population drops 2 resilience ranks if % increase in urbanization exceeds >50% threshold

Future Resilience

Our focus on future resilience of dwarf-flowered heartleaf is on the potential impacts from urbanization. Table 6.6 shows a summary of currently delineated populations and the predicted urban development to occur within each of the populations. The table only includes those populations that already have some current amount of urban development, or are predicted to have some amount of development occur by the year 2040. Populations not included in this table are not predicted to be urbanized at all, so for the purposes of future analysis, will be assumed to retain the same resilience category as current. For those populations included in the table, we focus on those populations that are anticipated to increase in urbanization beyond a threshold value, depending on the scenario, but thresholds include >25% >50%, and >90% increases. Also taken into account is whether or not a population is on protected lands, and if so, whether the population is protected in perpetuity or not. Below is a summary of projected future resilience under each of the three scenarios.

Table 6.6. Results of the SLEUTH model. Populations consist of both stand-alone EOs and aggregates of multiple EOs following the definition of delineating demographic populations from Chapter 4. Included are only those populations that already have some current amount of urban development, or are predicted to have some amount of development occur by the year 2040. Red cells indicate populations that are predicted to increase >50% in urbanization. Orange cells indicate populations that are predicted to increase >25% in urbanization.

Population Number	Total Area (sq m)	Already classed Urban	80% chance	90% chance	95% chance	97.5% chance	100% chance	>80%
206	17346.37096	0.40%	0.00%	0.00%	0.00%	6.24%	93.41%	99.65%
306	7804.656249	0.00%	15.11%	49.91%	7.83%	0.00%	22.40%	95.24%
208	55360.86786	17.31%	0.00%	0.00%	0.00%	0.00%	82.69%	82.69%
279	1951.661571	0.00%	0.00%	0.00%	0.00%	0.00%	80.85%	80.85%
214	15043.2984	0.00%	0.00%	1.44%	10.97%	0.00%	55.72%	68.13%
248	25486.15611	28.80%	0.00%	3.22%	0.02%	0.02%	53.03%	56.30%
316	43177.79587	20.06%	0.00%	16.68%	7.08%	0.00%	20.67%	44.43%
247	49898.17159	5.87%	0.00%	6.37%	0.00%	0.00%	23.35%	29.73%
291	11666.76374	35.39%	12.28%	13.53%	2.43%	0.00%	0.23%	28.47%
287	7901.775408	0.00%	0.00%	11.50%	0.00%	0.00%	14.25%	25.75%
312	6535.273235	0.00%	25.28%	0.00%	0.00%	0.00%	0.00%	25.28%
32	31220.60253	60.74%	0.00%	20.39%	0.00%	0.00%	0.00%	20.39%
177	26954.54153	25.34%	12.19%	0.92%	0.10%	5.31%	0.13%	18.66%
292	15611.18205	0.00%	0.00%	0.00%	0.00%	0.00%	18.40%	18.40%
261	21644.22924	0.00%	0.00%	13.21%	3.35%	0.00%	0.00%	16.56%
295	23486.00987	18.20%	0.00%	3.41%	11.99%	0.25%	0.00%	15.65%
125	20742.3249	0.00%	1.02%	5.65%	0.00%	6.67%	0.00%	13.34%
59	8172.007769	0.00%	13.09%	0.00%	0.00%	0.00%	0.00%	13.09%
302	120342.0641	1.46%	2.55%	2.55%	0.77%	2.33%	3.98%	12.19%
178	376781.2214	28.59%	2.79%	2.40%	0.68%	0.59%	2.64%	9.11%
93	43754.11642	0.19%	0.00%	0.00%	0.00%	0.00%	7.82%	7.82%
77	6044.427562	0.00%	1.51%	6.14%	0.00%	0.00%	0.00%	7.64%
179	15145.19453	85.06%	1.14%	0.00%	5.12%	0.00%	0.49%	6.75%
44	15081.76951	61.17%	0.27%	0.00%	0.00%	0.00%	4.68%	4.95%
252	39595.93143	63.47%	0.00%	3.80%	0.00%	0.00%	0.00%	3.80%
100	423621.7376	9.01%	1.32%	1.10%	0.72%	0.14%	0.00%	3.27%
276	123688.7819	0.61%	0.36%	1.87%	0.01%	0.00%	0.00%	2.24%
216	66424.06073	0.00%	0.91%	0.00%	0.00%	0.00%	0.00%	0.91%
154	33924.92259	0.00%	0.00%	0.37%	0.00%	0.00%	0.00%	0.37%
29	249998.8742	0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.05%
1	30711.68144	0.41%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	36339.91976	11.32%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
3	24498.03483	24.77%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
31	42929.76479	100.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
96	95947.32128	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
130	1168.240433	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
176	39787.48373	0.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
195	7805.599588	99.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
317	584.7346337	99.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
318	5396.859208	99.74%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
320	125.5182447	98.79%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Status Quo Scenario

In the Status Quo scenario, there are predicted to be 75 populations of dwarf-flowered heartleaf on the landscape in 2040 (Table 6.7). The predicted resilience of the extant populations are as follows: very high (27); high (6); moderate (23); low (17); and two additional populations identified as persisting, with an unknown resilience. Six EOs within currently delineated populations not included in our Current Conditions analysis are predicted to persist, but resilience is unchanged because each of the populations are already predicted to be of very high resilience. When comparing future population resilience to current condition a few populations drop in their resilience category. One current population of very high resilience is predicted to drop to high resilience; two moderate populations are predicted to drop to low resilience; and five populations (one currently moderate and four currently low) are predicted to be extirpated due to urban development.

Table 6.7. Predicted resilience categories for *Hexastylis naniflora* populations under the Status Quo scenario, and comparison to current condition.

Site Name	Current Resilience	Status Quo
DNR Peters Creek Heritage Preserve	very high	very high
Cowpens NBF	very high	very high
Mill Creek Forest and Seep	very high	very high
Island Creek Heath Bluff	very high	very high
NCDOT TIP: R-2824	very high	very high
Murrays Mill/Upper Balls Creek NA	very high	very high
Big Horse Creek Rare Plant Site	very high	very high
Broad River/Sandy Run NA	very high	very high
New Hope Springhead Swamp	very high	very high
Facebook Site	very high	very high
Davenport Road/Mountain View Rare Plant Site	very high	very high
Broad River: Floyds Creek	very high	very high
Catawba River: Hoyle Crk-Micol Crk	very high	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	very high	very high
Buffalo Creek: Tributaries N and S of SR 2047	very high	high
Buffalo Creek: Kings Mountain Res	very high	very high
Broad River: Brushy Creek	very high	very high
Peaked Top Rare Plant Site/Foothills Landfill	very high	very high
Jacob Fork West Corridor	very high	very high
Floyds Creek Tributray Rare Plant Site	very high	very high
New Bethel Rare Plant Site	very high	very high
Leepers Creek Heartleaf Site	very high	very high
Cliffside Steam Station	very high	very high
Rhyne Conservation Preserve	very high	very high
Glade Creek, Alex County	very high	very high

Site Name	Current Resilience	Status Quo
Richardson Creek trib above Toms Lake	very high	very high
Gunpowder Creek: South of Hudson	very high	very high
Taylor Blaylock Res	very high	very high
Little Gunpowder Creek Rare Plant Site 1	high	high
Little Gunpowder Creek Rare Plant Site 2	high	high
Buffalo Creek Rare Plant Site	high	high
Northern Catawba County	high	high
Rock Barn Solar Farm	high	high
NCDOT TIP R-2824	moderate	moderate
Third Creek Rare Plant Site	moderate	moderate
Knob Creek NA	moderate	moderate
Buffalo Creek: Northeast of SR 1903	moderate	moderate
West Shelby Mesic Slope	moderate	low
Cat Square Heartleaf Forest	moderate	low
Kross Keys NA	moderate	moderate
First Broad River: Crooked Run Creek	moderate	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	moderate	moderate
Catawba River: North Fork Mountain Creek	moderate	moderate
Catawba River: Lake James	moderate	moderate
Hogpen Branch Transplant Site	moderate	moderate
Jonas Road Rare Plant Site	moderate	extirpated
South Fork Catawba River, Henry Fork	moderate	moderate
No Business Creek, Boyd Tract	moderate	moderate
Broad River/Sandy Run NA	moderate	moderate
Buffalo Shoals Creek	moderate	moderate
Fox Knoll Farm	moderate	moderate
Forest City: Adj to Isothermal CC	moderate	moderate
Hickory Area	moderate	moderate
UT of Kings Mountain Res	moderate	moderate
Brushy Creek Headwaters	moderate	moderate
Smith Cliff/Henry Fork River	moderate	moderate
Simms Hill/Little River Uplands	moderate	moderate
Collinsville (Hughes) Creek Slopes	moderate	moderate
Burke County - Drowning Creek UT	moderate	moderate
Sandy Spring Church Springhead Swamp	low	low
First Broad River: Hickory Creek	low	low
Buffalo Creek: Ravine	low	extirpated
Buffalo Creek: Potts Creek	low	extirpated
Smith Cliff/Henry Fork River	low	low

Site Name	Current Resilience	Status Quo
Pott Creek	low	low
Northeast Lincolnton: UT Walker Branch	low	extirpated
Gunpowder Creek	low	low
Killian Crossroads	low	low
Beaverdam Crk at First Broad River	low	low
Lincoln County, SR-1314	low	low
Levan Family Farm	low	low
Fanjoy Road Site	low	extirpated
First Broad River: Beaverdam Creek Tribs	low	low
South Mountains Pleasant Grove Uplands	low	low
NCDOT TIP R-3603A	low	low
Hickory Creek - UT (Shelby High School)	low	low
Boulder Creek Subdivision	low	low
Gateway Elementary School	low	low
First Broad River (North Carolina)	n/a	present
Cherokee Creek/Bonner and Robin School Roads	n/a	present

High Development Scenario

In the High Development scenario, there are predicted to be 72 populations of dwarf-flowered heartleaf on the landscape in 2040 (Table 6.8). The predicted resilience of the extant populations are as follows: very high (27); high (4); moderate (25); and low (16). No additional populations are identified as persisting. When comparing future population resilience to current condition a few populations drop in their resilience category. One current population of very high resilience is predicted to drop to moderate resilience; one high resilience population is predicted to drop to moderate; two moderate populations are predicted to drop to low resilience; and six populations (one currently moderate and five currently low) are predicted to be extirpated due to urban development.

Table 6.8. Predicted resilience categories for *Hexastylis naniflora* populations under the High Development scenario, and comparison to current condition.

Site Name	Current Resilience	High Development
DNR Peters Creek Heritage Preserve	very high	very high
Cowpens NBF	very high	very high
Mill Creek Forest and Seep	very high	very high
Island Creek Heath Bluff	very high	very high
NCDOT TIP: R-2824	very high	very high
Murrays Mill/Upper Balls Creek NA	very high	very high
Big Horse Creek Rare Plant Site	very high	very high
Broad River/Sandy Run NA	very high	very high
New Hope Springhead Swamp	very high	very high

Site Name	Current Resilience	High Development
Facebook Site	very high	very high
Davenport Road/Mountain View Rare Plant Site	very high	very high
Broad River: Floyds Creek	very high	very high
Catawba River: Hoyle Crk-Micol Crk	very high	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	very high	very high
Buffalo Creek: Tributaries N and S of SR 2047	very high	moderate
Buffalo Creek: Kings Mountain Res	very high	very high
Broad River: Brushy Creek	very high	very high
Peaked Top Rare Plant Site/Foothills Landfill	very high	very high
Jacob Fork West Corridor	very high	very high
Floyds Creek Tributary Rare Plant Site	very high	very high
New Bethel Rare Plant Site	very high	very high
Leepers Creek Heartleaf Site	very high	very high
Cliffside Steam Station	very high	very high
Rhyne Conservation Preserve	very high	very high
Glade Creek, Alex County	very high	very high
Richardson Creek trib above Toms Lake	very high	very high
Gunpowder Creek: South of Hudson	very high	very high
Taylor Blaylock Res	very high	very high
Little Gunpowder Creek Rare Plant Site 1	high	high
Little Gunpowder Creek Rare Plant Site 2	high	high
Buffalo Creek Rare Plant Site	high	high
Northern Catawba County	high	moderate
Rock Barn Solar Farm	high	high
NCDOT TIP R-2824	moderate	moderate
Third Creek Rare Plant Site	moderate	moderate
Knob Creek NA	moderate	moderate
Buffalo Creek: Northeast of SR 1903	moderate	moderate
West Shelby Mesic Slope	moderate	low
Cat Square Heartleaf Forest	moderate	low
Kross Keys NA	moderate	moderate
First Broad River: Crooked Run Creek	moderate	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	moderate	moderate
Catawba River: North Fork Mountain Creek	moderate	moderate
Catawba River: Lake James	moderate	moderate
Hogpen Branch Transplant Site	moderate	moderate
Jonas Road Rare Plant Site	moderate	extirpated
South Fork Catawba River, Henry Fork	moderate	moderate
No Business Creek, Boyd Tract	moderate	moderate

Site Name	Current Resilience	High Development
Broad River/Sandy Run NA	moderate	moderate
Buffalo Shoals Creek	moderate	moderate
Fox Knoll Farm	moderate	moderate
Forest City: Adj to Isothermal CC	moderate	moderate
Hickory Area	moderate	moderate
UT of Kings Mountain Res	moderate	moderate
Brushy Creek Headwaters	moderate	moderate
Smith Cliff/Henry Fork River	moderate	moderate
Simms Hill/Little River Uplands	moderate	moderate
Collinsville (Hughes) Creek Slopes	moderate	moderate
Burke County - Drowning Creek UT	moderate	moderate
Sandy Spring Church Springhead Swamp	low	low
First Broad River: Hickory Creek	low	low
Buffalo Creek: Ravine	low	extirpated
Buffalo Creek: Potts Creek	low	extirpated
Smith Cliff/Henry Fork River	low	low
Pott Creek	low	low
Northeast Lincolnton: UT Walker Branch	low	extirpated
Gunpowder Creek	low	extirpated
Killian Crossroads	low	low
Beaverdam Crk at First Broad River	low	low
Lincoln County, SR-1314	low	low
Levan Family Farm	low	low
Fanjoy Road Site	low	extirpated
First Broad River: Beaverdam Creek Tribs	low	low
South Mountains Pleasant Grove Uplands	low	low
NCDOT TIP R-3603A	low	low
Hickory Creek - UT (Shelby High School)	low	low
Boulder Creek Subdivision	low	low
Gateway Elementary School	low	low

Targeted Conservation Scenario

In the Targeted Conservation scenario, there are predicted to be 79 populations of dwarf-flowered heartleaf on the landscape in 2040 (Table 6.9). The predicted resilience of the extant populations are as follows: very high (27); high (6); moderate (23); low (17); and six additional populations identified as persisting, with an unknown resilience. Six EOs within currently delineated populations not included in our Current Conditions analysis are predicted to persist, but resilience is unchanged because each of the populations are already predicted to be of very high resilience. When comparing future population resilience to current condition a few populations drop in their resilience category. One current population of very high resilience is predicted to drop to high resilience; two moderate populations are predicted to drop to low resilience; and five populations (one currently moderate and four currently low) are predicted to be extirpated due to urban development.

Table 6.9. Predicted resilience categories for *Hexastylis naniflora* populations under the Targeted Conservation scenario, and comparison to current condition.

Site Name	Current Resilience	Targeted Conservation
DNR Peters Creek Heritage Preserve	very high	very high
Cowpens NBF	very high	very high
Mill Creek Forest and Seep	very high	very high
Island Creek Heath Bluff	very high	very high
NCDOT TIP: R-2824	very high	very high
Murrays Mill/Upper Balls Creek NA	very high	very high
Big Horse Creek Rare Plant Site	very high	very high
Broad River/Sandy Run NA	very high	very high
New Hope Springhead Swamp	very high	very high
Facebook Site	very high	very high
Davenport Road/Mountain View Rare Plant Site	very high	very high
Broad River: Floyds Creek	very high	very high
Catawba River: Hoyle Crk-Micol Crk	very high	very high
South Fork Catawba R: Clark Crk, Miller Br, Cata Mem Hos	very high	very high
Buffalo Creek: Tributaries N and S of SR 2047	very high	high
Buffalo Creek: Kings Mountain Res	very high	very high
Broad River: Brushy Creek	very high	very high
Peaked Top Rare Plant Site/Foothills Landfill	very high	very high
Jacob Fork West Corridor	very high	very high
Floyds Creek Tributray Rare Plant Site	very high	very high
New Bethel Rare Plant Site	very high	very high
Leepers Creek Heartleaf Site	very high	very high
Cliffside Steam Station	very high	very high
Rhyne Conservation Preserve	very high	very high
Glade Creek, Alex County	very high	very high
Richardson Creek trib above Toms Lake	very high	very high
Gunpowder Creek: South of Hudson	very high	very high
Taylor Blaylock Res	very high	very high
Little Gunpowder Creek Rare Plant Site 1	high	high
Little Gunpowder Creek Rare Plant Site 2	high	high
Buffalo Creek Rare Plant Site	high	high
Northern Catawba County	high	high
Rock Barn Solar Farm	high	high

Site Name	Current Resilience	Targeted Conservation
NCDOT TIP R-2824	moderate	moderate
Third Creek Rare Plant Site	moderate	moderate
Knob Creek NA	moderate	moderate
Buffalo Creek: Northeast of SR 1903	moderate	moderate
West Shelby Mesic Slope	moderate	low
Cat Square Heartleaf Forest	moderate	low
Kross Keys NA	moderate	moderate
First Broad River: Crooked Run Creek	moderate	moderate
NCDOT non-TIP Div 12 road const at SR 1115 South Fork Catawba River Jacobs Fork and Camp Creek	moderate	moderate
Catawba River: North Fork Mountain Creek	moderate	moderate
Catawba River: Lake James	moderate	moderate
Hogpen Branch Transplant Site	moderate	moderate
Jonas Road Rare Plant Site	moderate	extirpated
South Fork Catawba River, Henry Fork	moderate	moderate
No Business Creek, Boyd Tract	moderate	moderate
Broad River/Sandy Run NA	moderate	moderate
Buffalo Shoals Creek	moderate	moderate
Fox Knoll Farm	moderate	moderate
Forest City: Adj to Isothermal CC	moderate	moderate
Hickory Area	moderate	moderate
UT of Kings Mountain Res	moderate	moderate
Brushy Creek Headwaters	moderate	moderate
Smith Cliff/Henry Fork River	moderate	moderate
Simms Hill/Little River Uplands	moderate	moderate
Collinsville (Hughes) Creek Slopes	moderate	moderate
Burke County - Drowning Creek UT	moderate	moderate
Sandy Spring Church Springhead Swamp	low	low
First Broad River: Hickory Creek	low	low
Buffalo Creek: Ravine	low	extirpated
Buffalo Creek: Potts Creek	low	extirpated
Smith Cliff/Henry Fork River	low	low
Pott Creek	low	low
Northeast Lincolnton: UT Walker Branch	low	extirpated
Gunpowder Creek	low	low
Killian Crossroads	low	low
Beaverdam Crk at First Broad River	low	low
Lincoln County, SR-1314	low	low
Levan Family Farm	low	low
Fanjoy Road Site	low	extirpated

Site Name	Current Resilience	Targeted Conservation
First Broad River: Beaverdam Creek Tribs	low	low
South Mountains Pleasant Grove Uplands	low	low
NCDOT TIP R-3603A	low	low
Hickory Creek - UT (Shelby High School)	low	low
Boulder Creek Subdivision	low	low
Gateway Elementary School	low	low
First Broad River (North Carolina)	n/a	present
First Broad Hop-Hornbeam NA	n/a	present
Big Island Carolina Hemlock Bluff	n/a	present
Cherokee Creek/Bonner and Robin School Roads	n/a	present
Arrowood Branch	n/a	present
Cherokee Creek/SC 11	n/a	present

Viability Summary

Urban development is predicted to have negative impacts on several of the current populations under all of our scenarios. However, this loss of resilience and extirpation of a few populations is offset by the fact that several additional populations were found to persist in the Status Quo and Targeted Conservation scenarios. In the High Development Scenario, there is a predicted loss of 6 populations, with loss of resilience in several additional populations. Regardless of the scenario, the majority of the populations expected to persist on the landscape in 2040 are of at least moderate resilience.

Given the relatively high number of populations across each scenario, redundancy remains similar to current conditions. That is to say, there appears to be adequate redundancy within the range of dwarf-flowered heartleaf to withstand the impacts of localized press catastrophic disturbances; however, the species range is relatively small, making it potentially vulnerable to long-term catastrophic events, such as climate change.

Given that dwarf-flowered heartleaf has a very limited range, and after consulting with experts, we decided delineating representative units was not appropriate for this species. It is worth noting that in two of our scenarios (Status Quo and Targeted Conservation), additional populations are found to persist in South Carolina, an area where we have relatively few current populations. As discussed below, we believe there are opportunities to find additional populations based on the amount of predicted unoccupied potential habitat. Although we did not delineate representative units, we believe our scenarios do not predict declines in species representation.

Table 6.10. Viability summary for *Hexastylis naniflora* under 3 future scenarios (projected to year 2040) and compared to Current Condition.

	Current	Status Quo	High Development	Targeted Conservation
Very High	28	27	27	27
High	5	6	4	6
Moderate	26	23	25	23
Low	19	17	16	17
Extirpated	n/a	5	6	5
Persisting	n/a	2	0	6
Total	**78**	**75**	**72**	**79**

Opportunities for Additional Conservation

Although our scenarios focus on areas where dwarf-flowered heartleaf have been found in the past, the Maxent model identifies a number of areas as high quality potential habitat for the species that falls outside the immediately known occurrence areas. A few of these areas are detailed below (Figure 6.2).

1. West of the city of Lenoir, south of Highway 90/Adako Rd., north of Highway 64 within Caldwell County. This area identifies a large block of potential habitat. This area falls just outside the administrative boundary of the Pisgah National Forest. The bluffs and tributaries along the Johns River are identified as the best habitat, but there is also ample habitat identified along the forested areas of Celia, Husband, Abingdon and Greasy Creeks. The only known occurrence within this area is associated with Abingdon Creek and is under a conservation easement.
2. Henry Fork River bluffs and tributaries east of Highway 18 within Burke County. A historic EO is present by the Burke County line, but the entire area is identified as good quality potential habitat for the species where forested habitats remain.
3. Southwest corner of Catawba County west of Highway 321. Several disjointed patches of high quality potential habitat are identified in this region associated with the river and creek slopes. Rock Creek, Jacob Fork River, Pott Creek, and their associated tributaries all contain blocks of potential habitat. A number of EOs are identified within this area, but additional habitat is identified both upstream and downstream of the known occurrences.
4. Clark, Pinch Gut, Maiden, and Allen Creeks, north of the town of Maiden. The slopes along these creeks all contain quality potential habitat. Known EOs are in the general area, but none are situated within the creeks listed.
5. First Broad River north of Highway 74, Rutherford County. Two older EOs are located within this area, however, the forested bluffs along the First Broad River and associated tributaries are identified as good quality potential habitat in many additional upstream and downstream areas in this system.

6. Hickory Creek, Sulphur Springs Branch (Little Hickory), Shoal Creek, and tributaries draining into First Broad River south of the Town of Shelby, north of the South Carolina border. The town of Shelby has likely disconnected this site from area 5 listed above. Here, slopes along the creeks and tributaries draining into the First Broad River are identified as potential habitat more so than the slopes along the First Broad River themselves. There is only a single EO known upstream along Hickory Creek.
7. North Pacolet River and Obed Creek, north of where they join. The majority of potential habitat falls along the slopes of the North Pacolet River. Two older EOs (1991 last observation) are found in the tributaries draining into the North Pacolet River, and many occurrences are found further upstream. The habitat model suggests that additional undiscovered habitat areas are present.
8. Pacolet River and Island Creek, north of Peters Creek, downstream of the Pacolet River dam. This area displays limited amounts of good quality potential habitat. Recent EOs are present in the upper headwaters of Peters and Zekial Creeks (Zekial Creek drains into Peters Creek) and in areas north of the Pacolet River dam, but none are known along the areas identified in this immediate area.

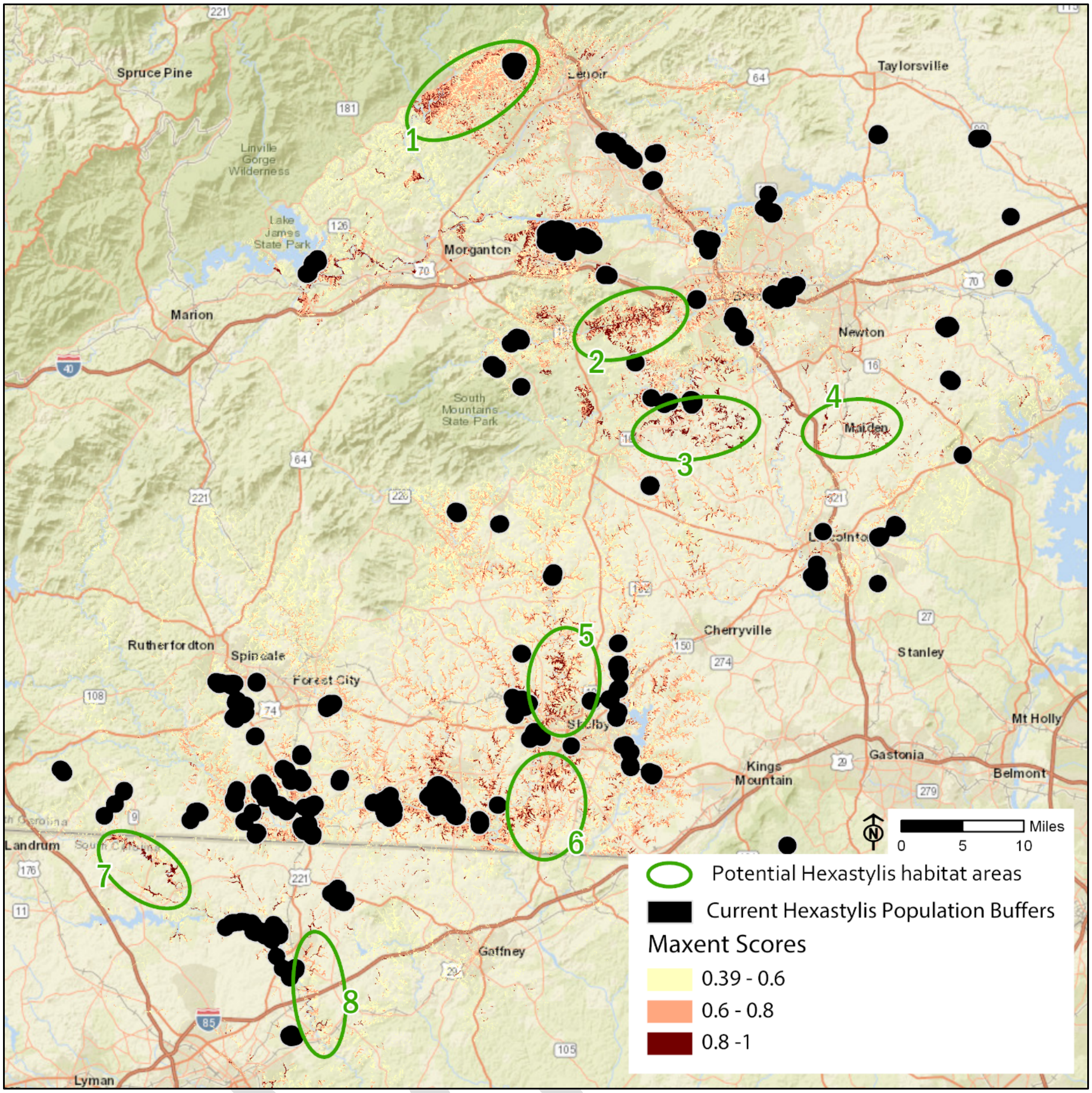


Figure 6.2. Areas identified as high quality potential habitat by Maxent model for *Hexastylis naniflora* that fall outside the immediately known occurrence areas.

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