USING DIGITIZED HERBARIUM SPECIMENS TO PREDICT POTENTIAL DISTRIBUTIONS OF TENNESSEE'S HISTORICAL ANGIOSPERM SPECIES

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ABSTRACT

Species distribution models (SDMs) have become an essential tool in focusing conservation efforts for species with incomplete distribution records. SDMs enable conservation managers to increase field survey efficiency by prioritizing areas to invest time and financial resources. This application is invaluable for historical species which remain suspended between extant and extirpated, having not been documented in many years, but lack sufficient evidence to be determined extirpated. Identifying suitable habitat and previously unknown locations for species of conservation-concern has historically represented an overwhelming and often impractical task, however the development of model-based sampling approaches has made this task more feasible. Here, SDMs are trained using digitized herbarium specimens to identify suitable habitat and therefore, the potential distribution of 16 historical plant species in Tennessee. The ultimate goal of this work is to provide conservation managers with an effective tool for guiding sampling strategies, enabling the rediscovery of Tennessee's lost plant species.

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LIST OF ABBREVIATIONS

10PTP, 10th Percentile Training Presence

AUC, Area Under the Curve

DNA, Division of Natural Areas

ESA, Endangered Species Act

FNA, Flora of North America

GBIF, Global Biodiversity Information Facility

GIS, Geographical Information Systems

iDigBio, Integrated Digitized Biocollections

MaxEnt, Maximum Entropy

MSS, Maximum Test Sensitivity Plus Specificity

MTP, Minimum Training Presence

NRCS, Natural Resource Conservation Service

OCR, Optical Character Recognition

SDM, Species Distribution Model

SERNEC, Southeast Regional Network of Expertise and Collections

SNA, State Natural Area

TCN, Thematic Collections Networks

TDEC, Tennessee Department of Environment and Conservation

TNHP, Tennessee Natural Heritage Program

USFWS, U.S. Fish and Wildlife Service

USGS, U.S. Geological Survey

USNVC, National Vegetation Classification System

WMA, Wildlife Management Area

CHAPTER I

INTRODUCTION

In recent times, the dramatic loss of global biodiversity has become a pressing concern. According to the Millennium Ecosystem Assessment Report (2005), the loss of biodiversity due to human activities was more rapid over the last 50 years than at any other time in human history. In response to human-driven threats such as global climate change, habitat alteration, and the introduction and spread of invasive species, species ranges are shifting, decreasing and fragmenting. Simultaneously, the number of threatened species is constantly increasing. Within the U.S., an estimated 31% of native plant species are at risk of extinction, however only 11% of plant species are protected by the Endangered Species Act (ESA) (NatureServe, 2019). Effective conservation requires an understanding of how species are distributed across the landscape and which environmental factors influence that distribution, information which is limited both in availability and accessibility on a global scale (Newbold, 2010). However, these efforts are often influenced by the availability of time and funding resources and the allocation of such resources across competing species of conservation concern. Current funding for conservation is insufficient relative to the extent and intensity of current threats and, furthermore, conservation efforts must compete with other societal priorities such as food production, human habitation, and resource extraction (James et al., 2001; Wilson et al., 2009).

Faced with such constraints (i.e., time and funding), conservation managers are frequently required to make difficult resource allocation decisions in order to simultaneously maximize conservation efforts and cost effectiveness. Consequently, some species in need of conservation remain unaddressed or under-studied, such is often the case with state historic species. State historic species, known only from historical records, have not been documented in a state for many years despite some sampling efforts, yet cannot be safely presumed extirpated (Master et al., 2012). Exhaustive surveys aiming to rediscover such species are rarely given conservation priority over verified extant species of concern. The rediscovery of historic species has been documented, although this is often the result of coincidence, personally funded expeditions, or work by private organizations such as the Global Wildlife Conservation's Search for Lost Species initiative.

Over the last two decades, there has been a significant increase in the availability of biodiversity data and spatially explicit environmental data, in addition to an increase in the capacities of computing and analytical tools to make use of such information. This increase in availability of biodiversity data began 1999 with the Biodiversity Informatics Subgroup of the Organization for Economic Cooperation and Development's Megascience Forum's recommendation to establish an international mechanism to make biodiversity data and information globally accessible in an effort to advance scientific research and increase knowledge of the natural world (Global Biodiversity Information Facility, 2019). Following this recommendation, the Global Biodiversity Informatics Facility (GBIF) was founded in 2001, providing open access to vast quantities of biodiversity data (Global Biodiversity Information Facility, 2019). By mid-2018, GBIF housed over one billion biodiversity records, with nearly 150 million records based on preserved specimens contained in natural history collections (Nelson & Ellis, 2018).

In the U.S., the initiative to increase accessibility to biodiversity information through biological specimen digitization has been driven largely by the 2011 launch of the U.S. National Science Foundation's Advancing the Digitization of Biodiversity Collections (ADBC) program, giving rise to the Integrated Digitized Biocollections (iDigBio) and several associated Thematic Collections Networks (TCN) (Nelson & Ellis, 2018). These TCNs represent networks of institutions strategizing to digitize information which addresses a particular research theme, such as biodiversity of a particular region or impacts of climate change (iDigBio, 2020). This digitized information is then aggregated into iDigBio, the national resource for digitized information about vouchered natural history collections, establishing integration and interconnectivity among the data generated by TCNs (iDigBio, 2012). The

ADBC program involves 708 collections across nearly 500 institutions, representing all 50 U.S. states, which have contributed over 180 million records to the iDigBio portal.

Concurrent with the increasing availability of biodiversity data, species distribution modeling (SDM) has experienced rapid growth in the scientific literature resulting from the conflux of the increased need for information on species distributions and improved techniques and data for assessing such information. SDMs originated in the late 1970s, a time when computing capacity was severely limited compared to today's technologies (Zimmermann et al., 2010). However, beginning in the 1990s, SDMs began to be revolutionized by the availability of remote-sensed data derived from satellites and the increased accessibility to geographical information systems (GIS) which enable spatial data to be stored and manipulated (Guisan & Thuiller, 2005; Rushton et al., 2004). Parallel with developments in computer and statistical sciences, there have been enormous advancements in SDM techniques and the way in which they can be applied (Guisan & Thuiller, 2005; Rushton et al., 2004; Zimmermann et al., 2010). Consequently, conservation managers have access to powerful information and tools able to help guide conservation efforts unlike any other time in history.

The objective of this study is to use SDMs in combination with digitized natural history data to predict the potential distribution of historical angiosperm species in Tennessee. Through the completion of this objective, we aim to provide conservation managers with a model-based sampling strategy, which will increase field survey efficiency and reduce sampling costs, to rediscover Tennessee's historical angiosperm species

CHAPTER II

TENNESSEE'S HISTORICAL PLANT SPECIES

Introduction

The Division of Natural Areas (DNA) began in 1974, with the assistance of The Nature Conservancy and at the time was known as the Tennessee Natural Heritage Program (TNHP). This was one of the first state Natural Heritage programs developed by The Nature Conservancy (NatureServe, 2015). The purpose of developing the TNHP was to gather science-based information on biodiversity to assist with the selection of sites considered for the Tennessee's natural areas system. Today, the mission of the DNA is to protect the state's plants, animals, and natural communities that represent the natural biological diversity of Tennessee (Division of Natural Areas, 2016). This mission is carried out across several programs, developed for the conservation, restoration, and management of Tennessee's natural resources.

Administered by the DNA, the TNHIP provides public and private land managers with technical assistance on the distribution, conservation and management of the state's biological diversity to ensure management decisions are made with knowledge of the significance and value of the natural resource (Division of Natural Areas, 2016). Information on rare, threatened and endangered species is gathered by research and field investigations conducted by the DNA, TNHIP, and other scientists in Tennessee, as well as from scientific literature, museum collections, and other sources (Tennessee Department of Environment and Conservation, 2019). Currently, the DNA tracks over 1,100 rare and endangered plant and animal species through the TNHIP. Rare plants in Tennessee are protected by the Tennessee Rare Plant Protection and Conservation Act of 1985, which requires a list of endangered, threatened, or special concern plant species to be published and maintained to assist federal, state, and private agencies, organizations, and individuals with environmental review and land management decisions (*Tenn. Comp. R. & Regs. 0400-06-02*). The Tennessee Rare Plant List is a product of the TNHIP and is administered by the DNA. The Tennessee Rare Plant Scientific Advisory Committee, consisting of twelve botanists who are knowledgeable of the state's flora, meet every three years to review and make appropriate modifications to the Tennessee Rare Plant List (*Tenn. Comp. R. & Regs. 0400-06-02*). As of the 2016 Rare Plant List, 535 rare plant species are tracked by the state including 208 plant species listed as state-endangered by the Tennessee Department of Environment and Conservation (TDEC) and 23 species listed by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA) (Division of Natural Areas, 2016).

Species on the Tennessee Rare Plant List may be assigned various statuses and ranks. Federal status signifies plants which are federally listed and are protected by the Endangered Species Act as determined by the USFW. Descriptions of federal status codes adapted from the TNHP Rare Plant List are listed in Table 2.1. Species which are listed as LE, LT, PE and PT are required to be given consideration in environmental planning that involves federal funds, lands, or permits. These species should also be given consideration in all non-federal activities. Furthermore, species listed as C may be added to the list of endangered and threatened species and therefore should be given consideration in environmental planning. The state status signifies plants which are formally listed as state endangered, threatened, or special concern under the authority of TDEC. This status is determined by the Tennessee Rare Plant Scientific Advisory Committee using the listing criteria presented above. Descriptions of state status codes adapted from the TNHP Rare Plant List are listed in Table 2.2.

Table 2.1 Descriptions of Federal status codes assigned by U.S. Fish and Wildlife Service (USFWS)

Federal status code	Description
LE- Listed Endangered	A species or subspecies that is threatened by extinction throughout all or a significant part of its range.
LT- Listed Threatened	A species or subspecies that is likely to become endangered in the foreseeable future.
PE- Proposed Endangered	A species or subspecies that is proposed for listing as endangered.
PT- Proposed Threatened	A species or subspecies that is proposed for listing as threatened.
C- Candidate Species	A species or subspecies for which current information indicates necessity for listing as endangered or threatened. These species have been published in the Federal Register as a candidate for listing under the ESA.
DM- Delisted Species	A species or subspecies that has been recovered and is being monitored for the first 5 years.

Table 2.2 Descriptions of state status codes assigned by the Tennessee Department of Environment and Conservation (TDEC)

State status code	Description
E- Endangered Species	Any species or subspecies of plant whose continued existence is determined to be in jeopardy, including but not limited to all species determined to be endangered species under the ESA.
T- Threatened Species	Any species or subspecies of plant which appears likely to become endangered throughout all or a significant portion of its range in Tennessee within the foreseeable future, including but not limited to all species determined to be a threatened species under the ESA.
S- Special Concern Species	Any species or subspecies of plant that is rare in Tennessee, or has unique or highly specific habitat requirements or scientific value and therefore requires close monitoring

In contrast, state ranks are non-legal rankings assigned by the DNA which are used only to suggest the rarity of a species and do not provide any protection for species. The state rank is a numeric rating (S1 through S5) of rarity based primarily on the number of occurrences of the species in the state. In addition to the number of occurrences in the state, other factors are considered when assigning rank, so the number of occurrences provided for each numeric rank are flexible. Descriptions of state ranks adapted from the TNHP Rare Plant List are listed in Table 2.3. All listed species should be given some amount of consideration in environmental planning, however species given a state rank of S1 to S3 should be given special consideration. In addition to the S1 through S5 state ranks, there are two state rank modifiers, SX and SH, which may be assigned.

Table 2.3 Descriptions of state ranks assigned by the Division of Natural Areas (DNA)

State Rank	**Description**
S1	Species or subspecies which are extremely rare and critically endangered in the state. Typically, 5 or less occurrences, or very few remaining individuals, or because of some factor(s), the species is particularly vulnerable to extirpation from Tennessee.
S2	Species or subspecies which are very rare and endangered within the state. Typically, 6 to 20 occurrences and less than 3,000 individuals, or few remaining individuals, or because of some factor(s), the species is vulnerable to extirpation from Tennessee.
S3	Species or subspecies which are uncommon in the state. Typically, 21 to 100 occurrences.
S4	Species or subspecies which are widespread, abundant, and apparently secure within the state. However, it may be rare in portions of its range, especially at the perimeter. These species are of long-term concern.
S5	Species or subspecies which are widespread and secure within the state.
SH	Species or subspecies which are of historical occurrence in the state. These species have been known to occur in Tennessee in the past, and there is some expectation that they may be rediscovered.
SX	Species or subspecies which are believed to be extirpated from Tennessee, with essentially no likelihood of being rediscovered within the state.

Species assigned an SX state rank were historically known to occur in the state, however all known populations have been destroyed or no longer exist within the state despite intensive searches of historical sites and other appropriate habitat (Division of Natural Areas, 2016; Master et al., 2012). Five vascular plant species are presumed to be extirpated from Tennessee, with virtually no likelihood of being rediscovered in the state. Species considered to be extirpated from Tennessee are listed in Table 2.4. Although some were previously listed on the Rare Plant List, these species are no longer documented on the list but remain on the state’s watchlist. However, if any of these species were to be rediscovered, they would be recommended for listing.

Table 2.4 Vascular plant species considered to be extirpated from Tennessee (State Rank: SX)

Extirpated plant species	**Last Year of Observation in TN**
Anemone canadensis	1888
Kalmia angustifolia var. *carolina*	1940
Linnaea borealis	1892
Ribes americanum	1938
Schwalbea americana	1879

Species assigned an SH state rank are known only from historical records, however there is hope that they may be rediscovered in the state (Division of Natural Areas, 2016; Master et al., 2012). Although these species may have once been a part of the established flora of the state, they have not been documented in the state for approximately 20-40 years, despite some searching, however not thoroughly enough to presume it has been extirpated (Master et al., 2012). Many examples of rediscovering species thought to be extirpated or unseen for decades exist. In 2012, a population of *Lysimachia venosa* H. St. John was rediscovered in Kauai, Hawaii after not being documented for 101 years (Wood, 2013). *Eriogonum truncatum* Torr. & Gray, known only from Mount Diablo in the San Francisco Bay area, was presumed extinct since its last documentation in 1936, but was rediscovered in 2005 (Sanders, 2005). *Clermontia grandiflora* Gaudich. subsp. m*axima* Lammers was rediscovered in Hawaii in 2012 after being known only from a single collection made in 1973 on the slopes of Haleakala (Wood, 2012). David Snyder, a New Jersey botanist with an affinity for searching for “lost” species, relocated over 100 plant species thought to be extirpated or historical species in New Jersey over the course of 20 years (Snyder, 1993, 2000). Snyder (1993) describes historical species being caught in a sort of limbo, between extant and extirpated, as their presence is neither currently verifiable, nor have they been determined extirpated. Snyder (1993) argues that historical species are ranked as such because their historically documented or potential localities have not been adequately surveyed and therefore, historical species are an active conservation priority that, with additional field work, can be rediscovered.

There are 24 vascular plant species known from historical records in Tennessee. The last year of observation for these species ranges from 1884 to 1989 across 19 Tennessee counties. Most species ranked as state historic have been removed from the Rare Plant List but remain on the state's watchlist with the hope that they may be rediscovered in the state. If any of these species were to be rediscovered in Tennessee, they would be recommended for listing. The species considered to be of historical occurrence in Tennessee are listed in Table 2.5. This study will focus on identifying potential habitat for the 21 historical angiosperm species in Tennessee; seedless vascular plants will not be considered for this study (Table 2.5).

Table 2.5 Vascular plant species known historically from Tennessee (State Rank: SH). †Seedless vascular plants not included in study.

State historical vascular plant species	**Last year of observation in Tennessee**
Agalinis setacea	1970
Agrostis mertensii	1966
Calopogon oklahomensis	1937
Carex alopecoidea	1966
Carex sterilis	1935
Carex vestita	1962
Clematis pitcheri	1942
Crotalaria purshii	1934
Helianthemum bicknellii	1965
Helianthemum canadense	1979
Juncus trifidus	1959
Lachnocaulon anceps	1973
Leavenworthia exigua var. *lutea*	1989
Lycopodium annotinum†	1970
Ophioglossum crotalophoroides†	1973
Rhynchospora alba	1949
Rhynchospora latifolia	1901
Rhynchospora wrightiana	1935
Scrophularia lanceolata	1947
Seymeria cassioides	1903
Sida hermaphrodita	1901
Silene regia	1960
Tetragonotheca helianthoides	1968
Thelypteris simulata†	1931

Tennessee's Historical Angiosperm Species Profiles

Information on the last date and county of observation for these taxa were obtained from the Tennessee state botanist, Todd Crabtree. The nomenclature, family, duration, and growth habit of the following taxa follows the USDA PLANTS Database (USDA, NRCS, 2020). Habitat descriptions were adapted from the Flora of North America online key (FNA, 2008), the Flora of the Southern and Mid-Atlantic States (Weakley, In Preparation), and the Tennessee Vascular Plant Guide (Tennessee Flora Committee, 2014). Information on rankings in other states was obtained from the NatureServe Explorer database (NatureServe, 2019). Information on state status (i.e., special concern, threatened, endangered) were obtained from individual states' rare plant lists.

Species distribution analysis methodology was adapted from Blyveis (Blyveis, 2011; Blyveis & Shaw, 2012) and distribution maps from the USDA PLANTS Database (USDA, NRCS, 2020) and the BONAP North American Plant Atlas (Kartesz, 2015) were used to develop range descriptions. A "center of distribution" was determined for each species based on the approximate center of their distributional spread with a more detailed range description following each "center of distribution" determination (i.e., western, midwestern, northern, northeastern, or southern). Species with distributions ranging from the west coast to midwestern states were categorized as "western" species. "Midwestern" species were those with distributions centralized in midwestern states which may taper southward. Species with ranges spanning midwestern states to northeastern states and possibly tapering southward we categorized as "northern" species. "Northeastern" species were those with distributions centralized in the northeastern states which may taper southward. Similarly, species with distributions centralized in southern states which may taper northward were considered "southern" species. Furthermore, each species distribution in Tennessee was categorized as intraneous, extraneous, or endemic (Blyveis, 2011; Blyveis & Shaw, 2012). This study defines taxa having intraneous distributions as those in which Tennessee is located well within the limits of their range, whereas extraneous distributions are those in which Tennessee is located on the outer limits of their range.

Agalinis setacea

Agalinis setacea (J.F. Gmel.) Raf., or threadleaf false foxglove, is an annual forb in Scrophulariaceae, the figwort family. *A. setacea* was last observed in Tennessee in Greene county in 1970 and in Blount county in 1965. This species has a southern extraneous distribution ranging from the southeastern coastal plain northward to the Mid-Atlantic coastal plain with scattered occurrences inland. Its historical occurrences in Tennessee lie on the northwestern edge of its range. This species is ranked as S1 in Delaware; S2 in Maryland; S3 in New Jersey; S4 in New York, Virginia, North Carolina, and Georgia; and SH in Tennessee. It is listed as state endangered in one state (Maryland). This species is found primarily in sandhills, dry, sandy pine-oak woods and other dry forests and openings. *A. setacea* can be observed in flower from September to October.

Agrostis mertensii

Agrostis mertensii Trin., or northern bentgrass, is a perennial graminoid in Poaceae, the grass family. *A. mertensii* was last observed in Tennessee in 1933 in Sevier county and in 1966 in Carter county. This species has a northern extraneous distribution. Its distribution is circumboreal in Canada, ranging south from Maine to New York on the eastern coast and south to Washington on the western coast, east from Montana to Colorado. There is a southeastern disjunction in West Virginia, Virginia, North Carolina, and Tennessee. *A. mertensii* historical occurrences in Tennessee lie on the southeastern edge of its range. This species is ranked as S1 in Washington, Vermont, West Virginia, and North Carolina; S2 in Wyoming, New York, and Maine; S3 in Montana and New Hampshire; and SH in Tennessee. It is listed as state threatened in two states (Maine and New York) and state endangered in one state (North Carolina). This species is found primarily in thin soil of high elevation rocky summits and slopes as well as streambanks and gravel-bars. *A. mertensii* can be observed in flower from July to August.

Calopogon oklahomensis

Calopogon oklahomensis D.H. Goldman, or Oklahoma grass pink, is a perennial forb in Orchidaceae, the orchid family. *C. oklahomensis* was last observed in Tennessee in 1937 in Bledsoe county. This species has a southern extraneous distribution with its historical range extending from Minnesota south to the Gulf Coast of Texas, scattering eastward to South Carolina and southward to southern Georgia. *C. oklahomensis* historical occurrences in Tennessee lie on the eastern edge of its range. Both range extent and number of extant sites have been significantly reduced from historical levels, presumably due to habitat loss from agriculture, fire suppression, forestry and urbanization (NatureServe, 2019). Extant populations of *C. oklahomensis* are known primarily from south-central states including Missouri, Arkansas, Louisiana, Oklahoma, Texas, and Mississippi; one extant occurrence is known from Illinois and Wisconsin is thought to have one small extant occurrence (Goldman, 2008). Goldman (2008) conducted a range-wide study of 230 known site records estimating approximately 25-35 extant populations and nearly 200 potentially historical or extirpated sites. This species is ranked S1 in Kansas, Texas, Louisiana, Mississippi, Alabama, and Illinois; S2 in Oklahoma and Arkansas; SH in Minnesota, Wisconsin, Iowa, Indiana, Tennessee, and Georgia; and SX in South Carolina. *C. oklahomensis* is listed as state endangered in one state (Illinois).

This species occurs primarily in mesic, acidic, sandy to loamy prairies, longleaf pine savannas, moderately open woodlands, on the periphery of bogs, and in wet meadows. It has been found in prairie remnants such as railroads edges, hay fields, and other mowed meadows, pine plantations, and acidic wet barrens (NatureServe, 2019). *C. oklahomensis* can be observed in flower from March to July. This species appears to thrive with frequent, mild disturbances such as fires occurring every one to three years, late season hay field mowing, and possibly light grazing (NatureServe, 2019). Threats to *C. oklahomensis* were summarized by Goldman (2008) as: (1) Fire suppression; (2) Extreme drainage causing mesic sites to become too dry to sustain the species; (3) Mowing without thatch removal; (4) Too-frequent mowing or mowing before fruit ripening; (5) Overgrazing; (6) Natural biological disturbances such as insects, rodents, and herbivores; (7) Natural local or regional climate disturbances such as drought; (8) Intensive trampling, deep soil disturbance, and damage from off-road vehicle traffic; (9) Soil disturbance and shading from conversion to forestry plantations; and (10) Urbanization and other development.

Carex alopecoidea

Carex alopecoidea Tuck., or foxtail sedge, is a perennial graminoid in Cyperaceae, the sedge family. *C. alopecoidea* was last observed in Tennessee in 1966 in Knox county. This species has a northern extraneous distribution extending from Maine westward through the Midwestern states to northeastern Wyoming. *C. alopecoidea* historical occurrences in Tennessee lie on the southernmost edge of its range. This species is ranked as S1 in Indiana, Ohio, New Jersey, Connecticut, and Vermont; S2 in Wyoming, North Dakota, South Dakota, and Massachusetts; S3 in Iowa and Illinois; and SH in Tennessee and Maine. It is state listed as state special concern in one state (Connecticut), state threatened in one state (Massachusetts), and state endangered in three states (Indiana, New Jersey, and Ohio). This species occurs primarily in seasonally saturated habitats and typically over calcareous substrates such as wet meadows, openings in alluvial woods, and stream banks. *C. alopecoidea* can be observed in flower in July.

Carex sterilis

Carex sterilis Willd., or dioecious sedge, is a perennial graminoid in Cyperaceae, the sedge family. It was last observed in Tennessee in 1935 in Fentress county. This species has a northern extraneous distribution ranging from Maine, south to Virginia, westward through the midwestern states to Montana. The *C. sterilis* historical occurrence in Tennessee occurs at the southern edge of its range. This species is ranked as S1 in North Dakota, Iowa, Virginia, Pennsylvania, and Vermont; S2 in Minnesota, Missouri, New Jersey, and Massachusetts; S3 in Illinois and Connecticut; S4 in Ohio and New York; and

SH in Tennessee, West Virginia, and Rhode Island. It is state listed as state special concern in two states (Connecticut and Iowa), state threatened in two states (Massachusetts, and Minnesota) and state endangered in one state (Pennsylvania). This species occurs in mafic and calcareous fens, openings in white-cedar swamps, fresh interdunal meadows, seeps, lake and river shorelines, and wet limestone outcrops. *C. sterilis* can be observed in flower from May to June. In Tennessee, *C. sterilis* is known only from a collection from the historic "Clarkrange Bog," an acidic seepage bog located in Fentress county within the northern Cumberland Plateau and Mountains physiographical province which was significantly altered in the mid-20th century (Tennessee Flora Committee, 2014).

Carex vestita

Carex vestita Willd., or velvet sedge, is a perennial graminoid in Cyperaceae, the sedge family. It was last observed in Tennessee in 1962 in Franklin county. This species has a northeastern extraneous distribution ranging from the northeastern coast, south to Virginia with inland occurrences in North Carolina, Tennessee, and Alabama. The historical *C. vestita* occurrence lies at the westernmost edge of its range. This species is ranked as S1 in North Carolina and Maine; S2 in Virginia, Delaware, and Maryland; S4 in New York and New Jersey; and SH in Tennessee. It is listed as state threatened in one state (Maryland) and state endangered in one state (Maine). This species occurs in acidic soils in low, open woods, bogs, seepage swamps, open, sandy meadows, and wet clearings. *C. vestita* is understood to be long persistent in shaded conditions; flowering a fruiting is stimulated by fire and other disturbances (FNA, 2008). *C. vestita* can be observed in flower from April to May.

Clematis pitcheri

Clematis pitcheri Torr. & A. Gray, or bluebill, is a perennial vine in Ranunculaceae, the buttercup family. It was last observed in Tennessee in 1942 in Montgomery county. This species has a midwestern, intraneous distribution ranging from northern Illinois to southern Texas, west southwestern New Mexico with disjunct occurrences in Alabama and Mississippi. The historical *C. pitcheri* occurrence in Tennessee lies on the southeastern edge of its range. This species is ranked as S2 in Indiana; S3 in Illinois and Kentucky; S4 in Iowa; and SH in Tennessee. It is not listed as special concern, threatened, or endangered in any state. This species primarily occurs on limestone outcrops in dry to moist woods, calcareous river bluffs, limestone glades and barrens, and disturbed sites. *C. pitcheri* can be observed in flower from April to October.

Crotalaria purshii

Crotalaria purshii DC., or Pursh's rattlebox, is a perennial forb in Fabaceae, the legume family. It was last seen in Tennessee in 1934 in Blount county. This species has a southern extraneous distribution extending along the southeastern coastal plain with scattered inland occurrences. Historical occurrences of *C. purshii* in Tennessee occur at the northwesternmost edge of its range. It is ranked as S1 in Virginia; S3 in Louisiana; S4 in North Carolina; and SH in Tennessee. This species is not listed as special concern, threatened, or endangered in any state. *C. purshii* occurs in mesic to dry pinelands, sandy openings, and along roadsides. This species can be observed in flower from May to July. In Tennessee *C*. purshii is known from one historic collection in the Great Smoky Mountains National Park, within the Unakas physiographical province (Tennessee Flora Committee, 2014). *C. purshii* is considered to be highly threatened by forest management practices and is especially vulnerable to succession (NatureServe, 2019).

Helianthemum bicknellii

Helianthemum bicknellii Fernald, or hoary frostweed, is a perennial forb in Cistaceae, the rock-rose family. It was last observed in Tennessee in 1965 in Blount and Monroe counties. This species has a northern extraneous distribution. It is known from Colorado and Wyoming, east through the midwestern states to the eastern coast. Historical *H. bicknellii* occurrences in Tennessee lie at the southeastern edge of its range. This species is ranked as S1 in North Dakota, Wyoming, Colorado, Nebraska, Kentucky, West Virginia, Virginia, North Carolina, and Maryland; S2 in Ohio, Pennsylvania, and Vermont; S3 in Indiana and New Jersey; S4 in Iowa; S5 in New York; SH in Tennessee and Arkansas; and SX in Delaware. It is listed as state special concern in one state (North Carolina), state threatened in one state (Vermont), and state endangered in three states (Kentucky, Pennsylvania, and Maryland). *H. bicknellii* occurs in sandy or rocky glades and barrens, open woodlands, prairies, and montane outcrops and balds. This species can be observed in flower from June to September.

Helianthemum canadense

Helianthemum canadense (L.) Michx., or longbranch frostweed, is a perennial forb in Cistaceae, the rock-rose family. It was last observed in Tennessee in Monroe county in 1966 and in Blount county in 1979. This species has a northern extraneous distribution ranging from southeastern Wisconsin through the midwestern states to the northeast, south to Georgia along the eastern coast with disjunct occurrences in southeastern Alabama. Historical occurrences of *H. canadense* in Tennessee lie on the western edge of the east coast portion of its range. This species is ranked as S1 in Kentucky and Georgia; S2 in Ohio, West Virginia, and Vermont; S3 in Minnesota, North Carolina, and Delaware; S4 in Iowa; S5 in New York, Virginia, and New Jersey; and SH in Tennessee. *H. canadense* is listed as state special concern in one state (Minnesota), state threatened in one state (Ohio), and state endangered in one state (Kentucky). This species occurs in sandy or rocky barrens and glades, sandhills, prairies, maritime grasslands, interdunes, forest edges, disturbed areas, and along roadsides. *H. canadense* can be observed in flower from April to August.

Juncus trifidus

Juncus trifidus L., or highland rush, is a perennial graminoid in Juncaceae, the rush family. It was last observed in Tennessee in 1959 in Sevier county. This species has a northeastern extraneous distribution ranging from the northeastern states south along the Appalachian Mountains to West Virginia, Virginia, North Carolina, and Tennessee. Historical occurrences of *J. trifidus* in Tennessee lie at the southernmost edge of its range. This species is ranked as S1 in West Virginia, Virginia, North Carolina, Maryland, and Vermont; S2 in New York; S3 in New Hampshire and Maine; and SH in Tennessee and Pennsylvania. *J. trifidus* is listed as state threatened in one state (New York) and state endangered in two states (Maryland and North Carolina). This species occurs in high-elevation rock crevices and outcrops. *J. trifidus* can be observed in flower from June to September. This species is vulnerable to human disturbance, such as trampling, primarily in the southern Appalachians due to its limited distribution (NatureServe, 2019).

Lachnocaulon anceps

Lachnocaulon anceps (Walter) Morong, or whitehead bogbutton, is a perennial forb in Eriocaulaceae, the pipewort family. It was last observed in Tennessee in 1973 in Cumberland county. This species has a southern extraneous distribution ranging along the southeastern coastal plain with scattered inland occurrences. *L. anceps* historical occurrences in Tennessee lie at the northwesternmost edge of its range. This species is ranked as S1 in Virginia; S4 in North Carolina; and SH in Tennessee. It is not listed as special concern, threatened, or endangered in any state. *L. anceps* occurs in moist sands and peats of shores, pine savannas, boggy meadows, and flatwoods clearings. This species can be observed in flower from May to October.

Leavenworthia exigua* var. *lutea

Leavenworthia exigua Rollins var. *lutea*, or Tennessee gladecress, is an annual forb in Brassicaceae, the mustard family. It was last observed in Tennessee in 1989 in Maury county. This species has a southern endemic distribution. It is endemic to five counties in central Alabama (Frings et al., 2019) and two counties in central Tennessee (Weakley, In Preparation). It is ranked as S1 in Alabama and SH in Tennessee. *L. exigua* var. *lutea* occurs primarily in limestone glades, pastures, roadsides, and disturbed calcareous sites. It was first reported to occur in Tennessee on shallow depressions in cedar glade soils, about 5 cm deep, underlain by Ordovician limestone (Baskin & Baskin, 1973). *L. exigua* var. *lutea* can be observed in flower from March to April. The primary threat to this species is habitat alteration via commercial development, road widening, and the use of herbicides (NatureServe, 2019). Additional threats as a result of such alterations in the habitat include flooding by impoundment, clearcutting, construction, and competition with other plant species (NatureServe, 2019).

Rhynchospora alba

Rhynchospora alba (L.) Vahl, or white beaksedge, is a perennial graminoid in Cyperaceae, the sedge family. It was last observed in Tennessee in 1949 in Johnson county. This species has a northern extraneous distribution. Its range is circumboreal from Newfoundland (Canada) west to Alaska. From Newfoundland its range extends south along the east coast to Maryland and west to the Great Lakes Basin. From Alaska its range extends south along the west coast to southcentral California. There are disjunct occurrences from southern Virginia to southern Alabama and in one county in Colorado. This species is ranked as S1 in Colorado, Illinois, South Carolina, and Georgia; S2 in Oregon, Idaho, California, Virginia, North Carolina, and Delaware; S3 in Ohio, West Virginia, and Maryland; S5 in New York and New Jersey; and SH in Tennessee. It is listed as state endangered in one state (Illinois). This species primarily occurs in extremely open, harsh and peaty conditions such as open, acidic, bogs and poor fens on floating mats or peaty interstices of rocky shores. *R. alba* can be observed in flower from July to October. In Tennessee, *R. alba* is known from only one historical collection in the northern Unakas physiographic province (Tennessee Flora Committee, 2014). *R. alba* is thought to be primarily threatened by habitat fragmentation, land-use conversion, and pollution such as sediment and chemicals applied to Christmas tree plantations (NatureServe, 2019).

Rhynchospora latifolia

Rhynchospora latifolia (Baldw. Ex Elliott) W.W. Thomas, or sandswamp whitetop, is a perennial graminoid in Cyperaceae, the sedge family. There is no known last date of observation for this species as it is not confirmed in the state (Tennessee Flora Committee, 2014). However, a specimen reported as *Dichromena latifolia* (now *R. latifolia*) was collected in 1901 near Tullahoma, Tennessee (Coffee County) by Augustin Gattinger (FNA, 2008). This specimen was later destroyed by fire, leaving the occurrence of *R. latifolia* in Tennessee unconfirmed. This species has a southern extraneous distribution, primarily occurring in the southeastern coastal plains from southeastern North Carolina to southern Florida, west to southeastern Texas. It is disjunct in central Oklahoma and presumably in south-central Tennessee. The unconfirmed historical *R. latifolia* occurrence lies at the northernmost edge of its range. This species is ranked as S2 in Mississippi; S3 in North Carolina; and SH in Tennessee. It is not ranked as special concern, threatened, or endangered in any state. This species occurs in sandy and peaty bogs in pine savannas and flatwoods. *R. latifolia* can be observed in flower from May to September.

Rhynchospora wrightiana

Rhynchospora wrightiana Boeckeler, or Wright's beaksedge, is a perennial graminoid in Cyperaceae, the sedge family. It was last observed in Tennessee in 1935 in Bledsoe county. This species has a southern extraneous distribution occurring primarily along the southeastern coastal plain from southeastern Virginia to southern Florida, west to peninsular Florida and southern Alabama. There are disjunct inland occurrences in northwestern South Carolina and eastern Tennessee. The historical *R. wrightiana* occurrence in Tennessee lies on the northwesternmost edge of its range. This species is ranked as S1 in Virginia; S2 in Mississippi; S3 in North Carolina; and SH in Tennessee. This species occurs in sandy and peaty flatwoods, pine savannas, seeps, and along pond and stream banks. *R. wrightiana* can be observed in flower from July to September.

Scrophularia lanceolata

Scrophularia lanceolata Pursh, or lanceleaf figwort, is a perennial forb in Scrophulariaceae, the figwort family. It was last observed in Tennessee in 1947 in Johnson county. A center of distribution for this species was not assigned as *S. lanceolata* has been documented in nearly every state apart from eight southern states, Alaska and Hawaii. Its distribution ranges from northern Maine south to Virginia, west to northern New Mexico, and northwest to Washington. Occurrences in Missouri, Kansas and Oklahoma are sparse relative to surrounding states. There are disjunct occurrences in North Carolina and South Carolina. The historical occurrence in Tennessee occurs at the southeastern edge of this species's range. *S. lanceolata* is ranked as S1 in North Carolina; S2 in Kansas and Rhode Island; S3 in Wyoming, New Mexico, Maryland, and Vermont; S4 in Iowa, West Virginia and New Jersey; S5 in New York and Virginia; and SH in Tennessee, Missouri, and Delaware. It is listed as state special concern in one state (Rhode Island). *S. lanceolata* occurs in mesic to dry upland forest, open woods, shale barrens, clearings, and along roadsides. This species can be observed in flower from May to early July.

Seymeria cassioides

Seymeria cassioides (J.F. Gmel.) S.F. Blake, or yaupon blacksenna, is an annual forb in Scrophulariaceae, the figwort family. It was last observed in Tennessee in 1903 in Bradley county. This species has a southern intraneous distribution occurring primarily along the southeastern coastal plain from southeastern Virginia to central Florida, west to Louisiana. There are disjunct occurrences north-central Alabama, northwestern Georgia, and southeastern Tennessee. The historical *S. cassioides* occurrence in Tennessee lies at the northwesternmost edge of its range. *S. cassioides* is ranked as S1 in Arkansas and Virginia; S3 in North Carolina; and SH in Tennessee. It is not listed as special concern, threatened or endangered in any state. *S. cassioides* occurs in dry to moist pinelands, pine-oak woods, sandy sites and other dry woodlands. This species can be observed in flower from August to October.

Sida hermaphrodita

Sida hermaphrodita (L.) Rusby, or Virginia fanpetals, is a perennial forb in Malvaceae, the mallow family. It was last observed in Tennessee in Cocke county in 1884, in Claiborne county in 1886, in Washington county in 1890, and in Knox county in 1901. *S. hermaphrodita* has a northern extraneous distribution ranging from southeastern Pennsylvania to central Virginia, west to southeastern Indiana. There are disjunct occurrences in northwestern Ohio, northeastern Indiana, southeastern Michigan, and northeastern Tennessee. The historical *S. hermaphrodita* occurrences in Tennessee are located at the southernmost edge of its range. This species is ranked as S1 in Indiana, Virginia, and Maryland; S2 in Kentucky and Pennsylvania; S3 in Ohio and West Virginia; and SH in Tennessee. *S. hermaphrodita* is listed as special concern in Kentucky. Indiana, Maryland, and Pennsylvania have listed this species as endangered. *S. hermaphrodita* is considered rare throughout its range; however, in parts of Ohio, Kentucky, and West Virginia it is locally abundant, primarily in non-natural habitat (NatureServe, 2019). *S. hermaphrodita* occurs in sandy or rocky areas along roadsides, railroad embankments, disturbed sites, and periodically flooded streambanks. It can thrive in unnaturally disturbed sites, however most of its natural habitat throughout its range has been destroyed via flood control and development along river corridors (NatureServe, 2019). This species can be observed in flower from July to August. *S.*

hermaphrodita is threatened by trampling, use of herbicides, road widening, flood control, and competition from invasive plant species (NatureServe, 2019).

Silene regia

Silene regia Sims, or royal catchfly, is a perennial forb in Caryophyllaceae, the pink family. This species was last observed in Tennessee in Knox county in 1902 and in Marion county in 1960. *S. regia* has a midwestern extraneous distribution ranging from eastern Kansas to Ohio, south to peninsular Florida. Its distribution is concentrated in the central midwestern states with disjunct occurrences in Tennessee, Alabama, Georgia, and Florida. This species appears to be most abundant in Missouri (NatureServe, 2019). Historical *S. regia* occurrences in Tennessee are located towards the easternmost edge of its range. This species is ranked as S1 in Oklahoma, Illinois, Kentucky, Mississippi, and Georgia; S2 in Arkansas, Indiana, Ohio, and Alabama; S3 in Missouri; and SH in Tennessee and Kansas. *S. regia* is listed as state threatened in Ohio and Arkansas and as state endangered in Indiana, Georgia, Kentucky, and Illinois. This species occurs in both dry and wet prairies, meadows, open woods, glades, barrens, woodland edges and thickets, and along roadsides; *S. regia* frequently occurs in calcareous soils (Edgin & Mankowski, 2013). This species can be observed in flower from July to August. Many remnant *S. regia* populations occur along roadsides where they are threatened by construction or changes in roadside vegetation management regimes (NatureServe, 2019). The largest threat to *S. regia* is habitat destruction or conversion; lesser threats include fire suppression, depredation and browsing, and woody encroachment as *S. regia* individuals appear smaller and produce fewer flowers in shaded conditions (Edgin & Mankowski, 2013).

Tetragonotheca helianthoides

Tetragonotheca helianthoides L., or pineland nerveray, is a perennial forb in Asteraceae, the aster family. This species was last observed in Tennessee in Blount county in 1968 and in Knox county in 1905. *T. helianthoides* has a southern extraneous distribution along the southeastern coastal plain from Mississippi to central Florida, north to southeastern Virginia with disjunct occurrences in east Tennessee. Historical *T. helianthoides* occurrences in Tennessee are located at the northwesternmost edge of its range. This species is ranked as S1 in Virginia; S3 in North Carolina; and SH in Tennessee. *T. helianthoides* is not listed as special concern, threatened or endangered in any state. It occurs in sandy and rocky soils of sandhills, woodlands, open hammocks, thickets, and roadsides. *T. helianthoides* can be observed in flower from April to July.

CHAPTER III

SPECIES DISTRIBUTION MODELING OF HISTORIC SPECIES IN TENNESSEE USING HERBARIUM SPECIMENS

Introduction

SDMs are a method for quantifying complex distribution patterns of species by integrating known occurrences with meaningful environmental variables that influence their distribution (Elith & Leathwick, 2007; Guisan & Zimmermann, 2000; Miller, 2010). With the development of analytical tools to predict the occurrence of species from environmental variables, SDMs have become an effective tool in spatial ecology, biogeography, conservation biology, climate change research, and land management practices (Graham et al., 2004; Guisan & Thuiller, 2005; Guisan & Zimmermann, 2000; Newbold, 2010).

Methods for SDMs can be separated into two general categories: modeling methods that require presence and absence data and modeling methods that use presence-only data as a basis for generating predictions (Elith et al., 2006; Tsoar et al., 2007). Unlike presence-absence data, presence-only data indicate locations where a species is observed to occur; it cannot be used to determine locations in which the species does not occur. Modeling techniques that utilize pseudo-absence data have been developed, however these methods are still classified as presence-only models because they do not utilize real absence data to construct the model (Tsoar et al., 2007). In most cases, resources are too limited to allow large datasets including presences and absences to be gathered and therefore SDMs have relied heavily on presence-only data in the form of occurrence records from natural history collections, such as herbaria (Elith & Leathwick, 2007; Graham et al., 2004; Ponder et al., 2001).

With new developments in museum-based informatics, herbarium specimens have been recognized as records of fundamental importance for biodiversity analysis and conservation. In addition to the preserved specimens themselves, herbaria contain vast amounts of information on the specific place and point in time the collection was made. These data are recorded on the specimen's label, and in aggregate may be used to assess the distributions of species. For example, SDMs can be trained using specimen occurrence data extracted from specimen labels to predict species' distributions by quantifying the correlation between species occurrences and environmental variables (Elith & Leathwick, 2007; Guisan & Zimmermann, 2000; Miller, 2010). As of December 2019, 392,353,689 specimens are held in 3,324 herbaria worldwide containing well documented records of plant distributions through time and space (Index Herbariorum, 2020). Over the last 10 years, herbarium specimens have become increasingly accessible through online portals such as the Global Biodiversity Information Facility (GBIF), the Southeast Regional Network of Expertise and Collections (SERNEC), the Consortium of Midwest Herbaria, the Mid-Atlantic Herbaria Consortium, the Great Plains Regional Herbarium, and the North American Network of Small Herbaria.

Species Distribution Models for Rare Species

In recent times, SDMs have become a useful tool in the conservation of rare, threatened, and endangered species, which is often a difficult task due to incomplete knowledge of their biology and distributions (Gogol-Prokurat, 2011; Wang et al., 2019). Collecting enough data from in-depth species surveys to characterize species ranges is an impractical and expensive task and often, the time sensitiveness of conservation planning does not allow land managers to wait until enough information is available to make conservation decisions (Marcer et al., 2013). Marcer et al. (2013) suggest that combining expert judgement with modeling techniques may be the best strategy to mitigate these challenges. In addition, many software packages for conducting SDMs are free, open source and can be used without incurring additional costs (Fois et al., 2015). SDMs are well suited for species in need of conservation because they are able to illustrate key associations between landscape characteristics and the occurrence of a species. Furthermore, SDMs help predict suitable habitat, allowing land managers to focus survey and research efforts on areas having a greater likelihood of occurrence of such species for more effective conservation planning (Wang et al., 2019).

However, modeling rare species can be difficult. Rare species are characterized by restricted geographic ranges, habitat specialization, and small population sizes (Aitken et al., 2007). Consequent to their rarity, datasets for such species' distributions are characterized by few observations, gathered over long time periods with limited spatial accuracy, and lack valid absences (Engler et al., 2004). While rare species have the most need for predictive distribution modeling, they may also be the most difficult to model, a contradiction in which Lomba et al. (2010) refers to as the "rare species modeling paradox." While modeling rare species poses difficulties, several studies have successfully applied SDM techniques to existing species occurrence data to predict species distributions despite the data being limited and presence-only (Elith et al., 2006; Gogol-Prokurat, 2011; Phillips & Dudík, 2008; Razgour et al., 2011; Rebelo & Jones, 2010; Williams et al., 2009).

Due to their ability to highlight niche requirements as well as predict species' potential distributions, the use of SDMs has been gaining interest for conservation approaches. Such efforts include: guiding searches for unknown populations by identifying unsurveyed areas with a high potential of rare species occurrence (Bourg et al., 2005; de Siqueira et al., 2009; Elith et al., 2006; Engler et al., 2004; Fois et al., 2015; Guisan et al., 2013; Stratmann et al., 2016; Williams et al., 2009), determining areas of suitable habitat for restoration or reintroduction (McKenna et al., 2013; Wang et al., 2015, 2019; Wiser et al., 1998), supporting conservation planning and reserve selection (Ferrier, 2002), assessing the threat of invasive species (Alley, 2019; Peterson, 2003) and modeling global warming responses (Gómez-Mendoza & Arriaga, 2007; Iverson et al., 2004). Several studies have been able to document previously unknown populations of rare plant species in locations where SDMs predicted a high degree of habitat suitability (Elith et al., 2006; Elith & Burgman, 2002; Engler et al., 2004; Marage et al., 2008; Williams et al., 2009). These results indicate that SDMs are capable of successfully predicting rare plant occurrences at high habitat suitability values determined by SDMs. Furthermore, SDMs can be useful as a tool to significantly reduce the extent of field surveys and the required efforts related to time and economic resources (Fois et al., 2015).

Utilizing Presence Only-Data from Herbarium Specimens for Predictive Modeling

As herbarium collections are becoming increasingly available in online databases, locality data from herbarium specimens are being used as input for predictive models due to their accessibility and cost effectiveness. Locality data extracted from herbarium specimens are inherently presence only data, i.e., herbarium specimens provide information only on where a species is present and not where it is absent. In light of this increasingly available resource, several modeling techniques have been developed which utilize presence-only data (Elith & Leathwick, 2007; Graham et al., 2004; Miller, 2010; Tsoar et al., 2007).

However, the use of presence-only data in the form of herbarium specimens has implications on the accuracy of predictive models. First, if presence data are absent from an environmentally suitable area, for example an area where past disturbances have caused local extinctions or an area that has not been sampled, the distribution of the presence records will suggest the environmentally suitable area is unsuitable (Elith et al., 2011). Furthermore, the number of occurrence points used to develop an SDM may greatly influence the model's prediction accuracy and therefore under-collected species can be difficult to model (Stockwell & Peterson, 2002).

Second, presence-only models may reflect sample bias associated with herbarium specimens. The majority of herbarium specimens have been collected for qualitative taxonomic and systematic studies and therefore have been primarily collected non-randomly and sampling designs have often not been quantified leading to spatial biases (Daru et al., 2018). Spatial bias is the unbalanced sampling across the landscape, typically due to accessibility or an area of interest to a particular study. Sampling is often biased towards areas which are easily, or frequently accessed by researchers such as: roadsides, rivers, towns, cities, nearby herbaria, or in protected lands (Daru et al., 2018; Graham et al., 2004; Newbold, 2010). For applications of herbarium specimens involving analyses of the environment a species inhabits, spatial bias could potentially lead to environmental bias, meaning the full range of environments a species could inhabit is not proportionately covered by the spatially biased sample (Newbold, 2010; Phillips et al., 2009). However, some studies have shown that museum records may be spatially biased without introducing major environmental bias (Newbold, 2010).

Third, presence-only data in the form of herbarium specimens may have errors associated with locality data and, furthermore, precise locality data can be difficult to extract from the specimen (Graham et al., 2004; Newbold, 2010). Herbarium specimens typically contain a textual description of the locality from which the specimen was collected. However, in the past, geographical coordinates were only occasionally recorded, and recorded geographic coordinates with high precision are typically available only for specimens collected within the last 20 years. Moreover, textual locality descriptions range from extremely precise, detailed locations to very broad, unspecific locations. Recently, there has been an effort to assign geographical coordinates to records, a process referred to as 'georeferencing' (Hill et al., 2009; Newbold, 2010). However, when georeferencing a specimen's locality, the accuracy of the assigned geographic coordinates relies heavily on the precision and specificity of the textual locality description (Daru et al., 2018; Graham et al., 2004; Newbold, 2010). For example, one *Seymeria cassioides* (Fabaceae) specimen locality reads "Alabama. St. Clair County. 3.5 air miles north of Wattsville. West side of U.S. 231, about 2 miles south of junction with County Road 22" while another specimen locality simply reads "Florida. Franklin County. Apalachicola." The first specimen's textual locality description would allow for a reasonably accurate geographic coordinate assignment. However, when georeferencing the second specimen, it would be impossible to assign accurate geographic coordinates based on the vagueness of the textual locality description. For spatial studies using herbarium specimens where the precise location of occurrence is needed, the usable data may be significantly less than the total available data due to having to exclude specimens which do not contain precise, detailed locality descriptions.

Despite the disadvantages associated with using presence-only data, they have been shown to be useful in developing effective predictive models (Elith et al., 2006; Elith & Leathwick, 2007). Presence-only data are easily accessible through online data portals and are less expensive and labor intensive to obtain than presence-absence data (Newbold, 2010; Tobler et al., 2007). Furthermore, reliable absence data are more difficult to obtain than reliable presence data (Jiménez-Valverde et al., 2008). Presence-only data are a valuable resource in SDMs, provided that the challenges associated with this type of data are well understood and mitigated when possible.

Maximum Entropy Modeling

Maximum Entropy (MaxEnt) is a complex machine learning model the uses an iterative approach to approximate species distributions based on the principle of maximum entropy, in which habitat suitability is predicted across the landscape based on the values of environmental variables at known occurrence locations (Phillips et al., 2006). MaxEnt models are based on presence-only data; absence data are compensated for by randomly selecting background points from the area of interest to characterize the range and variation of the environmental variables available within the range of a species, rather than requiring the user to select pseudo-absence points (Stratmann et al., 2016). MaxEnt compares the environment in areas with known species occurrence to the environment available to it (background points) in order to identify preferences of species for certain ranges of environmental variables (Stratmann et al., 2016). The direction and strength of these preferences allows for predictions on the probability of suitable conditions in unsurveyed areas (Stratmann et al., 2016). This modeling method has been shown to outperform other methods (e.g. generalized linear models, generalized additive models, multivariate adaptive regression splines, and boosted regression trees) and has consistently high accuracy when available species occurrence data are limited (Elith et al., 2006; Hernandez et al., 2006; Wisz et al., 2008). Furthermore, MaxEnt is a generative approach, rather than discriminative, which is advantageous when the amount of training data (species occurrences) is limited (Phillips et al., 2006).

Consequently, MaxEnt is one of the most applied methods for modeling species distributions with limited presence data and typically outperforms other presence-only modeling methods (Elith et al., 2006; Fois et al., 2015; Wisz et al., 2008). MaxEnt is optimal for modeling rare species for several reasons. (1) It is a presence-only method that does not require the identification of absence locations (Phillips et al., 2006). (2) It can incorporate both continuous (e.g. precipitation and elevation) and categorical (e.g. land cover and soil) environmental data (Phillips et al., 2006). (3) Model prediction remains robust at sample sizes as small as 10 occurrences (Hernandez et al., 2006; Wisz et al., 2008). (4) The output is continuous, allowing the user to make fine distinctions between the modeled suitability of different areas (Phillips et al., 2006). (5) It has consistently superior habitat suitability discrimination success compared to other predictive modeling methods (Elith et al., 2006; Guisan et al., 2007; Wisz et al., 2008).

The objectives of this study are to (1) create SDMs using digitized herbarium specimens to indicate the potential distribution of historical angiosperms in Tennessee; (2) identify the environmental variables that most significantly influence the distribution of each species based on the model's output; (3) build an "environmental profile" for each species indicating suitable habitat in Tennessee based on the environmental variables used in the SDM; (4) identify areas of suitable habitat for each species located within Tennessee's protected areas. Through the completion of these four objectives, the overarching goal for this work is to provide Tennessee's conservation managers with data to restrict survey efforts to areas with suitable, legally protected habitat thereby increasing survey efficiency and reducing sampling costs to rediscover Tennessee's historical angiosperms. Additionally, these data could be used to identify areas with highly suitable habitat for the potential reintroduction or relocation of such species.

Methods and Materials

Acquisition of Herbarium Specimen Data

Occurrence data in the form of digitized herbarium specimens were obtained from the SERNEC data portal for 21 Tennessee historical angiosperm species. These occurrence data were used as input occurrence points for SDMs. The initial SERNEC query was limited to herbarium specimens collected in Tennessee, which returned only 16 of the 21 species (Table 3.1). Of those 16 species, only one species, *L. exigua* var. *lutea*, had sufficient occurrence records to be suitable for modeling (Table 3.1).

Table 3.1 Tennessee historical species with available digitized herbarium specimens collected in Tennessee

Species	**Specimens in Tennessee**
Agalinis setacea	7
Agrostis mertensii	1
Carex alopecoidea	1
Carex sterilis	4
Clematis pitcheri	8
Crotalaria purshii	2
Helianthemum bicknellii	4
Helianthemum canadense	4
Juncus trifidus	3
Lachnocaulon anceps	1
Leavenworthia exigua var. *lutea*	96
Rhynchospora alba	1
Scrophularia lanceolata	2
Sida hermaphrodita	2
Silene regia	3
Tetragonotheca helianthoides	1

Due to the limited number of herbarium specimens returned from the initial SERNEC query, the study area extent was widened to include any U.S. state sharing at least one EPA Level III Ecoregion with Tennessee. This resulted in an expanded study area consisting of Tennessee and an additional 17 states (AL, AR, FL, GA, IL, IN, KY, LA, MS, MO, NY, NC, OH, PA, SC, VA, and WV). A second SERNEC query was conducted to include the additional states and it resulted in 8,339 occurrence records across the 21 historical species.

Data Cleaning

The data cleaning process began by filtering the 8,339 initial occurrence records by date, selecting only herbarium specimens with collection dates not preceding 1990, based on the assumption that herbarium specimens collected prior to 1990 would not contain sufficiently precise GPS coordinates on the specimen labels. Filtering by date returned a total of 1,616 herbarium specimens from post-1990. However, during the digitization process, label data from many herbarium specimens were only minimally transcribed, focusing on so-called "skeletal data" such as the taxonomic identification of the specimen and the state and county from which the specimen was collected. A total of 3,193 herbarium specimens for which the collection date was not transcribed were individually evaluated for inclusion in the dataset. After filtering the dataset, each herbarium specimen image was inspected to determine if the specimen's label contained GPS coordinates. If the label contained GPS coordinates, the coordinates were converted to decimal degrees and recorded. During this process, if a specimen label did not contain GPS coordinates, but contained a descriptive locality string, the specimen was manually georeferenced using Google Earth Pro version 7.3.2.

During the data cleaning process, the initial dataset of 8,339 was reduced by 91%, resulting in 756 occurrence records containing spatial data. Specimen records having coordinates extracted directly from the label data accounted for 74% of the final dataset (558 records), while specimen records which were georeferenced to obtain longitude and latitude coordinates for this study accounted for the remaining

26% (198) records. Each species had an average of 27 specimen records containing label coordinates and nine records with georeferenced coordinates for an average of 36 total specimen records per species. The final dataset obtained after increasing study area, filtering by collection date, extracting coordinates from label data, and georeferencing is summarized in Table 3.2. This dataset contained only 47 occurrence records collected within the political boundary of Tennessee, 39 of which were *Leavenworthia exigua* var. *lutea*, a species endemic to two counties in central Tennessee (Weakley, In Preparation) and five counties in central Alabama (Frings et al., 2019). Occurrence points for only four other species were located in Tennessee. *Agalinis setacea* had five occurrence points in Tennessee while *Agrostis mertensii*, *Carex alopecoidea*, and *Juncus trifidus* each had one occurrence point in the state.

Table 3.2 Summary of the final herbarium specimen records, including pre-data cleaning and post-data cleaning datasets. Daggers denote species with enough records to model distributions.

Species	Records Prior to Data Cleaning	Records Containing Label Coordinates	Georeferenced Records	Total Records	Percentage of Initial Dataset
Agalinis setacea†	449	37	10	47	10%
Agrostis mertensii	26	0	5	5	2%
Calopogon oklahomensis	62	1	11	12	19%
Carex alopecoidea†	139	14	18	32	23%
Carex sterilis†	301	28	5	33	11%
Carex vestita	191	1	0	1	19%
Clematis pitcheri†	318	21	9	30	9%
Crotalaria purshii†	638	34	6	40	6%
Helianthemum bicknellii†	347	17	17	34	10%
Helianthemum canadense†	590	31	4	35	6%
Juncus trifidus	35	3	1	4	11%
Lachnocaulon anceps†	1559	110	1	111	7%
Leavenworthia exigua var. *lutea*†	183	22	29	51	28%
Rhynchospora alba†	316	22	11	33	10%
Rhynchospora latifolia†	674	37	3	40	6%
Rhynchospora wrightiana†	370	46	1	47	13%
Scrophularia lanceolata†	741	19	10	29	4%
Seymeria cassioides†	742	75	9	84	11%
Sida hermaphrodita	98	1	16	17	17%
Silene regia†	169	14	25	39	23%
Tetragonotheca helianthoides†	391	25	7	32	8%
Total for all species	**8339**	**558**	**198**	**756**	**9%**

Species Selection

A study by Pearson et al. (2007) assessed the ability of two modeling algorithms (MaxEnt and GARP) to predict species occurrence with fewer than 25 occurrence records. The results of this study found high success rates and statistical significance with sample sizes as low as five, supporting the use of MaxEnt when sample sizes are small (Pearson et al., 2007). Similarly, a study by Wisz et al. (2008) found that for exploratory modelling with sample sizes between 10 and 30 records, MaxEnt had the best performance power across all sample sizes. Based on these results, a minimum sample size of 25 records was selected as the threshold for this study. Of the 21 historical angiosperm species in Tennessee, five species did not meet this criterion and therefore were not modeled in this study. The final dataset used to train the MaxEnt models ranged from 29 occurrences points (*S. lanceolata*) to 111 occurrence points (*L. anceps*) with an average sample size of 45 occurrence records (Table 3.2).

Environmental Variable Selection and Processing

An environmental dataset consisting of land cover, solar radiation, climate, soil, and topography variables were selected to model each species' distribution. Land cover data were obtained from the GAP/LANDFIRE National Terrestrial Ecosystems dataset (U.S. Geological Survey Gap Analysis Program, 2011). Climate data comprised of 19 bioclimatic variables representing annual trends, seasonality, and extreme or limiting factors were obtained from the WorldClim Dataset Version 2.0 (Fick & Hijmans, 2017). To reduce collinearity effects on the model, a correlation analysis of the 19 bioclimatic variables was performed using ENMtools (Warren et al., 2009) and highly correlated variables were removed. The following bioclimatic variables were used to develop the models: BIO1 (Annual Mean Temperature), BIO2 (Mean Diurnal Range), BIO7 (Temperature Annual Range), BIO12 (Annual Precipitation), and BIO15 (Precipitation Seasonality). Additionally, average monthly solar radiation (kJ m^{-2} day^{-1}) was obtained from the WorldClim Dataset (Fick & Hijmans, 2017). The Raster Calculator tool was used in ArcGIS Pro Version 2.4.0 to find the mean annual solar radiation (kJ m^{-2} day^{-1}). Soil pH data were obtained from the International Soil Reference and Information Centre (ISRIC) Soil Data Hub (Kempen et al., 2019) and Web Soil Survey (WSS) data were obtained from the Natural Resource Conservation Service (NRCS) (Web Soil Survey Staff, 2019). Elevation data were obtained from the U.S. Geological Survey's (USGS) 3D Elevation Program (3DEP) (U.S. Geological Survey, 2017). Using the Slope and Aspect function in ArcGIS Pro, aspect and slope were calculated from the USGS digital elevation model.

Initially, each species was modeled using the complete set of environmental variables. Based on Worthington's (2016) approach, optimum environmental variables were selected for each species by stepwise removal of variables having 0% contribution to the model (Wei et al., 2018). In this way, extraneous variables that could potentially obscure the effects of significant variables, add noise to the predictive models, and increase the over-parametrization of the models were removed (Warren & Seifert, 2011; Wei et al., 2018; Worthington et al., 2016; Zeng et al., 2016). As required by MaxEnt for model execution, all environmental variables were modified in ArcGIS Pro to have the same extent, cell size (30m x 30m), and projection system and were converted to ASCII format.

Accounting for Sample Bias

Without correcting for sample bias, presence-only models may reflect survey effort rather than the distribution of the species (Phillips et al., 2009). To correct for sample bias, some studies have manipulated the background data by selecting background points that reflect the same sample selection bias as the occurrence points. (Engler et al., 2004; Ferrier, 2002; Zaniewski et al., 2002). The thought with this approach is that a model based on presence and background data with the same bias will focus on any differentiation between the distribution of the occurrences and the background, rather than focusing on the sample selection bias (Phillips et al., 2009). For example, one study randomly sampled 10,000 pseudo-absences within 100 km – 500 km buffers around occurrences and used these points as background samples to reflect any sample bias associated with the occurrence points (Fourcade et al., 2014).

Another approach is spatial thinning where occurrences are filtered to create a dataset that is more uniformly distributed in space. This can be done by spatially stratified subsampling or setting a minimum distance between occurrence points (Aiello-Lammens et al., 2015). Spatial thinning is a frequently applied method and has shown to result in better performing SDMs (Boria et al., 2014; Fourcade et al., 2014; Pearson et al., 2007; Verbruggen et al., 2013; Vollering et al., 2019). Unlike target-group background selection, spatial thinning does not make storing assumptions about the true sampling probability distribution and are less likely to overcorrect for sampling bias (Vollering et al., 2019). Using this spatial thinning approach, occurrence points for each species were filtered to obtain the maximum number of occurrences that were at least 5 km apart (Aiello-Lammens et al., 2015; Boria et al., 2014; Fourcade et al., 2014; Pearson et al., 2007).

Preliminary model prediction results indicated significant bias towards “Developed and Urban” pixels in the GAP 2011 land cover layer, presumably due to collection bias along roadside, by development since the time when the specimens were collected, or by inaccurately georeferencing specimens collected in areas proximal to roadways. For example, the results of a preliminary model for *Tetragonotheca helianthoides* revealed that of the 1,515 km^2 of predicted suitable habitat in Tennessee, 100% of the land cover was categorized as “Developed and Urban.” Further analysis of occurrence points’ distribution across the GAP 2011 land cover layer revealed that 23.71% of the occurrence points were located within the “Developed and Urban” land cover class (Table 3.3). The percentage of points located within this land cover class ranged from 6.06% (*Rhynchospora alba* and *Carex sterilis*) to 45.10% (*Leavenworthia exigua* var. *exigua*).

Table 3.3 Percentage of occurrence points located within “Developed and Urban” GAP 2011 land cover class

Species	Occurrence Points	Percentage of Points in “Developed and Urban” Class
Agalinis setacea	47	19.15%
Carex alopecoidea	32	28.13%
Carex sterilis	33	6.06%
Clematis pitcheri	30	26.67%
Crotalaria purshii	40	22.50%
Helianthemum bicknellii	34	23.53%
Helianthemum canadense	35	14.29%
Lachnocaulon anceps	111	18.92%
Leavenworthia exigua var. *lutea*	51	45.10%
Rhynchospora alba	33	6.06%
Rhynchospora latifolia	40	17.50%
Rhynchospora wrightiana	47	29.79%
Scrophularia lanceolata	29	17.24%
Seymeria cassioides	84	28.57%
Silene regia	39	30.77%
Tetragonotheca helianthoides	32	37.50%
Total	**717**	**23.71%**

Although roadside collection bias is one of the most recognized forms of bias in distributional data, the degree to which roadside bias affects the performance of distribution models is unknown (Kadmon et al., 2004). A study by Kadmon et. al (2004) suggests correcting for roadside bias by removing points collected along roadsides from the dataset. However, due to the limited sample sizes in this study, removing roadside occurrences from the dataset was not feasible. To account for collection bias, roadside points located within “Developed and Urban” land cover pixels were shifted to the nearest non-Developed and Urban land cover pixel. A total of 170 points located within “Developed and Urban” pixels were adjusted by an average distance of 46 meters. The distance adjusted ranged from 3 meters (*A.*

setacea) to 306 meters (*S. regia*). To our knowledge, no study has used this method to correct for roadside bias opting instead to omit roadside collections. However, MaxEnt does not appear to be heavily influenced by moderate spatial error associated with occurrence data and is particularly robust to error compared to other modeling algorithms. A study comparing the influence of spatial errors on different modeling algorithms found that location errors up to 5 kilometers, using 100 meter data, appeared to have no impact on MaxEnt model performance, indicating MaxEnt's ability to produce useful species distribution predictions even when occurrence data include moderate levels of spatial error (Graham et al., 2007). In this study, the maximum distance adjusted was 306 meters (0.3 kilometers) (Table 3.4).

Table 3.4 Summary of the total number of occurrence points adjusted and the average, minimum and maximum distance in meters adjusted for each species

Species	Number of Occurrence Points Adjusted	Average Distance Adjusted	Minimum Distance Adjusted	Maximum Distance Adjusted
Agalinis setacea	9	43.99	2.96	227.45
Carex alopecoidea	9	35.26	5.46	71.77
Carex sterilis	2	39.58	36.90	42.25
Clematis pitcheri	8	36.02	7.98	67.08
Crotalaria purshii	9	13.85	4.14	39.23
Helianthemum bicknellii	8	45.72	8.08	123.50
Helianthemum canadense	5	30.34	21.57	39.07
Lachnocaulon anceps	21	41.76	6.74	166.43
Leavenworthia exigua var. *lutea*	23	107.10	4.46	288.94
Rhynchospora alba	2	45.94	4.57	105.81
Rhynchospora latifolia	7	25.77	12.03	59.78
Rhynchospora wrightiana	14	42.63	5.31	109.24
Scrophularia lanceolata	5	57.64	11.12	99.40
Seymeria cassioides	24	29.33	6.40	79.09
Silene regia	12	44.18	8.75	306.27
Tetragonotheca helianthoides	12	23.26	3.93	52.55

Model Algorithm and Settings Selection

MaxEnt (version 3.4.1), a complex machine learning algorithm created by Phillips et al. (2004), was used to model the potential distribution of each study species in Tennessee. MaxEnt estimates species' distributions by finding the distribution with maximum entropy subject to constraints obtained from environmental conditions at known occurrence points (Phillips et al., 2006). In recent years, MaxEnt has been one of the most widely used modeling algorithms and has proved to be useful in conservation applications for modeling species distributions with scarce presence-only data (Elith et al., 2006; Fois et al., 2015; Hernandez et al., 2006; Pearson et al., 2007; Phillips et al., 2006; Rebelo & Jones, 2010; Stratmann et al., 2016). MaxEnt's modeling approach is generative, rather than discriminative, which is an inherent advantage in the case of limited training data (occurrence points) (Phillips et al., 2006). Furthermore, MaxEnt has been able to predict new localities for poorly documented species (Engler et al., 2004; Marage et al., 2008; Pearson et al., 2007; Rebelo & Jones, 2010; Williams et al., 2009). MaxEnt's output is continuous, which allows the user to make fine distinctions to be made between the predicted habitat suitability. In addition, this continuous output gives the user flexibility when selecting suitability thresholds for creating binary maps (Phillips et al., 2006).

MaxEnt settings for initial models were selected based on guidelines published by Young et al. (2011) and adjusted as necessary. Recommended default values were used for the convergence threshold (10^{-5}) (Phillips et al., 2006) and maximum number of iterations was increased from the default value of 500 to 5,000 to allow the model adequate time to converge, reducing the likelihood of over-predicting or under-predicting relationships between occurrences and environmental variables (Young et al., 2011). Analysis of variable importance was measured using jackknife, response curves and random seed (Young et al., 2011). Features were set to default allowing MaxEnt to automatically select the feature type based on the number of occurrence points (linear is always used; quadratic is used with at least 10 samples; hinge with at least 15 samples; threshold and product with at least 80 samples) (Elith et al., 2011). The default value of 10,000 random background samples was used (Elith et al., 2011). MaxEnt output was set to “logistic” output format resulting in a habitat suitability map ranging from values of 0 to 1 per grid cell where values closer to 1 indicated higher habitat suitability (Phillips, 2010; Phillips & Dudík, 2008).

Due to its ability to fit complex responses, MaxEnt has the potential to produce overfit models (Phillips & Dudík, 2008; Radosavljevic & Anderson, 2014). Overfitting occurs when a model fits the calibration data too closely and fails to predict independent evaluation data accurately (Radosavljevic & Anderson, 2014). In order to control overfitting and achieve an optimal level of model complexity, a relaxation component, called regularization, has been added to MaxEnt (Anderson & Gonzalez, 2011; Hernandez et al., 2006). The regularization multiplier adds new constraints to the model in order to reduce over-complexity and overfitting by controlling the intensity of the chosen feature classes used to build the model (Morales et al., 2017). Increasing the regularization multiplier penalizes model complexity, producing simpler models that are more biologically interpretable and transferable (Worthington et al., 2016). Overfitting evaluation and optimization was conducted by evaluating the difference between calibration (training data) and evaluation (test data) area under the receiver operating characteristic (ROC) curve values, or AUC, based on the assumption that overfit models will generally perform well on training data but poorly on test data (Radosavljevic & Anderson, 2014; Springer et al., 2015; Warren & Seifert, 2011). Similar to trends found by Radosavljevic and Anderson (2004), for initial models the difference between training and test AUC values was relatively high at the default regularization multiplier (1.0), decreased as the regularization multiplier was increased at intervals of 0.5, and leveled off with a regularization multiplier value of 4.0. For all final models the regularization multiplier was set to 4.0.

Model Evaluation and Analysis

To evaluate model performance, the replicated run type “cross-validation” was selected as suggested by Pearson et al. (2007) for modeling small sample sizes. Using cross-validation, occurrence data is randomly partitioned into a number of equal-size bins or “folds” and models are created by leaving out each fold in turn which is then used for model evaluation (Phillips, 2010). This replicated run type is preferred for small sample sizes because it uses all of the data for validation as opposed to setting aside a predetermined percentage of the data for validation (Phillips, 2010). Across ten replications, each replicate was run using a different set of randomly selected occurrence points to calibrate (train) and evaluate (test) the model.

The 10-fold average test AUC was used to measure the ability of a model to discriminate between sites where a species is present, versus sites where it is absent. The AUC has been used extensively as a measure of the discrimination ability of SDMs (Elith et al., 2006; Gogol-Prokurat, 2011; Hernandez et al., 2006; Rivera & López-Quílez, 2017; Rushton et al., 2004; Wang et al., 2019). AUC values can be interpreted as the probability that a presence chosen at random will be assigned a higher habitat suitability value than an absence chosen at random and therefore are used as a measure of the model's overall performance (Elith et al., 2006; Gogol-Prokurat, 2011; Hernandez et al., 2006; Phillips et al., 2006). AUC values range from 0 to 1, where values < 0.5 indicate performance worse than random, a value of 0.5 implies discrimination is no better than random chance, and a value of 1 indicates perfect discrimination (Elith et al., 2006; Hernandez et al., 2006). Given the large variation in sample sizes across species, the Pearson correlation coefficient was calculated to measure the statistical relationship between sample size and AUC value.

To simplify the visualization and analysis of predicted distributions, model predictions were converted from continuous output to a binary map by applying a suitability threshold value to distinguish suitable habitat from unsuitable habitat. Often, a threshold value of 0.5 has been used, however this threshold value is arbitrarily selected and does not necessarily preserve the observed prevalence (the overall proportion of locations where the species is observed to be present), especially when using datasets with very high or very low observed prevalence (Freeman & Moisen, 2008). Objective approaches such as maximizing agreement between observed and predicted distributions or metrics quantifying the trade-off between sensitivity and specificity are preferred for threshold value selection

(Liu et al., 2005). Three potential threshold values, varying in conservativeness, were selected to create binary habitat suitability maps for this study.

Minimum training presence (MTP) is the logistic threshold resulting in the inclusion of all training presences, ensuring a zero omission rate (no false-negative predictions) (Marcer et al., 2013; Pearson et al., 2007). MTP is the least conservative threshold value, including all sites that are at least as suitable as sites where the species has been recorded as present (Pearson et al., 2007); however, the use of this threshold value has been successful in guiding field surveys resulting in the discovery of unknown localities for rare species (Fois et al., 2015). The 10th percentile training presence (10PTP) threshold selects the value that excludes the 10% of the localities having the lowest predicted values as the threshold (Rebelo & Jones, 2010). This commonly used threshold value is more restrictive than MTP and is particularly useful when outliers or inaccurately georeferenced points are present in the training data (Raes et al., 2009; Rebelo & Jones, 2010). Maximum test sensitivity plus specificity (MSS) threshold value is that which maximizes the sum of sensitivity (proportion of observations correctly predicted as presence) and specificity (proportion of observation correctly predicted as an absence) (Liu et al., 2005, 2013). MSS is more conservative than the MTP and 10PTP thresholds and is recommended for use when possible as it optimizes the discrimination between presence and absence and minimizes the rate of both false-positives and false-negatives (Liu et al., 2013).

The conservativeness of each threshold value was used to delineate habitat as minimally suitable (MTP), moderately suitable (10PTP) and highly suitable (MSS) for each species. For all three thresholds, any predicted suitable habitat falling within the Developed and Urban low-, medium-, or high-intensity land cover classes was removed based on the assumption that these rare species would not realistically occur in such areas having low quality habitat. Then, the area of minimally, moderately, and highly suitable habitat was calculated to evaluate the extent of suitable habitats in Tennessee for each species. In addition, the area of suitable habitat contained within protected land was calculated to determine the amount of suitable habitat within areas where conservation efforts could be maximized for each species. Finally, the area of suitable habitat contained within the last known county of observation and any adjacent counties was calculated for each species to identify suitable habitat predicted within relative proximity to each last known observation. All area calculations were performed in ArcGIS Pro. Data on protected areas in Tennessee were obtained from the Protected Areas Database of the United States (PAD-US version 2.0) (U.S. Geological Survey Gap Analysis Project, 2018).

Analysis of Variable Contribution and Environmental Profile

During a model run, MaxEnt estimates the importance of the variables used in the model with percent contribution and permutation importance values. Percent contribution is heuristically defined; it represents how much the variable contributed to the model based on the path selected for a particular run, a second run might use a different path and ultimately result in different percent contributions (Phillips, 2010; Songer et al., 2012). In contrast, permutation importance randomizes the values for each environmental variable between presence and background points and then measures the resulting drop in the AUC (Phillips, 2010; Searcy & Shaffer, 2016; Songer et al., 2012). The greater the drop in AUC, the more important that variable is to the overall model (Phillips, 2010). Permutation importance is better suited to evaluate the importance of a particular variable since this value depends on the final model, not the path used in an individual model run (Phillips, 2010; Searcy & Shaffer, 2016; Songer et al., 2012; Wei et al., 2018). For all variables, both percent contribution and permutation importance are reported, however assessment of variable importance is based solely on permutation importance.

To build an environmental profile for each species, the binary habitat suitability maps were used to extract cell values from the environmental variable rasters containing predicted suitable habitat in Tennessee. For continuous variables, statistics were calculated in ArcGIS Pro. For categorical variables, the values extracted from the environmental variable rasters were exported into Excel for further analysis. The minimum, maximum, mean, median, and mode of each environmental variable are reported for continuous variables. For categorical variables, the three most frequently occurring categories and the frequencies at which they occur are reported as percentage of suitable habitat. The following continuous variables were examined for each species: Annual mean temperature (BIO1); annual mean diurnal range (BIO2) indicating the mean of the monthly temperature ranges; annual temperature range (BIO7); annual precipitation (BIO12); precipitation seasonality (BIO15), an index which provides a percentage of precipitation variability where larger percentages represent greater precipitation variability; elevation (meters); aspect (0°-360°); annual mean solar radiation (kJ m^{-2} day^{-1}); and soil pH. Temperature variables are measured in units of degrees Celsius, annual precipitation in millimeters, and precipitation seasonality as a percentage of precipitation variability. While MaxEnt treats aspect as a continuous variable, it will be evaluated as a categorical variable as each degree corresponds to the cardinal direction in which a slope faces. As for categorical variables, land cover type is categorized in terms of ecological system level data based on the National Vegetation Classification System (USNVC) which incorporates dominant vegetation types, landform position, substrates, hydrology, and climate (U.S. Geological Survey Gap Analysis Program, 2011). Soil type is categorized into map units indicating physical and chemical soil properties, parent material, hydrological features, landform features, pH, and associated land use and native vegetation (Web Soil Survey Staff, 2019).

Results and Discussion

The average discrimination ability of predictive models displayed moderate strength and averaged 0.832 and ranged from 0.685 to 0.964. Models for two species (*L. exigua* var. *lutea* and *C. alopecoidea*) produced AUC values above 0.900, indicating excellent model performance. Nine species models had AUC values between 0.800 and 0.899, indicating very good model performance (*H. bicknellii*, *R. wrightiana*, *S. regia*, *L. anceps*, *R. latifolia*, *C. pitcheri*, *C. sterilis*, *S. lanceolata*, and *C. purshii*). Models for four species had AUC values between 0.700 and 0.799, indicating good model performance (*T. helianthoides*, *A. setacea*, *S. cassioides*, and *R. alba*). For one species, *H. canadense*, the model produced an AUC value of 0.685, indicating poor discrimination ability. The AUC values for all species models are presented in Table 3.5. A Pearson correlation analysis indicated a weak negative correlation between sample size and AUC value; however, this correlation was not statistically significant (r = -0.02, p = 0.95).

Table 3.5 Area Under the Curve (AUC) values for all species distribution models (SDMs)

Species	**AUC Value**
Agalinis setacea	0.754
Carex alopecoidea	0.920
Carex sterilis	0.870
Clematis pitcheri	0.863
Crotalaria purshii	0.892
Helianthemum bicknellii	0.800
Helianthemum canadense	0.685
Lachnocaulon anceps	0.837
Leavenworthia exigua var. *lutea*	0.964
Rhynchospora alba	0.799
Rhynchospora latifolia	0.862
Rhynchospora wrightiana	0.808
Scrophularia lanceolata	0.890
Seymeria cassioides	0.793
Silene regia	0.829
Tetragonotheca helianthoides	0.750

Of the 16 species modeled, all but one species, *Rhynchospora latifolia*, had some level of suitable habitat predicted in Tennessee (Table 3.6). On average, total suitable habitat for each of the 16 historical species covered 13.72% (14,960 km^2) of Tennessee, ranging from 0.05% (52 km^2) (*S. lanceolata*) to 44.44% (31,542 km^2) (*L. exigua* var. *lutea*). Of the total suitable habitat, an average of 45.58% (8,083 km^2) was predicted within Tennessee's protected lands (Table 3.6). *S. lanceolata* had the smallest percentage of potential suitable habitat in protected lands (5.79%) (3 km^2) while *C. pitcheri* had the largest percentage (66.26%) (13,832 km^2). The total predicted suitable habitat was then delineated into areas of minimally, moderately, and highly suitable habitat using the MTP, 10PTP, and MSS thresholds, respectively, and evaluated for each species.

Table 3.6 Percentage and area (km^2) of total suitable habitat in Tennessee and within protected areas

Species	**Percentage (km^2) of TN Containing Suitable Habitat**	**Percentage (km^2) of Suitable Habitat within Protected Land**
Agalinis setacea	29.87% (31,476 km^2)	58.78% (18,501 km^2)
Carex alopecoidea	3.41% (3,718 km^2)	64.21% (2,387 km^2)
Carex sterilis	10.61% (11,566 km^2)	61.28% (7,088 km^2)
Clematis pitcheri	19.15% (20,876 km^2)	66.26% (13,832 km^2)
Crotalaria purshii	0.68% (740 km^2)	48.82% (361 km^2)
Helianthemum bicknellii	3.15% (3,436 km^2)	32.82% (1,128 km^2)
Helianthemum canadense	36.40% (39,680 km^2)	49.68% (19,712 km^2)
Lachnocaulon anceps	0.07% (78 km^2)	41.26% (32.185 km^2)
Leavenworthia exigua var. *lutea*	44.44% (48,451 km^2)	65.10% (31,452 km^2)
Rhynchospora alba	22.29% (24,297 km^2)	64.55% (15,683 km^2)
Rhynchospora latifolia	0.00% (0 km^2)	0.00% (0 km^2)
Rhynchospora wrightiana	6.38% (6,952 km^2)	45.28% (3,148 km^2)
Scrophularia lanceolata	0.05% (52 km^2)	5.79% (3 km^2)
Seymeria cassioides	4.54% (4,945 km^2)	48.89% (2,418 km^2)
Silene regia	22.73% (24,782 km^2)	20.37% (5,049 km^2)
Tetragonotheca helianthoides	3.08% (3,353 km^2)	10.60% (356 km^2)

Highly suitable habitat was predicted in Tennessee for eight species (*A. setacea*, *C. pitcheri*, *H. canadense*, *L. exigua* var. *lutea*, *R. alba*, *S. cassioides*, *S. regia*, and *T. helianthoides*) (Table 3.7). For these species, highly suitable habitat covered an average of 4.50% (4,908 km^2) of Tennessee, ranging from 0.20% (223 km^2) (*S. cassioides*) to 16.11% (17,564 km^2) (*L. exigua* var. *lutea*). An average of 34.10% (2,259 km^2) of highly suitable habitat was located within protected areas in Tennessee (Table 3.8), ranging from 1.82% (4 km^2) (*S. cassioides*) to 78.04% (2,546 km^2) (*R. alba*).

Moderately suitable habitat was predicted in the state for ten species (Table 3.7). For these species, moderately suitable habitat covered an average of 6.59% (7,179 km^2) of Tennessee, ranging from 0.13% (137 km^2) (*R. wrightiana*) to 22.15% (24,146 km^2) (*H. canadense*). An average of 37.73% (3,173 km^2) of moderately suitable habitat was located within protected areas in Tennessee (Table 3.8), ranging from 6.61% (36 km^2) (*T. helianthoides*) to 65.00% (6,622 km^2) (*A. setacea*).

Minimally suitable habitat was predicted in Tennessee for 15 species (Table 3.7). Five species did not have any moderately or highly suitable habitat predicted in Tennessee, only minimally suitable habitat was predicted within the state (*C. alopecoidea*, *C. purshii*, *H. bicknellii*, *L. anceps*, and *S. lanceolata*). On average, minimally suitable habitat covered 6.93% (7,556 km^2) of Tennessee, ranging from 0.05% (52 km^2) (*S. lanceolata*) to 21.71% (23,668 km^2) (*L. exigua* var. *lutea*). An average of 51.53% (4,763 km^2) of minimally suitable habitat was located within protected areas in Tennessee (Table 3.8), ranging from 5.79% (3 km^2) (*S. lanceolata*) to 86.04% (6,109 km^2) (*C. pitcheri*). The SDM for *R. latifolia* did not predict any level of suitable habitat predicted in Tennessee.

Table 3.7 Percentage and area (km^2) of Tennessee containing minimally, moderately, and highly suitable habitat for each species

Species	Percentage (km^2) of TN with Minimally Suitable Habitat	Percentage (km^2) of TN with Moderately Suitable Habitat	Percentage (km^2) of TN with Highly Suitable Habitat
Agalinis setacea	10.80% (11,778 km^2)	9.34% (10,187 km^2)	8.72% (9,511 km^2)
Carex alopecoidea	3.41% (3,718 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Carex sterilis	9.55% (10,410 km^2)	1.06% (1,156 km^2)	0.00% (0 km^2)
Clematis pitcheri	6.51% (7,100 km^2)	11.59% (12,633 km^2)	1.05% (1,142 km^2)
Crotalaria purshii	0.68% (740 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Helianthemum bicknellii	3.15% (3,436 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Helianthemum canadense	11.80% (12,863 km^2)	22.15% (24,146 km^2)	2.45% (2,672 km^2)
Lachnocaulon anceps	0.07% (78 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Leavenworthia exigua var. *lutea*	21.71% (23,668 km^2)	6.62% (7,220 km^2)	16.11% (17,564 km^2)
Rhynchospora alba	13.91% (15,160 km^2)	5.39% (5,874 km^2)	2.99% (3,263 km^2)
Rhynchospora latifolia	0% (0 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Rhynchospora wrightiana	6.25% (6,814 km^2)	0.13% (137 km^2)	0.00% (0 km^2)
Scrophularia lanceolata	0.05% (52 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Seymeria cassioides	3.77% (4,111 km^2)	0.56% (612 km^2)	0.20% (223 km^2)
Silene regia	11.57% (12,617 km^2)	8.51% (9,279 km^2)	2.65% (2,886 km^2)
Tetragonotheca helianthoides	0.74% (802 km^2)	0.50% (545 km^2)	1.84% (2,005 km^2)

Table 3.8 Percentage and area (km^2) of minimally, moderately, and highly suitable habitat within protected land in Tennessee

Species	Percentage (km^2) of Minimally Suitable Habitat in Protected Land	Percentage (km^2) of Moderately Suitable Habitat in Protected Land	Percentage (km^2) of Highly Suitable Habitat in Protected Land
Agalinis setacea	53.20% (6,266 km^2)	65.00% (6,622 km^2)	59.02% (5,614 km^2)
Carex alopecoidea	64.21% (2,387 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Carex sterilis	64.61% (6,726 km^2)	31.27% (362 km^2)	0.00% (0 km^2)
Clematis pitcheri	86.04% (6,109 km^2)	55.11% (6,962 km^2)	66.58% (761 km^2)
Crotalaria purshii	48.82% (361 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Helianthemum bicknellii	32.82% (1,128 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Helianthemum canadense	82.78% (10,648 km^2)	37.12% (8,963 km^2)	3.78% (101 km^2)
Lachnocaulon anceps	41.26% (32 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Leavenworthia exigua var. *lutea*	82.15% (19,442 km^2)	46.94% (3,389 km^2)	49.59% (8,710 km^2)
Rhynchospora alba	63.87% (9,682 km^2)	58.81% (3,455 km^2)	78.04% (2,546 km^2)
Rhynchospora latifolia	0.00% (0 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Rhynchospora wrightiana	45.25% (3,083 km^2)	46.99% (64 km^2)	0.00% (0 km^2)
Scrophularia lanceolata	5.79% (3 km^2)	0.00% (0 km^2)	0.00% (0 km^2)
Seymeria cassioides	57.24% (2,353 km^2)	9.87% (60 km^2)	1.82% (4 km^2)
Silene regia	24.18% (3,051 km^2)	29.57% (1,816 km^2)	6.30% (188 km^2)
Tetragonotheca helianthoides	20.67% (166 km^2)	6.61% (36 km^2)	7.66% (154 km^2)

Agalinis setacea **(threadleaf false foxglove)**

The AUC value for this model was 0.754 indicating good discrimination ability. The final model for *A. setacea* predicted 31,476 km^2 of suitable habitat across Tennessee (37.42% minimally suitable; 32.36% moderately suitable; 30.22% highly suitable). Of the total suitable habitat, 18,501 km^2 (58.78%) was contained within protected lands (33.87% minimally suitable; 35.79% moderately suitable; 30.34% highly suitable). Notable protected areas containing suitable habitat include the Great Smoky Mountains

National Park, Cherokee National Forest, Savage Gulf State Natural Area (SNA), North Chickamauga Creek Gorge SNA, Walls of Jericho SNA, Tims Ford State Park, Laurel Hill Wildlife Management Area (WMA), and the Tennessee National Wildlife Refuge. The amount of highly suitable habitat decreased from east to west across Tennessee, the majority being predicted in the Southwestern Appalachians (37%) and Blue Ridge (28%) ecoregions. These predictions align with the last known occurrences for this species being in Blount and Greene counties which are divided between these two ecoregions. The last known counties of observation and adjacent counties contained 7,455 km^2 (24%) of the suitable habitat predicted (Figure 3.1).

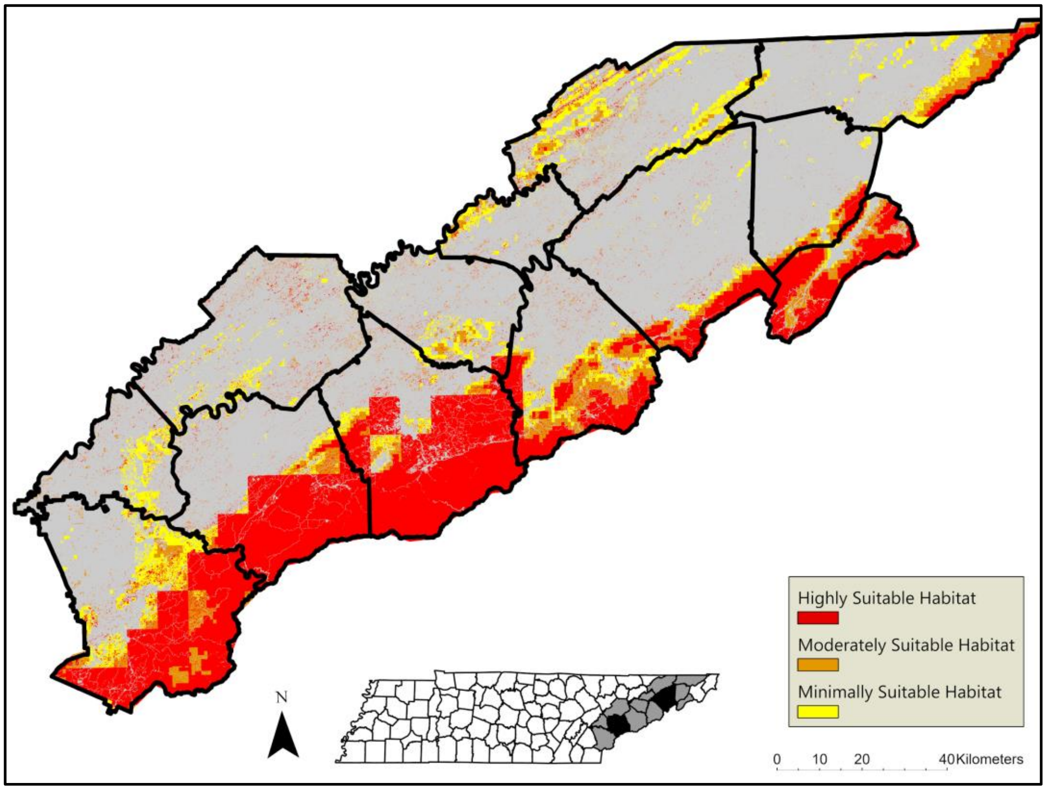

Figure 3.1 Predicted suitable habitat for *A. setacea* within the last known counties of observation (Blount and Greene, shown in black) and adjacent counties

Environmental variables used in the final SDM for *A. setacea* were soil type, soil pH, land cover, elevation, temperature annual range (BIO7), and precipitation seasonality (BIO15). Soil type had the highest permutation importance (29.68%), indicating this was the most important variable for the overall model; precipitation seasonality had the lowest permutation importance (0.51%), indicating the variable was not very important for the overall model (Table 3.9). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 15℃, a mean diurnal range (BIO2) of 13℃ to 14℃, and an annual temperature range (BIO7) of 34℃ to 37℃. For the majority of predicted suitable habitat, BIO2 values were above the average value in Tennessee while BIO1 and BIO7 values fell around the average values in the state. The annual precipitation (BIO12) was above the average annual precipitation in Tennessee with the majority of suitable habitat predicted in areas having an annual precipitation of 1,367 mm to 1,495 mm of rainfall. The majority of suitable habitat was predicted to occur at elevations ranging from 278 m to 573 m and in soils with a pH ranging from 5.0-5.4. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.10. West facing slopes were the most common within predicted suitable habitat (13.5%), followed by northwest facing (13.4%) and southeast facing slopes (12.8%).

Table 3.9 Variable permutation importance and percent contribution for *A. setacea*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Soil Type	29.68%	74.64%
Land Cover	29.03%	15.24%
Temperature Annual Range	19.93%	4.46%
Elevation	11.70%	4.04%
Soil pH	9.15%	1.50%
Precipitation Seasonality	0.51%	0.12%

Table 3.10 Bioclimatic, elevation, and soil pH variable trends for *A. setacea* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7℃	16℃	13℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	8℃	15℃	13℃	13℃	13℃	8℃ - 15℃
Temperature Annual Range	25℃	38℃	35℃	35℃	35℃	25℃ - 38℃
Annual Precipitation	1074mm	2013mm	1405mm	1420mm	1437mm	1073mm - 2013mm
Precipitation Seasonality	9%	22%	15%	15%	15%	9% - 22%
Elevation	57m	1973m	437m	412m	304m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14070	15502	14838	14842	14598	14070 - 15502
Soil pH	4.2	6.6	5.2	5.2	5.1	4.2 - 7.5

The majority of suitable habitat (15.13%) for *A. setacea* was predicted in the Southern Interior Low Plateau Dry-Mesic Oak Forest ecological system which encompasses upland forests in unglaciated landscapes on dry-mesic to mesic, gentle to moderately steep slopes (NatureServe, 2009). Soils are often moderately to well-drained and are typically more fertile than soils associated with oak woodlands (USNVC, 2019). The Allegheny-Cumberland Dry Oak Forest and Woodland ecological system accounted for 10.91% of the total suitable habitat. This system encompasses dry, hardwood forests on predominantly acidic substrates in the Cumberland Plateau as well as acidic sandstone ridges in the southern Ridge and Valley (NatureServe, 2009). The topography varies from rolling hills to steep slopes with typically dry, coarse soils that are relatively infertile (USNVC, 2019). At moderate to low elevations, stands are naturally stable, uneven-aged forests, with canopy dynamics generally dominated by gap-phase regeneration and subcanopy, shrub and herb layers are typically moderately well- to well-developed (USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system accounted for 10.10% of the total predicted suitable habitat. This system is defined by productive forests in the Central and Southern Appalachians, Cumberland and Allegheny plateaus, and the Interior Low Plateau of the eastern

United States (USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *A. setacea* (13.38%) occurred within the Ramsey-Muskingum-Lonewood-Lily soil series. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Tyler-Nolichucky-Holston soil series accounted for 8.63% of soils within the suitable habitat predicted for *A. setacea*. The Tyler soil series consists of fine-silty loam soils which are very deep, somewhat poorly drained and have very slow to moderately slow permeability. These soils formed in silty alluvium, in a mantle of loess on high Illinoian age terraces or dissected valley fills. The majority of areas where these soils occur are cultivated croplands for hay, pasture, corn, soybeans and wheat. Some areas are found in mixed deciduous woodlands. The Nolichucky soil series consists of fine-loamy soils which are very deep and well drained with moderate permeability. These soils formed in moderately fine-textured alluvium derived from sandstone, shale, quartzite and limestone and occur on gently sloping to steep high terraces. The majority of areas containing these soils are cleared for pasture and hay crops. These soils are found in the Appalachian ridges and valleys in Tennessee. The Holston soil series consists of fine-loamy soils which are very deep, well drained and have moderate permeability. These soils formed in old alluvium or colluvium and occur on nearly level to moderately steep stream terraces high above the floodplains and on foot slopes and benches in uplands. The majority of areas containing these soils have been cleared for crops such as tobacco, cotton, hay and pasture however, original forests consisted of mixed hardwoods and pines.

The Ramsey soil series accounted for 6.82% of soils within the suitable habitat predicted for *A. setacea*. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils occur on the Cumberland Plateau and Blue Ridge Mountains in Tennessee.

In summary, modeling for *A. setacea* predicted suitable habitat across 28% of Tennessee, with a significant portion of suitable habitat (65%) being predicted in the Southwestern Appalachians and Blue Ridge ecoregions and 24% predicted within the last known counties of observation (Blount and Greene) and adjacent counties. Fortunately, much of the suitable habitat predicted (59%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Southern Interior Low Plateau Dry-Mesic Oak Forest and Allegheny-Cumberland Dry Oak Forest Woodland ecological systems, aligning with the Tennessee Flora Committee (Tennessee Flora Committee, 2014) and Weakley's (Weakley, In Preparation) described habitat of dry pine-oak forests and openings.

Carex alopecoidea (foxtail sedge)

The AUC value for this model was 0.920 indicating excellent discrimination ability. The final model for *C. alopecoidea* predicted 3,718 km^2 of minimally suitable habitat across Tennessee, moderately suitable and highly suitable habitat was not predicted in the state. Of the minimally suitable habitat predicted, 2,387 km^2 (64.21%) was contained within protected lands. Notable protected areas containing suitable habitat include the Cherokee National Forest, Lick Creek Bottoms WMA, Henderson Swamp State Conservation Area, Warriors Path State Park, and Bays Mountain SNA. The majority of suitable habitat (98%) was predicted in the Ridge and Valley ecoregion; 2% occurred within the Blue Ridge ecoregion. The last known county of observation, Knox county, and adjacent counties contained 405 km^2 (11%) of the suitable habitat predicted (Figure 3.2).

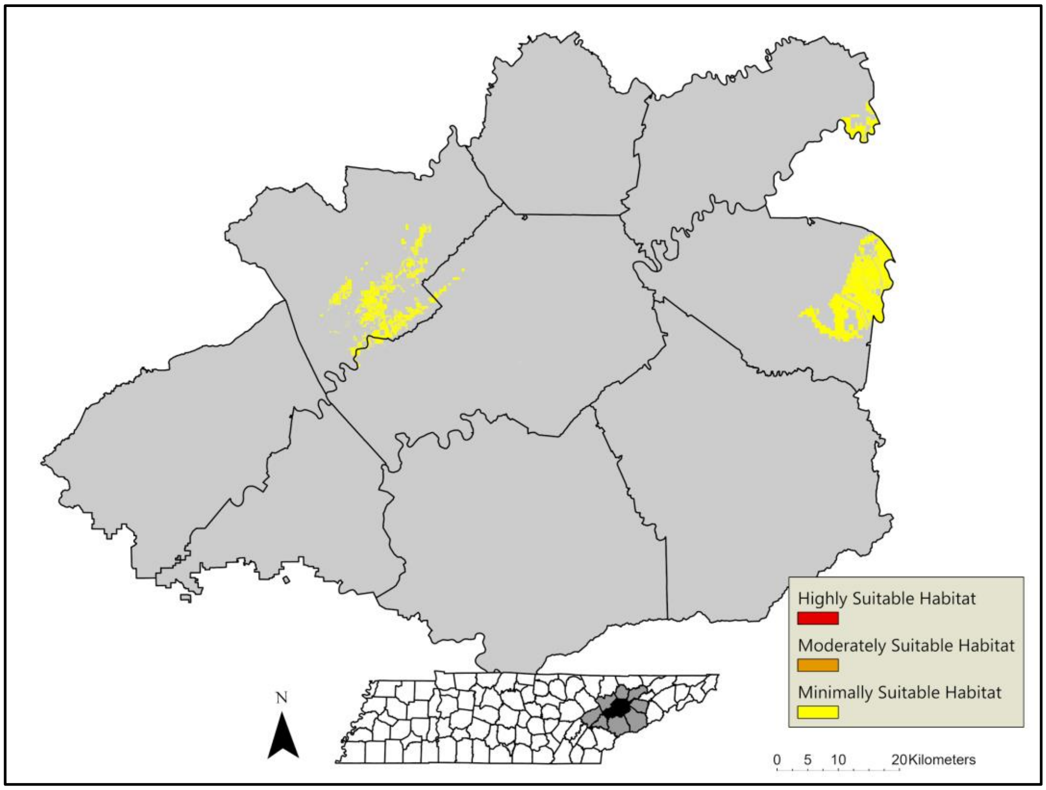

Figure 3.2 Predicted suitable habitat for *C. alopecoidea* within the last known county of observation (Knox County, shown in black) and adjacent counties

Environmental variables used in the final SDM for *C. alopecoidea* were annual precipitation (BIO12), precipitation seasonality (BIO15), land cover, soil, solar radiation, and elevation. Annual precipitation had the highest permutation importance (52.04%), indicating this was the most important variable for the overall model; precipitation seasonality had the lowest permutation importance (1.17%), indicating the variable was not very important for the overall model (Table 3.11). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 14℃, a mean diurnal range (BIO2) of 14℃ to 15℃, and an annual temperature range (BIO7) of 36℃ to 37℃. For the majority of suitable habitat, BIO2 and BIO7 values were above the average values in Tennessee while BIO1 values were below the average value in the state. BIO12 values fell below the average annual precipitation for Tennessee with the majority of suitable habitat predicted in areas having an annual precipitation of 1,099 mm to 1,123 mm of rainfall. The majority of suitable habitat was predicted at elevations ranging from 347 m to 387 m and in soils with a pH ranging from 5.6-5.8. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.12. Southeast facing slopes were the most common within predicted suitable habitat (15.0%), followed by northwest facing (14.6%) and west facing slopes (13.2%).

Table 3.11 Variable permutation importance and percent contribution for *C. alopecoidea*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Annual Precipitation	52.04%	43.05%
Land Cover	26.94%	40.08%
Soil	7.53%	12.56%
Elevation	7.14%	0.88%
Solar Radiation	5.18%	3.12%
Precipitation Seasonality	1.17%	0.31%

Table 3.12 Bioclimatic, elevation, and soil pH variable trends for *C. alopecoidea* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	12℃	14℃	13℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	11℃	14℃	14℃	14℃	14℃	8℃ - 15℃
Temperature Annual Range	33℃	37℃	36℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1073mm	1218mm	1117mm	1115mm	1100mm	1073mm - 2073mm
Precipitation Seasonality	12%	16%	14%	14%	15%	9% - 22%
Elevation	239m	616m	414m	411m	319m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14327	14945	14695	14700	14716	14070 - 15502
Soil pH	5.0	6.4	5.6	5.7	5.7	4.2 - 7.5

The majority of suitable habitat (50.96%) for *C. alopecoidea* was predicted in the Pasture and Hay Field Crop ecological system which consists of areas of grasses, legumes, and grass-legume mixtures planted for livestock grazing or the production of seed or hay crops on a perennial cycle where pasture and hay vegetation accounts for at least 20% of the total vegetation (NatureServe, 2009). The Southern Ridge and Valley Dry Calcareous Forest ecological system accounted for 20.31% of predicted suitable habitat. This ecological system is found in the temperate portions of the eastern United States and is associated with calcareous substrates such as limestone and dolomite (USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system accounted for 8.60% of predicted suitable habitat. This ecological system is comprised of productive forests in the Central and Southern Appalachians, Cumberland and Allegheny plateaus, and the Interior Low Plateau of the eastern United States (USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019). Soils may be rocky or fine-textured and may be residual, alluvial or colluvial (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *C. alopecoidea* (29.85%) occurred within the Montevallo-Hamblen-Dandridge-Bays soil series. The Montevallo soil series consists of channery silt loam soils which are shallow, well drained and have moderate permeability. These soils formed in residuum weathered from acidic shale, siltstone, and possibly sandstone and occur on dissected hills, river valleys, and valleys underlain by shale. The majority of areas where these soils occur consists of mixed hardwood forests containing hickories, oaks, and pines. Few areas have been cleared for pasture, hay, and small grain crops. The Hamblen soil series consists of fine-loamy soils which are very deep, moderately well drained and are moderately permeable. These soils formed in loamy alluvium from watersheds dominated by limestone, sandstone and shale and occur on floodplains which are subject to flooding unless protected. The majority of areas where these soils occur have been cleared for crop production and pastures. The native vegetation associated with these soils consists of hardwood forests containing oak, hickories, maples, elms and sycamores. These soils are found in the Appalachian valleys, Highland Rim and Nashville Basin in Tennessee. The Dandridge soil series consists of channery silty clay loam soils which are shallow, excessively drained and have moderately slow permeability. These soils formed in residuum of calcareous shale and limestone and range from slightly acidic to moderately alkaline. Typically occurring on highly dissected uplands, these soils are found in the Appalachian ridges and valleys in Tennessee. The majority of areas where these soils occur have been cleared primarily for pastures. The native vegetation associated with these soils consists of forests containing oaks, hickories, beeches, maples and elms. The Bays soil series consists of silty clay loam soils which are shallow, well drained and are moderately well drained. These soils formed in residuum from calcareous shale bedrock and occur on shale uplands with narrow convex ridges and long convex side slopes in the Ridge and Valley portion of the Southern Appalachians in Tennessee. Over half of the area where these soils occur has been cleared, primarily for pasture and hay crops. In wooded areas, the dominant vegetation consists of upland oak species.

The Dunmore soil series accounted for 22.40% of soils within the suitable habitat predicted for *C. alopecoidea*. This soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, with some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee.

The Dunmore-Collegedale soil series accounted for 6.54% of soils within the suitable habitat predicted for *C. alopecoidea*. The Dunmore soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, with some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee. The Collegedale soil series consists of fine silt-loam soils which are very deep, well drained, and have moderately slow permeability. These soils formed in material weathered from limestone or limestone interbedded with shale and occur on uplands in valleys which are underlain by limestone. The majority of areas containing these soils are used for pasture, a small portion is used for crops including hay, cotton, and corn. The native vegetation associated with these soils consists of mixed hardwood forests. These soils are found in the Southern Appalachian valleys in Tennessee.

In summary, modeling for *C. alopecoidea* predicted suitable habitat across 3% of Tennessee, with the majority of suitable habitat (98%) being predicted in the Ridge and Valley ecoregion and 11% being predicted within the last known county of observation (Knox) and adjacent counties. Fortunately, while only a small amount of suitable habitat was predicted in Tennessee, a significant portion of habitat (64%) was located within protected areas in Tennessee. Interestingly, around half of the suitable habitat predicted occurred within the Pasture and Hay Field Crop ecological system; however this finding needs further evaluation as this does not align with the FNA's habitat description of seasonally saturated soils in wet meadows and alluvial woods, particularly on calcareous substrates (FNA, 2008). However, the Southern Ridge and Valley Dry Calcareous Forest ecological system, which accounted for 20% of predicted suitable habitat, aligns somewhat well with habitat described for *C. alopecoidea* occurring on calcareous substrates. However, taking into account the variable permutation importance, annual precipitation (BIO12) had a 25% higher permutation importance than land cover, indicating the model predictions relied more heavily on precipitation than land cover, which may account for the discrepancy between the predicted habitat type and the described habitat for *C. alopecoidea*.

***Carex sterilis* (dioecious sedge)**

The AUC value for this model was 0.870 indicating very good discrimination ability. The final model for *C. sterilis* predicted 11,566 km^2 of suitable habitat across Tennessee (90.00% minimally suitable and 10.00% moderately suitable). Of the suitable habitat predicted, 7,088 km^2 (61.28%) was contained within protected lands (94.90% minimally suitable and 5.10% moderately suitable). Notable protected areas containing suitable habitat include the Cherokee National Forest, Great Smoky Mountains National Park, Warriors Path State Park, Bays Mountain SNA, and Phipps Bend Refuge. Predicted suitable habitat decreased from east to west across Tennessee. The Ridge and Valley ecoregion contained 79% of predicted suitable habitat, the Blue Ridge ecoregion contained 19% and the Interior Plateau and Mississippi Alluvial Plain ecoregions both contained less than 1% of predicted suitable habitat. The last known county of observation, Fentress county, did not contain any predicted suitable habitat. Of the adjacent counties, Morgan county contained only 15 km^2 (0.13%) of the suitable habitat predicted. Figure 3.3 shows the last known observation county and adjacent counties in relation to the predicted suitable habitat.

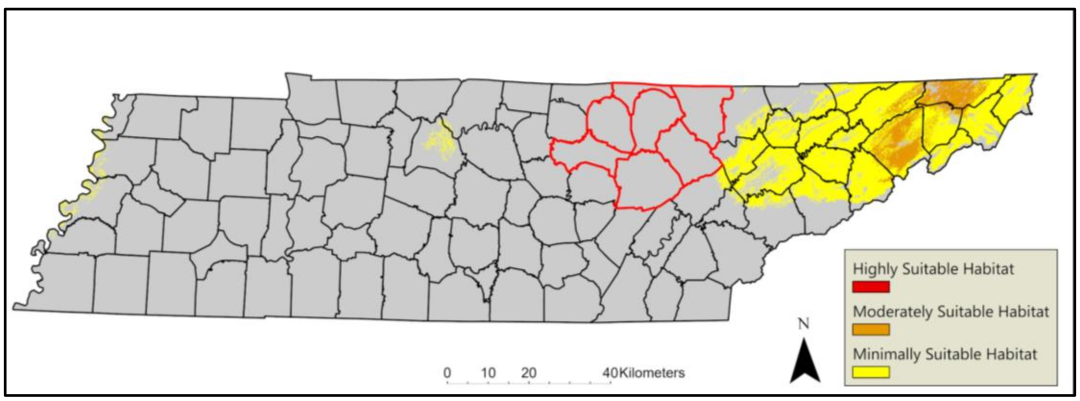

Figure 3.3 Predicted suitable habitat for *C. sterilis* in relation to the last known county of observation (Morgan) and adjacent counties (outlined in red)

Environmental variables used in the final SDM for *C. sterilis* were annual precipitation (BIO12), temperature annual range (BIO7), land cover, soil, and aspect. Land cover had the highest permutation importance (60.93%), indicating this was the most important variable for the overall model; temperature annual range had the lowest permutation importance (0.96%), indicating the variable was not very important for the overall model (Table 3.13). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 14℃, a mean diurnal range (BIO2) of 14℃ to 15℃, and an annual temperature range (BIO7) of 36°C to 37℃. For the majority of predicted suitable habitat, BIO1 values were below the average value in Tennessee while values for BIO2 and BIO7 were above the average values in the state. Suitable habitat was predicted most frequently in areas with an annual precipitation (BIO12) ranging from 1,192 mm to 1,236 mm, falling below the average annual precipitation in Tennessee. The majority of suitable habitat was predicted to occur at lower elevations ranging from 304 m to 424 m and in soils with a pH ranging from 5.5-5.8. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.14. Southeast facing slopes were the most common within predicted suitable habitat (15.8%), followed by northwest facing (15.4%) and south facing slopes (13.5%).

Table 3.13 Variable permutation importance and percent contribution for *C. sterilis*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Landcover	60.93%	53.48%
Soil Type	18.50%	43.96%
Annual Precipitation	16.17%	2.10%
Aspect	3.43%	0.46%
Temperature Annual Range	0.96%	0.01%

Table 3.14 Bioclimatic, elevation, and soil pH variable trends for *C. sterilis* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	9℃	16℃	13℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	9℃	15℃	13℃	14℃	14℃	8℃ - 15℃
Temperature Annual Range	30℃	38℃	35℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1073mm	1355mm	1176mm	1187mm	1211mm	1073mm - 2073mm
Precipitation Seasonality	11%	21%	14%	14%	13%	9% - 22%
Elevation	24m	1304m	453m	408m	319m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14226	15411	14699	14703	14697	14070 - 15502
Soil pH	4.6	6.8	5.5	5.5	5.6	4.2 - 7.5

The majority of suitable habitat (30.72%) for *C. sterilis* was predicted in the Pasture and Hay Field Crop ecological system, areas comprised of grasses, legumes, and grass-legume mixtures planted for livestock grazing or the production of seed or hay crops on a perennial cycle where pasture and hay vegetation accounts for over 20% of the total vegetation (NatureServe, 2009). The Southern Ridge and Valley Dry Calcareous Forest ecological system accounted for 20.77% of predicted suitable habitat. This ecological system is found in the temperate portions of the eastern United States and is associated with calcareous substrates such as limestone and dolomite (USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system accounted for 7.79% of predicted suitable habitat. This ecological system is comprised of productive forests in the Central and Southern Appalachians, Cumberland and Allegheny plateaus, and the Interior Low Plateau of the eastern United States (USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019). Soils may be rocky or fine-textured and may be residual, alluvial or colluvial (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *C. sterilis* (14.89%) occurred within the Dunmore soil series. This soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee.

The Montevallo-Hamblen-Dandridge-Bays soil series accounted for 11.84% of soils within the suitable habitat predicted for *C. sterilis*. The Montevallo soil series consists of channery silt loam soils which are shallow, well drained and have moderate permeability. These soils formed in residuum weathered from acidic shale, siltstone, and possibly sandstone and occur on dissected hills, river valleys, and valleys underlain by shale. The majority of areas where these soils occur consists of mixed hardwood forests containing hickories, oaks, and pines. Few areas have been cleared for pasture, hay, and small grain crops. The Hamblen soil series consists of fine-loamy soils which are very deep, moderately well drained and are moderately permeable. These soils formed in loamy alluvium from watersheds dominated by limestone, sandstone and shale and occur on floodplains which are subject to flooding unless protected. The majority of areas where these soils occur have been cleared for crop production and pastures. The native vegetation associated with these soils consists of hardwood forests containing oak, hickories, maples, elms and sycamores. These soils are found in the Appalachian valleys, Highland Rim and Nashville Basin in Tennessee. The Dandridge soil series consists of channery silty clay loam soils which are shallow, excessively drained and have moderately slow permeability. These soils formed in residuum of calcareous shale and limestone and range from slightly acidic to moderately alkaline. Typically occurring on highly dissected uplands, these soils are found in the Appalachian ridges and valleys in Tennessee. The majority of areas where these soils occur have been cleared primarily for pastures. The native vegetation associated with these soils consists of forests containing oaks, hickories, beeches, maples and elms. The Bays soil series consists of silty clay loam soils which are shallow, well drained and are moderately well drained. These soils formed in residuum from calcareous shale bedrock and occur on shale uplands with narrow convex ridges and long convex side slopes in the Ridge and Valley portion of the Southern Appalachians in Tennessee. Over half of the area where these soils occur has been cleared, primarily for pasture and hay crops. In wooded areas, the dominant vegetation consists of upland oak species.

The Fullerton-Clarksville-Bodine soil series accounted for 10.47% of soils within the suitable habitat predicted for *C. sterilis*. The Fullerton soil series consists of gravelly silt-loam soils which are deep, well drained, have moderate permeability and are strongly to very strongly acidic except where limed. These soils formed in colluvium or residuum weathered from cherty limestone and occur on crests, side slopes and base slopes of ridges. The majority of areas containing these soils are cleared primarily for pasture. Woodlands where these soils occur contain oaks, hickories, elms, poplars, and dogwoods. The Clarksville soil series consists of gravelly silt-loam soils which are very deep, somewhat excessively drained and have moderate permeability. These soils formed in hillslope sediments with underlying clayey residuum from cherty dolomite or limestone and occur on steep side slopes and narrow ridge tops. The majority of areas containing these soils are in second growth timber while some areas are used for hay and pasture crops. The native vegetation associated with these soils are mixed forests containing various oak species, shortleaf pines, hickories, maples, and dogwoods. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. These soils are often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occur in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture.

In summary, modeling for *C. sterilis* predicted suitable habitat across 11% of Tennessee, with almost all of the suitable habitat (98%) being predicted within the Ridge and Valley and Blue Ridge ecoregions. The last known county of observation, Fentress, did not contain any predicted suitable habitat and only 0.13% was predicted within adjacent counties. Over half of the suitable habitat predicted (61%) was located within protected areas in Tennessee. Similar to *C. alopecoidea*, a significant portion of suitable habitat predicted occurred within the Pasture and Hay Field Crop ecological system. Again, this finding should be evaluated further as this does not align with previously described habitats which include calcareous fens, acidic bogs, openings in white-cedar swamps, fresh interdunal meadows, seeps, lake and river shorelines, and wet limestone outcrops (FNA, 2008; Tennessee Flora Committee, 2014; Weakley, In Preparation). However, the Southern Ridge and Valley Dry Calcareous Forest ecological system, which accounted for 21% of predicted suitable habitat, aligns somewhat with the described habitat as these forests are associated with calcareous substrates such as limestone.

***Clematis pitcheri* (bluebill)**

The AUC value for this model was 0.863 indicating very good discrimination ability. The final model for *C. pitcheri* predicted 20,876 km^2 of suitable habitat across Tennessee (34.01% minimally suitable; 60.52% moderately suitable; 5.47% highly suitable). Suitable habitat was predicted primarily in western Tennessee in the Interior Plateau ecoregion (42%) and the Southeastern Plains ecoregion (36%). Of the total suitable habitat, 13,832 km^2 (66.26%) was contained within protected lands (44.16% minimally suitable; 50.34% moderately suitable; 5.50% highly suitable). Notable protected areas containing suitable habitat include Montgomery Bell State Park, Big Hill Pond State Park, Shelby Forest State Park, Reelfoot National Wildlife Refuge, Land Between the Lakes National Recreation Area and Shiloh National Battlefield. The last known county of observation, Montgomery county, and adjacent counties contained 8,789.2 km^2 (42%) of the suitable habitat predicted (Figure 3.4).

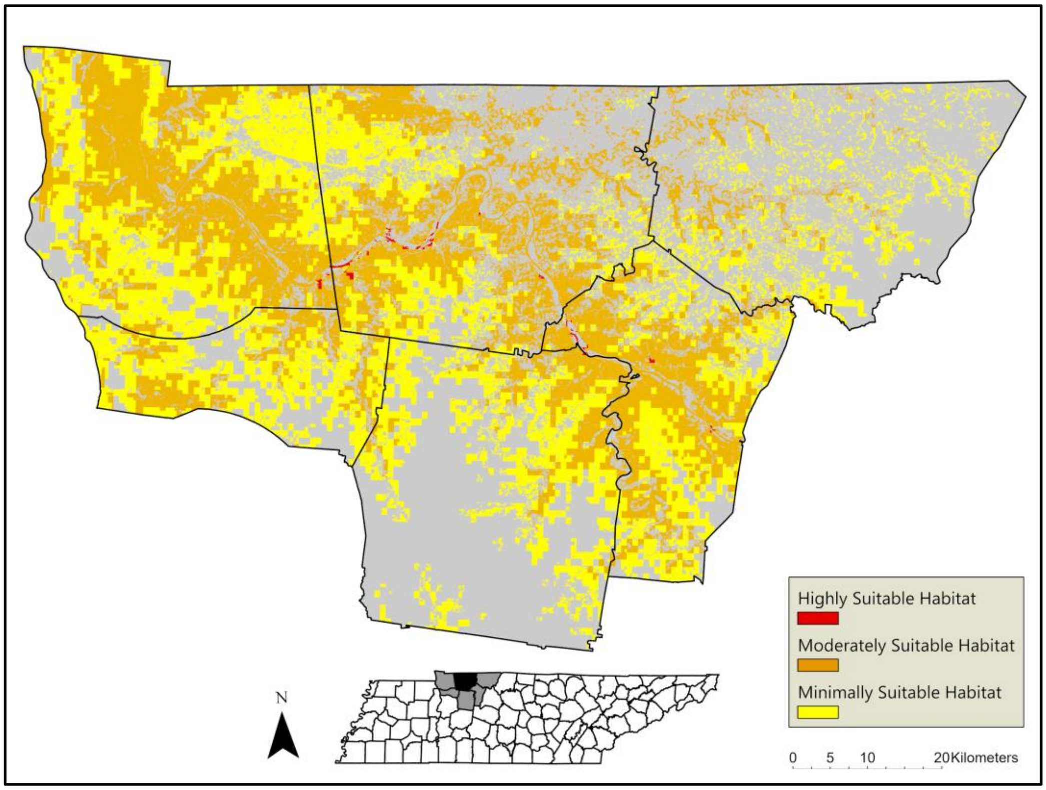

Figure 3.4 Predicted suitable habitat for *C. pitcheri* within the last known county of observation (Montgomery, shown in black) and adjacent counties

Environmental variables used in the final SDM for *C. pitcheri* were mean diurnal range (BIO2), temperature annual range (BIO7), annual precipitation (BIO12), precipitation seasonality (BIO15), elevation, land cover, soil pH, soil type, and solar radiation. Elevation had the highest permutation importance (29.44%), indicating this was the most important variable for the overall model; soil pH had the lowest permutation importance (0.03%), indicating the variable was not very important for the overall model (Table 3.15). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 14℃ to 15℃, a mean diurnal range (BIO2) of 12℃ to 13℃, and an annual temperature range (BIO7) of 36°C to 38°C. For the majority of suitable habitat predicted, values for BIO1 and BIO7 were above the average for the state while values for BIO2 were below the average value in Tennessee. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,347 mm to 1,372 mm, occurring at lower elevations ranging from 123 m to 166 m and in soils with a pH ranging from 5.2-5.4. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.16. West facing slopes were the most common within predicted suitable habitat (12.6%), followed by northwest facing (11.8%) and southwest facing slopes (11.5%).

Table 3.15 Variable permutation importance and percent contribution for *C. pitcheri*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Elevation	29.44%	11.21%
Temperature Annual Range	22.44%	19.65%
Land Cover	17.01%	41.75%
Solar Radiation	13.69%	6.67%
Annual Precipitation	7.35%	0.77%
Precipitation Seasonality	5.23%	3.99%
Soil Type	4.47%	15.57%
Mean Diurnal Range	0.33%	0.30%
Soil pH	0.03%	0.09%

Table 3.16 Bioclimatic, elevation, and soil pH variable trends for *C. pitcheri* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	14℃	16℃	15℃	15℃	14℃	6℃ - 16℃
Mean Diurnal Range	10℃	14℃	13℃	13℃	13℃	8℃ - 15℃
Temperature Annual Range	35℃	38℃	37℃	37℃	37℃	25℃ - 38℃
Annual Precipitation	1168mm	1487mm	1352mm	1356mm	1356mm	1073mm - 2013mm
Precipitation Seasonality	13%	22%	17%	17%	15%	9% - 22%
Elevation	24m	251m	143m	144m	109m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14456	15502	15044	15043	14836	14070 - 15502
Soil pH	4.9	6.8	5.3	5.3	5.3	4.2 - 7.5

The majority of suitable habitat (18.13%) for *C. pitcheri* was predicted in the Southern Interior Low Plateau Dry-Mesic Oak Forest ecological system which encompasses upland forests in unglaciated landscapes on dry-mesic to mesic, gentle to moderately steep slopes (NatureServe, 2009). Soils are often moderately to well-drained and are typically more fertile than soils associated with oak woodlands (USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system (14.20% of suitable habitat) are productive forests in the Central and Southern Appalachians, Cumberland and Allegheny plateaus, and the Interior Low Plateau of the eastern United States (USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019). The South-Central Interior Oak Forest and Woodland ecological system (13.39% of suitable habitat) is comprised of upland, dry-mesic hardwood forests extending west of the Appalachian Mountains in unglaciated landscapes (USNVC, 2019). Canopy closure ranges from closed to somewhat open and occurs in substrates ranging from calcareous to acidic with shallow, well- to excessively well-drained soils (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *C. pitcheri* (14.73%) occurred within the Smithdale-Lexington soil series. The Smithdale soil series consists of fine-loamy soils which are very deep, well drained, and moderately permeable. These soils formed in the thick beds of loamy marine sediments and occur on ridge tops and hill slopes in uplands of the Southern and Western Coastal Plains. Most areas of this soil contain loblolly, longleaf and shortleaf pine woodlands. The majority of cleared areas are used for pastures while some areas are used for corn, cotton, soybean and grain crops. The Lexington soil series consists of fine-silty soils which are very deep, well drained and have moderately to moderately rapid permeability. These soils occur on level to moderately steep uplands which have a thin mantle of loess, underlain by loamy and sandy marine sediments. A small extent of this soil is within forests while the majority is used for crops including hay and pasture.

The Hammack-Brandon-Bodine-Baxter soil series accounted for 10.33% of soils within the suitable habitat predicted for *C. pitcheri*. The Hammack soil series consists of fine-silty soils which are very deep, well drained and have moderate permeability. These moderately to strongly acidic soils formed in a loess mantle underlain with limestone and occur on ridge tops and side slopes of rolling to hilly areas with some areas having karst topography. The majority of areas with this soil are used for hay, pasture and crops such as corn, soybeans, and tobacco. Steeper areas in forests contain oaks, hickories, maples and hackberry. The Bradon soil series consists of fine-silty soils which are very deep, well drained and typically range from strongly to very strongly acidic. In the silty upper areas, permeability is moderate however, in the gravelly substratum permeability is variable and can range from moderately rapid to slow. These soils formed in a silty mantle presumably consisting of loess over gravelly marine and riverine deposited materials and occur on gently sloping to steep upland ridges and hillsides. The majority of areas containing these soils consist of hardwood forests with the dominant woodland species being oaks, hickories, black gum, elms, and dogwoods. Few areas are in pasture and hay croplands. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

The Memphis-Loring-Grenada-Collins soil series accounted for 6.79% of soils within the suitable habitat predicted for *C. pitcheri*. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Loring soil series consists of fine-silty soils which are moderately well drained and formed in loess on level to strongly sloping uplands and stream terraces. While many of the areas containing this soil have been cleared for crops, wooded areas contain oak, hickory, elm, maple and tulip poplar tree species. The Grenada series consists of very deep, fine-silty soils that are moderately well drained and formed in thick loess. These moderately to strongly acidic soils occur in the southern Mississippi valley silty uplands on uplands and stream terraces. The Collins series consists of very deep, coarse-silty soils which are moderately well drained and permeable. These soils formed in silty alluvium on flood plains of streams in the southern Mississippi Valley silty uplands. While many of the areas containing this soil have been cleared for crops including hay and pastures, wooded areas contain bottomland hardwood vegetation.

In summary, modeling for *C. pitcheri* predicted suitable habitat across 19% of Tennessee, with a significant portion of the suitable habitat (78%) being predicted within the Interior Plateau and Southeastern Plains ecoregions and 42% being predicted within the last known county of observation (Montgomery) and adjacent counties. Fortunately, much of the suitable habitat predicted (66%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Southern Interior Low Plateau Dry-Mesic Oak Forest and South-Central Interior Mesophytic Forest ecological systems, aligning with the Tennessee Flora Committee (Tennessee Flora Committee, 2014) and FNA's (FNA, 2008) described habitat of limestone outcrops in dry to moist woods and calcareous river bluffs.

Crotalaria purshii **(Pursh's rattlebox)**

The AUC value for this model was 0.892 indicating very good discrimination ability. The final model for *C. purshii* predicted 740 km^2 of minimally suitable habitat across Tennessee, moderately suitable and highly suitable habitat was not predicted in the state. Of the minimally suitable habitat predicted, 361 km^2 (48.82%) was contained within protected lands. Notable protected areas containing suitable habitat include the Cherokee National Forest, Great Smoky Mountains National Park, Savage Gulf SNA, North Chickamauga Creek Gorge SNA, and Pickwick Landing State Park. The majority of suitable habitat was predicted in east Tennessee. The Blue Ridge ecoregion contained 41% of predicted suitable habitat while the Southwestern Appalachians ecoregion contained 39%. The last known county of observation, Blount county, and adjacent counties contained 296 km^2 (40%) of the suitable habitat predicted (Figure 3.5).

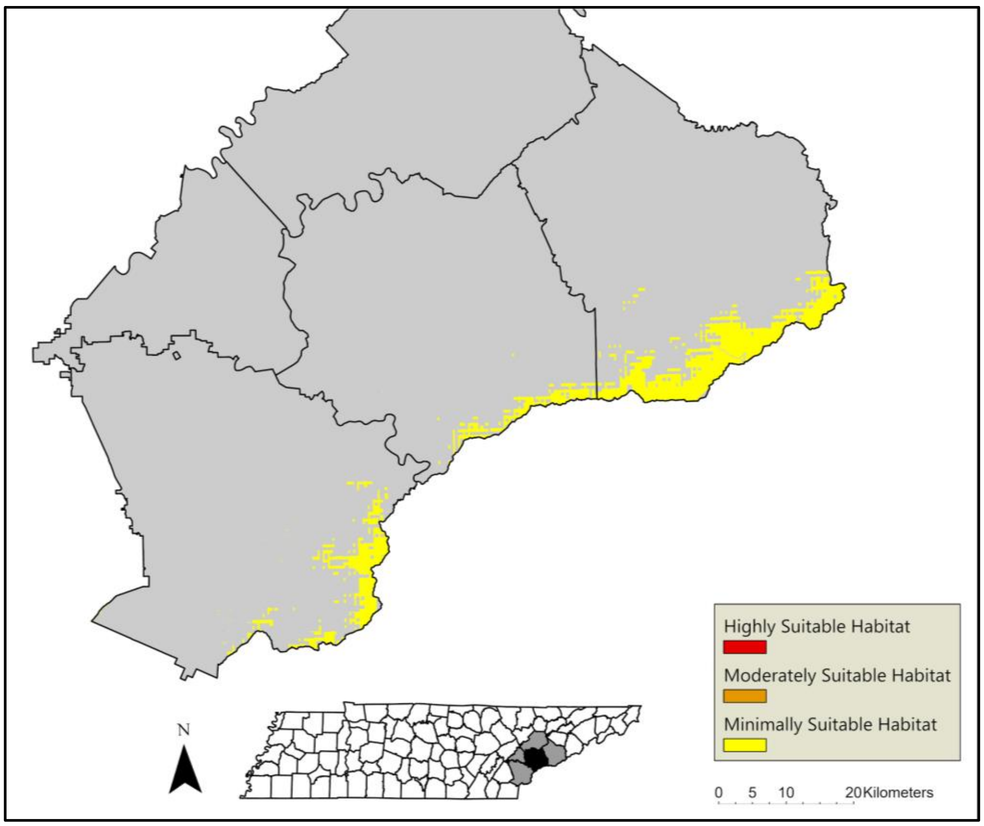

Figure 3.5 Predicted suitable habitat for *C. purshii* within the last known county of observation (Blount, shown in black) and adjacent counties

Environmental variables used in the final SDM for *C. purshii* were land cover, temperature annual range (BIO7), soil type, elevation, solar radiation, precipitation seasonality (BIO15), annual precipitation (BIO12), and soil pH. Soil pH had the highest permutation importance (34.62%), indicating this was the most important variable for the overall model; precipitation seasonality (BIO15) had the lowest permutation importance (1.08%), indicating the variable was not very important for the overall model (Table 3.17). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 14℃, a mean diurnal range (BIO2) of 12℃ to 13℃, and an annual temperature range (BIO7) of 34°C to 36°C. For the majority of suitable habitat, BIO1, BIO2, and BIO7 values fell below the average values in Tennessee. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,536mm to 1,586mm, falling above the average values in the state. Suitable habitat was predicted most frequently at elevations ranging from 501 m to 634 m and in soils with a pH ranging from 4.8-5.1. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.18. West facing slopes were the most common within predicted suitable habitat (14.9%), followed by northwest facing (14.6%) and southwest facing slopes (12.9%).

Table 3.17 Variable permutation importance and percent contribution for *C. purshii*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Soil pH	34.62%	11.10%
Temperature Annual Range	20.74%	38.58%
Annual Precipitation	12.40%	8.10%
Land Cover	9.53%	24.07%
Soil Type	8.22%	11.26%
Solar Radiation	7.57%	0.86%
Elevation	5.85%	4.72%
Precipitation Seasonality	1.08%	1.32%

Table 3.18 Bioclimatic, Elevation, and Soil pH Variable Trends for *C. purshii* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7℃	16℃	12℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	8℃	14℃	12℃	12℃	13℃	8℃ - 15℃
Temperature Annual Range	25℃	36℃	32℃	33℃	34℃	25℃ - 38℃
Annual Precipitation	1335mm	2013mm	1628mm	1577mm	1544mm	1073mm - 2013mm
Precipitation Seasonality	9%	21%	14%	15%	15%	9% - 22%
Elevation	99m	1973m	780m	586m	565m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14376	15372	14838	14831	14730	14070 - 15502
Soil pH	4.2	5.8	4.8	4.9	4.9	4.2 - 7.5

The majority of suitable habitat (48.23%) for *C. purshii* was predicted in the Southeastern Native Ruderal Forest ecological system which occurs in old-field and other human disturbed areas in the southeastern United States such as formerly cleared or planted sites that have been allowed to undergo succession (USNVC, 2019). The canopy varies from hardwood- to conifer-dominated, with open to closed canopies where vegetation is dominated by ruderal native tree species; Understory shrub and herbaceous species may be a mix of both exotic species and native generalist species (USNVC, 2019). Tree stands typically have an irregular structure, though remnants of abandoned forest plantation structure may be evident. This system includes upland and marginally wet areas that may have been altered by logging or clearing for agriculture on dry- to wet-mesic sites (USNVC, 2019). The Southern and Central Appalachian Oak Forest accounted for 11.41% of suitable habitat. This ecological system consists of primarily dry-mesic forests which occur on open and exposed topography at low to mid elevation in the southern Blue Ridge and southern Ridge and Valley ecoregions (NatureServe, 2019). At these low to moderate elevations, forests are uneven in age and naturally stable, with canopies typically dominated by gap-phase regeneration (NatureServe, 2019; USNVC, 2019). This system occurs on predominately acidic substrates with coarse, infertile soils and topography varies from rolling hills to steep slopes (USNVC, 2019). The Central and Southern Appalachian Northern Hardwood Forest accounted for 6.97% of suitable habitat. This system is comprised primarily of long-lived, mesic species forming multi-layered uneven-aged forests with canopies dominated by single and multiple disturbances which promote gap phase regeneration (USNVC, 2019). These forests occur primarily on mesic sites over a wide range of topographies at elevations ranging from 305 m to 915 m (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series (19.31%) occurred within the Ramsey-Muskingum-Lonewood-Lily soil series. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Ramsey soil series accounted for 18.20% of soils within the suitable habitat predicted for *C. purshii*. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils occur on the Cumberland Plateau and Blue Ridge Mountains in Tennessee.

The Ramsey-Lily soil series accounted for 10.86% of soils within the suitable habitat predicted for *C. purshii*. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

In summary, modeling for *C. purshii* predicted suitable habitat across less than 1% of Tennessee, with a significant portion of the suitable habitat (80%) being predicted within the Blue Ridge and Southwestern Appalachians ecoregions and 40% being predicted within the last known county of observation (Blount) and adjacent counties. While only a small amount of suitable habitat was predicted, almost half of the habitat predicted (48%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Southeastern Native Ruderal Forest ecological system, which includes ruderal fields and other human disturbed areas such as formerly cleared or planted sites. Habitat for *C. purshii* has been described by Weakley as mesic to dry pinelands, sandy openings and roadsides (Weakley, In Preparation), while habitat for other *Crotalaria* species in Tennessee is described as fields, barrens, woodland openings and other ruderal sites (Tennessee Flora Committee, 2014). These habitat descriptions align well with the model predictions for *C. purshii*.

Helianthemum bicknellii **(hoary frostweed)**

The AUC value for this model was 0.800 indicating very good discrimination ability. The final model for *H. bicknellii* predicted 3,436 km^2 of minimally suitable habitat across Tennessee, moderately suitable and highly suitable habitat was not predicted in the state. Of the minimally suitable habitat predicted, 1,128 km^2 (32.82%) was contained within protected lands. Notable protected areas containing suitable habitat include the Land Between the Lakes National Recreation Area, Reelfoot Lake SNA & WMA, Tennessee National Wildlife Refuge, and Johnsonville State Historic Park. The majority of suitable habitat was predicted in west and central Tennessee. The Mississippi Valley Loess Plains ecoregion contained 39% of suitable habitat, Interior Plateau contained 38%, Southeastern Plains contained 10% and the Mississippi Alluvial Plain contained 9%. The last known counties of observation, Blount and Monroe, and adjacent counties contained only 3 km^2 (0.09%) of the suitable habitat predicted (Figure 3.6).

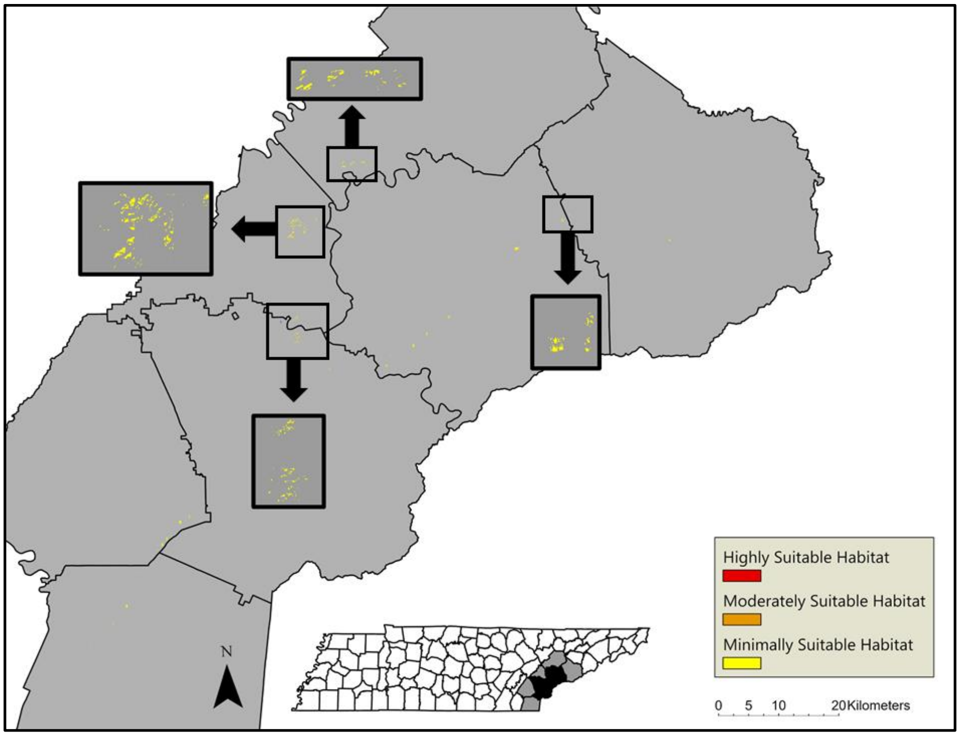

Figure 3.6 Predicted suitable habitat for *H. bicknellii* within the last known counties of observation (Blount and Monroe, shown in black) and adjacent counties

Environmental variables used in the final SDM for *H. bicknellii* were annual mean temperature (BIO1), mean diurnal range (BIO2), temperature annual range (BIO7), annual precipitation (BIO12), precipitation seasonality (BIO15), soil type, land cover, solar radiation, elevation, and aspect. Annual mean temperature (BIO1) had the highest permutation importance (24.26%), indicating this was the most important variable for the overall model; aspect had the lowest permutation importance (0.60%), indicating the variable was not very important for the overall model (Table 3.19). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 14℃ to 16℃, a mean diurnal range (BIO2) of 12℃ to 13℃, and an annual temperature range (BIO7) of 36℃ to 38℃. For the majority of suitable habitat, BIO1 and BIO7 values were above the average values in Tennessee and BIO2 values were below the average in the state. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,287mm to 1,344mm of rainfall, falling below the average annual precipitation in the state. Suitable habitat was predicted primarily at lower elevations ranging from 86 m to 148 m and in soils with a pH ranging from 5.2-5.5. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.20. Northwest facing slopes were the most common within predicted suitable habitat (31.38%), followed by west facing (19.23%) and north facing slopes (17.78%).

Table 3.19 Variable permutation importance and percent contribution for *H. bicknellii*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Annual Mean Temperature	24.26%	1.79%
Mean Diurnal Range	22.74%	5.22%
Land Cover	17.09%	17.39%
Elevation	14.13%	3.30%
Soil Type	6.65%	25.62%
Solar Radiation	5.67%	7.08%
Annual Precipitation	4.56%	2.01%
Temperature Annual Range	3.28%	35.26%
Precipitation Seasonality	1.03%	0.53%
Aspect	0.60%	1.79%

Table 3.20 Bioclimatic, elevation, and soil pH variable trends for *H. bicknellii* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	11℃	16℃	14℃	14℃	14℃	6℃ - 16℃
Mean Diurnal Range	10℃	15℃	12℃	12℃	12℃	8℃ - 15℃
Temperature Annual Range	32℃	38℃	37℃	37℃	37℃	25℃ - 38℃
Annual Precipitation	1080mm	1607mm	1317mm	1316mm	1312mm	1073mm - 2013mm
Precipitation Seasonality	11%	22%	16%	16%	14%	9% - 22%
Elevation	24m	520m	131m	120m	107m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14356	15460	14976	14965	14951	14070 - 15502
Soil pH	4.9	6.9	5.5	5.4	5.3	4.2 - 7.5

The majority of suitable habitat for *H. bicknellii* was predicted within the Cultivated Cropland ecological system (33.01%) which consists of agricultural vegetation including row crops such as corn, soybeans, cotton, tobacco, sunflowers and some planted grain crops (USNVC, 2019). In such areas, crop vegetation accounts for at least 20% of the total vegetation and includes land being actively tilled (U.S. Geological Survey Gap Analysis Project, 2018). The Southern Interior Low Plateau Dry-Mesic Oak Forest accounted for 13.73% of suitable habitat. This ecological system consists of upland hardwood-dominated forests occurring in the Interior Low Plateau ecoregion along ridgetops and slopes of various aspects which encompasses a variety of associations ranging from submesic to dry moisture gradients (NatureServe, 2009). Substrates range from calcareous to acidic with shallow, well- to excessively well-drained soils in drier areas and moderately well-drained soils in submesic to dry-mesic areas (NatureServe, 2009; USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system accounted for 11.43% of suitable habitat. This system consists of high-diversity, primarily deciduous forests occurring on deep and enriched soils in the Cumberland and Allegheny plateaus, Ridge and Valley, and the Interior Low Plateau of the eastern United States (NatureServe, 2009; USNVC, 2019).

These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *H. bicknellii* (16.08%) occurred within the Memphis-Loring-Grenada-Collins soil series. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Loring soil series consists of fine-silty soils which are moderately well drained and formed in loess on level to strongly sloping uplands and stream terraces. While many of the areas containing this soil have been cleared for crops, wooded areas contain oak, hickory, elm, maple and tulip poplar tree species. The Grenada series consists of very deep, fine-silty soils that are moderately well drained and formed in thick loess. These moderately to strongly acidic soils occur in the southern Mississippi Valley silty uplands on uplands and stream terraces. The Collins series consists of very deep, coarse-silty soils which are moderately well drained and permeable. These soils formed in silty alluvium on flood plains of streams in the southern Mississippi Valley silty uplands. While many of the areas containing this soil have been cleared for crops including hay and pastures, wooded areas contain bottomland hardwood vegetation.

The Memphis-Adler soil series accounted for 11.43% of soils within the suitable habitat predicted for *H. bicknellii*. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Adler soil series consists of moderately deep, well drained soils on sedimentary plains, hills and escarpments. These coarse-silty soils formed in silty alluvial areas and occur on flood plains. These soils are subject to brief to long flooding during winter and early spring. The majority of areas containing this soil has been cleared for croplands however native vegetation includes mixed bottomland hardwoods.

The Hammack-Brandon-Bodine-Baxter soil series accounted for 10.11% of soils within the suitable habitat predicted for *H. bicknellii*. The Hammack soil series consists of fine-silty soils which are very deep, well drained and have moderate permeability. These moderately to strongly acidic soils formed in a loess mantle underlain with limestone and occur on ridge tops and side slopes of rolling to hilly areas with some areas having karst topography. The majority of areas with this soil are used for hay, pasture and crops such as corn, soybeans, and tobacco. Steeper areas in forests contain oaks, hickories, maples and hackberry. The Bradon soil series consists of fine-silty soils which are very deep, well drained and typically range from strongly to very strongly acidic. In the silty upper areas, permeability is moderate however, in the gravelly substratum permeability is variable and can range from moderately rapid to slow. These soils formed in a silty mantle presumably consisting of loess over gravelly marine and riverine deposited materials and occur on gently sloping to steep upland ridges and hillsides. The majority of areas containing these soils consist of hardwood forests with the dominant woodland species being oaks, hickories, black gum, elms, and dogwoods. Few areas are in pasture and hay croplands. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

In summary, modeling for *H. bicknellii* predicted suitable habitat across 3% of Tennessee, with a significant portion of the suitable habitat (77%) being predicted within the Mississippi Valley Loess Plains and the Interior Plateau ecoregions and less than 1% being predicted within the last known county of observation (Blount) and adjacent counties. While only a small amount of suitable habitat was predicted in the state, a fair amount of habitat predicted (33%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Cultivated Cropland ecological system, which consists of areas where crop vegetation accounts for at least 20% of total vegetation and includes land that is actively tilled. This prediction should be further evaluated as habitat for *H. bicknellii* has been described as sandy or rocky barrens, glades, rock outcrops, prairies, fields, and open woodlands (FNA, 2008; Weakley, In Preparation). It may be the case that the model is highlighting these open, human-disturbed areas which share similarities to the open, naturally disturbed habitats this species frequently occupies.

***Helianthemum canadense* (longbranch frostweed)**

The AUC value for this model was 0.685 indicating minimal discrimination ability. The final model for *H. canadense* predicted 39,680 km^2 of suitable habitat across Tennessee (32.42% minimally suitable; 60.85% moderately suitable; 6.73% highly suitable). Of the total suitable habitat, 19,712 km^2 (49.68%) was contained within protected lands (54.02% minimally suitable; 45.47% moderately suitable; 0.51% highly suitable). Notable protected areas containing suitable habitat include the Meeman-Shelby Forest SNA, Hatchie National Wildlife Refuge, Chickasaw National Wildlife Refuge, Land Between the Lakes National Recreation Area, Montgomery Bell State Park, and Natchez Trace State Park. The amount of highly suitable habitat was concentrated in west and central Tennessee, the majority being predicted in the Interior Plateau (41%), Mississippi Valley Loess Plains (21%), and Southeastern Plains (19%) ecoregions. These predictions do not align with the last known occurrences for this species which were located in Blount and Monroe counties in east Tennessee. The last known counties of observation and adjacent counties contained only 615 km^2 (2%) of the suitable habitat predicted (Figure 3.7).

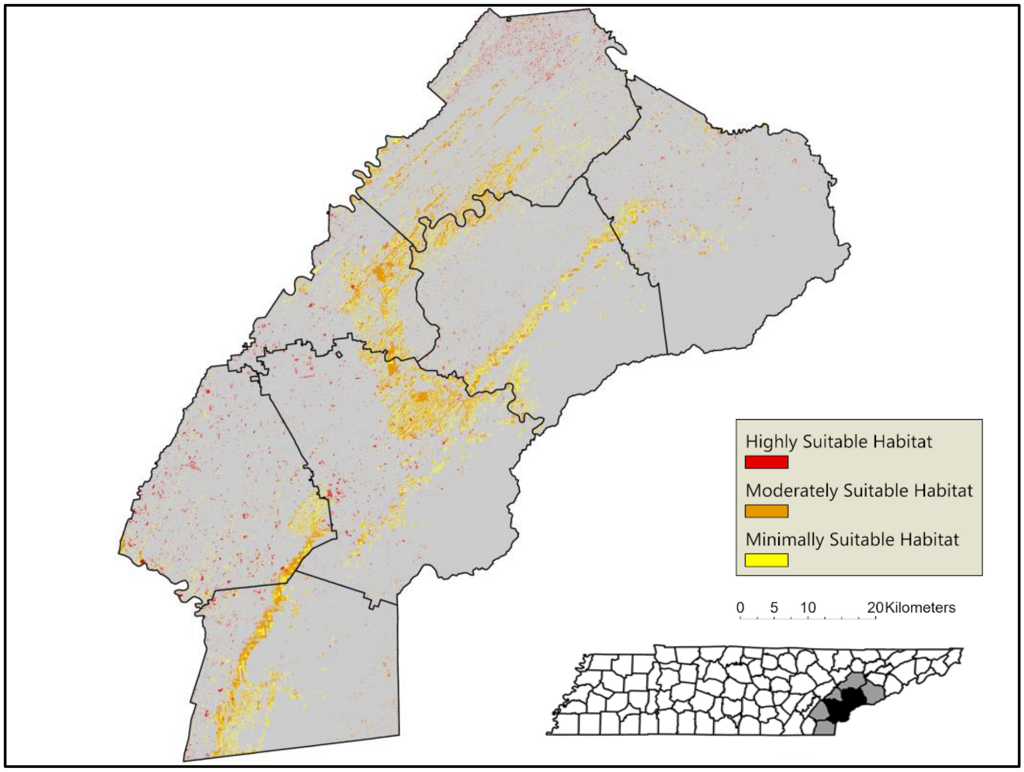

Figure 3.7 Predicted suitable habitat for *H. canadense* within the last known counties of observation (Blount and Monroe, shown in black) and adjacent counties

Environmental variables used in the final SDM for *H. canadense* were annual mean temperature (BIO1), mean diurnal range (BIO2), annual precipitation (BIO12), precipitation seasonality (BIO15), soil type, land cover, solar radiation, elevation, and aspect. Land cover had the highest permutation importance (37.29%), indicating this was the most important variable for the overall model; annual precipitation had the lowest permutation importance (0.16%), indicating the variable was not very important for the overall model (Table 3.21). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 14℃ to 16℃, a mean diurnal range (BIO2) of 12℃ to

14°C, and an annual temperature range (BIO7) of 36°C to 38°C. For the majority of suitable habitat, BIO1, BIO2, and BIO7 values fell just above the average temperature values in Tennessee. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,333mm to 1,380mm, falling around the average annual precipitation for the state. Suitable habitat was predicted at lower elevations ranging primarily from 84 m to 174 m and in soils with a pH ranging from 5.1-5.5. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.22. Northwest facing slopes were the most common within predicted suitable habitat (17.6%), followed by west facing (16.7%) and southwest facing slopes (13.3%).

Table 3.21 Variable permutation importance and percent contribution for *H. canadense*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Land Cover	37.29%	27.13%
Soil Type	25.28%	65.58%
Elevation	20.13%	1.96%
Mean Diurnal Range	9.02%	2.28%
Aspect	4.14%	1.51%
Solar Radiation	1.84%	0.93%
Precipitation Seasonality	1.13%	0.23%
Annual Mean Temperature	1.01%	0.32%
Annual Precipitation	0.16%	0.06%

Table 3.22 Bioclimatic, elevation, and soil pH variable trends for *H. canadense* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	10℃	16℃	14℃	14℃	14℃	6℃ - 16℃
Mean Diurnal Range	10℃	15℃	12℃	13℃	13℃	8℃ - 15℃
Temperature Annual Range	30℃	38℃	36℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1074mm	1663mm	1353mm	1352mm	1356mm	1073mm - 2013mm
Precipitation Seasonality	11%	22%	16%	16%	15%	9% - 22%
Elevation	24m	987m	188m	160m	109m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14283	15502	14973	14980	15074	14070 - 15502
Soil pH	4.7	6.9	5.4	5.3	5.3	4.2 - 7.5

The majority of suitable habitat for *H. canadense* was predicted within the Southern Interior Low Plateau Dry-Mesic Oak Forest (17.82%). This ecological system consists of upland hardwood-dominated forests occurring in the Interior Low Plateau ecoregion along ridgetops and slopes of various aspects which encompasses a variety of associations ranging from submesic to dry moisture gradients (NatureServe, 2009). Substrates range from calcareous to acidic with shallow, well- to excessively well-drained soils in drier areas and moderately well-drained soils in submesic to dry-mesic areas (NatureServe, 2009; USNVC, 2019). The Cultivated Cropland ecological system accounted for 15.62% of total suitable habitat. This ecological system consists of agricultural vegetation including row crops such as corn, soybeans, cotton, tobacco, sunflowers and some planted grain crops (USNVC, 2019). In such areas, crop vegetation accounts for at least 20% of the total vegetation and includes land being actively tilled (U.S. Geological Survey Gap Analysis Program, 2011). The South-Central Interior Mesophytic Forest ecological system accounted for 10.12% of total suitable habitat. This system consists of high-diversity, primarily deciduous forests occurring on deep and enriched soils in the Cumberland and Allegheny plateaus, Ridge and Valley, and the Interior Low Plateau of the eastern United States

(NatureServe, 2009; USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *H. canadense* (9.95%) occurred within the Memphis-Loring-Grenada-Collins soil series. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Loring soil series consists of fine-silty soils which are moderately well drained and formed in loess on level to strongly sloping uplands and stream terraces. While many of the areas containing this soil have been cleared for crops, wooded areas contain oak, hickory, elm, maple and tulip poplar tree species. The Grenada series consists of very deep, fine-silty soils that are moderately well drained and formed in thick loess. These moderately to strongly acidic soils occur in the southern Mississippi Valley silty uplands on uplands and stream terraces. The Collins series consists of very deep, coarse-silty soils which are moderately well drained and permeable. These soils formed in silty alluvium on flood plains of streams in the southern Mississippi Valley silty uplands. While many of the areas containing this soil have been cleared for crops including hay and pastures, wooded areas contain bottomland hardwood vegetation.

The Smithdale-Lexington soil series accounted for 8.17% of soils within the suitable habitat predicted for *H. canadense*. The Smithdale soil series consists of fine-loamy soils which are very deep, well drained, and moderately permeable. These soils formed in the thick beds of loamy marine sediments and occur on ridge tops and hill slopes in uplands of the Southern and Western Coastal Plains. Most areas of this soil contain loblolly, longleaf and shortleaf pine woodlands. The majority of cleared areas are used for pastures while some areas are used for corn, cotton, soybean and grain crops. The Lexington soil series consists of fine-silty soils which are very deep, well drained and have moderately to moderately rapid permeability. These soils occur on level to moderately steep uplands which have a thin mantle of loess, underlain by loamy and sandy marine sediments. A small extent of this soil is within forests while the majority is used for crops including hay and pasture.

The Mountview-Dickson-Baxter soil series accounted for 6.30% of soils within the suitable habitat predicted for *H. canadense*. The Mountview soil series consists of fine-silty soils which are very deep, well to moderately well drained and have moderately slow to moderate permeability. These soils formed in a silty loess mantle on underlying residuum of limestone or old alluvium and occur on undulating to rolling ridge tops and broad, plateau-like areas. The majority of areas containing these soils are used for hay, pasture, cotton, corn and tobacco. Some areas are in woodlands containing primarily oak, hickory, and maple species. The Dickson soil series consists of fine-silty soils which are very deep, moderately well drained and have very slow to moderate permeability. These soils formed in a silty mantle with underlying residuum of limestone and occur on nearly level to sloping ridges on uplands. The majority of areas have been clearing for hay, pasture, corn, soybean, and tobacco crops. Some areas occur in forests containing oaks, poplar, hickories, gums and maples. These soils are found in the Highland Rim in Tennessee. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

In summary, modeling for *H. canadense* predicted suitable habitat across 36% of Tennessee, with a significant portion of suitable habitat (41%) being predicted within the Interior Plateau ecoregion and only 2% being predicted in the last known counties of observation, Blount and Monroe, and adjacent counties. Half of the suitable habitat predicted (50%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Southern Interior Low Plateau Dry-Mesic Oak Forest ecological system which aligns with the habitat described by FNA, Weakley, and the Tennessee

Flora Committee as dry, upland oak-hickory woods, rocky slopes, forest edges and disturbed areas (FNA, 2008; Tennessee Flora Committee, 2014; Weakley, In Preparation).

***Lachnocaulon anceps* (whitehead bogbutton)**

The AUC value for this model was 0.837 indicating very good discrimination ability. The final model for *L. anceps* predicted only 78 km^2 of minimally suitable habitat across Tennessee, moderately suitable and highly suitable habitat were not predicted in the state. Of the minimally suitable habitat predicted, 32 km^2 (41%) was contained within protected lands. Notable protected areas containing suitable habitat include Harrison Bay State Park, Pickwick Landing State Park, T.O. Fuller State Park, Lucias E. Burch Jr. SNA, and Meeman-Shelby Forest SNA. Suitable habitat was predicted in all Tennessee ecoregions except the Central Appalachians. The majority of suitable habitat was concentrated in the southwestern corner of the state in the Mississippi Valley Loess Plains (43%) and Mississippi Alluvial Plain (19%) ecoregions. The last known county of observation, Cumberland county, and adjacent counties contained only 1 km^2 (1%) of the suitable habitat predicted (Figure 3.8).

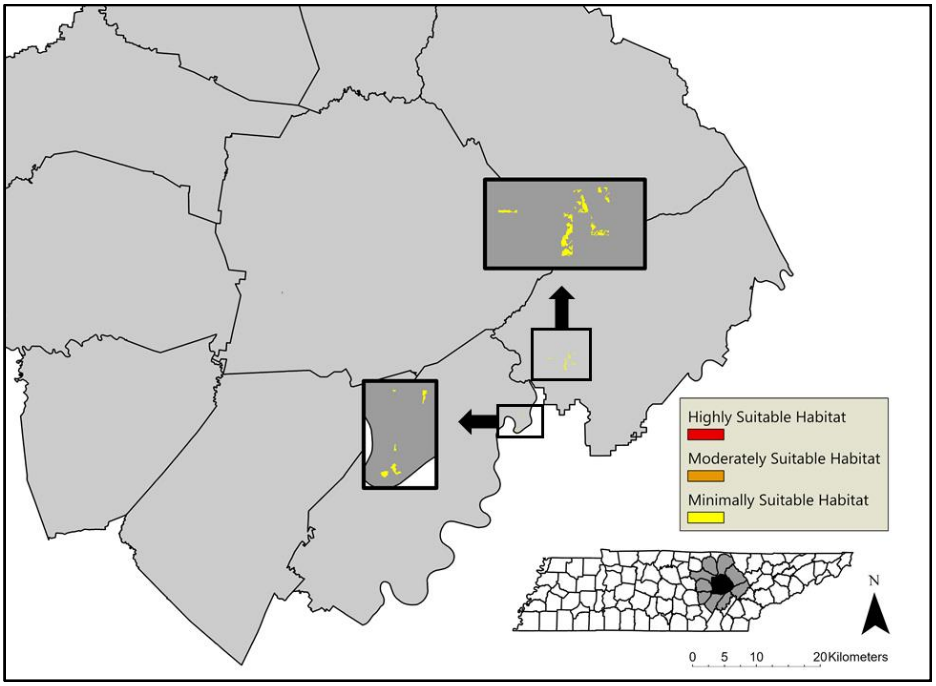

Figure 3.8 Predicted suitable habitat for *L. anceps* within the last known county (Cumberland, shown in black) of observation and adjacent counties

Environmental variables used in the final SDM for *L. anceps* were annual mean temperature (BIO1), mean diurnal range (BIO2), annual precipitation (BIO12), temperature annual range (BIO7), precipitation seasonality (BIO15), soil type, land cover, solar radiation, elevation, soil pH, and aspect. Temperature annual range (BIO7) had the highest permutation importance (44.45%), indicating this was the most important variable for the overall model; annual precipitation (BIO12) had the lowest permutation importance (0.01%), indicating the variable was not very important for the overall model (Table 3.23). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 16℃ to 17℃, a mean diurnal range (BIO2) of 11℃ to 12℃, and an annual temperature range (BIO7) of 35°C to 36℃. For the majority of suitable habitat, BIO2 and BIO7 values fell just below the average temperature ranges in Tennessee while BIO1 values were above the average value for the state. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,315mm to 1,359mm, falling just below the average annual precipitation for the state, and a precipitation seasonality value of 21-22%, falling well above the average value in Tennessee. Suitable habitat was predicted most frequently at lower elevations ranging from 57 m to 94 m and in soils with a pH ranging from 5.5-5.7. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.24. West facing slopes were the most common within predicted suitable habitat (14.4%), followed by northwest facing (12.5%) and northeast facing slopes (11.7%).

Table 3.23 Variable permutation importance and percent contribution for *L. anceps*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Temperature Annual Range	44.45%	56.54%
Land Cover	22.98%	13.66%
Annual Mean Temperature	13.59%	2.33%
Soil pH	4.58%	3.85%
Elevation	4.13%	2.15%
Precipitation Seasonality	3.01%	11.50%
Soil Type	2.33%	3.48%
Mean Diurnal Range	2.28%	1.51%
Aspect	1.79%	0.26%
Solar Radiation	0.87%	3.87%
Annual Precipitation	0.01%	0.85%

Table 3.24 Bioclimatic, elevation, and soil pH variable trends for *L. anceps* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	12°C	16°C	15°C	16°C	16°C	6°C - 16°C
Mean Diurnal Range	11°C	13°C	12°C	11°C	11°C	8°C - 15°C
Temperature Annual Range	32°C	36°C	35°C	35°C	35°C	25°C - 38°C
Annual Precipitation	1184mm	1549mm	1351mm	1339mm	1323mm	1073mm - 2013mm
Precipitation Seasonality	12%	22%	19%	21%	21%	9% - 22%
Elevation	57m	595m	132m	93m	206m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14614	15496	15226	15291	15428	14070 - 15502
Soil pH	5.1	6.6	5.6	5.6	5.6	4.2 - 7.5

The majority of suitable habitat for *L. anceps* was predicted within the East Gulf Coastal Plain Northern Loess Plain Oak-Hickory Upland (20.03%) ecological system. This ecological system occurs on xeric sites in western Tennessee including sandy river bluffs, sandy uplands, and clayey uplands (USNVC, 2019). The soils in this ecological system are typically silty and rich being derived from loess deposits and some are poorly drained (NatureServe, 2009). The East Gulf Coastal Plain Northern Loess Bluff Forest ecological system accounted for 16.45% of suitable habitat. This ecological system consists of upland, hardwood dominated forests along steep loess bluffs bordering the eastern edge of the Mississippi Alluvial Plain as well as hardwood vegetation immediately to the east of such bluffs and ravines within the Mississippi Valley Loess Plains (USNVC, 2019). In such areas, vegetation is typically richer than in surrounding areas without loess deposits (USNVC, 2019). The Southern Ridge and Valley Dry Calcareous Forest ecological system accounted for 12.81% of suitable habitat. This system consists of rich forests occurring on moderately steep slopes across various limestone and dolomitic formations in the Ridge and Valley ecoregion (NatureServe, 2009; USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *L. anceps* (36.75%) occurred within the Memphis-Adler soil series. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Adler soil series consists of moderately deep, well drained soils on sedimentary plains, hills and escarpments. These coarse-silty soils formed in silty alluvial areas and occur on flood plains. These soils are subject to brief to long flooding during winter and early spring. The majority of areas containing this soil has been cleared for croplands however native vegetation includes mixed bottomland hardwoods.

The Robinsonville-Commerce soil series accounted for 9.75% of soils within the suitable habitat predicted for *L. anceps*. The Robinsonville soil series consists of deep, well drained soils with moderately rapid permeability. The level to gently sloping soils formed in loamy alluvium on the flood plain of the Mississippi River. These soils are in natural levee positions along the current and former channels of the river and many areas containing this soil are subject to flooding unless protected. The majority of areas containing this soil series are cleared and used for growing cotton, corn, soybeans, hay and pastures. In wooded areas where this soil occurs, mixed hardwoods are present. The Commerce soil series consists of deep, somewhat poorly drained soils which are moderately slowly permeable. These soils formed in loamy alluvial sediments similar to the Robinsonville soils. These soils are located on the alluvial plains of the Mississippi plains of the Mississippi River and its tributaries and the majority of areas are protected from flooding by man-made levees. Unprotected areas are subject to occasional or frequent flooding for short to long durations due to runoff. The majority of areas containing this soil series are used for croplands including hay and pasture crops. The native vegetation where this soil occurs consists of mixed hardwoods.

The Jefferson-Allen soil series accounted for 9.65% of soils within the suitable habitat predicted for *L. anceps*. The Jefferson soil series consists of gravelly, silt loam soils which are deep to very deep, well drained and have moderately rapid permeability. These soils formed in colluvium from soils formed in residuum of acidic sandstone, shale and siltstone and occur on steep mountain sides and foot slopes, often below sandstone escarpments. The majority of area where these soils occur consists of oak, pine, hickory and laurel dominated forests however, some of the less steep areas have been cleared for pastures. The Allen soil series consists of fine-loamy soils which are very deep, well drained and moderately permeable. These soils formed in alluvium or colluvium or in residuum of sandstone and shale and occur on hillsides, foot slopes, and terraces in the Appalachian ridges and valleys and Highland Rim Plateau of Tennessee. About one-fourth of these soils are in forested areas containing oaks, hickories, poplars, beeches, and pines. Other areas have been cleared primarily for pasture; however, some areas are used for tobacco, corn and small grain crops.

In summary, modeling for *L. anceps* predicted suitable habitat across less than 1% of Tennessee, with a significant portion of suitable habitat (62%) being predicted within the Mississippi Valley Loess Plains and Mississippi Alluvial Plains ecoregions and only 1% being predicted in the last known county of observation, Cumberland, and adjacent counties. While only a small area suitable habitat was predicted in Tennessee, a significant portion of this habitat predicted (41%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the East Gulf Coastal Plain Northern Loess Plain Oak-Hickory Upland ecological system which includes sandy river bluffs and upland woods. This prediction aligns with the habitat described for *L. anceps* as moist sands, pinelands, seep edges and flatwoods clearings (FNA, 2008; Weakley, In Preparation).

***Leavenworthia exigua* var. *lutea* (Tennessee gladecress)**

The AUC value for this model was 0.964 indicating excellent discrimination ability. The final model for *L. exigua* var. *lutea* predicted 48,451 km^2 of suitable habitat across Tennessee (48.85%

minimally suitable; 14.90% moderately suitable; 36.25% highly suitable). Of the total suitable habitat, 31,452 km^2 (64.91%) was contained within protected lands (61.53% minimally suitable; 10.78% moderately suitable; 27.69% highly suitable). Notable protected areas containing suitable habitat include the Cedars of Lebanon State Park, Montgomery Bell State Park, Tims Ford State Park, Gattinger's Cedar Glade and Barrens SNA, Vine Cedar Glade SNA, Couchville Cedar Glade SNA, and Stones River National Battlefield. The highly suitable habitat predicted was concentrated in central Tennessee, the majority being predicted in the Interior Plateau (72%) and Southeastern Plains (13%) ecoregions. The last known county of observation, Maury county, and adjacent counties contained 26,448 km^2 (55%) of the suitable habitat predicted (Figure 3.9).

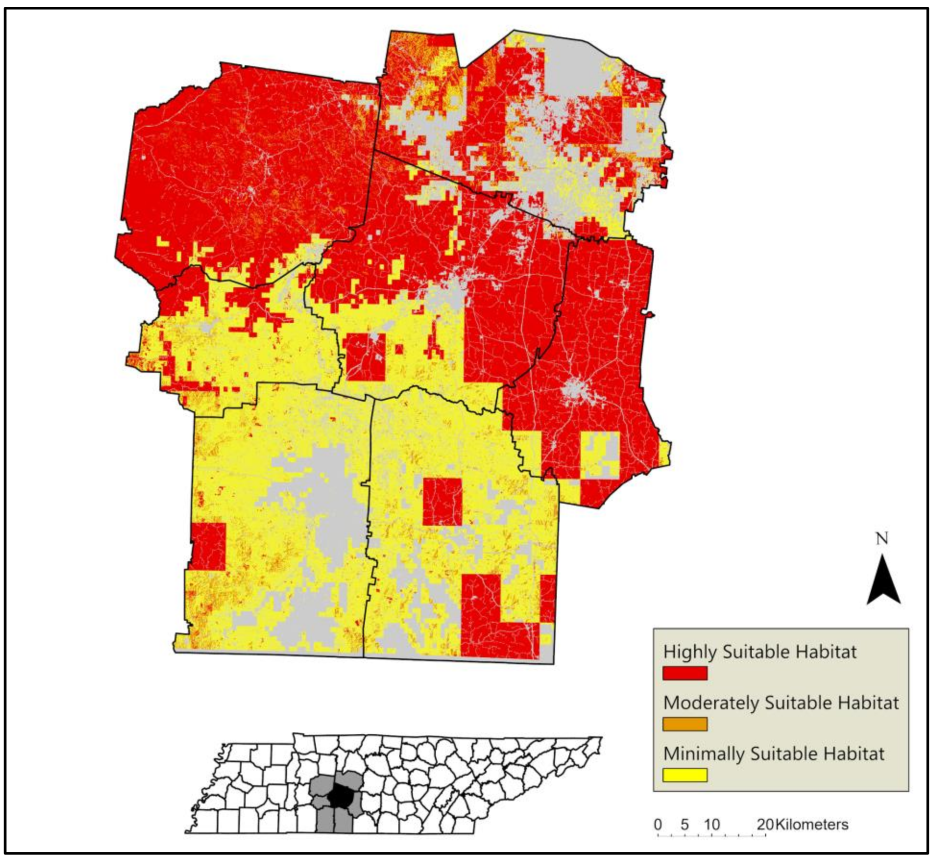

Figure 3.9 Predicted suitable habitat for *L. exigua* var. *lutea* within the last known county of observation (Maury, shown in black) and adjacent counties

Environmental variables used in the final SDM for *L. exigua* var. *lutea* were soil type, soil pH, land cover, elevation, aspect, mean diurnal range (BIO2), temperature annual range (BIO7), and annual precipitation (BIO12). Temperature annual range (BIO7) had the highest permutation importance (69.59%), indicating this was the most important variable for the overall model; elevation had the lowest permutation importance (0.07%), indicating the variable was not very important for the overall model (Table 3.25). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 14℃ to 16℃, a mean diurnal range (BIO2) of 13℃ to 15℃, and an annual temperature range (BIO7) of 36°C to 38°C. BIO1, BIO2, and BIO7 values for the majority of predicted suitable habitat were above the average values in Tennessee. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,342 mm to 1,382 mm of rainfall and a precipitation seasonality (BIO15) of 15-17%. Suitable habitat was most frequently predicted at lower elevations ranging from 128 m to 258 m and in soils with a pH ranging from 5.3-5.6. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.26. West facing slopes were the most common within predicted suitable habitat (13.4%), followed by northwest facing (12.7%) and southwest facing slopes (12.5%).

Table 3.25 Variable permutation importance and percent contribution for *L. exigua* var. *lutea*. Variables are listed in order of permutation importance.

Variable	**Permutation Importance**	**Percent Contribution**
Temperature Annual Range	69.59%	25.15%
Soil Type	19.85%	49.37%
Annual Precipitation	5.75%	3.24%
Land Cover	1.91%	9.90%
Soil pH	1.76%	0.16%
Aspect	0.76%	0.50%
Mean Diurnal Range	0.30%	0.39%
Elevation	0.07%	11.30%

Table 3.26 Bioclimatic, elevation, and soil pH variable trends for *L. exigua* var. *lutea* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	12°C	16°C	14°C	14°C	14°C	6°C - 16°C
Mean Diurnal Range	11°C	15°C	13°C	13°C	13°C	8°C - 15°C
Temperature Annual Range	33°C	38°C	36°C	37°C	37°C	25°C - 38°C
Annual Precipitation	1084mm	1581mm	13741mm	1376mm	1356mm	1073mm - 2013mm
Precipitation Seasonality	11%	22%	16%	16%	15%	9% - 22%
Elevation	24m	803m	202m	199m	109m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14362	15502	14960	14977	15045	14070 - 15502
Soil pH	4.8	6.9	5.4	5.3	5.4	4.2 - 7.5

The majority of suitable habitat (22.72%) for *L. exigua* var. *lutea* was predicted in the Pasture and Hay Field Crop ecological system which consists of areas of grasses, legumes, and grass-legume mixtures planted for livestock grazing or the production of seed or hay crops on a perennial cycle where pasture and hay vegetation accounts for at least 20% of the total vegetation (NatureServe, 2009). The Southern Interior Low Plateau Dry-Mesic Oak Forest ecological system accounted for 19.42% of suitable habitat. This ecological system consists of upland hardwood-dominated forests occurring in the Interior Low Plateau ecoregion along ridgetops and slopes of various aspects which encompasses a variety of associations ranging from submesic to dry moisture gradients (NatureServe, 2009). Substrates range from calcareous to acidic with shallow, well- to excessively well-drained soils in drier areas and moderately well-drained soils in submesic to dry-mesic areas (NatureServe, 2009; USNVC, 2019). The Cultivated Cropland ecological system accounted for 14.94% of suitable habitat. This ecological system consists of agricultural vegetation including row crops such as corn, soybeans, cotton, tobacco, sunflowers and some planted grain crops (USNVC, 2019). In such areas, crop vegetation accounts for at least 20% of the total vegetation and includes land being actively tilled (U.S. Geological Survey Gap Analysis Program, 2011).

The Nashville Basin Limestone Glade and Woodland ecological system, which is known to contain highly suitable habitat for *L. exigua* var. *lutea*, covers 612 km^2 of Tennessee. Suitable habitat for *L. exigua* var. *lutea* was predicted across 609 km^2 (99%) of this ecological system. This system consists of a range of plant communities which are associated with thin soils over flat areas of Ordovician limestone in the Inner Nashville Basin of Tennessee (NatureServe, 2019). Habitats include vegetated rock outcrops, grasslands, seasonally wet herbaceous seeps, shrublands and woodlands dominated by *Juniperus virginiana* and various oak species (NatureServe, 2009).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *L. exigua* var. *lutea* (8.13%) occurred within the Hammack-Brandon-Bodin-Baxter soil series. The Hammack soil series consists of fine-silty soils which are very deep, well drained and have moderate permeability. These moderately to strongly acidic soils formed in a loess mantle underlain with limestone and occur on ridge tops and side slopes of rolling to hilly areas with some areas having karst topography. The majority of areas with this soil are used for hay, pasture and crops such as corn, soybeans, and tobacco. Steeper areas in forests contain oaks, hickories, maples and hackberry. The Bradon soil series consists of fine-silty soils which are very deep, well drained and typically range from strongly to very strongly acidic. In the silty upper areas, permeability is moderate however, in the gravelly substratum permeability is variable and can range from moderately rapid to slow. These soils formed in a silty mantle presumably consisting of loess over gravelly marine and riverine deposited materials and occur on gently sloping to steep upland ridges and hillsides. The majority of areas containing these soils consist of hardwood forests with the dominant woodland species being oaks, hickories, black gum, elms, and dogwoods. Few areas are in pasture and hay croplands. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

The Mountview-Dickson-Baxter soil series accounted for 7.83% of soils within the suitable habitat predicted for *L. exigua* var. *lutea*. The Mountview soil series consists of fine-silty soils which are very deep, well to moderately well drained and have moderately slow to moderate permeability. These soils formed in a silty loess mantle on underlying residuum of limestone or old alluvium and occur on undulating to rolling ridge tops and broad, plateau-like areas. The majority of areas containing these soils are used for hay, pasture, cotton, corn and tobacco. Some areas are in woodlands containing primarily oak, hickory, and maple species. The Dickson soil series consists of fine-silty soils which are very deep, moderately well drained and have very slow to moderate permeability. These soils formed in a silty mantle with underlying residuum of limestone and occur on nearly level to sloping ridges on uplands. The majority of areas have been clearing for hay, pasture, corn, soybean, and tobacco crops. Some areas occur in forests containing oaks, poplar, hickories, gums and maples. These soils are found in the Highland Rim in Tennessee. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

The Sulphura-Dellrose-Bodine soil series accounted for 7.33% of soils within the suitable habitat predicted for *L. exigua* var. *lutea*. The Sulphura soil series consists of silt loam soils which are moderately deep and somewhat excessively drained with moderately rapid permeability. These soils formed in residuum of interbedded siltstone, limestone and shale and occur on highly dissected uplands and occasionally on rolling upland ridgetops. In the upper portion, soils range from strongly to moderately acidic while in the lower portion, soils range from strongly to slightly acidic. The majority of areas contain these soils are woodlands consisting of chestnut, oak, hickory, hackberry, pine and redcedar species. Few ridgetops have been cleared for use as pasture. These soils are primarily distributed in the Nashville Basin and Highland Rim in Tennessee. The Dellrose soil series consists of fine-loamy soils which are very deep, well drained and have moderately rapid permeability. These moderately to strongly acidic soils formed in medium textured cherty colluvium and occur on foot slopes and steep hillsides. While the majority of areas have been pastured, native vegetation consists of hardwoods such as beech, hickory, oaks and hackberry. These soils are distributed on slopes from the Highland Rim Plateau to the Central Basin in Tennessee. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture.

In summary, modeling for *L. exigua* var. *lutea* predicted suitable habitat across 44% of Tennessee, with the majority of suitable habitat (72%) being predicted within the Interior Plateau ecoregion and 55% being predicted in the last known county of observation, Maury, and adjacent counties. A significant portion of predicted suitable habitat (65%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Pasture and Hay Field Crop ecological system, which aligns with the habitat described as limestone glades, pastures old fields, and disturbed calcareous sites (FNA, 2008; Tennessee Flora Committee, 2014; Weakley, In Preparation). This species has been specifically documented in heavy, clay soil surrounding localized outcrops of limestone often occurring in pastures (NatureServe, 2019). Furthermore, the model predicted suitable habitat in 99% of the Nashville Basin Limestone Glade and Woodland ecological system, which is known to contain highly suitable habitat for this limestone endemic species.

***Rhynchospora alba* (white beaksedge)**

The AUC value for this model was 0.799 indicating good discrimination ability. The final model for *R. alba* predicted 24,297 km^2 of suitable habitat across Tennessee (62.39% minimally suitable; 24.18% moderately suitable; 13.43% highly suitable). Of the total suitable habitat, 15,683 km^2 (64.55%) was contained within protected lands (61.74% minimally suitable; 22.03% moderately suitable; 16.23% highly suitable). Notable protected areas containing suitable habitat include the Tennessee National Wildlife Refuge, Land Between the Lakes National Recreation Area, Reelfoot Lake SNA & WMA, Radnor Lake SNA, Savage Gulf SNA, North Chickamauga Creek Gorge SNA, Big South Fork National River and Recreation Area, Cherokee National Forest and Great Smoky Mountains National Park. Suitable habitat was predicted in all ecoregions in Tennessee, the majority being predicted in the Southwestern Appalachian (33%) and Blue Ridge (18%) ecoregions. The last known county of observation, Johnson county, and adjacent counties contained 1,397 km^2 (6%) of the suitable habitat predicted (Figure 3.10).

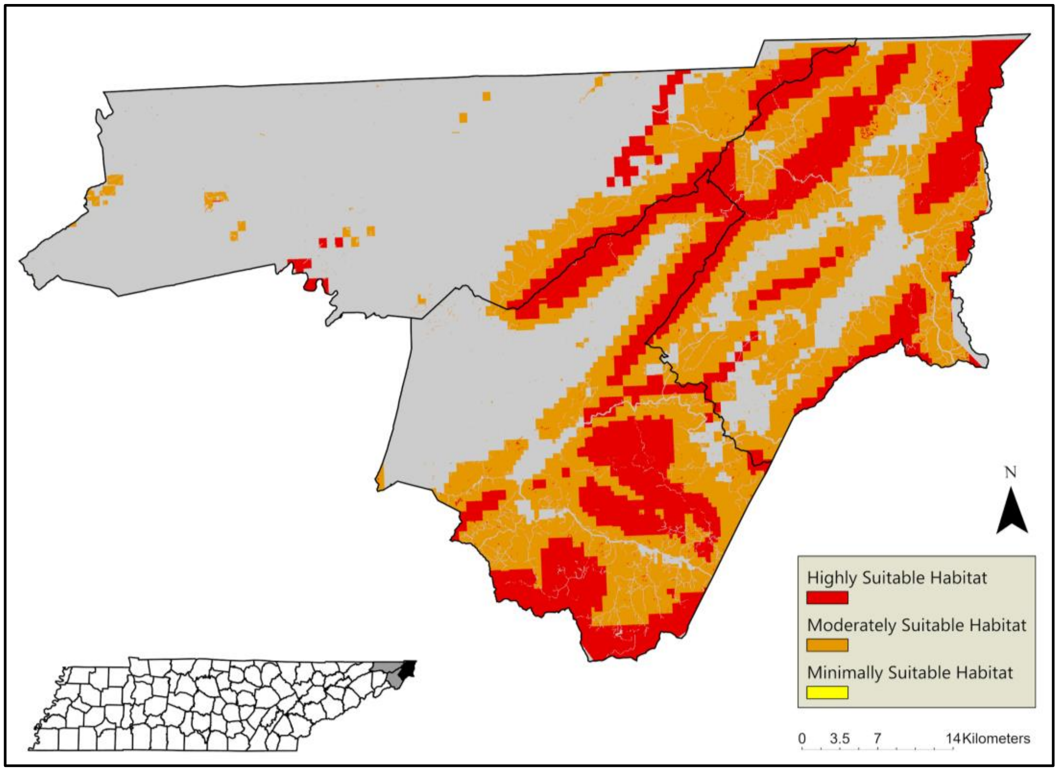

Figure 3.10 Predicted suitable habitat for *R. alba* within the last known county of observation (Johnson, shown in black) and adjacent counties

Environmental variables used in the final SDM for *R. alba* were annual mean temperature (BIO1), mean diurnal range (BIO2), soil type, land cover, elevation, and soil pH. Land cover had the highest permutation importance (29.45%), indicating this was the most important variable for the overall model; annual mean temperature (BIO1) had the lowest permutation importance (0.33%), indicating the variable was not very important for the overall model (Table 3.27). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 15℃, a mean diurnal range (BIO2) of 12℃ to 14℃, and an annual temperature range (BIO7) of 34℃ to 37℃. BIO1, BIO2 and BIO7 values fell around the average of the temperature ranges in Tennessee. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,290mm to 1,398mm, falling around the average annual precipitation for the state. Suitable habitat was predicted most frequently at lower elevations ranging from 56 m to 152 m and in soils with a pH ranging from 5.0-5.4. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.28. West facing slopes were the most common within predicted suitable habitat (12.7%), followed by northwest facing (12.5%) and southeast facing slopes (12.4%).

Table 3.27 Variable permutation importance and percent contribution for *R. alba*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Land Cover	29.45%	68.95%
Mean Diurnal Range	26.26%	5.83%
Soil Type	23.33%	15.30%
Soil pH	18.79%	7.85%
Elevation	1.84%	1.33%
Annual Mean Temperature	0.33%	0.74%

Table 3.28 Bioclimatic, elevation, and soil pH variable trends for *R. alba* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7℃	16℃	13℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	8℃	14℃	12℃	12℃	12℃	8℃ - 15℃
Temperature Annual Range	25℃	38℃	35℃	35℃	36℃	25℃ - 38℃
Annual Precipitation	1073mm	2013mm	1397mm	1372mm	1342mm	1073mm - 2013mm
Precipitation Seasonality	9%	22%	15%	15%	15%	9% - 22%
Elevation	56m	1973m	435m	459m	109m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14070	15502	14841	14820	14631	14070 - 15502
Soil pH	4.2	6.8	5.2	5.2	5.1	4.2 - 7.5

The majority of suitable habitat (21.99%) for *R. alba* was predicted in the Allegheny-Cumberland Dry Oak Forest and Woodland ecological system. This system encompasses dry, hardwood forests on predominantly acidic substrates in the Cumberland Plateau as well as acidic sandstone ridges in the southern Ridge and Valley (NatureServe, 2009). The topography varies from rolling hills to steep slopes with typically dry, coarse soils that are relatively infertile (USNVC, 2019). At moderate to low elevations, stands are naturally stable, uneven-aged forests, with canopy dynamics generally dominated by gap-phase regeneration and subcanopy, shrub and herb layers are typically moderately well- to well-developed (USNVC, 2019). The Southern and Central Appalachian Oak Forest accounted for 7.98% of suitable habitat. This ecological system consists of primarily dry-mesic forests which occur on open and exposed topography at low to mid elevation in the southern Blue Ridge and southern Ridge and Valley ecoregions (NatureServe, 2019). At these low to moderate elevations, forests are uneven in age and naturally stable, with canopies typically dominated by gap-phase regeneration (NatureServe, 2019; USNVC, 2019). This system occurs on predominately acidic substrates with coarse, infertile soils and topography varies from rolling hills to steep slopes (USNVC, 2019). The Harvested Forest-Shrub Regeneration ecological system accounted for 7.06% of suitable habitat. This ecological system encompasses disturbed areas dominated by shrubs less than 5 meters high including true shrubs, young trees in early successional stages, or trees stunted from the environmental conditions that follow a tree harvesting event (U.S. Geological Survey Gap Analysis Program, 2011).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *R. alba* (16.14%) occurred within the Ramsey-Muskingum-Lonewood-Lily soil series. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The

Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Tyler-Nolichucky-Holston soil series accounted for 8.47% of soils within the suitable habitat predicted for *R. alba*. The Tyler soil series consists of fine-silty loam soils which are very deep, somewhat poorly drained and have very slow to moderately slow permeability. These soils formed in silty alluvium, in a mantle of loess on high Illinoian age terraces or dissected valley fills. The majority of areas where these soils occur are cultivated croplands for hay, pasture, corn, soybeans and wheat. Some areas are found in mixed deciduous woodlands. The Nolichucky soil series consists of fine-loamy soils which are very deep and well drained with moderate permeability. These soils formed in moderately fine-textured alluvium derived from sandstone, shale, quartzite and limestone and occur on gently sloping to steep high terraces. The majority of areas containing these soils are cleared for pasture and hay crops. These soils are found in the Appalachian ridges and valleys in Tennessee. The Holston soil series consists of fine-loamy soils which are very deep, well drained and have moderate permeability. These soils formed in old alluvium or colluvium and occur on nearly level to moderately steep stream terraces high above the floodplains and on foot slopes and benches in uplands. The majority of areas containing these soils have been cleared for crops such as tobacco, cotton, hay and pasture however, original forests consisted of mixed hardwoods and pines.

The Memphis-Loring-Grenada-Collins soil series accounted for 7.35% of soils within the suitable habitat predicted for *R. alba*. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Loring soil series consists of fine-silty soils which are moderately well drained and formed in loess on level to strongly sloping uplands and stream terraces. While many of the areas containing this soil have been cleared for crops, wooded areas contain oak, hickory, elm, maple and tulip poplar tree species. The Grenada series consists of very deep, fine-silty soils that are moderately well drained and formed in thick loess. These moderately to strongly acidic soils occur in the southern Mississippi Valley silty uplands on uplands and stream terraces. The Collins series consists of very deep, coarse-silty soils which are moderately well drained and permeable. These soils formed in silty alluvium on flood plains of streams in the southern Mississippi Valley silty uplands. While many of the areas containing this soil have been cleared for crops including hay and pastures, wooded areas contain bottomland hardwood vegetation.

In summary, modeling for *R. alba* predicted suitable habitat across 22% of Tennessee, with a significant portion of suitable habitat (51%) being predicted within the Southwestern Appalachian and Blue Ridge ecoregions and 6% being predicted in the last known county of observation, Johnson, and adjacent counties. Over half of the predicted suitable habitat (65%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Allegheny-Cumberland Dry Oak Forest and Woodland ecological system; however, this prediction should be evaluated further as this does not align with the described habitat. Habitat for *R. alba* has been described as acidic, sphagnum bogs, poor fens and open sites (FNA, 2008; Tennessee Flora Committee, 2014; Weakley, In Preparation). While the Allegheny-Cumberland Dry Oak Forest and Woodland system is drier than the described habitat for *R. alba*, it does occur on predominantly acidic substrates with infertile soils which may provide unknown suitable habitat for this species.

Rhynchospora latifolia **(sandswamp whitetop)**

The AUC value for this model was 0.862 indicating very good discrimination ability. However, the final model for *R. latifolia* did not predict any suitable habitat in Tennessee for this species. Suitable habitat was predicted for this species primarily in the southern coastal plains which aligns with its known distribution (Figure 3.11). The historical *R. latifolia* observation in Tennessee was never confirmed as the specimen held in the University of Tennessee Knoxville Herbarium was destroyed by fire (FNA, 2008). These model results support the speculation that *R. latifolia* has never occurred in Tennessee and that the specimen collected in 1901 in Coffee County by Augustin Gattinger was likely *R. colorata*, which was not described as a species until 1935. *R. colorata* occurs just over the state border in north eastern Alabama (FNA, 2008).

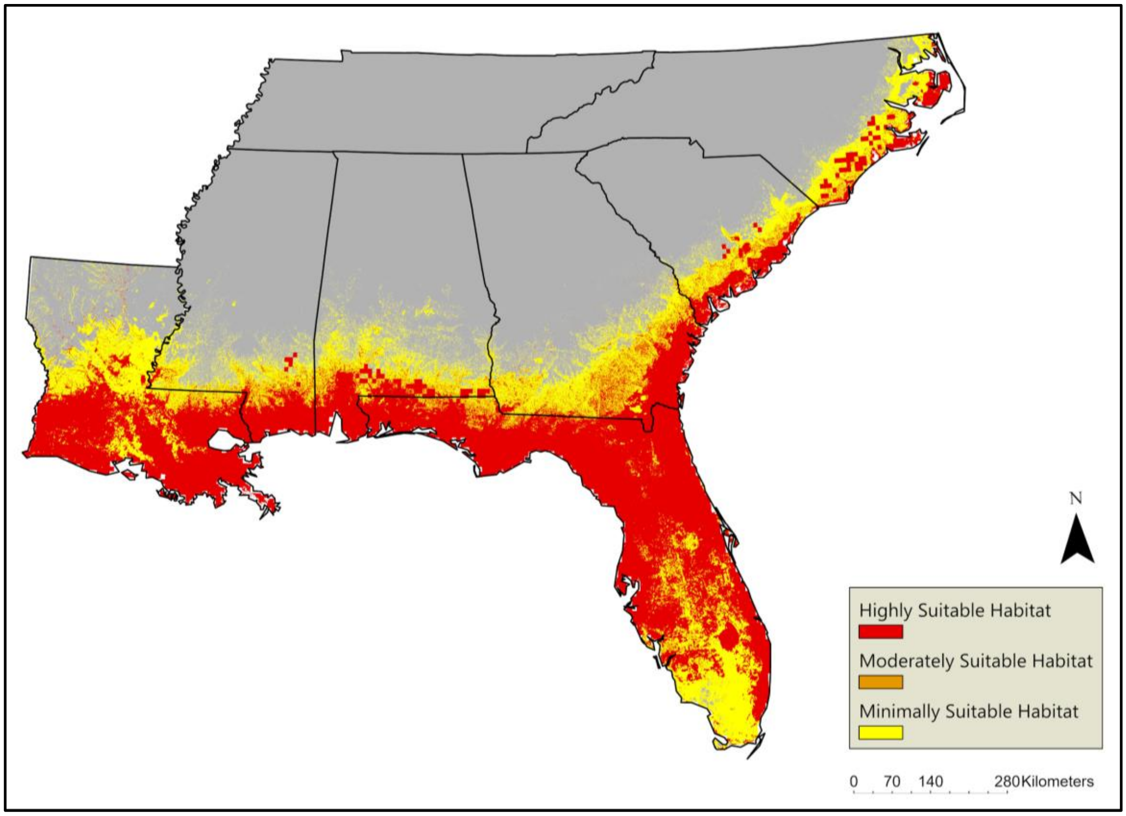

Figure 3.11 Predicted suitable habitat for *R. latifolia* in the southern coastal plains

Rhynchospora wrightiana **(Wright's beaksedge)**

The AUC value for this model was 0.808 indicating very good discrimination ability. The final model for *R. wrightiana* predicted 6,952 km^2 of suitable habitat across Tennessee (98.03% minimally suitable; 1.97% moderately suitable). Highly suitable habitat was not predicted in Tennessee for this species. Of the total suitable habitat, 3,1474 km^2 (45.28%) was contained within protected lands (97.95% minimally suitable; 2.05% moderately suitable. Notable protected areas containing suitable habitat include the Tennessee National Wildlife Refuge, Land Between the Lakes National Recreation Area, Pickwick Landing State Park, Natchez Trace State Park, Big Hill Pond State Park, Wolf River SNA and WMA, Meeman-Shelby Forest State Park and Reelfoot Lake SNA & WMA. Predicted suitable habitat was concentrated in western Tennessee. The majority of suitable habitat was predicted in the Mississippi

Valley Loess Plains (66%), Southeastern Plains (14%) and Mississippi Alluvial Plain (11%) ecoregions. The last known county of observation, Bledsoe county, and adjacent counties contained 5 km^2 (0.07%) of the suitable habitat predicted (Figure 3.12).

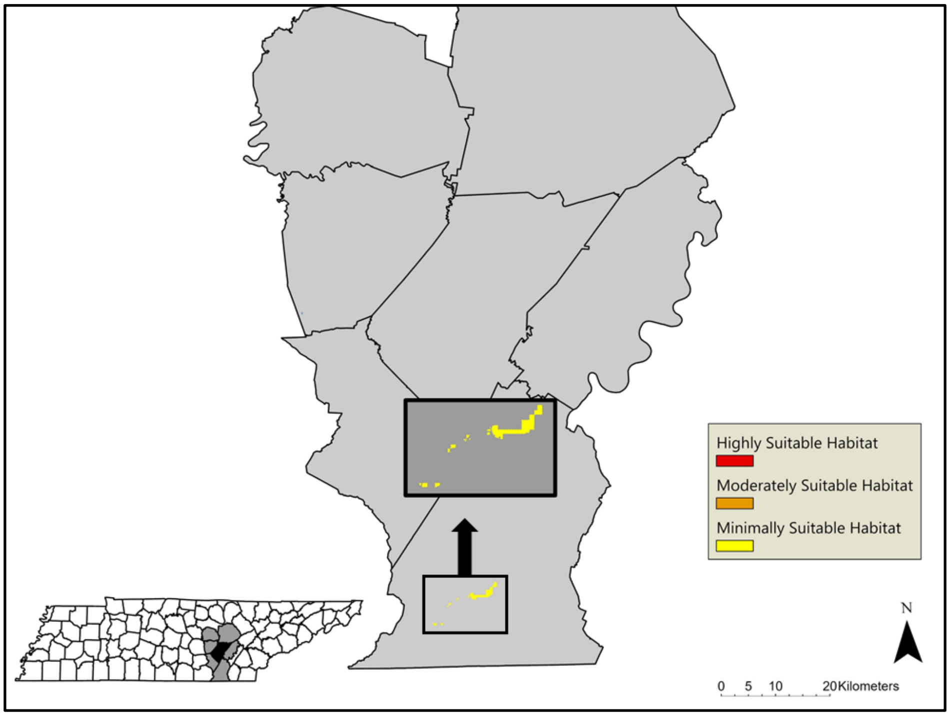

Figure 3.12 Predicted suitable habitat for *R. wrightiana* within the last known county (Bledsoe, shown in black) of observation and adjacent counties

Environmental variables used in the final SDM for *R. wrightiana* were temperature annual range (BIO7), annual precipitation (BIO12), precipitation seasonality (BIO15), soil type, land cover, elevation, and soil pH. Soil type had the highest permutation importance (30.53%), indicating this was the most important variable for the overall model; temperature annual range (BIO7) had the lowest permutation importance (2.04%), indicating this variable was not very important for the overall model (Table 3.29). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 16℃ to 17℃, a mean diurnal range (BIO2) of 12℃ to 13℃, and an annual temperature range

(BIO7) of 36°C to 37°C. For the majority of predicted suitable habitat, BIO1 and BIO7 values were above the average values in Tennessee while BIO2 values were below the average in the state. The majority of suitable habitat was predicted in areas having an annual precipitation (BIO12) of 1,312mm to 1,339mm, falling below the average annual precipitation for the state. Suitable habitat was predicted most frequently in soils with a pH ranging from 5.0-5.3. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.30. West facing slopes were the most common within predicted suitable habitat (12.7%), followed by northwest facing (12.5%) and southeast facing slopes (12.4%).

Table 3.29 Variable permutation importance and percent contribution for *R. wrightiana*. Variables are listed in order of permutation importance

Variable	Permutation Importance	Percent Contribution
Soil Type	30.53%	26.40%
Precipitation Seasonality	24.47%	58.07%
Elevation	24.24%	4.09%
Annual Precipitation	7.42%	1.36%
Land Cover	5.69%	7.74%
Soil pH	5.61%	1.52%
Temperature Annual Range	2.04%	0.82%

Table 3.30 Bioclimatic, elevation, and soil pH variable trends for R. wrightiana in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	14℃	16℃	15℃	16℃	16℃	6℃ - 16℃
Mean Diurnal Range	10℃	14℃	12℃	12℃	12℃	8℃ - 15℃
Temperature Annual Range	34℃	38℃	36℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1239mm	1466mm	1325mm	1324mm	1323mm	1073mm - 2013mm
Precipitation Seasonality	13%	22%	19%	20%	20%	9% - 22%
Elevation	24m	206m	100m	101m	109m	24 m - 1973m
Solar Radiation (kJ m-2 day-1)	14495	15502	15243	15265	15256	14070 - 15502
Soil pH	4.9	6.8	5.5	5.4	5.3	4.2 - 7.5

The majority of suitable habitat for *R. wrightiana* (38.02%) was predicted in the Cultivated Cropland ecological system. This ecological system consists of agricultural vegetation including row crops such as corn, soybeans, cotton, tobacco, sunflowers and some planted grain crops (USNVC, 2019). In such areas, crop vegetation accounts for at least 20% of the total vegetation and includes land being actively tilled (U.S. Geological Survey Gap Analysis Program, 2011). The East Gulf Coastal Plain Small Stream and River Floodplain Forest ecological system accounted for 12.62% of suitable habitat. This ecological system is associated with small rivers and creeks of the East Gulf Coastal Plain and is restricted to floodplains or terraces of streams and creeks (NatureServe, 2009). In such areas, flooding typically occurs annually, however the water table remains well below the soil’s surface during the majority of the growing season (NatureServe, 2009). Bottomland hardwood trees are an indicator of this system, however mesic hardwood species may also be present, especially in areas with less flooding such as upper terraces (NatureServe, 2009). The Open Freshwater ecological system accounted for 10.53% of suitable habitat. This ecological system consists of all areas of open water, generally less than 25% cover of vegetation or soil. Specifically, inland waters of streams, rivers, ponds and lakes (U.S. Geological Survey Gap Analysis Program, 2011).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *R. wrightiana* (32.35%) occurred within the Memphis-Loring-Grenada-Collins soil series. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Loring soil series consists of fine-silty soils which are moderately well drained and formed in loess on level to strongly sloping uplands and stream terraces. While many of the areas containing this soil have been cleared for crops, wooded areas contain oak, hickory, elm, maple and tulip poplar tree species. The Grenada series consists of very deep, fine-silty soils that are moderately well drained and formed in thick loess. These moderately to strongly acidic soils occur in the southern Mississippi Valley silty uplands on uplands and stream terraces. The Collins series consists of very deep, coarse-silty soils which are moderately well drained and permeable. These soils formed in silty alluvium on floodplains of streams in the southern Mississippi Valley silty uplands. While many of the areas containing this soil have been cleared for crops including hay and pastures, wooded areas contain bottomland hardwood vegetation.

The Memphis-Adler soil series accounted for 15.33% of soils within the suitable habitat predicted for *R. wrightiana*. The Memphis soil series consists of very deep, well drained soils with moderate permeability. These soils formed in loess deposits of the Coastal Plain. These silt loam and silty clay loam soils are moderately to strongly acidic and occur on nearly level to very steep uplands and terraces. Many areas with this soil type have been cleared for cotton, soybean, small grains, hay and pasture crops. In wooded areas where this soil occurs, mixed hardwoods and pines are present. The Adler soil series consists of moderately deep, well drained soils on sedimentary plains, hills and escarpments. These coarse-silty soils formed in silty alluvial areas and occur on flood plains. These soils are subject to brief to long flooding during winter and early spring. The majority of areas containing this soil has been cleared for croplands however native vegetation includes mixed bottomland hardwoods.

The Waverly-Falaya-Amagon soil series accounted for 13.31% of soils within the suitable habitat predicted for *R. wrightiana*. The Waverly soil series consists of acidic, coarse-silty soils which are very deep, typically poorly drained soils with moderate permeability. These soils formed in silty alluvium derived from loess and are found on floodplains of streams and alluvial fans. These soils are subject to flooding for brief to long durations after heavy rainfall and are ponded during wet seasons in areas with depressions. The majority of these soils are in bottomland hardwoods with oaks, eastern cottonwoods, loblolly pines and cypress. Cleared areas where this soil is present are used typically for cotton, corn, soybean and hay crops. The Falaya soil series consists of acidic, coarse-silty soils which are very deep, somewhat poorly drained and have moderate permeability. Like the Waverly series, these soils formed in silty alluvium derived from loess. These soils are subject to flooding and are frequently saturated with water during periods of high rainfall occurring on level to nearly level, wide flood plains. The majority of areas with this soil are used for corn, cotton, soybean, hay and pasture crops. The native vegetation in this soil series consists of mixed hardwoods. The Amagon soil series consists of fine-silty, very deep and poorly drained soils which are slowly permeable. These soils formed in loamy alluvium and occur on level to nearly level low terraces. The majority of areas with this soil have been cleared and are used for soybean, grain sorghum and rice crops. The native vegetation in this soil series consists of mixed hardwood forests.

In summary, modeling for *R. wrightiana* predicted suitable habitat across 6% of Tennessee, with a significant portion of suitable habitat (66%) being predicted within the Mississippi Valley Loess Plains ecoregion and less than 1% being predicted in the last known county of observation, Bledsoe, and adjacent counties. Almost half of the predicted suitable habitat (45%) was located within protected areas in Tennessee. Suitable habitat was predicted most frequently within the Cultivated Cropland ecological system, which does not align with the habitat described for *R. wrightiana*. The habitat described for this species includes flatwoods, pine savannas, pond and stream banks, as well as bogs and seeps (FNA, 2008). This result is likely due to the fact that much of the Mississippi Valley Loess Plains, which historically contained large areas of forested wetlands containing rich, alluvial soils, has been converted for agricultural purposes. When taking into consideration the permutation importance of the land cover and soil type variables, 5.69% and 30.5% respectively, it is apparent that the prediction of suitable habitat within cultivated croplands is associated with the rich soils they occupy, rather than the land cover type itself. However, the East Gulf Coastal Plain Small Stream and River Floodplain Forest ecological system, which accounted for 13% of suitable habitat, does align with the described habitat for this species. This ecological system is associated with small rivers and creeks and is restricted to floodplains and terraces of streams and creeks which are flooded annually.

Scrophularia lanceolata **(lanceleaf figwort)**

The AUC value for this model was 0.890 indicating very good discrimination ability. The final model for *S. lanceolata* predicted only 52 km^2 of minimally suitable habitat across Tennessee, moderately suitable and highly suitable habitat were not predicted in the state. Of the minimally suitable habitat predicted, 3 km^2 (5.79%) was contained within protected lands including the Cherokee National Forest, Warriors Path State Park, and land managed by Tennessee Valley Authority for multiple uses. Suitable habitat was predicted in two ecoregions in eastern Tennessee, the Ridge and Valley (92%) and the Blue Ridge (8%). The last known county of observation, Johnson county, and adjacent counties contained 16 km^2 (32%) of the suitable habitat predicted (Figure 3.13).

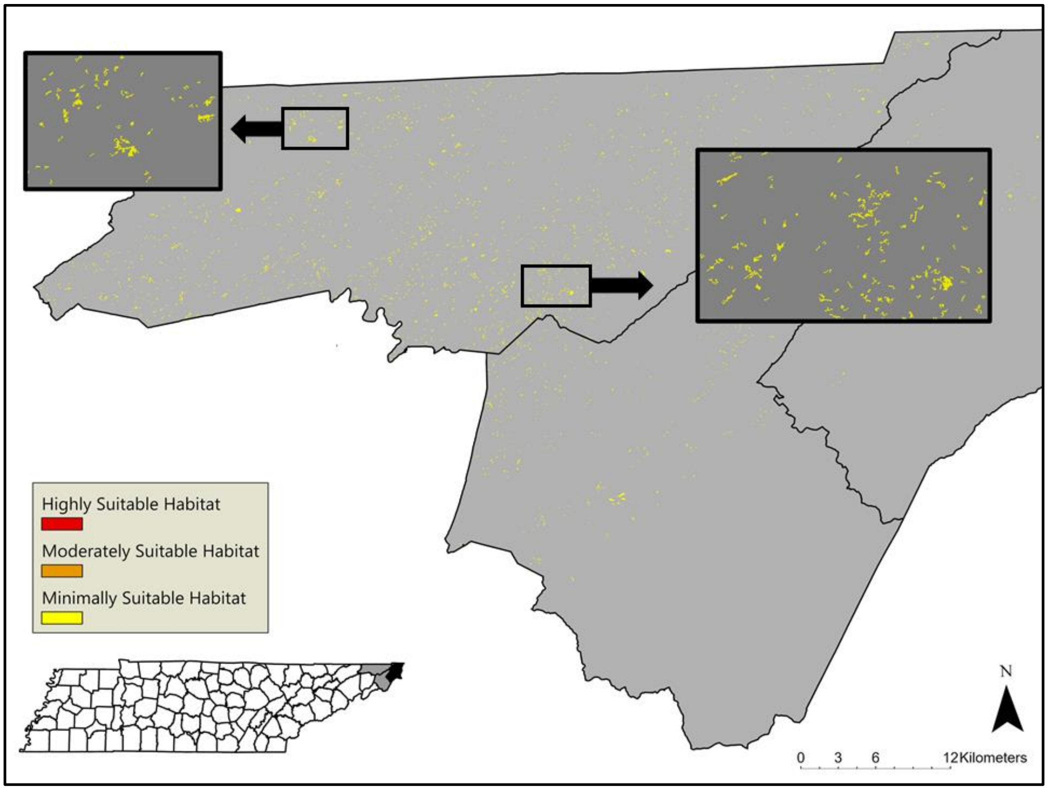

Figure 3.13 Predicted suitable habitat for *S. lanceolata* within the last known county of observation (Johnson, shown in black) and adjacent counties

Environmental variables used in the final SDM for *S. lanceolata* were annual mean temperature (BIO1), annual precipitation (BIO12), precipitation seasonality (BIO15), land cover, soil type, solar radiation. Land cover had the highest permutation importance (33.61%), indicating this was the most important variable for the overall model; solar radiation had the lowest permutation importance (3.25%), indicating the variable was not very important for the overall model (Table 3.31). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 14℃, a mean diurnal range (BIO2) of 14℃ to 15℃, and an annual temperature range (BIO7) of 36℃ to 37℃. BIO2 and BIO7 values were above the average values in Tennessee while BIO values were just below the average value for the state. The majority of suitable habitat was predicted in areas having an annual precipitation of 1,100 mm to 1,117 mm, falling below the average annual precipitation for the state. Suitable habitat was predicted most frequently at elevations ranging from 374 m to 487 m and in soils with a pH ranging from 5.6-5.8. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.32. Northwest facing slopes were the most common within predicted suitable habitat (23.2%), followed by west facing (17.3%) and north facing slopes (14.7%).

Table 3.31 Variable permutation importance and percent contribution for *S. lanceolata*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Land Cover	33.61%	28.82%
Annual Precipitation	30.00%	2.50%
Annual Mean Temperature	16.19%	1.64%
Soil Type	11.41%	30.90%
Precipitation Seasonality	5.54%	15.46%
Solar Radiation	3.25%	20.68%

Table 3.32 Bioclimatic, elevation, and soil pH variable trends for *S. lanceolata* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	9℃	14℃	13℃	13℃	13℃	6℃ - 16℃
Mean Diurnal Range	11℃	14℃	14℃	14℃	14℃	8℃ - 15℃
Temperature Annual Range	31℃	37℃	36℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1074mm	1333mm	1113mm	1333mm	1102mm	1073mm - 2013mm
Precipitation Seasonality	11%	16%	14%	14%	13%	9% - 22%
Elevation	318m	1133m	463m	451m	442m	24 m - 1973m
Solar Radiation (kJ m^{-2} day^{-1})	14309	14914	14653	14652	14689	14070 - 15502
Soil pH	4.8	6.4	5.6	5.6	5.7	4.2 - 7.5

Suitable habitat for *S. lanceolata* was predicted in only two land cover types. The Harvested Forest-Grass/Forb Regeneration ecological system accounted for 99.9% of suitable habitat. This ecological system consists of areas which are dominated by herbaceous ground cover following tree harvesting or other disturbance (U.S. Geological Survey Gap Analysis Program, 2011). The Eastern North American Ruderal Forest ecological system accounted for 0.1% of suitable habitat. This ecological system consists of areas on former agricultural or forest plantation sites, arising from degraded native forest sites (NatureServe, 2019). These typically dry- to wet-mesic areas often show evidence of former and heavy human use, particularly with extensive soil disturbances (NatureServe, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *S. lanceolata* (26.27%) occurred within the Dunmore soil series. This soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, with some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee.

The Montevallo-Hamblen-Dandridge-Bays soil series accounted for 25.83% of soils within the suitable habitat predicted for *S. lanceolata*. The Montevallo soil series consists of channery silt loam soils which are shallow, well drained and have moderate permeability. These soils formed in residuum weathered from acidic shale, siltstone, and possibly sandstone and occur on dissected hills, river valleys, and valleys underlain by shale. The majority of areas where these soils occur consists of mixed hardwood forests containing hickories, oaks, and pines. Few areas have been cleared for pasture, hay, and small grain crops. The Hamblen soil series consists of fine-loamy soils which are very deep, moderately well drained and are moderately permeable. These soils formed in loamy alluvium from watersheds dominated by limestone, sandstone and shale and occur on floodplains which are subject to flooding unless protected. The majority of areas where these soils occur have been cleared for crop production and pastures. The native vegetation associated with these soils consists of hardwood forests containing oak, hickories, maples, elms and sycamores. These soils are found in the Appalachian valleys, Highland Rim and Nashville Basin in Tennessee. The Dandridge soil series consists of channery silty clay loam soils which are shallow, excessively drained and have moderately slow permeability. These soils formed in residuum of calcareous shale and limestone and range from slightly acidic to moderately alkaline. Typically occurring on highly dissected uplands, these soils are found in the Appalachian ridges and valleys in Tennessee. The majority of areas where these soils occur have been cleared primarily for pastures. The native vegetation associated with these soils consists of forests containing oaks, hickories, beeches, maples and elms. The Bays soil series consists of silty clay loam soils which are shallow, well drained and are moderately well drained. These soils formed in residuum from calcareous shale bedrock and occur on shale uplands with narrow convex ridges and long convex side slopes in the Ridge and Valley portion of the Southern Appalachians in Tennessee. Over half of the area where these soils occur has been cleared, primarily for pasture and hay crops. In wooded areas, the dominant vegetation consists of upland oak species.

The Dunmore-Collegedale soil series accounted for 8.30% of soils within the suitable habitat predicted for *S. lanceolata*. The Dunmore soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, with some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee. The Collegedale soil series consists of fine silt-loam soils which are very deep, well drained, and have moderately slow permeability. These soils formed in material weathered from limestone or limestone interbedded with shale and occur on uplands in valleys which are underlain by limestone. The majority of areas containing these soils are used for pasture, a small portion is used for crops including hay, cotton, and corn. The native vegetation associated with these soils consists of mixed hardwood forests. These soils are found in the southern Appalachian valleys in Tennessee.

In summary, modeling for *S. lanceolata* predicted suitable habitat across less than 1% of Tennessee, with the majority of suitable habitat (92%) being predicted within the Ridge and Valley ecoregion and 32% being predicted in the last known county of observation, Johnson, and adjacent counties. However, only a small portion of predicted suitable habitat (6%) was located within protected areas in Tennessee. Suitable habitat was predicted within only two ecological systems. The Harvest Forest-Grass/Forb Regeneration ecological system, which accounted for over 99% of suitable habitat, consists of areas dominated by herbaceous ground cover following tree harvest or other disturbance. The Eastern North American Ruderal Forest system, which accounted for less than 1% of suitable habitat encompasses areas of former agricultural or plantation sites. This species habitat is described as upland forests, shale barrens, clearings, roadsides and other disturbed sites (Tennessee Flora Committee, 2014; Weakley, In Preparation), aligning with ecological systems predicted by the model.

***Seymeria cassioides* (yaupon blacksenna)**

The AUC value for this model was 0.793 indicating good discrimination ability. The final model for *S. cassioides* predicted 4,945 km^2 of suitable habitat across Tennessee (83.12% minimally suitable; 12.37% moderately suitable; 4.50% highly suitable). Of the total suitable habitat, 2,418 km^2 (48.89%) was contained within protected lands (97.44% minimally suitable; 2.39% moderately suitable; 0.17% highly suitable). Notable protected areas containing suitable habitat include the Cherokee National Forest, North Chickamauga Creek Gorge SNA, Prentice Cooper WMA, Savage Gulf SNA, Fall Creek Falls State Park SNA, and Big Hill Pond State Park. The majority of suitable habitat was predicted in the Interior Plateau (40%) and Southwestern Appalachian (32%) ecoregions in Tennessee. The last known county of observation, Bradley county, and adjacent counties contained 537 km^2 (11%) of the suitable habitat predicted (Figure 3.14).

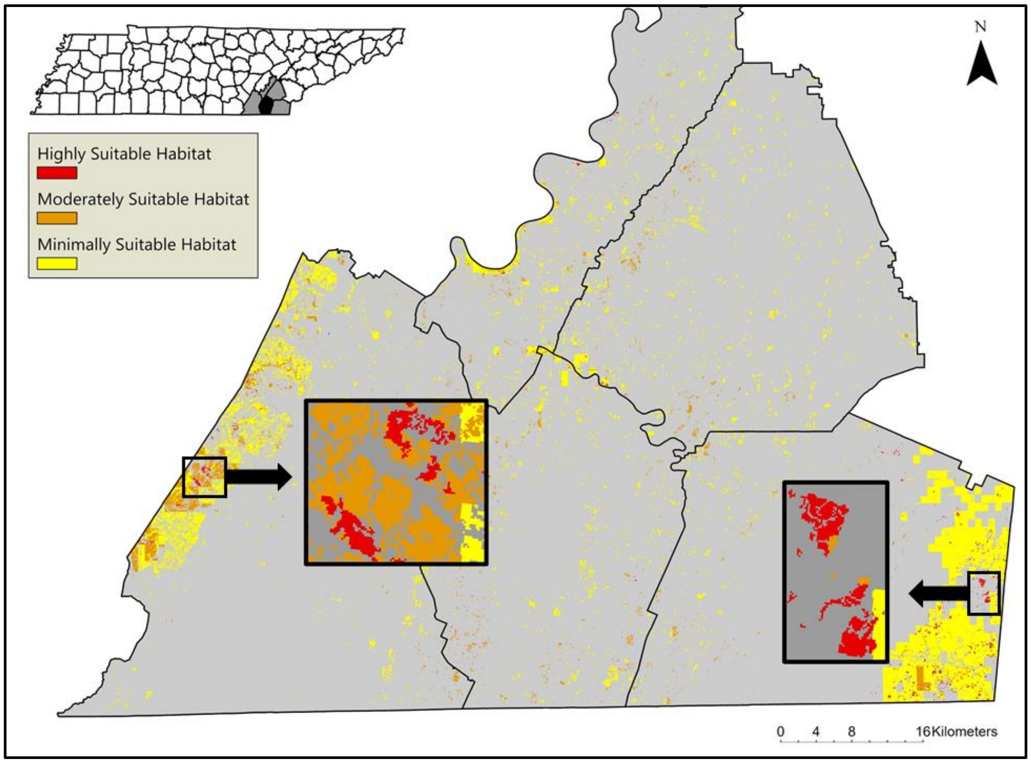

Figure 3.14 Predicted suitable habitat for *S. cassioides* within the last known county of observation (Bradley, shown in black) and adjacent counties

Environmental variables used in the final SDM for *S. cassioides* were mean diurnal range (BIO2), temperature annual range (BIO7), annual precipitation (BIO12), precipitation seasonality (BIO15), land cover, soil pH, soil type, and solar radiation. Solar radiation had the highest permutation importance (26.39%), indicating this was the most important variable for the overall model; temperature annual range (BIO7) had the lowest permutation importance (0.14%), indicating the variable was not very important for the overall model (Table 3.33). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 14°C to 15°C, a mean diurnal range (BIO2) of 14°C to 15°C, and an annual temperature range (BIO7) of 35°C to 36°C. BIO1 and BIO2 values for the majority of suitable habitat were above the average values in Tennessee while BIO7 values were below the average in the state. The majority of suitable habitat was predicted in areas having an annual precipitation of 1,448 mm to 1,1496 mm, falling above the average annual precipitation in the state. Suitable habitat was predicted most frequently at elevations ranging from 163 m to 322 m and in soils with a pH ranging from 5.0-5.3. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.34. West facing slopes were the most common within predicted suitable habitat (13.2%), followed by east facing (13.1%) and southeast facing slopes (13.0%).

Table 3.33 Variable permutation importance and percent contribution for *S. cassioides*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Solar Radiation	26.39%	23.07%
Annual Precipitation	18.11%	14.75%
Soil Type	17.00%	17.95%
Mean Diurnal Range	12.46%	5.88%
Soil pH	11.33%	14.05%
Land Cover	11.12%	14.68%
Precipitation Seasonality	3.45%	9.51%
Temperature Annual Range	0.14%	0.12%

Table 3.34 Bioclimatic, elevation, and soil pH variable trends for *S. cassioides* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7°C	16°C	14°C	14°C	15°C	6°C - 16°C
Mean Diurnal Range	9°C	15°C	14°C	14°C	14°C	8°C - 15°C
Temperature Annual Range	27°C	38°C	35°C	36°C	36°C	25°C - 38°C
Annual Precipitation	1234mm	1972mm	1485mm	1478mm	1481mm	1073mm - 2013mm
Precipitation Seasonality	10%	22%	17%	18%	18%	9% - 22%
Elevation	57m	1755m	338m	268m	268m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14428	15496	15060	15094	15179	14070 - 15502
Soil pH	4.3	6.2	5.1	5.1	5.1	4.2 - 7.5

The majority of suitable habitat for *S. cassioides* (22.00%) was predicted in the Allegheny-Cumberland Dry Oak Forest and Woodland ecological system. This system consists of dry, hardwood forests on predominantly acidic substrates in the Cumberland Plateau as well as acidic sandstone ridges in the southern Ridge and Valley (NatureServe, 2009). The topography varies from rolling hills to steep slopes with typically dry, coarse soils that are relatively infertile (USNVC, 2019). At moderate to low elevations, stands are naturally stable, uneven-aged forests, with canopy dynamics generally dominated by gap-phase regeneration and subcanopy, shrub and herb layers are typically moderately well- to well-developed (USNVC, 2019). The Southern Interior Low Plateau Dry-Mesic Oak Forest ecological system accounted for 14.95% of suitable habitat. This ecological system consists of upland hardwood-dominated forests occurring in the Interior Low Plateau ecoregion along ridgetops and slopes of various aspects which encompasses a variety of associations ranging from submesic to dry moisture gradients (NatureServe, 2009). Substrates range from calcareous to acidic with shallow, well- to excessively well-drained soils in drier areas and moderately well-drained soils in submesic to dry-mesic areas (NatureServe, 2009; USNVC, 2019). The South-Central Interior Mesophytic Forest ecological system accounted for 6.19% of suitable habitat. This system encompasses productive forests occurring on deep and enriched soils in the Central and Southern Appalachians, Cumberland and Allegheny plateaus, and the Interior Low Plateau of the eastern United States (USNVC, 2019). These forests are comprised of tall, broad-leaved deciduous trees with a well-developed herbaceous layer which is often dense and high in species richness (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *S. cassioides* (22.33%) occurred within the Hammack-Brandon-Bodine-Baxter soil series. The Hammack soil series consists of fine-silty soils which are very deep, well drained and have moderate permeability. These moderately to strongly acidic soils formed in a loess mantle underlain with limestone and occur on ridge tops and side slopes of rolling to hilly areas with some areas having karst topography. The majority of areas with this soil are used for hay, pasture and crops such as corn, soybeans, and tobacco. Steeper areas in forests contain oaks, hickories, maples and hackberry. The Bradon soil series consists of fine-silty soils which are very deep, well drained and typically range from strongly to very strongly acidic. In the silty upper areas, permeability is moderate however, in the gravelly substratum permeability is variable and can range from moderately rapid to slow. These soils formed in a silty mantle presumably consisting of loess over gravelly marine and riverine deposited materials and occur on gently sloping to steep upland ridges and hillsides. The majority of areas containing these soils consist of hardwood forests with the dominant woodland species being oaks, hickories, black gum, elms, and dogwoods. Few areas are in pasture and hay croplands. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

The Ramsey-Muskingum-Lonewood-Lily soil series accounted for 15.73% of soils within the suitable habitat predicted for *S. cassioides*. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Ramsey-Lily soil series accounted for 6.84% of soils within the suitable habitat predicted for *S. cassioides*. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

In summary, modeling for *S. cassioides* predicted suitable habitat across 5% of Tennessee, with a significant portion of suitable habitat (72%) being predicted within the Interior Plateau and Southwestern Appalachian ecoregions and 11% being predicted in the last known county of observation, Bradley, and adjacent counties. Almost half of predicted suitable habitat (49%) was located within protected areas in

Tennessee. Suitable habitat was most frequently predicted within the Allegheny-Cumberland Dry Oak Forest and Woodland ecological system. This prediction aligns with the habitat described as occurring in dry to wet pine-oak woodlands and sandy sites by the Tennessee Flora Committee (Tennessee Flora Committee, 2014).

Silene regia **(royal catchfly)**

The AUC value for this model was 0.826 indicating very good discrimination ability. The final model for *S. regia* predicted 24,782 km^2 of suitable habitat across Tennessee (50.91% minimally suitable; 37.44% moderately suitable; 11.65% highly suitable). Of the total suitable habitat, 5,049 km^2 (20.37%) was contained within protected lands (60.43% minimally suitable; 35.97% moderately suitable; 3.60% highly suitable). Notable protected areas containing suitable habitat include the Great Smoky Mountains National Park, Cherokee National Forest, Tellico Lake WMA, Warriors Path State Park, Bays Mountain SNA, House Mountain SNA, Royal Blue WMA, Frozen Head State Park SNA, Big South Fork National River and Recreation Area, Fall Creek Falls State Park SNA, Savage Gulf SNA, Walls of Jericho SNA, and Meeman-Shelby Forest State Park. Suitable habitat was predicted in all Tennessee ecoregions; however, the majority of suitable habitat was predicted in the Interior Plateau (35%) and the Ridge and Valley (28%) ecoregions. *S. regia* is known historically from two disjunct counties in Tennessee. Marion county and adjacent counties contained 1,937 km^2 (8%) of the suitable habitat predicted (Figure 3.15). Knox county and adjacent counties contained 3,179 km^2 (13%) of the suitable habitat predicted (Figure 3.16).

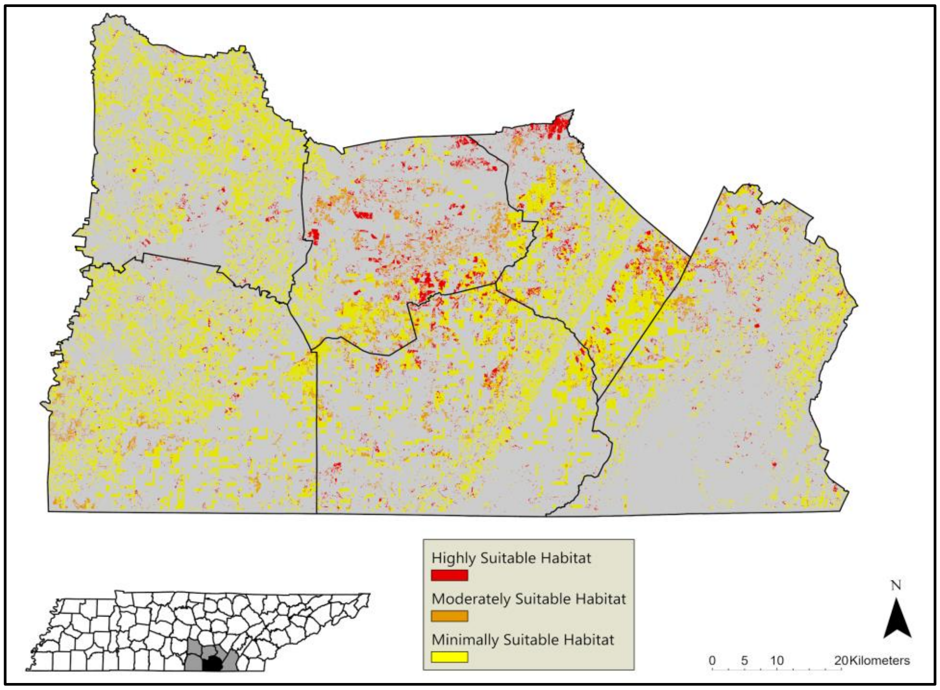

Figure 3.15 Predicted suitable habitat for *S. regia* within Marion county (shown in black) and adjacent counties

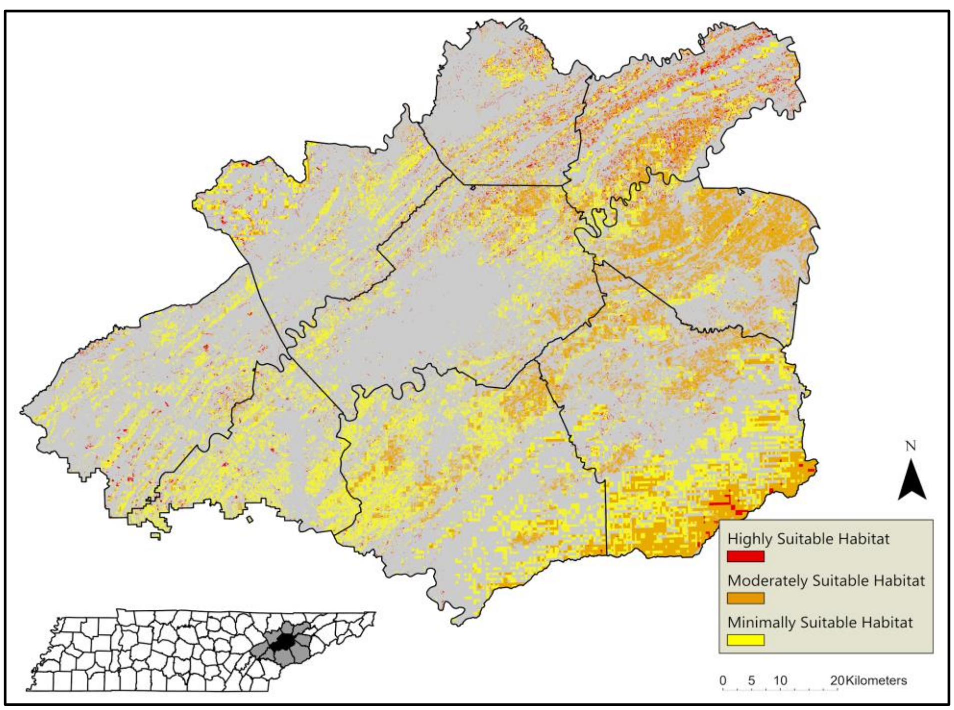

Figure 3.16 Predicted suitable habitat for *S. regia* within Knox county (shown in black) and adjacent counties

Environmental variables used in the final SDM for *S. regia* were aspect, annual mean temperature (BIO1), temperature annual range (BIO7), annual precipitation (BIO12), precipitation seasonality (BIO15), elevation, land cover, soil type, solar radiation. Soil type had the highest permutation importance (35.56%), indicating this was the most important variable for the overall model; annual mean temperature (BIO1) had the lowest permutation importance (0.16%), indicating this variable was not very important for the overall model (Table 3.35). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 16℃, a mean diurnal range (BIO2) of 13℃ to 14℃, and an annual temperature range (BIO7) of 35°C to 37℃. BIO1 and BIO7 values for the majority of predicted suitable habitat fell around the average values in Tennessee while BIO2 values were above the average value in the state. The majority of suitable habitat was predicted in areas having an annual precipitation of 1,352 mm to 1,1456 mm, falling above the average annual precipitation in the state. Suitable habitat was predicted most frequently at elevations ranging from 184 m to 312 m and in soils with a pH ranging from 5.2-5.6. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.36. Southeast facing slopes were the most common within predicted suitable habitat (15.5%), followed by east facing (13.6%) and south facing slopes (12.8%).

Table 3.35 Variable permutation importance and percent contribution for *S. regia*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Soil Type	35.56%	48.16%
Land Cover	19.89%	20.94%
Solar Radiation	17.88%	1.37%
Precipitation Seasonality	16.95%	21.8%
Temperature Annual Range	5.50%	0.72%
Elevation	2.95%	2.46%
Annual Precipitation	0.79%	4.25%
Aspect	0.32%	0.29%
Annual Mean Temperature	0.16%	0.06%

Table 3.36 Bioclimatic, elevation, and soil pH variable trends for *S. regia* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7°C	16°C	14°C	14°C	14°C	6°C - 16°C
Mean Diurnal Range	8°C	15°C	13°C	13°C	13°C	8°C - 15°C
Temperature Annual Range	25°C	38°C	35°C	36°C	36°C	25°C - 38°C
Annual Precipitation	1073mm	2013mm	1348mm	1371mm	1417mm	1073mm - 2013mm
Precipitation Seasonality	9%	22%	15%	15%	15%	9% - 22%
Elevation	56m	1973m	392m	305m	243m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14070	15496	14860	14871	14893	14070 - 15502
Soil pH	4.2	6.6	5.3	5.4	5.4	4.2 - 7.5

The majority of suitable habitat for *S. regia* (66.93%) was predicted in the Pasture and Hay Field Crop ecological system which consists of areas of grasses, legumes, and grass-legume mixtures planted for livestock grazing or the production of seed or hay crops on a perennial cycle where pasture and hay vegetation accounts for at least 20% of the total vegetation (NatureServe, 2009). The Harvested Forest-Grass/Forb Regeneration ecological system accounted for 13.17% of suitable habitat. This ecological system consists of areas which are dominated by herbaceous ground cover following tree harvesting or other disturbance (U.S. Geological Survey Gap Analysis Program, 2011). The Southern and Central Appalachian Oak Forest accounted for 4.76% of suitable habitat. This ecological system consists of primarily dry-mesic forests which occur on open and exposed topography at low to mid elevation in the southern Blue Ridge and southern Ridge and Valley ecoregions (NatureServe, 2019). At these low to moderate elevations, forests are uneven in age and naturally stable, with canopies typically dominated by gap-phase regeneration (NatureServe, 2019; USNVC, 2019). This system occurs on predominately acidic substrates with coarse, infertile soils and topography varies from rolling hills to steep slopes (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *S. regia* (5.49%) occurred within the Ramsey-Muskingum-Lonewood-Lily soil series. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Dunmore soil series accounted for 5.21% of soils within the suitable habitat predicted for *S. regia*. This soil series consists of fine silt-loam soils which are very deep, well drained and have moderate permeability. These soils formed in residuum of limestone and occur on uplands, some areas containing numerous limestone sinks. The majority of areas containing these soils have been cleared, primarily for pasture and hay crops, however small areas are used to grow corn, grain and tobacco crops. The native vegetation associated with these soils consists of mixed hardwoods such as oaks, hickories, maples, elms and dogwoods. These soils are found in the Appalachian ridges and valleys of Tennessee.

The Sulphura-Dellrose-Bodine soil series accounted for 5.05% of soils within the suitable habitat predicted for *S. regia*. The Sulphura soil series consists of silt loam soils which are moderately deep and somewhat excessively drained with moderately rapid permeability. These soils formed in residuum of interbedded siltstone, limestone and shale and occur on highly dissected uplands and occasionally on rolling upland ridgetops. In the upper portion, soils range from strongly to moderately acidic while in the lower portion, soils range from strongly to slightly acidic. The majority of areas contain these soils are woodlands consisting of chestnut, oak, hickory, hackberry, pine and redcedar species. Few ridgetops have been cleared for use as pasture. These soils are primarily distributed in the Nashville Basin and Highland Rim in Tennessee. The Dellrose soil series consists of fine-loamy soils which are very deep, well drained and have moderately rapid permeability. These moderately to strongly acidic soils formed in medium textured cherty colluvium and occur on foot slopes and steep hillsides. While the majority of areas have been pastured, native vegetation consists of hardwoods such as beech, hickory, oaks and hackberry. These soils are distributed on slopes from the Highland Rim Plateau to the Central Basin in Tennessee. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture.

In summary, modeling for *S. regia* predicted suitable habitat across 23% of Tennessee, with a significant portion of suitable habitat (63%) being predicted within the Interior Plateau and Ridge and Valley ecoregions and 21% being predicted in the last known counties of observation, Marion and Knox, and adjacent counties. A fair amount of predicted suitable habitat (20%) was located within protected areas in Tennessee. Suitable habitat was most frequently predicted within the Pasture and Hay Field Crop ecological system and in well-drained soils weathered from limestone or sandstone. These predictions align with described habitats being dry prairies, woodland edges, and calcareous woodlands (FNA, 2008; Weakley, In Preparation). *S. regia* has been documented as being associated with well-drained, calcareous soils and occurring in pastures adjacent to oak-hickory forests (NatureServe, 2019).

Tetragonotheca helianthoides **(pineland nerveray)**

The AUC value for this model was 0.750 indicating good discrimination ability. The final model for *T. helianthoides* predicted 3,353 km^2 of suitable habitat across Tennessee (23.93% minimally suitable; 59.81% moderately suitable; 16.25% highly suitable). Of the total suitable habitat, 356 km^2 (10.60%) was contained within protected lands (46.65% minimally suitable; 43.22% moderately suitable; 10.13% highly suitable). Notable protected areas containing suitable habitat include the Great Smoky Mountains National Park, Cherokee National Forest, Tellico Lake WMA, Big Ridge State Park, Fall Creek Falls State Park SNA, Savage Gulf SNA, Cedars of Lebanon State Park and State Forest SNA, Tennessee National Wildlife Refuge, Land Between the Lakes National Recreation Area, and Natchez Trace State Park. Suitable habitat was predicted in all Tennessee ecoregions; however, the majority of suitable habitat was predicted in the Interior Plateau (39%), Southwestern Appalachian (21%) and Southeastern Plains (18%) ecoregions. The last known counties of observation, Blount and Knox counties, and adjacent counties contained 214 km^2 (6%) of the suitable habitat predicted (Figure 3.17).

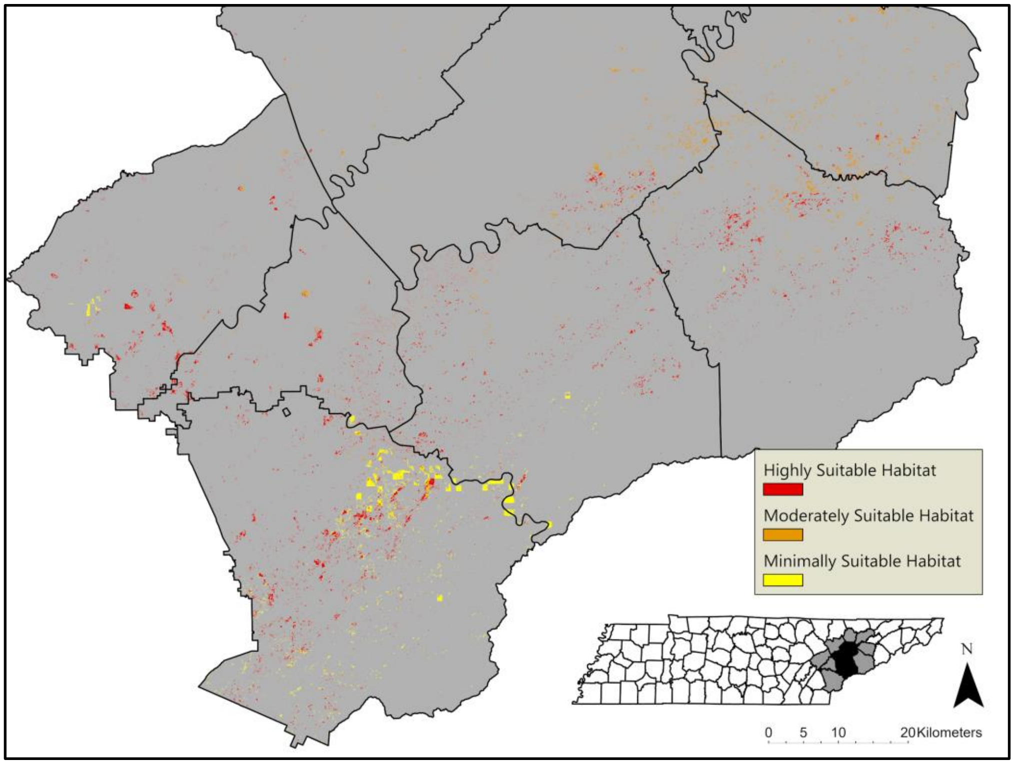

Figure 3.17 Predicted suitable habitat for *T. helianthoides* within the last known counties (Blount and Knox, shown in black) of observation and adjacent counties

Environmental variables used in the final SDM for *T. helianthoides* were aspect, temperature annual range (BIO7), annual precipitation (BIO12), land cover, soil type, soil pH, and solar radiation. Land cover had the highest permutation importance (54.90%), indicating this was the most important variable for the overall model; soil pH had the lowest permutation importance (0.42%), indicating this variable was not very important for the overall model (Table 3.37). The majority of suitable habitat was predicted in areas with an annual mean temperature (BIO1) ranging from 13℃ to 16℃, a mean diurnal range (BIO2) of 13℃ to 15℃, and an annual temperature range (BIO7) of 36℃ to 38℃. BIO2 and BIO7 values for the majority of predicted suitable habitat fell above the average values in Tennessee while BIO1 values fell around the average value in the state. The majority of suitable habitat was predicted in areas having an annual precipitation of 1,362 mm to 1,1488 mm, falling above the average annual precipitation in the state. Suitable habitat was predicted most frequently at low elevations ranging from

118 m to 303 m and in soils with a pH ranging from 5.0-5.4. Minimum, maximum, mean, median, and mode for each continuous variable are presented in Table 3.38. West facing slopes were the most common within predicted suitable habitat (14.6%), followed by northwest facing (13.5%) and southeast facing slopes (12.8%).

Table 3.37 Variable permutation importance and percent contribution for *T. helianthoides*. Variables are listed in order of permutation importance.

Variable	Permutation Importance	Percent Contribution
Land Cover	54.90%	62.55%
Soil Type	22.20%	21.27%
Solar Radiation	13.81%	6.15%
Aspect	6.07%	2.91%
Annual Precipitation	1.70%	0.17%
Temperature Annual Range	0.90%	6.22%
Soil pH	0.42%	0.73%

Table 3.38 Bioclimatic, elevation, and soil pH variable trends for *S. cassioides* in Tennessee

Variable	Minimum	Maximum	Mean	Median	Mode	Range of Values in TN
Annual Mean Temperature	7℃	16℃	14℃	14℃	14℃	6℃ - 16℃
Mean Diurnal Range	8℃	15℃	13℃	13℃	13℃	8℃ - 15℃
Temperature Annual Range	25℃	38℃	36℃	36℃	36℃	25℃ - 38℃
Annual Precipitation	1076mm	1996mm	1417mm	1425mm	1433mm	1073mm - 2013mm
Precipitation Seasonality	9%	22%	16%	16%	15%	9% - 22%
Elevation	56m	1973m	294m	249m	206m	24 m - 1973m
Solar Radiation ($kJ\ m^{-2}\ day^{-1}$)	14070	15502	14975	15004	15038	14070 - 15502
Soil pH	4.2	6.8	5.2	5.2	5.1	4.2 - 7.5

The Southeastern Native Ruderal Forest ecological system was the only land cover type contained within predicted suitable habitat for *T. helianthoides*. This ecological system occurs in old-field and other human disturbed areas in the southeastern United States such as formerly cleared or planted sites that have been allowed to undergo succession (USNVC, 2019). The canopy varies from hardwood- to conifer-dominated, with open to closed canopies where vegetation is dominated by ruderal native tree species; Understory shrub and herbaceous species may be a mix of both exotic species and native generalist species (USNVC, 2019). Tree stands typically have an irregular structure, though remnants of abandoned forest plantation structure may be evident. This system includes upland and marginally wet areas that may have been altered by logging or clearing for agriculture on dry- to wet-mesic sites (USNVC, 2019).

The following soil series descriptions were adapted from the USDA-NRCS Official Soil Series Descriptions database (Soil Survey Staff, 2019). The majority of suitable habitat predicted for *T. helianthoides* (11.98%) occurred within the Ramsey-Muskingum-Lonewood-Lily soil series. The Ramsey soil series consists of loamy, mesic soils which are shallow to very shallow, somewhat excessively drained and have rapid permeability. These soils formed in residuum or colluvium weathered from sandstone or quartzite and occur primarily on plateaus and upper slopes of mountains. The majority of areas where these soils occur consist of mixed hardwood and pine forests however some areas have been cleared for pastures. These soils are distributed on the Cumberland Plateau and Blue Ridge Mountains in Tennessee. The Muskingum soil series consists of fine-loamy soils which are moderately deep, well drained and have moderate permeability. These soils formed in residuum weathered from interbedded siltstone, sandstone, and shale and occur across rugged topography of dissected plateaus. The majority of areas with these soils are mixed forests containing oaks, poplars, hickories and maples. Some gently sloping areas are used for corn, wheat and hay crops. The Lonewood soil series consists of fine-loamy soils which are deep to very deep, well drained and are moderately permeable. These soils formed in a silty mantle with underlying residuum of weathered shale and sandstone and occur on broad, rolling plateaus and convex ridge tops of the Cumberland Plateau. About half of the area containing these soils has been cleared for pasture and hay crops. Forested areas contain oak, hickory, gum, and few pine species. The Lily soil series consists of fine-loamy soils which are moderately deep and well drained with moderately rapid permeability. These soils formed in residuum weathered from acidic sandstone and occur on upland ridges and hillsides. Areas containing these soils are primarily used for corn, tobacco, grain, hay and pasture crops. The native forests where these soils occur contain oaks, hickories, dogwoods, elms and Virginia, shortleaf or white pines.

The Hammack-Brandon-Bodine-Baxter soil series accounted for 8.37% of soils within the suitable habitat predicted for *T. helianthoides*. The Hammack soil series consists of fine-silty soils which are very deep, well drained and have moderate permeability. These moderately to strongly acidic soils formed in a loess mantle underlain with limestone and occur on ridge tops and side slopes of rolling to hilly areas with some areas having karst topography. The majority of areas with this soil are used for hay, pasture and crops such as corn, soybeans, and tobacco. Steeper areas in forests contain oaks, hickories, maples and hackberry. The Bradon soil series consists of fine-silty soils which are very deep, well drained and typically range from strongly to very strongly acidic. In the silty upper areas, permeability is moderate however, in the gravelly substratum permeability is variable and can range from moderately rapid to slow. These soils formed in a silty mantle presumably consisting of loess over gravelly marine and riverine deposited materials and occur on gently sloping to steep upland ridges and hillsides. The majority of areas containing these soils consist of hardwood forests with the dominant woodland species being oaks, hickories, black gum, elms, and dogwoods. Few areas are in pasture and hay croplands. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture. The Baxter soil series consists of very deep gravelly silty-loam soils which are well drained and have moderately slow to moderate permeability. These soils formed in fine-textured residuum of cherty limestone and occur on hillsides and ridgetops of uplands. Much of the area these soils cover have been cleared for tobacco, corn, grain, hay and pasture crops however many steep areas consist of native woodland forests containing oak, hickory, elm, maple, and pine species.

The Sulphura-Dellrose-Bodine soil series accounted for 6.42% of soils within the suitable habitat predicted for *T. helianthoides*. The Sulphura soil series consists of silt loam soils which are moderately deep and somewhat excessively drained with moderately rapid permeability. These soils formed in residuum of interbedded siltstone, limestone and shale and occur on highly dissected uplands and occasionally on rolling upland ridgetops. In the upper portion, soils range from strongly to moderately acidic while in the lower portion, soils range from strongly to slightly acidic. The majority of areas contain these soils are woodlands consisting of chestnut, oak, hickory, hackberry, pine and redcedar species. Few ridgetops have been cleared for use as pasture. These soils are primarily distributed in the Nashville Basin and Highland Rim in Tennessee. The Dellrose soil series consists of fine-loamy soils which are very deep, well drained and have moderately rapid permeability. These moderately to strongly acidic soils formed in medium textured cherty colluvium and occur on foot slopes and steep hillsides. While the majority of areas have been pastured, native vegetation consists of hardwoods such as beech, hickory, oaks and hackberry. These soils are distributed on slopes from the Highland Rim Plateau to the Central Basin in Tennessee. The Bodine soil series consists of very deep, gravelly silty-loam soils which are somewhat excessively drained. These soils formed in colluvium or residuum weathered from cherty limestone and occur on sharply dissected uplands. This soil is often found in the Highland Rim and Southern Appalachian Ridges and Valleys in Tennessee and occurs in forests of chestnut oaks, post oaks, white oaks, hickories, maples, and Virginia pines. There are some cleared areas which are used primarily for pasture.

In summary, modeling for *T. helianthoides* predicted suitable habitat across 3% of Tennessee, with a significant portion of suitable habitat (60%) being predicted within the Interior Plateau and Southwestern Appalachian ecoregions and 6% being predicted in the last known counties of observation, Blount and Knox, and adjacent counties. Only a small amount of predicted suitable habitat (11%) was located within protected areas in Tennessee. Suitable habitat was predicted in only one ecological system, the Southeastern Native Ruderal Forest, which occurs in old-field and other human disturbed sites such as formerly cleared or planted sites that have been allowed to undergo succession. While *T. helianthoides* habitat has been described as sandy woodlands, open hammocks, and roadsides (Weakley, In Preparation), there are numerous herbarium specimens collected in open fields dominated by young shrubs and trees, open pine stands, recently clear-cut areas, and powerline rights-of-way which support the prediction of suitable habitat in disturbed, ruderal fields and woods (Keener et al., 2020).

CHAPTER IV

CONCLUSIONS, CHALLENGES AND LIMITATIONS, AND FUTURE DIRECTIONS

Conclusions

The primary goal of this study was to identify suitable habitat, indicating the potential distribution of Tennessee's historical angiosperm species using SDMs trained with digitized herbarium specimen occurrence data. Of the 16 species modeled, 15 species were predicted to have at least minimally suitable habitat in Tennessee, 10 species were predicted to have moderately suitable habitat, and eight species were predicted to have highly suitable habitat. These results support the idea that there is still hope of rediscovering these species in Tennessee. This idea is further supported by the fact that at least four species previously listed as possibly extirpated in Tennessee, *Agalinis plukenetii* (Ell.) Raf. (Orobanchaceae), *Aristida ramosissima* Engelm. ex A. Gray (Poaceae), *Bulbostylis ciliatifolia* (Ell.) Fernald var. *coarctata* (Ell.) Kral (Cyperaceae), and *Pycnanthemum verticillatum* Pers. (Lamiaceae), have been rediscovered in the state (Tennessee Flora Committee, 2014).

Literature suggests that the concept of rediscovering "lost" species is not that uncommon (Loxdale et al., 2016; Scheffers et al., 2011; Silveira et al., 2019), and indicates that a ranking system which forces species to be classified as either extant or not can result in arbitrary decisions being made due to a lack of sufficient knowledge of a species distribution (Snyder, 1993). In light of conservation biology's limited time and financial resources, the concept of a "historical" ranking enables conservation managers to acknowledge uncertainties and gaps in our knowledge of species distributions rather than prematurely determining species to be extirpated or extinct. Unfortunately, while these species should be an active conservation priority, they often remain unaddressed or under-studied due to verified extant species of concern being prioritized over species whose existence is unverified.

Challenges and Limitations

The sheer amount of data required to complete this study presented a significant challenge. The data cleaning process for the initial 8,339 herbarium specimens obtained from the SERNEC portal posed an exceedingly time consuming and tedious task. Due to limited funding for biological specimen digitization projects, the majority of data on specimen labels are not transcribed; therefore, fields other than scientific name, the state, and county in which the specimen were collected must be obtained directly from the specimen's label. In order to obtain geographic coordinates from herbarium specimens for this study, 4,809 herbarium specimen records were visually inspected. Early on in this study, we attempted to use a pattern matching algorithm to identify coordinates from optical character recognition (OCR) results. Unfortunately, the excessive diversity of valid methods used to indicate geographic coordinates rendered this task infeasible in the context of this study. However, since the completion of this study, a successful method to extract geographic coordinates from herbarium specimen label data using OCR and regular expression pattern matching has been developed (Powell & Shaw, 2020). A method such as this would be recommended for future studies needing to extract geographic coordinates from a large number of herbarium specimens. Additionally, this study illustrates the fact that the amount of data suitable for geospatial studies often represents only a fraction of the total available data. For example, only 9% of the initial herbarium specimens obtained for this study were adequate to train SDMs. Furthermore, while this study set out to model the potential distribution of all historical angiosperm species in Tennessee, five species were unable to be modeled due to an insufficient amount of occurrence records having associated geographic coordinates.

Data storage itself was an overwhelming limitation with 1.23 TB of storage needed to store environmental variable rasters and 2.87 TB of storage for various MaxEnt outputs for the 16 modeled species. Due to the limited amount of storage space available for this study, all preliminary model outputs for each species had to be discarded in turn and only the final model outputs were kept. During a MaxEnt run, available storage space required frequent monitoring as the model would fail when storage space reached maximum capacity. This was particularly challenging when running multiple models at a time, which was required due to time constraints for this study. Because MaxEnt has very limited multi-threaded support and the extent of this study was so large, model runtime often exceeded 36 hours. This represented a significant challenge due to the fact that each species had to be modeled numerous times in order to determine the optimal model parameters and environmental variables for individual species. Furthermore, due to the large size of MaxEnt's outputs, tools and analyses executed in ArcGIS Pro ran exceptionally slow. Future SDM studies with large study areas and or many species should take into serious consideration the necessary data storage capacity as well as read and write speeds.

Future Directions

David Snyder, who has rediscovered more than 100 historical plant species over the course of his career, suggests that if suitable habitat for a historical species still exists, regardless of how much time has passed, there is a greater than even chance the species is still present (Snyder, 1993). Our hope is that Tennessee's conservationists and botanists, whether professional or amateur, will adopt Snyder's philosophy and use the work presented here as a guide to search for our state's "lost" species. To help guide survey efforts for Tennessee's historical species, geographic coordinates indicating areas in which the model predicted the highest probability of occurrence for each species are provided (Table 4.1). These coordinate points should be used as a general reference point for beginning future survey efforts.

Table 4.1 Geographic coordinates representing areas with the highest probability of occurrence for historical angiosperm species having suitable habitat predicted in Tennessee. The maximum predicted threshold is listed for each species. The minimum training presence (MTP) threshold indicates minimally suitable habitat predicted was predicted. The 10th percentile training presence (10PTP) threshold indicates moderately suitable habitat was predicted. The maximum test sensitivity plus specificity (MSS) threshold indicates highly suitable habitat was predicted.

Species	Latitude	Longitude	County	Protected Area	Flowering Period	Maximum Predicted Threshold
Agalinis setacea	35.64875827	-83.92385615	Blount	NA	Sept-Oct	MSS
Agalinis setacea	35.59618691	-84.02114632	Blount	NA	Sept-Oct	MSS
Agalinis setacea	35.28520345	-84.22128016	Monroe	Cherokee National Forest	Sept-Oct	MSS
Agalinis setacea	35.33098676	-84.14438187	Monroe	Cherokee National Forest	Sept-Oct	MSS
Agalinis setacea	35.58110137	-84.01077034	Blount	Foothills WMA	Sept-Oct	MSS
Agalinis setacea	35.60044688	-83.98875708	Blount	Foothills WMA	Sept-Oct	MSS
Agalinis setacea	35.6184801	-83.96467727	Blount	Great Smoky Mountains National Park	Sept-Oct	MSS
Agalinis setacea	35.6382159	-83.93827085	Blount	Great Smoky Mountains National Park	Sept-Oct	MSS
Agalinis setacea	35.63783026	-83.91610506	Blount	Great Smoky Mountains National Park	Sept-Oct	MSS

Agalinis setacea	35.2470865	-84.27298444	Monroe	NA	Sept-Oct	MSS
Carex alopecoidea	36.51289595	-82.53109371	Sullivan	NA	July	MTP
Carex alopecoidea	36.52284595	-82.55794746	Sullivan	NA	July	MTP
Carex alopecoidea	36.54194534	-82.57886906	Sullivan	NA	July	MTP
Carex alopecoidea	36.54677984	-82.52367451	Sullivan	NA	July	MTP
Carex alopecoidea	36.54623225	-82.49358092	Sullivan	NA	July	MTP
Carex alopecoidea	36.55198436	-82.48215003	Sullivan	NA	July	MTP
Carex alopecoidea	36.55674868	-82.46983335	Sullivan	NA	July	MTP
Carex alopecoidea	36.56059785	-82.46212342	Sullivan	NA	July	MTP
Carex alopecoidea	36.56853356	-82.44360828	Sullivan	NA	July	MTP
Carex alopecoidea	36.5690467	-82.44659387	Sullivan	NA	July	MTP
Carex sterilis	36.47842509	-82.30555302	Sullivan	NA	May-June	10PTP

Carex sterilis	36.47362257	-82.47679231	Sullivan	NA	May-June	10PTP
Carex sterilis	36.45844014	-82.39895069	Sullivan	NA	May-June	10PTP
Carex sterilis	36.46164812	-82.38832836	Sullivan	NA	May-June	10PTP
Carex sterilis	36.44177787	-82.42283927	Sullivan	TVA Conservation Area	May-June	10PTP
Carex sterilis	36.4402184	-82.41467901	Sullivan	TVA Conservation Area	May-June	10PTP
Carex sterilis	36.46322434	-82.38289731	Sullivan	TVA Conservation Area	May-June	10PTP
Carex sterilis	36.5079429	-82.48899374	Sullivan	Warriors Path State Park	May-June	10PTP
Carex sterilis	36.50173619	-82.48155902	Sullivan	Warriors Path State Park	May-June	10PTP
Carex sterilis	36.4926506	-82.47332647	Sullivan	Warriors Path State Park	May-June	10PTP
Clematis pitcheri	35.42413847	-90.16803105	Shelby	NA	Apr-Oct	MSS
Clematis pitcheri	36.37410984	-89.49448152	Lake	NA	Apr-Oct	MSS
Clematis pitcheri	35.44743539	-90.12845911	Shelby	NA	Apr-Oct	MSS

Clematis pitcheri	35.47765892	-90.08180485	Shelby	NA	Apr-Oct	MSS
Clematis pitcheri	35.5270353	-90.02255413	Tipton	NA	Apr-Oct	MSS
Clematis pitcheri	36.4736661	-89.41404346	Lake	NA	Apr-Oct	MSS
Clematis pitcheri	35.54098893	-90.04071541	Tipton	NA	Apr-Oct	MSS
Clematis pitcheri	35.53177435	-89.96662964	Tipton	NA	Apr-Oct	MSS
Clematis pitcheri	36.45076907	-89.47778354	Lake	NA	Apr-Oct	MSS
Clematis pitcheri	35.51812918	-90.03144198	Tipton	NRCS Conservation Easement	Apr-Oct	MSS
Crotalaria purshii	35.64562395	-83.38607581	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.64588057	-83.40418816	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.62536437	-83.43220046	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.63611975	-83.43114162	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.63455567	-83.44786602	Sevier	Great Smoky Mountains National Park	May-July	MTP

Crotalaria purshii	35.63286286	-83.43104486	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.6552016	-83.46467649	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.61642211	-83.48970048	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.63035838	-83.47221126	Sevier	Great Smoky Mountains National Park	May-July	MTP
Crotalaria purshii	35.67944228	-83.31898507	Sevier	Great Smoky Mountains National Park	May-July	MTP
Helianthemum bicknellii	36.42507855	-88.02180664	Stewart	NA	June-Sept	MTP
Helianthemum bicknellii	36.44007338	-88.04256553	Stewart	NA	June-Sept	MTP
Helianthemum bicknellii	36.23018568	-87.92514445	Humphreys	NA	June-Sept	MTP
Helianthemum bicknellii	36.04889876	-87.96736077	Humphreys	Johnsonville State Historic Park	June-Sept	MTP
Helianthemum bicknellii	36.47725566	-88.03898486	Stewart	Land Between the Lakes National Recreation Area	June-Sept	MTP
Helianthemum bicknellii	36.65421164	-88.03443302	Stewart	Land Between the Lakes National Recreation Area	June-Sept	MTP
Helianthemum bicknellii	36.67314657	-88.05118831	Stewart	Land Between the Lakes National Recreation Area	June-Sept	MTP

Helianthemum bicknellii	36.36377432	-88.0914111	Henry	TN National Wildlife Refuge	June-Sept	MTP
Helianthemum bicknellii	36.37145525	-88.08540914	Henry	TN National Wildlife Refuge	June-Sept	MTP
Helianthemum bicknellii	36.3983048	-88.05616665	Henry	TN National Wildlife Refuge	June-Sept	MTP
Helianthemum canadense	36.11475811	-87.88054212	Humphreys	NA	Apr-Aug	MSS
Helianthemum canadense	36.19044718	-87.91086367	Humphreys	NA	Apr-Aug	MSS
Helianthemum canadense	36.3180313	-87.9420848	Houston	NA	Apr-Aug	MSS
Helianthemum canadense	36.3548105	-87.96879308	Stewart	NA	Apr-Aug	MSS
Helianthemum canadense	36.215637	-87.9089544	Humphreys	NA	Apr-Aug	MSS
Helianthemum canadense	36.34401338	-87.95469084	Houston	NA	Apr-Aug	MSS
Helianthemum canadense	36.2812359	-87.92106735	Houston	NA	Apr-Aug	MSS
Helianthemum canadense	36.4213987	-88.02351331	Stewart	NA	Apr-Aug	MSS
Helianthemum canadense	36.41585542	-88.01393401	Stewart	NA	Apr-Aug	MSS

Helianthemum canadense	36.50953066	-88.00823803	Stewart	NA	Apr-Aug	MSS
Lachnocaulon anceps	35.18671727	-90.02282875	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.18960513	-90.01878457	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.09353152	-90.09061997	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.11261436	-90.0851721	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.1769236	-90.06640156	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.00473496	-90.11350406	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.09229434	-90.08391366	Shelby	NA	May-Oct	MTP
Lachnocaulon anceps	35.06829436	-90.12308204	Shelby	T.O. Fuller State Park	May-Oct	MTP
Lachnocaulon anceps	35.06773842	-90.11779592	Shelby	T.O. Fuller State Park	May-Oct	MTP
Lachnocaulon anceps	35.06965449	-90.11233554	Shelby	T.O. Fuller State Park	May-Oct	MTP
Leavenworthia exigua var. lutea	35.51829541	-86.86947928	Marshall	NA	Mar-Apr	MSS

Leavenworthia exigua var. lutea	36.08230355	-86.29817815	Wilson	NA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	36.08960916	-86.39338065	Wilson	Cedars of Lebanon State Forest SNA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	36.07549322	-86.31025185	Wilson	Cedars of Lebanon State Park	Mar-Apr	MSS
Leavenworthia exigua var. lutea	35.55929492	-86.88145596	Maury	Duck River Complex SNA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	36.03423685	-86.39324406	Rutherford	Gattinger's Cedar Glade and Barrens SNA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	35.84550046	-86.28080649	Rutherford	Overbridge SNA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	36.03298591	-86.34956324	Wilson	Vine Cedar Glade SNA	Mar-Apr	MSS
Leavenworthia exigua var. lutea	35.95582175	-86.30903675	Rutherford	Wittrig Cedar Glades	Mar-Apr	MSS
Leavenworthia exigua var. lutea	35.61207324	-86.88309121	Maury	Yanahli WMA	Mar-Apr	MSS
Rhynchospora alba	35.71977435	-83.24980945	Cocke	NA	July-Oct	MSS
Rhynchospora alba	35.56115366	-83.50539721	Sevier	NA	July-Oct	MSS
Rhynchospora alba	35.56069039	-83.51776808	Sevier	NA	July-Oct	MSS

Rhynchospora alba	36.10475658	-82.1194478	Carter	Cherokee National Forest	July-Oct	MSS
Rhynchospora alba	35.64574731	-83.42571711	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora alba	35.65120635	-83.43379752	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora alba	35.65236881	-83.44031812	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora alba	35.7123481	-83.25758942	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora alba	35.70416089	-83.25857148	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora alba	35.71072746	-83.28452906	Sevier	Great Smoky Mountains National Park	July-Oct	MSS
Rhynchospora wrightiana	35.0019148	-90.14657906	Shelby	NA	July-Sept	10PTP
Rhynchospora wrightiana	35.07656353	-90.11550547	Shelby	NA	July-Sept	10PTP
Rhynchospora wrightiana	35.11151696	-90.08676342	Shelby	NA	July-Sept	10PTP
Rhynchospora wrightiana	35.18009817	-90.06631191	Shelby	NA	July-Sept	10PTP
Rhynchospora wrightiana	35.08699362	-90.10238423	Shelby	NA	July-Sept	10PTP

Rhynchospora wrightiana	35.06646356	-90.17260679	Shelby	NA	July-Sept	10PTP
Rhynchospora wrightiana	35.00897776	-90.25061724	Shelby	NRCS Conservation Easement	July-Sept	10PTP
Rhynchospora wrightiana	35.02953416	-90.19658894	Shelby	NRCS Conservation Easement	July-Sept	10PTP
Rhynchospora wrightiana	35.01856439	-90.20963878	Shelby	NRCS Conservation Easement	July-Sept	10PTP
Rhynchospora wrightiana	35.03705552	-90.18451095	Shelby	NRCS Conservation Easement	July-Sept	10PTP
Scrophularia lanceolata	36.00833146	-82.89838645	Greene	NA	May-July	MTP
Scrophularia lanceolata	36.04352837	-82.78912343	Greene	NA	May-July	MTP
Scrophularia lanceolata	36.07638934	-82.72773284	Greene	NA	May-July	MTP
Scrophularia lanceolata	36.44261536	-82.38166815	Sullivan	NA	May-July	MTP
Scrophularia lanceolata	36.55071991	-82.34540244	Sullivan	NA	May-July	MTP
Scrophularia lanceolata	36.57549744	-82.30568126	Sullivan	NA	May-July	MTP
Scrophularia lanceolata	36.5906983	-82.32612494	Sullivan	NA	May-July	MTP

Scrophularia lanceolata	36.59079457	-82.34362934	Sullivan	NA	May-July	MTP
Scrophularia lanceolata	36.48065733	-82.35094005	Sullivan	NA	May-July	MTP
Scrophularia lanceolata	36.47498157	-82.3245675	Sullivan	TVA Conservation Area	May-July	MTP
Seymeria cassioides	35.24749711	-87.7039251	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.2257136	-87.68501622	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.23016399	-87.67850897	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.05812706	-87.93046251	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.04413928	-87.99615822	Hardin	NA	Aug-Oct	MSS
Seymeria cassioides	35.01658429	-88.10866521	Hardin	NA	Aug-Oct	MSS
Seymeria cassioides	35.1950875	-87.86108373	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.19337042	-87.90955487	Wayne	NA	Aug-Oct	MSS
Seymeria cassioides	35.07778787	-87.62543327	Wayne	NA	Aug-Oct	MSS

Seymeria cassioides	35.24681291	-87.66662257	Wayne	Natchez Trace Parkway and National Scenic Trail	Aug-Oct	MSS
Silene regia	36.49100998	-81.7148745	Johnson	NA	July-Aug	MSS
Silene regia	36.38437936	-81.78583671	Johnson	NA	July-Aug	MSS
Silene regia	36.16115861	-82.00602075	Carter	NA	July-Aug	MSS
Silene regia	35.89118765	-83.28994725	Cocke	NA	July-Aug	MSS
Silene regia	35.91450914	-83.05781808	Cocke	NA	July-Aug	MSS
Silene regia	36.44528794	-81.72107524	Johnson	NA	July-Aug	MSS
Silene regia	36.23226922	-82.23068448	Carter	Cherokee National Forest	July-Aug	MSS
Silene regia	35.97416609	-82.54185906	Unicoi	Cherokee National Forest	July-Aug	MSS
Silene regia	35.97076536	-82.542018	Unicoi	Cherokee National Forest	July-Aug	MSS
Silene regia	36.13661843	-82.04305082	Carter	Hampton Creek Cove SNA	July-Aug	MSS
Tetragonotheca helianthoides	35.05885229	-88.25182394	Hardin	NA	Apr-July	MSS

Tetragonotheca helianthoides	35.02861262	-85.67105193	Marion	NA	Apr-July	MSS
Tetragonotheca helianthoides	35.50879071	-84.22220266	Monroe	NA	Apr-July	MSS
Tetragonotheca helianthoides	35.51734214	-84.204538	Monroe	NA	Apr-July	MSS
Tetragonotheca helianthoides	35.5062019	-84.18449724	Monroe	NA	Apr-July	MSS
Tetragonotheca helianthoides	35.10312254	-84.59392817	Polk	Cherokee National Forest	Apr-July	MSS
Tetragonotheca helianthoides	35.09176664	-84.6186797	Polk	Cherokee National Forest	Apr-July	MSS
Tetragonotheca helianthoides	35.01839019	-88.18458584	Hardin	TVA Conservation Area	Apr-July	MSS
Tetragonotheca helianthoides	35.00576002	-85.59619023	Marion	TVA Conservation Area	Apr-July	MSS
Tetragonotheca helianthoides	35.32699657	-85.04543951	Hamilton	TVA Conservation Area	Apr-July	MSS

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VITA

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