Species Status Assessment Report for the Kentucky Glade Cress (*Leavenworthia exigua* var. *laciniata)*

Version 1.0

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VERSION UPDATES

EXECUTIVE SUMMARY

Leavenworthia exigua var. *laciniata* (Kentucky glade cress) is a winter annual herbaceous plant in the mustard family (Brassicaceae) known only from Bullitt and Jefferson Counties, Kentucky. The natural habitat for *L. exigua* var. *laciniata* is dolimitic limestone glades, but the taxon is also known from disturbed dolomite glades that are now pastures, lawns, and roadsides. The species is a poor competitor and relies on shallow soils or regular disturbance to reduce competition. The U.S. Fish and Wildlife Service (Service) listed this species as threatened under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543) (Act) in 2014 due to its narrow range, presumed low genetic diversity, low abundance, and ongoing threats to habitat from development (79 FR 25683). Since listing, genetic analyses have revealed extremely low levels of genetic diversity within and among populations, indicating that the species likely reproduces asexually through seeds (apomixis). Negative influences on the viability of this plant include habitat loss from residential and commercial development (including lawns, roads, and utility lines), incompatible agricultural use, off-road vehicle use, and forest encroachment resulting from fire suppression. It is uncertain how climate change will affect the plant. Current and potential future positive influences include land acquisition, easements and voluntary agreements with private landowners, and management activities like prescribed fire, soil scraping, cedar removal, invasive species control, and population augmentation or introduction.

The assessment of the current and future condition of *L. exigua* var. *laciniata* was based on element occurrence (EO) data from the Office of Kentucky Nature Preserves. We delineated 95 populations that correspond to the 95 EOs, 72 of which are confirmed extant. To characterize the current condition, we used element occurrence ranks that were based on population size, habitat quantity, and habitat quality. Habitat quality was weighted more heavily than population size. For example, a population with over 5,000 plants on highly degraded habitat where they do not fill their natural ecological role was ranked lower than a population with 500 plants in high quality natural habitat. Currently, there are 3 populations with excellent resiliency, 4 with good resiliency, 22 with fair resiliency, and 43 with poor resiliency. Very few populations exist in natural habitat; most occur in degraded remnant habitat like pastures and lawns, and where they do occur on glades, the habitat is often somewhat degraded by invasive species or from the legacy of previous land uses. Redundancy is inherently low for this endemic plant, and has declined over time, as 23 of the 95 known populations are extirpated or potentially extirpated (not found during most recent surveys). Within the narrow range of the species, the populations with good or excellent resiliency are distributed such that catastrophic events that affect one population (e.g. development) are unlikely to impact the others (Figure EX1). In addition, we determined that representation is inherently low due to very low levels of genetic variation within the species.

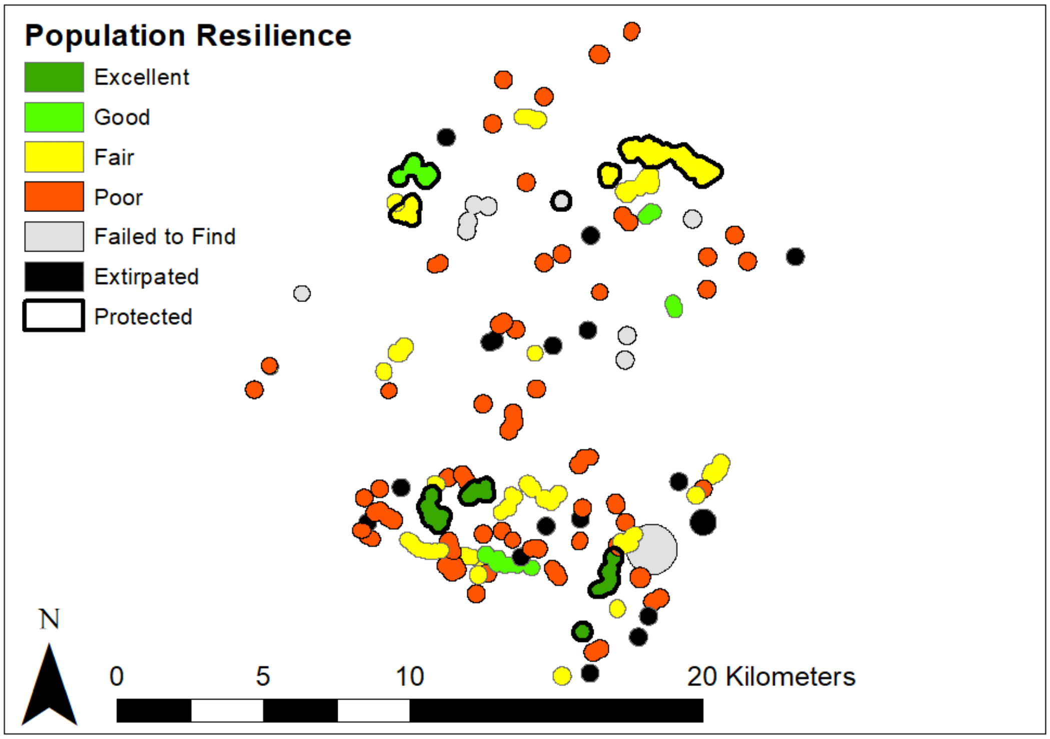

Figure EX1. Distribution of *L. exigua* var. *laciniata* populations and resiliency scores. Populations bordered in bold indicate those on public land or with significant private ownership (see section 2.6.3).

To assess the future condition, we used a three-tiered approach. First, populations were overlain with potential future development (urbanization, a proposed pipeline, and alternate routes for a proposed interstate) to identify those populations that may be at risk. Second, a conservation treatment was applied to certain populations based on ongoing conservation activities, land ownership, and location within critical habitat. Third, any populations that did not meet the criteria to be treated specifically in the conservation treatments were projected into the future using a probabilistic transition model based on past monitoring data. We projected the future condition in three scenarios. In the Status Quo Scenario, populations were projected to continue along present trajectories with no significant increases or decreases in management or conservation actions, except for populations where conservation activities are currently ongoing or planned. The Conservation 1 Scenario projected in the Status Quo Scenario but also projects a one-rank condition improvement every 20 years for populations occurring entirely or partially on critical habitat. The Conservation 2 Scenario projected a more moderate conservation approach under the assumption that resources and access may not be available to target all critical habitat. Instead, this scenario uses the projections in the Status Quo Scenario plus projects that additional conservation efforts will occur on habitat on protected lands and other lands with high quality habitat or high restoration potential identified by Office of Kentucky Nature Preserves (OKNP) as good conservation targets.

The trajectory of populations predicted by the transition model is downwards, leading to overall declines in the number of extant populations, but the conservation measures applied to populations in the conservation treatments led to increases in the number of extant populations with good or excellent resiliency. Even the Status Quo Scenario led to modest increases in the number of populations with good or excellent resiliency because we project that the current conservation actions or momentum by OKNP and partnering landowners will increase the number of populations with good or excellent resiliency from the current 7 populations to 8 and 9 populations, respectively, in 20 and 40 years. We predict further increases in the total number of these highly resilient populations in the Conservation 1 and Conservation 2 Scenarios (12 to 14 populations in 20 years, 13 to 19 populations in 40 years; Figure EX2). Under all scenarios, we project the number of extant populations (currently 72) to decline to 66 to 67 within 20 years, and 60 to 61 in 40 years. Because the transition model was not spatially explicit, it did not predict which populations are most likely to be extirpated, but we can get some insight by examining the spatial distribution of development threats (Figure EX3). Populations exposed to one or multiple development threats (e.g., where the proposed pipeline route intersects with a proposed interstate route) will likely have a higher risk of extirpation.

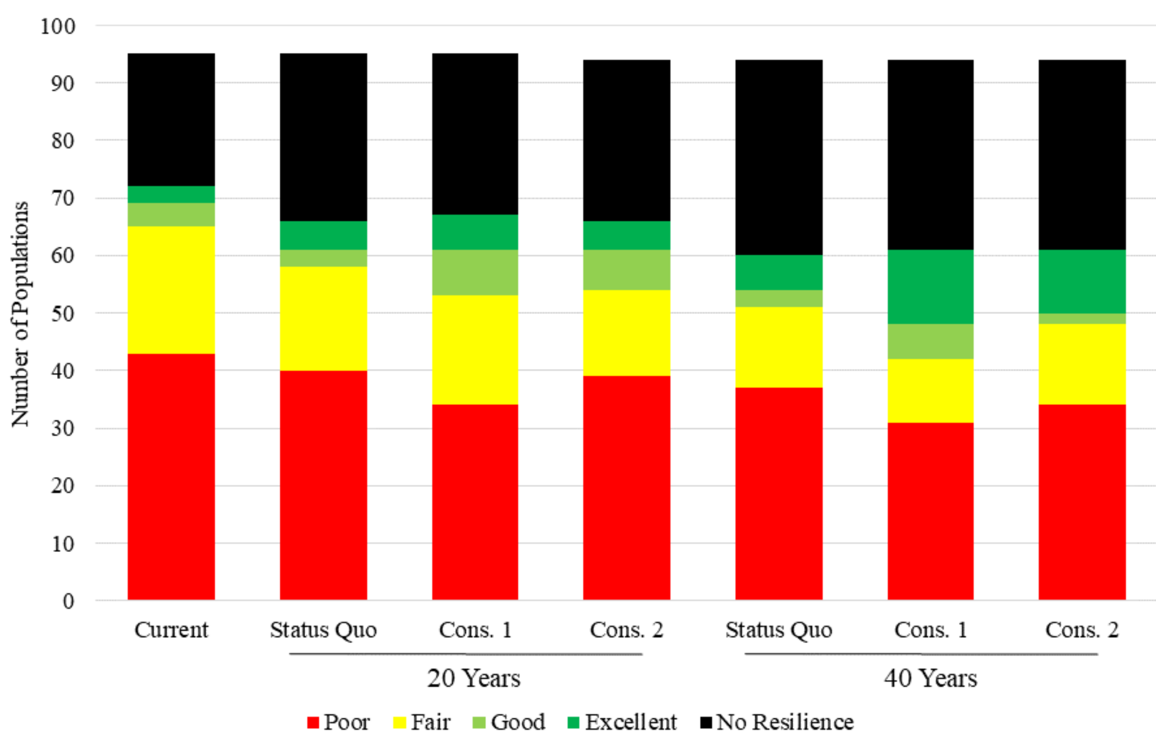

Figure EX2. Current and predicted future resiliency in 20 and 40 years under three scenarios.

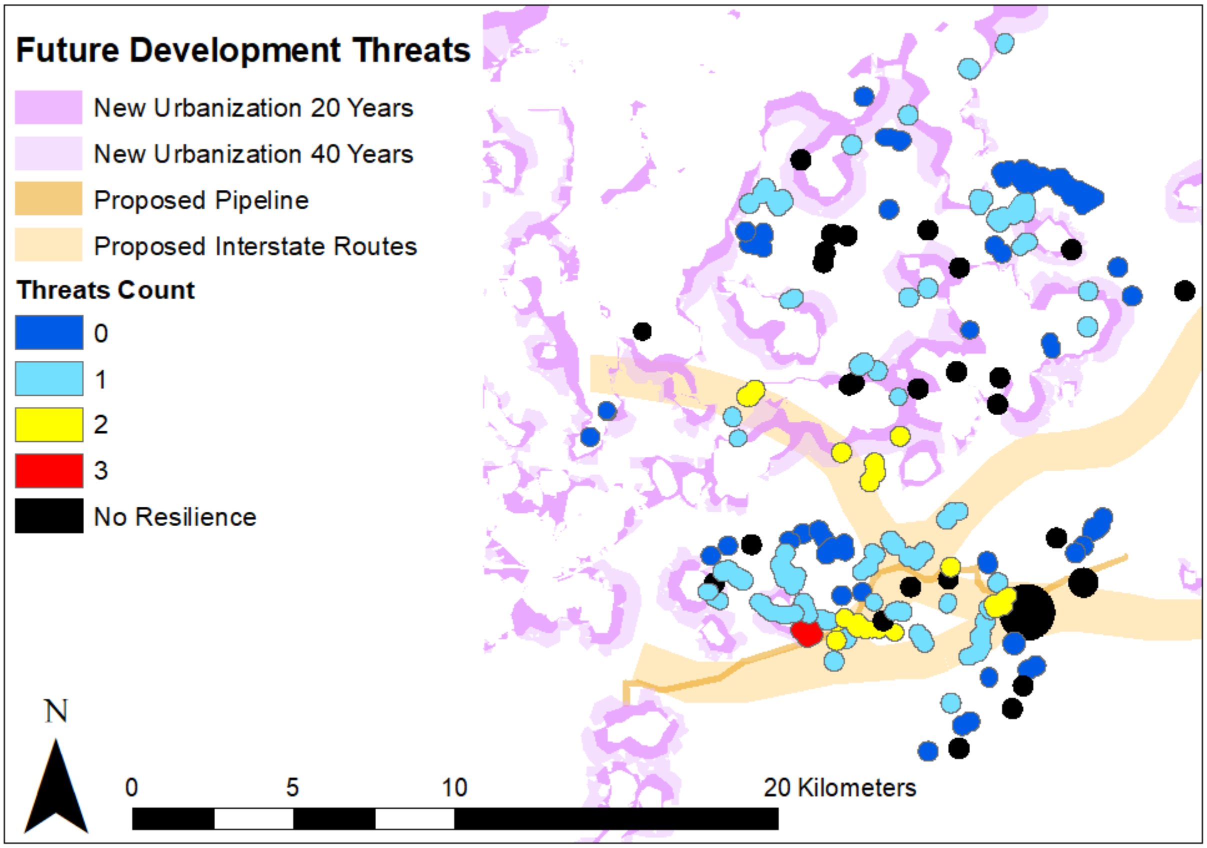

Figure EX3. Distribution of populations and their risk from future development. Threats count refers to the number of development threats (urbanization, proposed pipeline, proposed interstate) the population is potentially exposed to. Counts are only given for extant populations.

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CHAPTER 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

The Species Status Assessment (SSA) framework (USFWS 2016, entire) is intended to support an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA to be a living document, easily updated as new information becomes available, and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery.

Leavenworthia exigua var. *laciniata* (Kentucky glade cress) is an annual plant in the mustard family (Brassicaceae) known only from Bullitt and Jefferson Counties, Kentucky. The natural habitat for *L. exigua* var. *laciniata* is dolomite glades, but the taxon is also known from overgrazed pastures, eroded shallow soil areas with exposed bedrock, and areas where the soil has been scraped off the underlying bedrock. The U.S. Fish and Wildlife Service (Service) listed this species as threatened under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543) (Act) in 2014 due to its narrow range, presumed low genetic diversity, low abundance, and ongoing threats to habitat from development (79 FR 25683). This SSA for *L. exigua* var. *laciniata* is intended to provide the biological support for a 5-Year Review of the species' status and the development of a recovery plan. Importantly, the SSA does not result in any decisions or actions by the Service. Rather, this SSA provides a review of the available information strictly related to the biological status of *L. exigua* var. *laciniata*. Any future decisions will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of any proposed decisions will be announced in the Federal Register, with appropriate opportunities for public input.

For the purpose of this SSA, we define **viability** as a description of the ability of a species to sustain populations in the wild beyond a biologically meaningful time frame. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (USFWS 2016, p. 9). Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its **resiliency**, **representation**, and **redundancy** (Wolf et al. 2015, entire).

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors), and is positively related to population size and growth rates.

- **Redundancy** describes the ability of a species to withstand catastrophic impacts to any one population by having multiple populations, allowing species to spread risk across populations.

- **Representation** describes the breadth of genetic and environmental diversity within and among populations, which influences the ability of a species to adapt to changing environmental conditions over time.

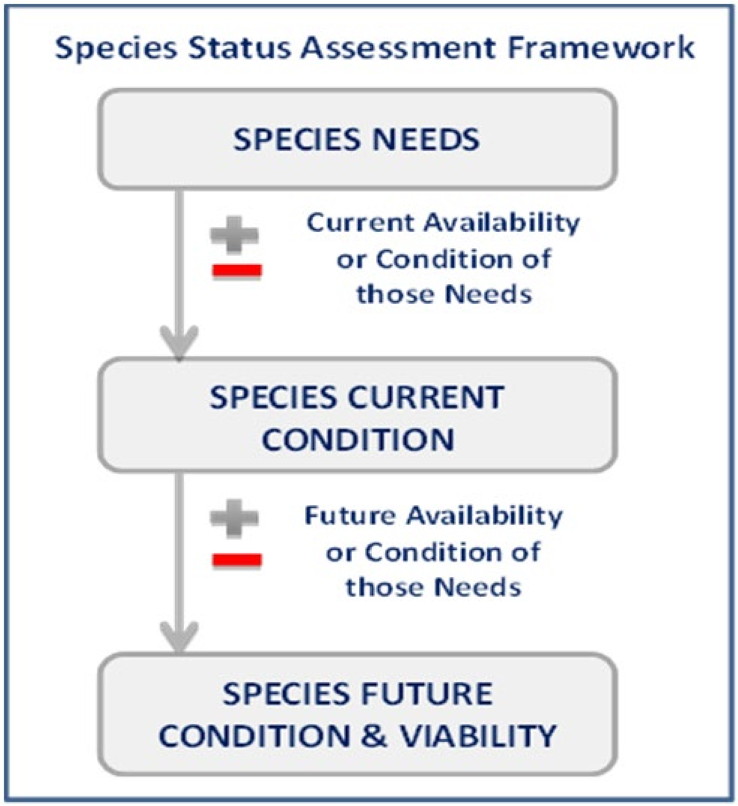

Figure 1. Species Status Assessment Framework

This SSA Report includes the following chapters:

1. Introduction;
2. Species Biology and Individual Needs. This chapter discusses the life history of the species and resource needs of individuals.
3. Factors Influencing Viability. This chapter provides a description of likely causal mechanisms, and their relative degree of impact, on the status of the species.
4. Population and Species Needs and Current Condition. This chapter provides a description of what the species needs across its range for viability and estimates of the species' current range and condition.
5. Future Conditions and Viability. This chapter provides descriptions of plausible future scenarios and predictions of their influence on the species' resiliency, representation, and redundancy.

CHAPTER 2 – SPECIES BIOLOGY AND INDIVIDUAL NEEDS

2.1 Taxonomy

Leavenworthia is a monophyletic genus (Urban and Bailey, 2013, p. 727) of herbaceous plants in the mustard family (Brassicaceae) that are found in the southeastern United States. *Leavenworthia* species are commonly sympatric, occurring primarily in central Tennessee, northern Alabama, Kentucky, and the Ozark Mountains of Arkansas and Missouri (Figure 2; Rollins 1963, p. 5; Baskin and Baskin 1985, p. 373). The genus *Leavenworthia* currently includes eight accepted species: *L. aurea*, *L. texana*, *L. uniflora*, *L. alabamica*, *L. crassa*, *L. exigua*, *L. torulosa*, and *L. stylosa*. *Leavenworthia exigua* var. *laciniata* is considered a distinct variety by some authors but is not presently accepted (as of October 2019) as its own species by the Integrated Taxonomic Information System, the federal entity that maintains and reviews data for taxonomic classifications. However, a recent conservation genetics study of the species suggested that *L. exigua* var. *laciniata* may warrant recognition as a unique species based on morphological and geographic distinctions, mode of reproduction, and lack of gene flow with other *L. exigua* varieties (Edwards 2018, p. 14-15).

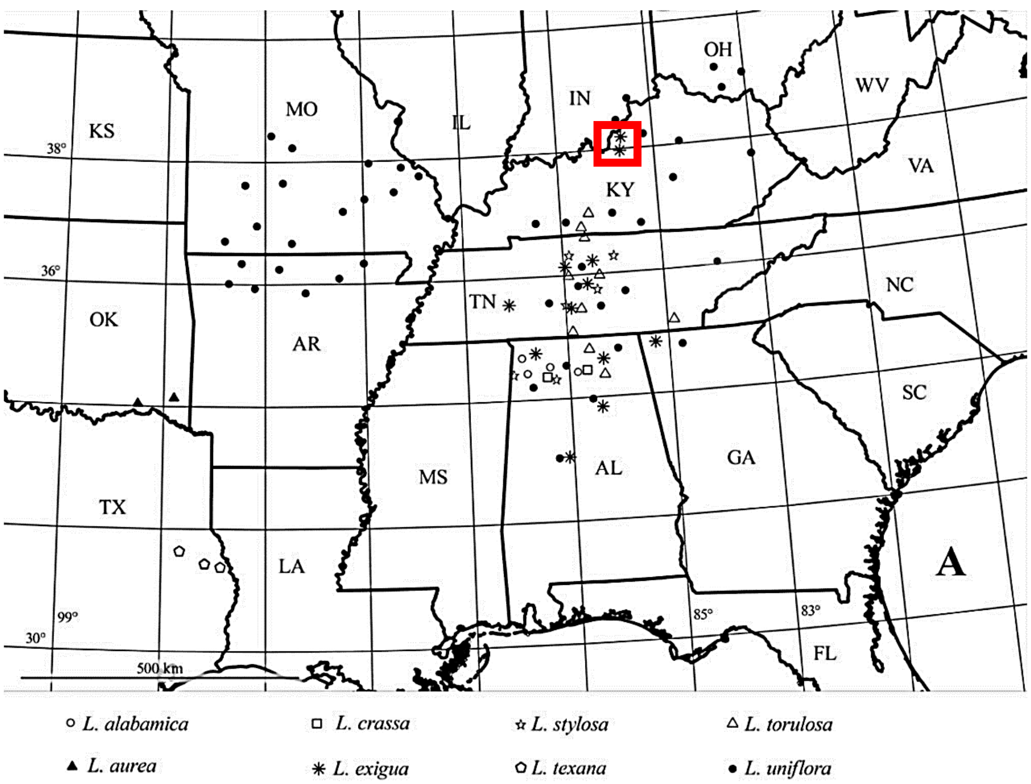

Figure 2. Distribution of *Leavenworthia* species, adapted from Urban and Bailey 2013, p. 724. A red box is drawn around *L. exigua* var. *laciniata* in Kentucky.

Rollins (1963, p. 75) described *L. exigua* var. *laciniata* as a new taxon in his monograph of the genus *Leavenworthia*. He found that the rather extensive populations of *L. exigua* located in Bullitt County, Kentucky, exhibited distinguishing characteristics compared to populations in Tennessee, northern Alabama, and northern Georgia (Rollins 1963, p. 51, 75). The Kentucky plants, which he described as *L. exigua* var. *laciniata*, had longer styles (usually slender and elongate extension of the ovary), and green instead of lavender sepals compared to *L. exigua* var. *exigua*. Kral (1983, p. 10-18) supported Rollins' recognition of the taxon as a distinct variety. Kartesz (1991, p. 449) recognized the taxon by including it in his vascular flora checklist for the United States, and Weakley (2012, p. 714) included the taxon in his list of Flora of the Southern and Mid-Atlantic States. In Flora of North America North of Mexico, Al-Shehbaz and Beck (2010, p. 486) do not recognize *L. exigua* var. *laciniata*, or any other infraspecific *L. exigua* taxa, because of the subtly of the morphological differences upon which these taxa are currently based.

The currently accepted taxonomic ranking for *L. exigua* var. *laciniata* is described below.

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Rosanae
Order	Brassicales
Family	Brassicaceae – mustards
Genus	*Leavenworthia* Torr. – gladecress
Species	*Leavenworthia exigua* Rollins – Tennessee gladecress[1]

2.2 Species Description

Leavenworthia exigua var. *laciniata* is an annual member of the mustard family (Brassicaceae). Plants are about 5 to 10 cm (1.97 to 3.94 in) in height with early leaves that are simple with a slender petiole (central stalk of the leaf) and mature leaves that are sharply lobed (appear as disconnected pieces along the main leaf vein), somewhat squared at the ends and arranged as a

[1] *Leavenworthia exigua* var. *laciniata*, Kentucky glade cress, is not at this time an accepted taxonomic classification by ITIS. The taxonomic ranking was retrieved 06/28/2019 from the Integrated Taxonomic Information System (ITIS) on-line database, http://www.itis.gov, on June 28, 2019.

rosette (circular cluster of leaves; Evans and Hannan 1990, p. 5; Figure 3). The flowers are small (3 to 6 mm (0.12 to 0.24 in)), white to lilac in color with four petals, green rather than lavender sepals (the outer of two floral leaves that make up the flower), and leafless stems. Leaves typically disappear by the time the plant is in fruit (Evans and Hannan 1990, p. 6). The fruit is flat and pod-shaped (Figure 3).

Figure 3. *Leavenworthia exigua* var. *laciniata*. Diagram credit: KSNPC n.d. Photo credits: flowering plant, Tara Littlefield, OKNP, USFWS; seed pods, Christy Edwards, Missouri Botanical Garden.

2.3 Life History

The life cycle of *L. exigua* var. *laciniata* is almost identical to that of all members of the genus *Leavenworthia* (Baskin and Baskin 1981, p. 246; Solbrig 1972, p. 155), except for the mode of reproduction. Rather than reproducing sexually through seed production, *L. exigua* var. *laciniata* has patterns of genetic diversity that suggest that it reproduces asexually, most likely through apomixis, the asexual formation of seeds from maternal ovule tissue without fertilization and recombination (Bicknell and Koltunow 2004, Edwards 2018 p. 13). However, additional research on the reproductive biology of this species is needed to understand how apomixis in this taxon is accomplished. While pollination and recombination seem to not be necessary for reproduction, bee flies (Bombyliidae) have been observed visiting flowers (Littlefield 2019*a*, pers. comm.). Successful reproduction requires sufficient moisture for germination, growth, flowering, and seed production. Seeds may fall to the ground, be transported by animals, or be carried by water runoff to precipitation to new sites during high precipitation events.

For *L. exigua* var. *laciniata*, seed germination occurs in September and October (Baskin and Baskin 1981, p. 246). The young plants survive through the winter as rosettes that then flower from late February to mid-April (Baskin and Baskin 1981, p. 246; Darnell 2019*a*, pers. comm.; Evans and Hannan 1990, p. 11). Peak flowering between 2012 and 2019 fell between March 11 and April 20 (Darnell 2019*a*, pers. comm.). Seed set and plant death occur in April and May as the glade habitats dry out (Baskin and Baskin 1985, pp. 378-379; Solbrig 1972, p. 155). Seeds are typically dispersed from mid- to late-May (Evans and Hannan 1990, p. 11). After the seeds ripen, the silique (pod) soon splits open. Seeds may immediately fall out or remain on the plant for several days.

At maturity, most of the seeds are dormant and will not germinate following dispersal, even if the soils are moist (Baskin and Baskin 1985, p. 379). During the summer these seeds undergo physical changes known as after-ripening and move from dormancy to conditional dormancy and, finally, become non-dormant for fall germination (Baskin and Baskin 1985, p. 379). Baskin and Baskin (1971, p. 33; 1972, p. 1716) found that freshly harvested *Leavenworthia* spp. seeds were dormant at any temperature and that, once dormancy was broken, germination was prevented by high temperatures, regardless of moisture levels. This characteristic seems to protect *Leavenworthia* spp. from germination following short summer showers that temporarily moisten the glade habitats (Baskin and Baskin 1985, p. 381), and allows them to avoid the hot, dry summer (Baskin and Baskin 1972, p. 1720). All seeds may not germinate each fall, allowing seed reserves to accumulate (Baskin and Baskin 1981, p. 246). A study by Baskin and Baskin (1981, p. 247) found that collected *L. exigua* var. *laciniata* seeds germinated in a greenhouse over four autumns, although at drastically reduced numbers after the first year (4,907 in 1976, 190 in 1977, 156 in 1978, and 71 in 1979). A strong seed bank is expected to be important for the continued existence of *L. exigua* var. *laciniata*, especially following a year when conditions are unfavorable for reproduction (e.g., damage, natural or manmade, to plants prior to seed set). Accordingly, *L. exigua* var. *laciniata* habitat must be protected from activities that would damage or destroy the seed bank.

The extent to which this plant can expand to new sites is unknown. Lloyd (1965, p. 92) noted that seeds from *Leavenworthia* lack adaptations that would allow for dispersal by wind or animals. Sheet flow likely provides local dispersion for seeds lying on the ground (Lloyd 1965, pp. 92-93; Evans and Hannan 1990, p. 11). In reviewing aerial photography and topographic mapping of known *L. exigua* var. *laciniata* occurrences, it appears that populations often follow suitable habitat as it extends along topographic contours or within drainage patterns. Seeds can also be dispersed by off-road vehicles and lawn mowers in disturbed habitat, and by cattle when mud that contains seeds get stuck in their hooves (Littlefield 2019*a*, pers. comm.). Areas of bare ground are essential in the dispersal and germination of seeds. The cyclical moisture availability on the thin soils of glades and other habitats acts to limit the number of plant species that can tolerate these extremes (Evans and Hannan 1990, pp. 9-10).

2.4 Genetics

What little information is known about *L. exigua* var. *laciniata* comes from a recent conservation genetics study that used 16 microsatellite loci to understand levels of genetic diversity within populations, genetic structure within and among populations, whether *L. exigua* var. *laciniata* is genetically distinct from *L. exigua* var. *exigua*, and implications for conservation (Edwards 2018, entire).

Genetic diversity for *L. exigua* var. *laciniata* is extraordinarily low. *Leavenworthia exigua* var. *laciniata* exhibits population genetic patterns consistent with clonality, including identical genotypes within populations, fixed heterozygosity at some loci indicating a lack of sexual recombination, an excess of heterozygotes compared to Hardy Weinberg equilibrium, and high negative inbreeding coefficients (Edwards 2018, p. 12.). Individuals within and among the 21 populations of *L. exigua* var. *laciniata* sampled were virtually genetically identical. Only a single genotype was found in each population (12-24 plants sampled per population; Edwards 2018, p. 26), and the majority of populations were identical except for 5 populations that showed 1-2 private alleles (i.e., alleles not found in any other population; Edwards 2018, p. 10). These findings were in contrast to those for *L. exigua* var. *exigua*, which exhibited higher amounts of genetic diversity both within and among populations (Figure 4). These population genetic findings supported the novel conclusion that *L. exigua* var. *laciniata* likely reproduces asexually through apomixis (Edwards 2018 p. 13). Because *L. exigua* var. *laciniata* reproduces asexually and is, therefore, reproductively isolated from the other varieties of *L. exigua*, it might warrant recognition as a unique species (Edwards 2018, p. 15).

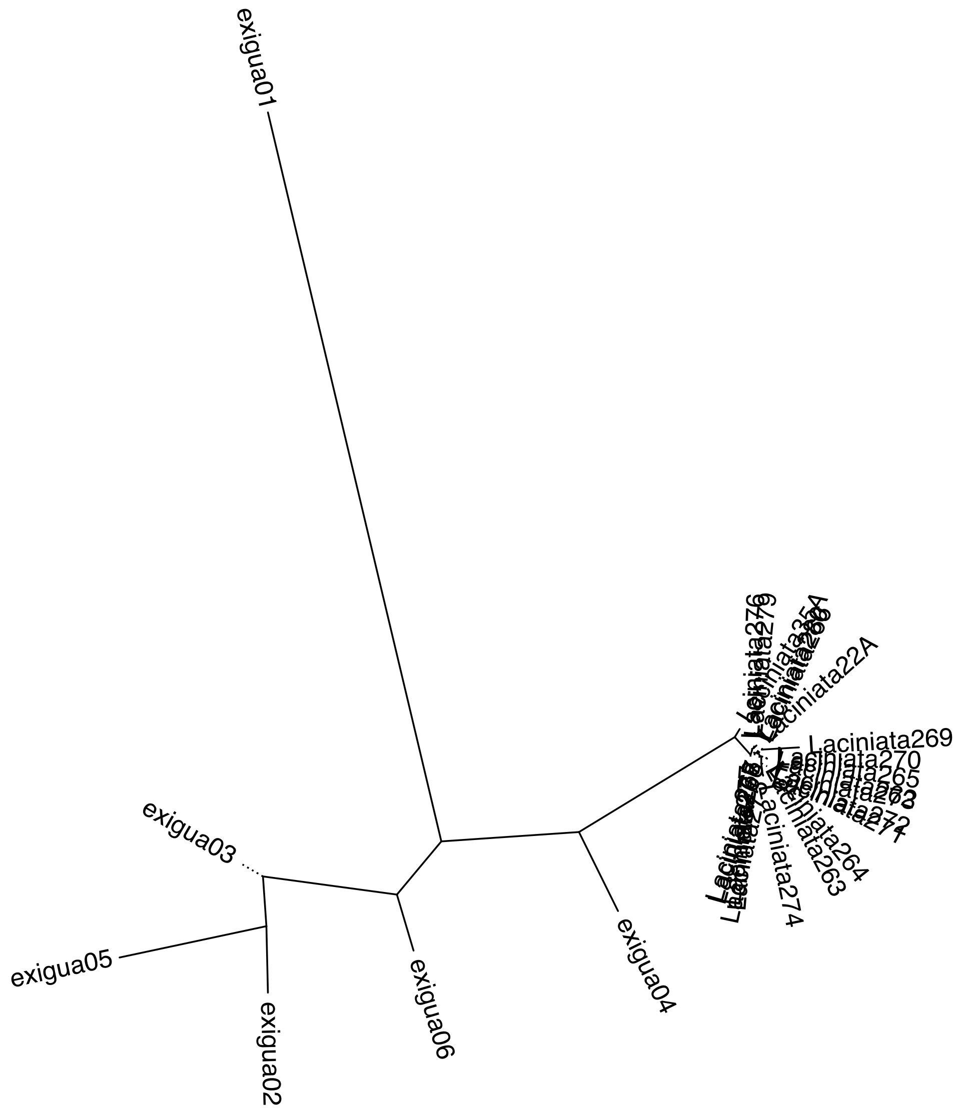

Figure 4. Neighbor-joining tree of Nei's genetic distance matrix, with branch lengths proportional to genetic distance. Results show that *L. exigua* var. *laciniata* populations are largely genetically identical whereas *L. exigua* var. *exigua* demonstrates genetic variation among populations. Figure and caption adapted from Edwards 2018, p. 32.

Compared to sexually reproducing species, adaptation is slow in asexual species with no genetic recombination (Edwards 2018, p. 16). Adaptation in asexual species occurs through recent somatic mutations, most of which are not expected to be beneficial (Orr 2010, p. 1195). To protect the adaptive potential of *L. exigua* var. *laciniata*, Edwards (2018, p. 16) recommends protecting the largest number of individuals possible *in-situ*, regardless of location, to maximize the chances that beneficial mutations will occur. Populations with private alleles can be targeted specifically to preserve those low levels of variation that do exist within the species. Implications for *ex-situ* conservation are that it is not necessary to collect seed from the entire geographic range of the species to preserve representative genotypes, as a few genotypes exist range-wide (Edwards 2018, p. 16-17). *Ex-situ* seed collections of the existing genotypes could be sourced from a small number of *in-situ* populations.

2.5 Habitat

Figure 5. *Leavenworthia exigua* var. *laciniata* in high-quality habitat at Apple Valley Glade SNP (Photo by Jennifer Koslow, Eastern Kentucky University) and good habitat at Pine Creek Barrens (Photo by Tara Littlefield, OKNP).

Leavenworthia exigua var. *laciniata* is adapted to environments with shallow soils interspersed with flat-bedded, Silurian dolomite and dolomitic limestones, which is an uncommon geological formation in Kentucky (Rollins 1963, p. 5; Evans and Hannan 1990, pp. 8-9). The soil on these horizontally bedded limestone areas is often only a few inches in depth or may be completely absent in some areas (Rollins 1963, p. 5; Figure 5). These dolomite glades are extremely wet from late winter to early spring and quickly become dry in May and June. Currently, the natural habitat for *L. exigua* var. *laciniata* is dolomite glades, but the taxon is also known from eroded shallow soil areas with exposed bedrock, areas where the soil has been scraped off the underlying bedrock, and former glade and barrens sites that have been converted to pastures, lawns, or roadsides (Evans and Hannan 1990, p. 8). *Leavenworthia exigua* var. *laciniata* does not appear to compete well with other vegetation and is shade intolerant (Evans and Hannan 1990, p. 14). This characteristic allows for the species to exist in high numbers in disturbed sites like lawns and pastures that receive regular disturbance from mowing or grazing.

Figure 6. *Leavenworthia exigua* var. *laciniata* in disturbed habitat. From left to right: lawn habitat (Photo by Christy Edwards, Missouri Botanical Garden), utility right-of-way, and pasture (Photos by Laura Darnell, Redwing Ecological Services, Inc.).

This taxon is not restricted to any specific soil type (Evans and Hannan 1990, p. 8). It appears to be more dependent upon lack of soil (and plant competition) and proximity of rock near or at the surface. It occurs primarily in open gravelly soils around rock outcrops in an area of the Caneyville-Crider soil association (Whitaker and Waters 1986, p. 16). Within this soil association, *L. exigua* var. *laciniata* occurs on the following mapped soil types: Caneyville-rock outcrop complex, 6 to 40 percent slope; Caneyville silt loam, 6 to 12 percent slope, eroded; Caneyville-Beasley-rock outcrop complex, 12 to 30 percent slope; Faywood-Beasley-rock outcrop complex, 25 to 60 percent slope; and Beasley silty clay loam, 6 to 12 percent slopes, severely eroded (Whitaker and Waters 1986, pp. 26-27, 29-31, 40-41; Evans and Hannan 1990, p. 8). Where *L. exigua* var. *laciniata* occurs on soils without bedrock near the surface, the soil is usually eroded to severely eroded with 25 to 100 percent of the original surface gone (Evans and Hannan 1990, p. 8).

The cyclical moisture availability on the thin soils of glades and other habitats acts to limit the number of plant species that can tolerate these extremes. Consequently, very few other plants occur on undisturbed glades (Evans and Hannan 1990, pp. 9-10). In areas where the glades have been disturbed, native and introduced weedy species (annual and perennial) have invaded glades from nearby roads, fields, and waste areas (Baskin and Baskin 1985, p. 375). Areas surrounding glade openings tend to have deeper soils that support plants with prairie/barren affinities. The following list of associates of *L. exigua* var. *laciniata* was compiled from Baskin and Baskin (1981, p. 245), Evans and Hannan (1990, p. 10), Littlefield (2019*a*, pers. comm.), and White (2004, p. 1):

> <u>Vascular plants</u>: *Hypoxis hirsuta* (common goldstar), *Scutellaria parvula* (little skullcap), *Viola egglestoni* (cedar glade violet), *Lithospermum canescens* (hoary pocoon), *Sabatia angularis* (rosepink), *Euphorbia commutata* (tinted woodland spurge), *Nothoscordum bivalve* (false garlic), *Ranunculus fascicularis* (early buttercup), *Houstonia canadensis* (Canadian bluets), and *Sporobolus vaginifloris* (poverty dropseed). In surrounding areas: *Echinacea simulata* (pale purple coneflower), *Hypericum dolabriforme* (straggling St. John's-wort), *Eleocharis bifida* (glades spikerush), *Silphium trifoliatum* (whorled rosinweed), *Manfreda virginica* (false aloe), *Viola pedata* (birdfoot violet), *Liatris aspera* (tall gayfeather), and *Schizochyrium scoparium* (little bluestem).
>
> <u>Cyanobacteria</u>: *Nostoc* spp.
>
> <u>Bryophytes</u>: *Tortella humulis* (tortella moss), *Ptychostomum pseudotriquetrum, Funaria hygrometrica* (funaria moss), *Physcomitrium pyriforme* (physcomitrium moss), and *Polytrichastrum ohioense* (Ohio haircap moss).
>
> <u>Lichens</u>: *Dermatocarpon miniatum,* and *Cladonia* spp.
>
> <u>Invasive Species</u>: *Lonicera japonica* (Japanese honeysuckle), *Lonicera mackii* (Amur honeysuckle), *Ligustrum sinense* (Chinese privet), *Melilotus spp.* (sweetclover), and *Festuca/Schedonorus* spp (fescues).

2.5.1 Critical Habitat

Under the Act and its implementing regulations, the Service designated critical habitat for the species in 2014. Critical habitat units were designated by considering the physical and biological features (referred to as primary constituent elements in the Final Rule) that provide for *L. exigua* var. *laciniata*'s life-history processes and are essential to the conservation of the species (78 FR 31479):

- Cedar glades and glade-like areas within the range *of L. exigua* var. *laciniata* that include:
    - Areas of rock outcrop, gravel, flagstone of Silurian dolomite or dolomitic limestone, and/or shallow (1 to 5 cm [0.393 to 1.97 in]), calcareous soils;
    - Intact cyclic hydrologic regime involving saturation and/or inundation of the area in winter and early spring, then drying quickly in the summer;
    - Full or nearly full sunlight; and
    - An undisturbed seed bank.
- Vegetated land around glades and glade-like areas that extends up and down slope and ends at natural (e.g., stream, topographic contours) or manmade breaks (e.g., roads).

The Service designated six units, consisting of 18 subunits, as critical habitat for *L. exigua* var. *laciniata* (Table 1).

Table 1. Designated critical habitat units for *L. exigua* var. *laciniata* (78 FR 31479). Area estimates reflect all land within critical habitat unit boundaries.

Critical Habitat Unit	Subunit	Land Ownership	Size of Unit in Acres (Hectares)
1 – McNeely Lake	(NA)	Louisville/Jefferson County Metro Government	18 (7)
2 – Old Mans Run	2A	Future Fund Land Trust	102 (41)
	2B	21st Century Parks, Future Fund Land Trust, Private	870 (352)
	2C	Private	42 (17)
3 – Mount Washington	3A	Private	25 (10)
	3B	Private	7 (3)
	3C	Private	10 (4)
4 – Cedar Creek	4A	The Nature Conservancy	91 (37)
	4B	OKNP; Private; Private with OKNP easement	69 (28)
	4C	Private	83 (34)
	4D	Private	46 (19)
	4E	Private	102 (41)
	4F	Private	120 (49)

Critical Habitat Unit	Subunit	Land Ownership	Size of Unit in Acres (Hectares)
	4G	Private	20 (8)
	4H	Private	16 (6)
5 – Cox Creek	5A	Private	8 (3)
	5B	Private	50 (20)
6 – Rocky Run	(NA)	Private (Registered Natural Area)	374 (151)
Total			***2,053 (830)***

2.6 Distribution and Abundance

2.6.1 Current and Historical Distribution

Leavenworthia exigua var. *laciniata* is a Kentucky endemic and is known from only northeastern Bullitt County and extreme southeastern Jefferson County (Evans and Hannan 1990, p. 6; Jones 2005, p. 294; White 2004, p. 1). Populations of *L. exigua* var. *laciniata* are separated from populations of the other two varieties of *L. exigua* that occur in Alabama, Georgia, and Tennessee (Rollins 1963, p. 5). Information regarding the historical range and distribution of *L. exigua* var. *laciniata* is largely lacking. The original description by Rollins (1963, p. 75) notes a single specimen collected in a cedar glade in Bullitt County and references an earlier specimen collected in 1954 by H. A. Korfhage from an open field in Bullitt County. The species is now known from 95 element occurrences (defined in the following section) including both historical and current locations in Bullitt and Jefferson Counties.

Over the last 20 years, the Office of Kentucky Nature Preserves (OKNP, formerly the Kentucky State Nature Preserves Commission [KSNPC]) has systematically used aerial photography to identify potential *L. exigua* var. *laciniata* glade habitat in areas of Laurel Limestone and other suitable types of limestone bedrock with the intent of identifying new populations within the known range and exploring potential areas to expand the known habitat. Very little potential habitat fitting these parameters has not been surveyed. Also, this part of Kentucky is heavily explored because it is so populated and accessible. There are still some un-surveyed areas in the region, and several new occurrences of *Leavenworthia exigua* var. *laciniata* have been discovered in the last few years (2015-2018), but the majority of potential sites have been surveyed and it is not likely that a substantial number of undiscovered populations exist (Littlefield 2019*a*, pers. comm.).

2.6.2 Current and Historical Population Conditions

Long-term quantitative monitoring data are unavailable for this taxon range-wide, but OKNP has recorded qualitative estimates of element occurrence size and quality at varying time intervals, along with quantitative consistent monitoring at a subset of sites. An element occurrence (EO) is the basic conservation unit used by OKNP in assessing species for the Natural Heritage Program. NatureServe defines an EO as "an area of land and/or water where a species or ecological community is or was present" (NatureServe 2004, p. 1). The terms element occurrence and occurrence are used interchangeably throughout this document. Each occurrence was evaluated with respect to size and resiliency, condition of the habitat, and degree of threat. As an annual species, plant numbers of *L. exigua* var. *laciniata* can naturally and greatly fluctuate from year to year based on a variety of factors, such as seed production in past years, germination rates, disturbance, and environmental conditions (e.g., temperature, rainfall; Bush and Lancaster 2005, n.p.). As such, habitat conditions often have a greater influence on the evaluation of resiliency than population numbers. Element occurrences have been ranked into the following categories: A (excellent estimated resiliency), B (good estimated resiliency), C (fair estimated resiliency), D (poor estimated resiliency), F (field surveys failed to relocate the plants at the site), or X (occurrence is considered extirpated). These rankings are explained in more detail in section 4.2.

<u>*Historical Populations*</u>

Evans and Hannan (1990, pp. 9, 19-20) conducted the first range-wide survey for the *L. exigua* var. *laciniata* and documented a total of 71 occurrences (61 extant at that time, 7 extirpated, 3 not found) in Bullitt and Jefferson Counties. At that time, approximately 70 percent (42/60) of the extant occurrences were ranked as A, B, or C in quality (Evans and Hannan 1990, pp. 24-94). White (1994, pp. 2-7) reevaluated the status of the taxon in April 1994 by visiting the occurrences documented by Evans and Hannan (1990, pp. 19-20) and provided updated ranks and descriptions of habitat conditions. White (1994, p. 4) recorded a decline in rank quality at 41 percent of the occurrences, with some of the occurrences decreasing by two levels of rank quality. Sixty-eight percent of these sites were degraded directly by human-related activities (e.g., house construction, lawn development, changes in grazing practices). Over 60 percent of the occurrences had quality ranks of "D" or were considered extirpated (White 1994, p. 4).

There is no monitoring schedule for *L. exigua* var. *laciniata* populations. Many occurrences have been surveyed recently (2015-2018 surveys by OKNP), but the last range-wide survey was completed at 50 known occurrences in April and early May of 2004 (White 2004, pp. 1-3). The number of plants and their condition (including flowering and fruiting) and general site conditions were recorded at the known occurrences. The results of these surveys were compared to results of previous surveys conducted in 1990 (Evans and Hannan 1990, pp. 19-20) and 1994

(White 1994, pp. 2-7) for the subset of occurrences that were visited in all 3 years. Of the 49 occurrences surveyed in all 3 years, 32 (65 percent) had decreased in quality between 1990 and 2004. This decrease in quality was commonly due to a reduction in the number of plants and an accompanying decline in habitat quality as the character of the area changed from rural to residential. Of those 32 occurrences that declined, half were extirpated or unable to be relocated in 2004. Table 2 and Figure 7 below illustrate the status of these 49 occurrences and their resiliency over this 14-year period. In 1990, 61 percent of these occurrences were considered to have a resiliency of fair or better. In 1994, this amount had dropped to 43 percent; and in 2004 it was down to only 14 percent. This value increased to 27 percent using the current ranks (some of which were from 2004), but these increases in rank were more often due to updating how rank criteria were applied rather than true improvements in condition (Littlefield 2019*b*, n.p.). These 49 occurrences that have been monitored over time represent approximately 60 percent (49 of 81) of the total occurrences known in 2004. Since that time additional occurrences have been identified, bringing the total known occurrences (historical and extant) to 95.

Table 2. Comparison of status ranks for 49 occurrences of *L. exigua* var. *laciniata* that were surveyed in 1990, 1994, and 2004. *Note that "Current" represents the most recent status for each occurrence and does not represent a new range-wide survey; 26 of 49 "Current" ranks were last updated in 2004 or earlier and 3 of the 2004 ranks were based on surveys from 1997-1998. See section 4.2 for an explanation of the rankings.

Rank	Resiliency	1990	1994	2004	Current*
A	Excellent	4	3	1	3
B	Good	9	2	3	3
C	Fair	17	16	3	7
D	Poor	12	23	22	20
F or X	Not Viable	7	5	20	16
Total		***49***	***49***	***49***	***49***

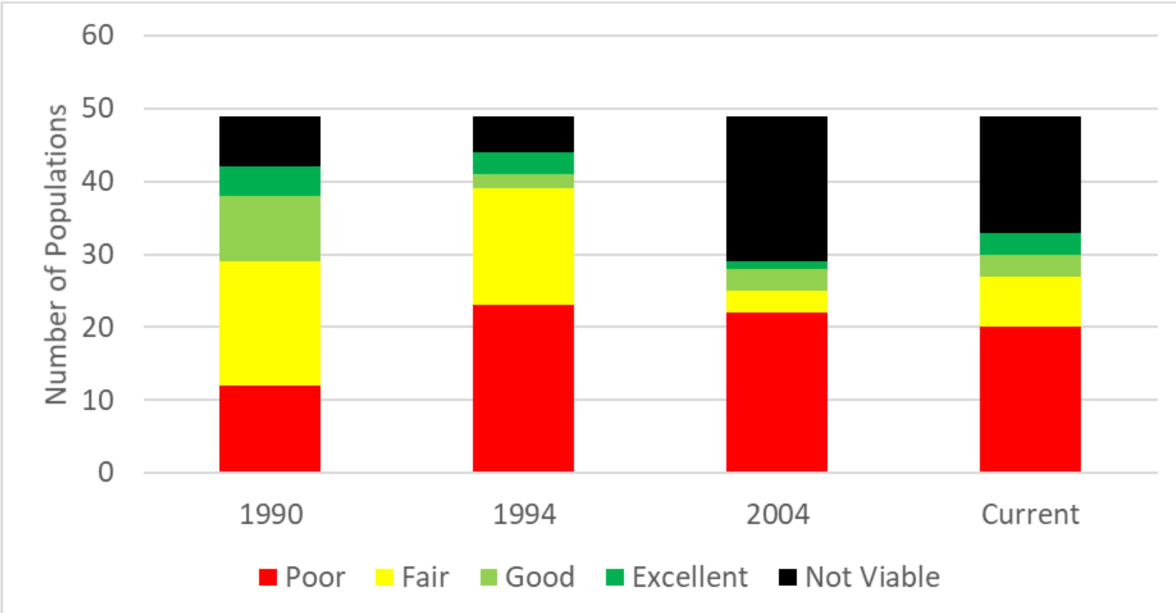

Figure 7. Comparison of status ranks for 49 occurrences of *L. exigua* var. *laciniata* that were surveyed in 1990, 1994, and 2004. *Note that "Current" represents the most recent status for each occurrence and does not represent a new range-wide survey; 26 of 49 "Current" ranks were last updated in 2004 or earlier. See section 4.2 for an explanation of the rankings.

At the time of listing, the species was limited to 61 extant occurrences. A total of 23 historical occurrences were considered extirpated or were not located by OKNP during the most recent surveys (KSNPC 2012, pp. 1-108). Of the 61 extant occurrences, 43 were of poor quality based on the most recent surveys at the time of listing (D-rank; 70 percent). Approximately half of these poor-quality occurrences were located on residential lawns, with few, if any, native plants. These lawn occurrences are not believed to be sustainable, due to competition from lawn grasses and lawn maintenance and improvement activities.

<u>*Current Populations*</u>

Currently (as of 2019), there are 95 occurrences, 72 of which were extant as of their most recent surveys. Of those, 32 were ranked poor as of the most recent surveys (44 percent). A summary of current status ranks for all known sites is shown in Table 3. The current status rank is the rank assigned at the last time a population was surveyed. Thirteen new occurrences have been discovered in the last five years. Fifty-eight occurrences have been surveyed since the last range-wide survey in 2004. Of the remaining 37, 18 were ranked as having poor resiliency (D) during their last survey, and 19 were previously ranked F or X. It is possible that some of these occurrences have become extirpated since they were last surveyed and, thus, we could be overestimating the number of extant populations. All the occurrences ranked as having fair (C), good (B), or excellent (A) resiliency have been surveyed as recently as 2011 or later; 26 out of 29 such occurrences have been surveyed since 2015.

Table 3. Current status ranks for *L. exigua* var. *laciniata*. The current status rank is the rank assigned at the last time a population was surveyed (OKNP 2019). See section 4.2 for an explanation of the rankings.

Rank	Resiliency	Number of Occurrences
A	Excellent	3
B	Good	4
BC	Good or Fair	4
C	Fair	18
CD	Fair or Poor	11
D	Poor	32
F	Not Located	7
X	Extirpated	16
Total		***95***

2.6.3 Land Ownership

The majority of land on which *L. exigua* var. *laciniata* occurs is privately owned, although some significant occurrences are located on public land. The taxon does occur within two protected areas in eastern Bullitt County: Pine Creek Barrens Preserve, a 110-acre (44.5 ha) property owned and managed by the Kentucky Chapter of The Nature Conservancy (TNC), and Apple Valley State Nature Preserve, with 46 acres (18.6 ha) owned by OKNP. A publicly owned occurrence is located within McNeely Lake Park, a site in southern Jefferson County owned by Louisville Metro Parks with a conservation easement held by OKNP. Pennsylvania Run (62 acres, 25.1 ha), south of McNeely Lake Park, is currently owned by the Kentucky Natural Land Trust, but will be transferred to OKNP in the future.

Significant private land ownerships within the range of *L. exigua* var. *laciniata* should be noted. The Future Fund Land Trust and its associated endowment were established to create an extensive "[Fredrick Law] Olmsted-like" greenway and park system along Floyds Fork in Jefferson County. The Future Fund Land Trust owns nearly 500 acres (202.3 ha) within the known range of *L. exigua* var. *laciniata*, including parcels with all or portions of two known occurrences. Another private, nonprofit group, 21st Century Parks, is also working along the Floyds Fork corridor and owns several parcels within the taxon's range totaling almost 600 acres (242.8 ha) and contains part of one occurrence. The 21st Century Parks Endowment acquired the land containing a separate occurrence, and this land is slated for residential development to help fund the adjacent park (Van Velzer 2018, n.p.). Rocky Run Glade Registered Natural Area (RNA) is a 25-acre (10.1 ha) privately owned tract of land in eastern Bullitt County. The owner of this land has entered into a voluntary agreement with OKNP not to alter the habitat and to allow OKNP personnel to enter the area. Three additional RNAs containing *L. exigua* var. *laciniata* are in process of becoming established, all in the Cedar Grove area in Bullitt County: Whitworth Glades RNA, Allen Glades RNA, and Iola/Ratliff Glades RNA.

Table 4. Significant land ownership information for occurrences of *L. exigua* var. *laciniata* (OKNP 2019).

Site	**Landowner**	**Current Resiliency Rank**	**Most Recent Population Assessment (Year)**
Pine Creek Barrens (EO 2)	The Nature Conservancy	A	7,264 plants (2019)
Apple Valley Glade (EO 57)	OKNP	A	5,134 plants (2019)
McNeely Lake Park (EO 72)	Louisville Metro Parks and OKNP conservation easement	B	1,856 plants (2019)
Pennsylvania Run (EOs 43, 68)	Kentucky Natural Land Trust, will be transferred to OKNP	C (EO 43) BC (EO 68)	21 plants (2018) (EO 43) > 247 plants (2019) (EO 68)
Floyds Fork area (EOs 37, 80)	Future Fund Land and 21st Century Parks	BC (EO 37) D (EO 80)	Thousands of plants (2018) / thousands of plants (2016)
Floyds Fork area (EO 47)	21st Century Parks Endowment	C	786 plants (2018)
Rocky Run RNA (EO 41)	Private, Registered Natural Area	A	5,797 plants (2012)

CHAPTER 3 – FACTORS INFLUENCING VIABILITY

In this chapter, we provide information on negative and positive influences on viability of *L. exigua* var. *laciniata*, including habitat loss and degradation, climate change, and conservation and management (Figure 8). We considered additional influences that we do not elaborate on in this chapter because we either do not believe they are significant threats to *L. exigua* var. *laciniata* or data is lacking to evaluate them. These include: over-collection, disease, herbivory, and additional sources of erosion and are not covered in the following sections.

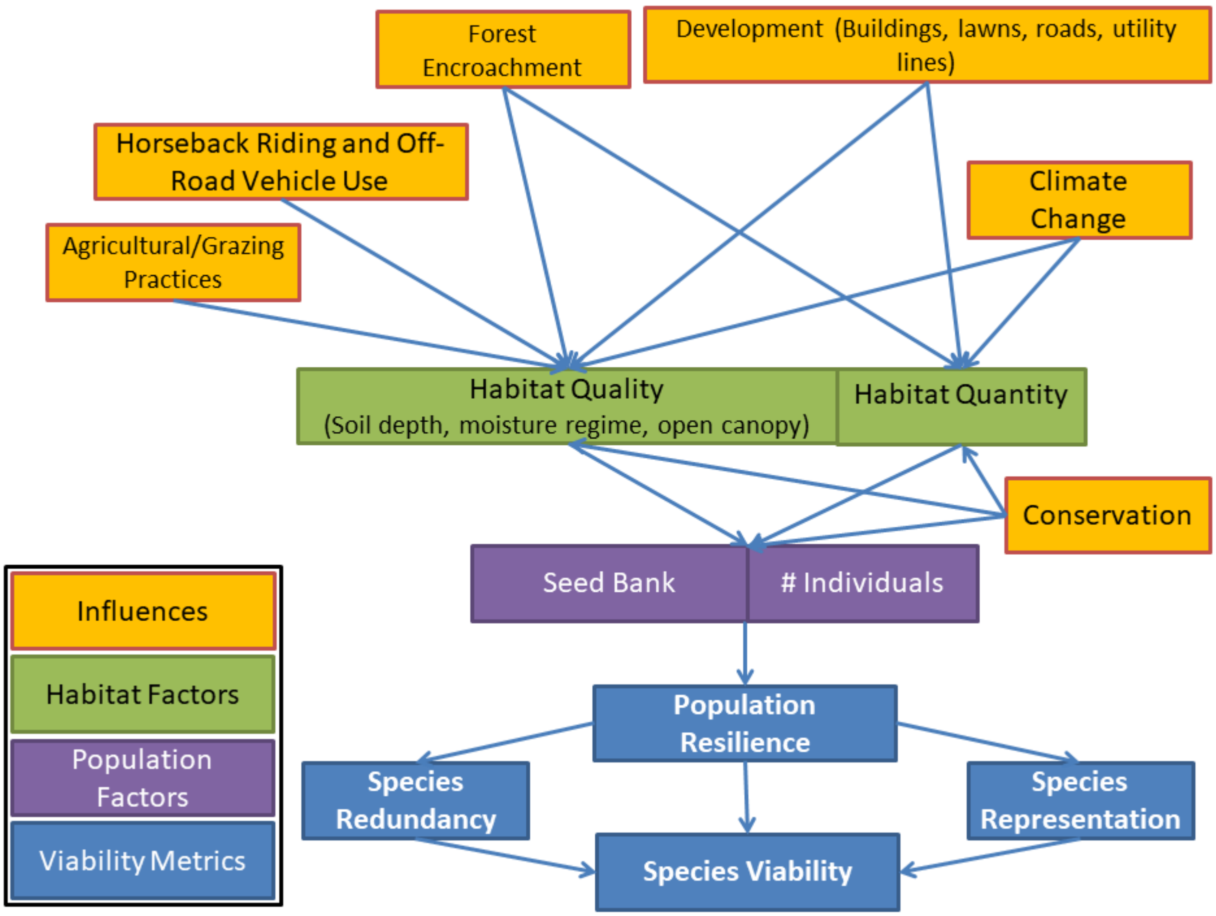

Figure 8. Simplified influence diagram illustrating how various impacts influence habitat and population factors that in turn influence the resiliency of populations and viability of the species.

3.1 Habitat Loss and Degradation

Habitat destruction and modification have been the primary causes of population declines and extirpations of *L. exigua* var. *laciniata*. Destruction and degradation of glades from development, roads, utilities, and conversion to lawns has resulted in fewer occurrences of *L. exigua* var. *laciniata* and reduced the quality of many of the remaining occurrences. Additional impacts of this nature are expected to continue for the foreseeable future as the human population within the range of *L. exigua* var. *laciniata* continues to grow. As the Louisville metropolitan area continues to expand, undeveloped portions of southern Jefferson and northeastern Bullitt counties will continue to be attractive to developers and, consequently, residential and commercial development and its ancillary activities will continue. Expansion of lawn grasses will continue to threaten *L. exigua* var. *laciniata* regardless of development rates as they encroach on glades and glade-like areas lacking the habitat management activities that would exclude them. As a poor competitor inhabiting areas of shallow soil and droughty conditions during the growing season, this species is particularly vulnerable to habitat degradation from nonnative and woody species.

3.1.1 Residential and Commercial Development

Development was recognized by Kral (1983, p. 10) as a primary threat to *Leavenworthia* spp., and this is true for *L. exigua* var. *laciniata*. The entire range of *L. exigua* var. *laciniata* has recently undergone rapid residential and commercial development as the greater Louisville metropolitan area expanded southward into southern Jefferson and northeastern Bullitt counties. Census data available from 1960 to 2010 show that the population growth in Bullitt County greatly exceeds that of the state and of neighboring Jefferson County (SSDAN 2012, website; Table 5).

Table 5. Population trends of Kentucky, Bullitt County, KY, and Jefferson County, KY (SSDAN 2012).

	Census Years				
	1960-1970	**1970-1980**	**1980-1990**	**1990-2000**	**2000-2010**
Kentucky	+ 5.94%	+ 13.73%	+ 0.67%	+ 9.67%	+ 7.36%
Bullitt County	+ 65.90%	+ 66.14%	+ 9.74%	+ 28.74%	+ 21.36%
Jefferson County	+ 13.77%	−1.45%	−2.93%	+ 4.31%	+ 6.85%

New residential developments have been and are expected to continue to be constructed throughout the taxon's range, along with associated roads and utilities. As shown in Table 5, from 2000 to 2010, Bullitt County's population increased by 21.4 percent, a significant increase compared to Kentucky's overall average growth rate of 7.4 percent (SSDAN 2012, website). The population growth of Jefferson County seems to have stabilized over the last 20 years, but much of the land in southern Jefferson County that contained suitable glade cress habitat has already been converted to residential, agricultural, and commercial land uses, as seen by viewing the 2006 National Land Cover Dataset (Fry et al. 2011).

Residential and commercial development activities can impact *L. exigua* var. *laciniata* during construction by destroying or modifying suitable habitat. At least five extirpated *L. exigua* var. *laciniata* occurrences were eliminated during construction of homes or facilities, and at least two more projects have been proposed that would impact the species. Even if the structure is not constructed on top of *L. exigua* var. *laciniata* or its habitat, grading and filling to level the site and soil compaction from the construction equipment can indirectly destroy or modify its habitat. Activities ancillary to residential and commercial construction such as roads, utilities, and lawn creation can also result in the destruction and modification of habitat for *L. exigua* var. *laciniata*. These other activities will be discussed in more detail below.

There are currently plans for the Oakland Hills development adjacent to the Parklands of Floyds Fork in southern Jefferson County. This parcel contains *L. exigua* var. *laciniata* (EO 47). The developers are aware of the locations of the plant and have plans to minimize impacts. Development plans as of September 2018 would directly impact less than two percent of the on-site population and include 100-foot buffers around occurrences (Van Velzer 2018, n.p.). However, some experts believe the development still increases the risk of invasion by weeds or invasive plants and the risk of careless management prior to seed set (Van Velzer 2018, n.p.).

3.1.2 Lawns

Nearly a third of the occurrences at the time of listing were of low quality and occurred in managed (e.g., residential, commercial, and agricultural) landscapes. Many of the extant occurrences are threatened by encroaching lawn grasses and nonnative plants that compete with *L. exigua* var. *laciniata* for space and nutrients. Winter annuals, such as *Leavenworthia* spp., are documented to be poor competitors (Rollins 1963, p. 17, Kral 1983, p. 2; Baskin and Baskin 1988, p. 835). Shading from shrubs and trees makes habitats unsuitable for *L. exigua* var. *laciniata*, which is shade-intolerant (Baskin and Baskin 1988, p. 837).

Conversion of natural habitat to lawns is likely the single greatest threat to *L. exigua* var. *laciniata* and its habitat. For every structure (residential, commercial, or other) that is built, an area much larger than the structure's footprint is modified to provide a lawn area for that property. Areas of bare ground where *L. exigua* var. *laciniata* occurs are known to be filled with topsoil or other materials to allow for a uniform landscape (D. White, pers. comm., 2012). These areas are maintained by activities such as mowing or herbicide application that alter the habitat and could damage or kill *L. exigua* var. *laciniata* plants. Most areas converted to lawns that have extant or historic *L. exigua* var. *laciniata* records have been seeded to tall fescue (*Schedonorus* [syn. *Festuca*] *arundinacea*), a common yard grass in Kentucky that competes well with weeds and develops a dense sod (Powell 2000, p. 2). While these features make tall fescue desirable to landowners, it can become weedy or invasive, displacing native vegetation such as *L. exigua* var. *laciniata* (USDA NRCS 2001, p. 3). In places where they occur together, tall fescue competes with *L. exigua* var. *laciniata* for water and nutrients and reduces the amount of stable, suitable habitat available for plant growth and seed dispersal (Kral 1983, p. 2; Baskin and Baskin 1988, p. 836).

Another threat to *L. exigua* var. *laciniata* is *Poa annua* (annual bluegrass), a weedy species common in lawns. Rollins (1963, p. 17) found that invading weeds (primarily *P. annua*) killed 30 well-established *L. crassa* var. *crassa* and *L. alabamica* var. *alabamica* plants in less than 2 months in the portion of a test plot that was left alone, without any weeding. More than 300 *Leavenworthia* individuals were documented to grow normally over the rest of the plot where weeding occurred.

At the time of listing, 22 of the 61 extant *L. exigua* var. *laciniata* occurrences were in lawns or other landscaped habitats. All of these 22 lawn occurrences were assessed as a D-rank based on habitat quality and/or population numbers. The lack of native plant associates and the presence of nonnative lawn species, against which *L. exigua* var. *laciniata* is a poor competitor (Rollins 1963, p. 17; Baskin and Baskin 1985, p. 387), contribute heavily to the poor resiliency assessed for these populations. Additionally, 17 of the 22 lawn occurrences had a low number of individuals assessed (100 or fewer plants) with 15 of these occurrences having fewer than 50 plants (KSNPC 2012, p. 1-108). The extirpation of two occurrences was attributed specifically to habitat conversion to lawns (OKNP 2019). However, if a lawn is kept in its original thin-soil, nutrient-deprived state, *L. exigua* var. *laciniata* can thrive in lawns, though long-term persistence is unknown and conditions can change rapidly if landowners change how they manage the lawn (Littlefield 2019*a*, pers. comm.).

3.1.3 Construction and Maintenance of Roads and Utility Lines

Construction and maintenance of linear infrastructure, such as roads and utility lines, can also destroy or degrade glade cress habitat. Many of the extant *L. exigua* var. *laciniata* occurrences are found in close proximity to roads. In the northern part of the range, most of the roads are small, local, and lead to residential areas. However, in the southwestern part of the range, near the community of Cedar Grove, many occurrences are located near larger state roads such as KY 1442 and KY 480. Several large populations occur near KY 480 on driveways, lawns, and roadsides that are still in a semi-natural state (i.e., not fertilized or sodded, still contain other native flora; Darnell 2019*b*, pers. comm., Littlefield 2019*a*, pers. comm.).

While the obvious threat to *L. exigua* var. *laciniata* from road construction is destruction of habitat, impacts associated with habitat degradation when a road is constructed or maintained adjacent to *L. exigua* var. *laciniata* are less clear. Road rights-of-way are often planted with dense-growing, nonnative species, such as fescue (KYTC 2012, p. 212-2)), that can outcompete *L. exigua* var. *laciniata*. Additionally, the soil erosion and changes in water runoff patterns associated with construction can alter soil and moisture conditions, making habitat unsuitable. Mowing in early spring as *L. exigua* var. *laciniata* is fruiting or before seed has reached maturity could crush plants before the seeds mature or cause seeds to fall prematurely, negatively impacting reproduction and populations in subsequent years. Application of herbicide on roadside banks can impact populations and likely caused a decline in abundance in the farthest west population on KY 480 (EO 27E) after being sprayed twice in three years (Littlefield 2019*a*, pers. comm.). As a winter annual, *L. exigua* var. *laciniata* may also be susceptible to impacts associated with winter road maintenance activities, such as snow plowing and application of salt or brine.

Construction and maintenance of utility lines (e.g., water, gas, electric, and sewer) can destroy or modify *L. exigua* var. *laciniata* habitat. Construction of new utility lines or maintenance of underground lines will most likely destroy habitat through excavation and backfilling of glade areas. Similarly, construction of substations or well pads can destroy habitat through the facility construction process. Additionally, replanting of areas disturbed during construction is commonly done with nonnative species, such as fescue (J. Garland, pers. obs., 2012), which may outcompete *L. exigua* var. *laciniata*. Any construction projects that involve federal entities (e.g. U.S. Army Corps of Engineers [USACE]) and are likely to adversely affect *L. exigua* var. *laciniata* require coordination with the Service to address those impacts.

Vegetation management activities, such as mowing and herbicide application for management of the utility right-of-way, can also modify and degrade habitat for *L. exigua* var. *laciniata*. While most of these vegetation management activities occur after seed set, they could affect seeds lying on top of the soil (Littlefield 2019*a*, pers. comm.). Right-of-way management could benefit *L. exigua* var. *laciniata* by maintaining open habitat and reducing competition from plants that would be impacted by summer mowing and herbicide applications. Large groups of *L. exigua* var. *laciniata* have been observed in power line rights-of-way. Four known occurrences of *L. exigua* var. *laciniata* occur within utility rights-of-way, including portions of one A-ranked (EO 57C), one B-ranked (EO 24B), and two C-ranked (EO 60A, 80A) occurrences.

In 2010, the Service became aware of a sewer line project in southeastern Jefferson County (Louisville Metropolitan Sewer District (MSD) Broad Run interceptor). The proposed project corridor was adjacent to at least one known occurrence of *L. exigua* var. *laciniata*, and the project corridor appeared to contain other suitable habitat for the species. A field review of the project corridor by the Service, OKNP, Palmer Engineering, and Louisville MSD was completed in April 2010 to determine if the species occupied the corridor or if suitable habitat was present. During the field review, the Service and OKNP confirmed the presence of the species within the proposed sewer line corridor (Jackson Environmental Consulting Services, LLC 2010, n.p.). Habitats for *L. exigua* var. *laciniata* were delineated in the field and mapped by Palmer Engineering. Louisville MSD agreed to relocate a portion of the sewer line to avoid adverse effects to these areas. In March 2011, the USACE Louisville District contacted the Service's Kentucky Field Office regarding potential adverse effects on the species within the project corridor (Jackson Environmental Consulting Services, LLC 2010, n.p.). Silt fencing designed to protect *L. exigua* var. *laciniata* habitats had failed in at least two areas during construction, allowing sediment to leave the construction site and impact the species' habitats (USACE 2011, pers. comm.). The USACE directed Louisville MSD to correct the failed silt fence within 48 hours, and corrective measures were taken. The site was visited by the Service in early April 2011; the silt fence had been repaired, and it appeared that *L. exigua* var. *laciniata* had not been harmed by the silt fence failure. No follow-up surveys have been completed to assess the long-term impacts to this population. Although direct effects were avoided in this example, it demonstrates how indirect impacts could occur due to proximity of the action to the *L. exigua* var. *laciniata* plants.

A new underground natural gas pipeline is being developed in the Cedar Grove area along KY 480 and will pass close to existing *L. exigua* var. *laciniata* occurrences. The proposed route will pass through or near areas occupied *L. exigua* var. *laciniata*. Preliminary plans are also being explored for a new interstate highway to connect I-65 and I-71. The route, not yet selected, will be based upon the results of a study due by the end of 2019 (KYTC 2019, n.p.). One alternative that the study will explore is a "no-build" scenario (KYTC 2019, n.p.). All of the route alternatives pass through the range of *L. exigua* var. *laciniata* (Figure 9).

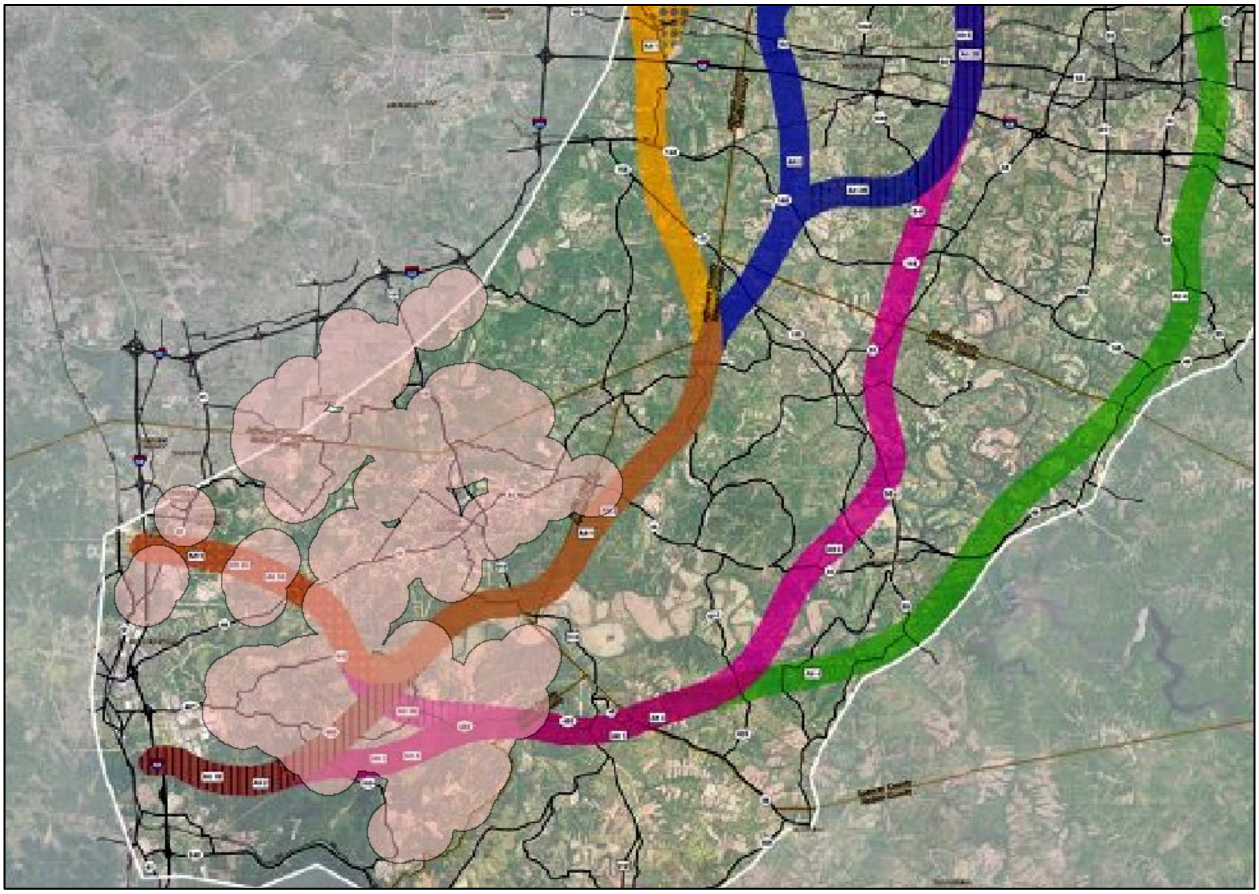

Figure 9. Proposed alternate routes for a new interstate, shown passing through the range of *L. exigua* var. *laciniata* shown in pink.

3.1.4 Incompatible Agricultural or Grazing Practices

Agricultural activities such as habitat conversion to pasture and changes in grazing intensity constitute a significant threat to *L. exigua* var. *laciniata*. A 2012 analysis of the known range of *L. exigua* var. *laciniata* found that approximately 22 percent of the total land area was in hay or pasture (USFWS 2012, p. 1). In addition to being a popular lawn species, tall fescue is also a popular hay/pasture grass in Kentucky (USDA NRCS 2001, p. 1). Impacts to *L. exigua* var. *laciniata* associated with the conversion of natural glade or glade-like habitat to fescue or other forage species is very similar to those discussed in the section on lawns (section 3.1.2). Grazing or haying of the pasture can help maintain the glade habitat, if it persists, by stunting the growth or invasion of woody species and maintaining the open herbaceous nature of the habitat. For example, along KY 480, there are patches in pasture with many more *L. exigua* var. *laciniata* plants than nearby patches in rocky glade habitat that has not been maintained for openness (Darnell 2019*b*, pers. comm.). Grazing seems to have benefitted *L. exigua* var. *laciniata* at multiple occurrences (EOs 62A, 54D, 34F, 37D) (Littlefield 2019*a*, pers. comm.). Prescribing some level of grazing in presently un-grazed glades, to mimic historical grazing by bison, might benefit *L. exigua* var. *laciniata* populations, but more study is needed before using this as a management tool (Littlefield 2019*a*, pers. comm.).

However, grazing or haying may have negative impacts on *L. exigua* var. *laciniata* occurrences if it occurs prior to seed set. Disturbance to the plants could cause mortality, and compaction of the soil from overgrazing could cause erosion or change soil moisture (USFWS 2009, p. 2). High-intensity grazing can also have negative impacts on both plants and the glade habitat by increasing soil compaction and erosion rates or excessive trampling (USFWS 2009, p. 2). Removing cattle from a habitat where grazing activities have helped to maintain the open habitat may result in an increase in forage grasses that may outcompete *L. exigua* var. *laciniata* and alter suitable habitat. This was seen in the Old Man's Run complex (EO 37C) where abundance was high until cattle were removed. After this removal, fescue and other plants were able to compete with *L. exigua* var. *laciniata* and abundance declined (Littlefield 2019*a*, pers. comm.). We are not aware of any studies that have looked at the timing and intensity of agricultural activities and their effects on *L. exigua* var. *laciniata*. However, changes in grazing activities (both increases and decreases) are considered threats to at least two known occurrences (KSNPC 2012, p. 1-108).

3.1.5 Off-road Vehicle (ORV) Use or Horseback Riding

Recreational activities such as horseback riding and off-road vehicle (ORV) use can change water flow patterns and damage fragile glade habitats. Documented impacts from horseback riding and ORV use have resulted in the loss or degradation of several *L. exigua* var. *laciniata* occurrences. These activities in close proximity to *L. exigua* var. *laciniata* populations are expected to continue in the future and can pose a threat to the species at those locations.

Although there are few established trails or designated areas specifically for riding horses or ORVs within the range of the species, evidence of these activities is apparent at several extant and historic *L. exigua* var. *laciniata* sites (KSNPC 2012, p. 1-108). A site visit to Pine Creek Barrens in April 2012 found evidence of unauthorized horse access. Glade habitat where *L. exigua* var. *laciniata* is known to occur at this site had fewer plants than in previous years (J. Garland, pers. obs., 2012). McNeely Lake Park has had a horseback riding trail through the southern portion of the park which supports *L. exigua* var. *laciniata*, but McNeely Lake Park is moving the trail off of the OKNP conservation easement area (Littlefield 2019*a*, pers. comm.).

At least four *L. exigua* var. *laciniata* sites appear to have been impacted by ORV usage (KSNPC 2012, p. 1-108). The habitat requirements of *L. exigua* var. *laciniata* are very specific with shallow soils and high moisture content in the winter and earlier spring, drying out by early summer. Frequent use by ORVs can result in soil compaction, increased weed invasion (both native and nonnative), wind and water erosion, altered water flow patterns, and decreased soil moisture (Stokowski & LaPointe 2000, p. 14-15). Changes to the habitat from ORV use can result in a loss of suitability. Erosion can remove soils needed for plant growth and seed dispersal. If the glade habitat is the recipient of the eroded material, the increase in soil depth can alter the habitat such that it is more suitable for species previously excluded from the habitat that will compete with *L. exigua* var. *laciniata* for water, nutrients, and/or sunlight.

3.1.6 Forest Encroachment Due to Fire Suppression

Fire suppression and subsequent forest encroachment is a threat to *L. exigua* var. *laciniata*. The dolomitic limestone glade habitat, with which *L. exigua* var. *laciniata* is associated, has a natural community of herbaceous, or nonwoody, plants. These open areas are maintained by their shallow soils (Baskin and Baskin 1978, p. 184; Barnes and Evan 2007, p. 12). Glades are often associated with barrens, which are believed to have been created and maintained by fire (Baskin et al. 1994, p. 238). The glades and barrens in Jefferson and Bullitt Counties may have been created and historically maintained by grazing (e.g. bison), and, while both likely contributed, the relative influence of grazing and fire on maintaining glades is not known (Littlefield 2019*a*, pers. comm.). Suppression of fire around a glade can result in the accumulation of organic matter in and around the glade. The buildup results in increased soil depth and allows for the growth of trees and other plants that require deeper soils than typically found in and around glades. Forest encroachment, whether due to lack of fire or other causes, threatens *L. exigua* var. *laciniata* by increasing shade, to which *L. exigua* var. *laciniata* is intolerant, and potentially changing the soil structure by adding organic materials.

OKNP has recommended cedar removal and/or prescribed fire as a management activity to promote *L. exigua* var. *laciniata* at more than 10 extant occurrences. Evans and Hannan (1990, p. 15) also recommended tree removal and prescribed fire as an important habitat management technique for *L. exigua* var. *laciniata*. More research is needed about the optimal timing of prescribed burns for this species; most prescribed fires in Kentucky now occur in March and April when *L. exigua* var. *laciniata* is in peak flowering. It is unknown how fires during this time directly or indirectly affect the species, how fires during the seed dormancy period affect seed viability, or how fires during the fall would affect seedlings (Littlefield 2019*a*, pers. comm.).

3.2 Climate Change

In the future, changing climatic conditions will likely impact *L. exigua* var. *laciniata*. The Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal (IPCC 2014, p. 2). The climate in the southeastern United States has warmed about 2 degrees F from a cool period in the 1960s and 1970s and is expected to continue to rise by 4°F to 8°F (2.2° to 4.4° C) by 2100 (Carter et al. 2014, p. 398-399). In Kentucky, average annual rainfall is increasing, and single rain events are heavier (i.e., receiving more rain) (EPA 2016, p. 1). Floods may be more frequent, and droughts may become longer and more severe (EPA 2016, p. 1).

Species that are dependent on specialized habitat types (e.g., glades) or are limited in distribution (e.g., *L. exigua* var. *laciniata*) may be the most susceptible to the impacts of climate change (Byers and Norris 2011, p. 5; Anacker et al. 2013, p. 197). There is evidence that some terrestrial plant populations have been able to adapt and respond to changing climatic conditions (Franks et al. 2014, entire); both plastic (phenotypic change such as leaf size or phenology) and evolutionary (shift in allelic frequencies) responses to changes in climate have been detected. Evolutionary changes however are unlikely to be options for *L. exigua* var. *laciniata* based on their very low levels of genetic variation (Edwards 2019, pers. comm.). Given enough time, some plant species may alter their ranges, resulting in range shifts, reductions, or increases (Kelly and Goulden 2008, entire; Loarie et al. 2008, p. 3-5). The habitat specialization and limited seed dispersal of *L. exigua* var. *laciniata* make it unlikely that it will be able to shift its range. A NatureServe climate change vulnerability assessment scored the species as extremely vulnerable (with very high confidence) to climate change due to limited habitat and inability to migrate (Littlefield 2019*c*, n.p.; Young et. al 2015, entire).

Exactly how *L. exigua* var. *laciniata* might respond to a changing climate is uncertain. A changing climate could alter the distribution of nonnative species that could compete with *L. exigua* var. *laciniata*. The impact of increased periods of drought on *L. exigua* var. *laciniata* is unknown. While drought during critical periods could impact the survival and reproduction of *L. exigua* var. *laciniata*, summer droughts could have a positive effect by making *L. exigua* var. *laciniata* habitat less hospitable for other species that might compete with it.

3.3 Conservation and Management

In terms of state and federal regulatory mechanisms with the power to reduce or remove threats, *L. exigua* var. *laciniata* only receives protection under the Act. As a plant, protections under the Act primarily apply to individual plants on federal land. Section 7 of the Act requires Federal agencies to consult with the Service to ensure that projects they fund, authorize, or carry out do not jeopardize the continued existence of a listed plant. The Act does not protect plants on private lands from effects of private actions. While the *L. exigua* var. *laciniata* is included and considered endangered on Kentucky's list of rare plants (Kentucky Administrative Regulations Title 400 Chapter 3:040), inclusion on this list does not lead to any prohibitions of activities or direct protections for any species on the list.

Conservation and management activities have occurred at individual properties supporting *L. exigua* var. *laciniata*. In 1986, the owner of Rocky Run Glade entered into a written agreement with OKNP not to alter the registered area and to allow OKNP agents to enter the area for scientific observation, research or education, in exchange for the Registered Natural Area (RNA) designation. The agreement will remain in effect until terminated by either the landowner or OKNP with 30-days' notice. While the agreement recognizes the conservation mindset of the property owner, it offers no long-term protection to *L. exigua* var. *laciniata* due to its nonbinding nature. The agreement has been in place for more than 30 years, but this property is currently under threat from the development of a new interstate and pipeline (Littlefield 2019*a*, pers. comm.). Three additional RNAs are in progress right now, all in the Cedar Grove area of Bullitt County which is at risk from future development: Whitworth Glades RNA (EO 60A), Allen Glades RNA (EO 96), and Iola/Ratliff Glades RNA (EO 34).

Habitat management activities can also reduce threats to *L. exigua* var. *laciniata* associated with habitat modification from invasive species and forest encroachment. Some habitat management has occurred on the previously mentioned conservation areas (Apple Valley Glade, Pine Creek Barrens and Rocky Run); however, it has been challenging to correlate management efforts with population fluctuations because of other confounding factors (e.g., temperature and precipitation), and funding for management on RNAs has dropped off since the cancellation of a landowner incentive program in 2008 (Littlefield 2019*a*, pers. comm.). In fall of 2019, OKNP will be setting up study plots to assess the effects of different disturbances (e.g., raking, trampling, fire) on populations (Littlefield 2019*a*, pers. comm.).

Jefferson Metro Parks, which manages McNeely Lake Park for the Jefferson County Metro Government, has received flexible funding from the Service to develop a management plan for the *L. exigua* var. *laciniata* occurrence within the park and to implement habitat improvement measures such as invasive species and woody plant removal in the areas surrounding *L. exigua* var. *laciniata*. A larger project has also been agreed upon with OKNP and the Louisville/Jefferson Metro Government to place a conservation easement on the glade/barren area of the park and manage the site with woody and invasive plant removal, soil scraping, re-siting trails to avoid sensitive glades, seeding of *L. exigua* var. *laciniata*, rerouting horse trails, and population monitoring (Louisville/Jefferson County Metro Government 2017, p. 3-4, Littlefield 2019*a*, pers. comm.).

The OKNP, Service, and the Missouri Botanical Garden (MOBOT) have recently been collecting seed from *L. exigua* var. *laciniata* sites in order to preserve genetic materials from sites that are considered to have poor resiliency and also for sites where habitat is sufficient to expand or supplement the existing populations. In 2012, seeds were collected and planted at Apple Valley Glade State Nature Preserve to expand the population into adjacent suitable habitat and supplement the seed source available for establishment. Seed was collected at two other sites; both areas where the suitable habitat is marginal. One of these sites is a roadside and another is in an area increasingly dominated by fescue. About 50 seeds were collected from each site at the end of the period for seed dispersal for *L. exigua* var. *laciniata*. In 2013 and 2015, seed was collected from over 20 populations to a seed bank at MOBOT facilities (Darnell 2019*b*, pers. comm.; Littlefield 2019*a*, pers. comm.).

Current and past management activities at *L. exigua* var. *laciniata* populations are detailed in Table 6.

Table 6. Management for *L. exigua* var. *laciniata* (Littlefield 2019*a*, pers. comm.)

Property	Years (when known)	Management
Pine Creek Barrens	? - 2019	Prescribed fire, cedar removal, and invasive species control (sweet clover removal).
Rocky Run	2005 - 2007	Cedar removal during landowner incentive program; no additional management since program was defunded in 2007.
Apple Valley Glade SNP	2011 - 2019	Cedar removal, prescribed fire, invasive species control (sweet clover removal); undergoing a disturbance experiment to assess raking/trampling
Pennsylvania Run	2017 - 2018	Cedar removal, prescribed fire, and invasive species removal (tree of heaven [*Ailanthus altissima*]).
Broad Run Park, 21st Century Parks		Cedar removal and mowing.
McNeely Lake Park	2014 - 2019	Cedar removal, invasive species control; recent 10-year restoration agreement with OKNP for future restoration.
Future Fund Land Trust		Management plan is being developed with OKNP for 3 properties with occurrences and several others with unoccupied suitable habitat; plans include glade restoration, seed augmentation, and other management.

Going forward, conservation measures that could address the threats to Kentucky glade cress habitat include (but are not limited to):

- Avoiding cedar glades (or suitable glade-like habitats) when planning the location of buildings, lawns, roads (including horse or ORV trails), or utilities;
- Avoiding aboveground construction and/or excavations in locations that would interfere with natural water movement to suitable habitat sites;
- Conducting research supporting the development of management recommendations for grazing and other agricultural practices;
- Offering technical or financial assistance to landowners to design and implement management actions that protect the plant and its habitat;
- Avoiding lawn grass or tree plantings near glades;
- Protecting and restoring as many glade complexes as possible; and
- Implementing habitat management, such as brush removal, soil scraping, prescribed grazing, prescribed fire, and/or eradication of lawn grasses, to maintain an intact native glade vegetation community.

CHAPTER 4 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

As the population is the basic unit of resiliency, which is then scaled up to redundancy and representation at the species level, examining the distribution of the species and appropriately defining and delineating populations is a crucial initial step to assess species viability. After delineating populations, we then assessed the resiliency of each population by synthesizing the best available information about population and habitat conditions. Population resiliency was then scaled up to describe current redundancy and representation for *L. exigua* var. *laciniata* range-wide.

4.1 Delineating Populations

Populations were delineated from spatial occurrence data to distinguish discrete groupings that were likely to interact with each other demographically, primarily via seed dispersal. Because *L. exigua* var. *laciniata* reproduces asexually, pollinator dispersal distance was not a consideration. We used the same criteria to delineate populations that OKNP used to delineate element occurrences for Kentucky's Natural Heritage database (Appendix A). A default separation distance of 1 km was used between element occurrences (and thus populations for this SSA) unless circumstances warranted grouping occurrences that were more distant from each other. This population delineating strategy resulted in 95 populations, equivalent to the 95 natural heritage program element occurrences (Figure 10). It is possible that element occurrence delineations might be reviewed and changed in the future (Littlefield 2019*a*, pers. comm.), especially after taking into account recent results from genetic analyses (Edwards 2018, entire). This could result in updated population delineations in a future version of this SSA. For the present time, however, we used the current element occurrence delineations, because those delineated units are the units at which population and habitat monitoring results have been aggregated for the existing natural heritage database.

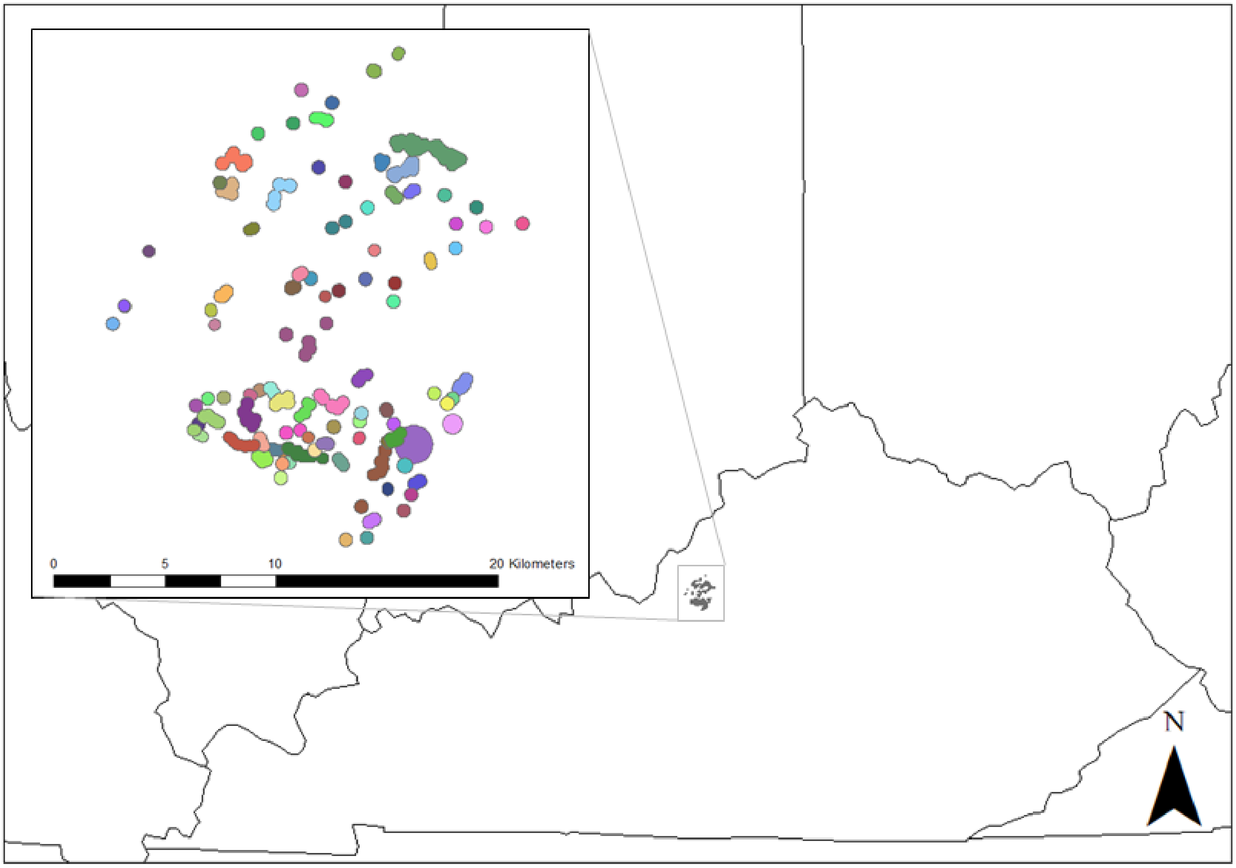

Figure 10. Populations of *L. laciniata* var. *exigua*. Occurrences were buffered in this figure to enhance visibility of populations, and do not represent overlapping populations.

4.2 Population Resiliency Factors – Element Occurrence Ranks

We assessed population resiliency using the ranks assigned to element occurrences by OKNP. Factors considered in the element occurrence ranks included population size, habitat quantity, and habitat quality.

4.2.1 Population Size

Population size is an important part of resiliency. Annual plants like *L. exigua* var. *laciniata* often have widely fluctuating population sizes (Bush and Lancaster 2004, n.p.), and a given year's population strongly influences the seed bank for future years. Large populations with larger seed banks will be better able to persist through environmental and demographic stochastic events (e.g., drought years that reduce seed production). Large populations will also be more likely to withstand short periods of poor habitat conditions due to human activities (e.g., mowing before seed set) because of their robust seed bank. Even large populations, however, will not be able to withstand repeated human activities over several years that reduce reproduction and deplete the seed bank. Although no studies have examined the long-term viability of *L. exigua* var. *laciniata* seed, Baskin and Baskin (1981, p. 247) found that more than 90 percent of the total germination took place in the first growing season, but germination can occur after at least 4 autumns.

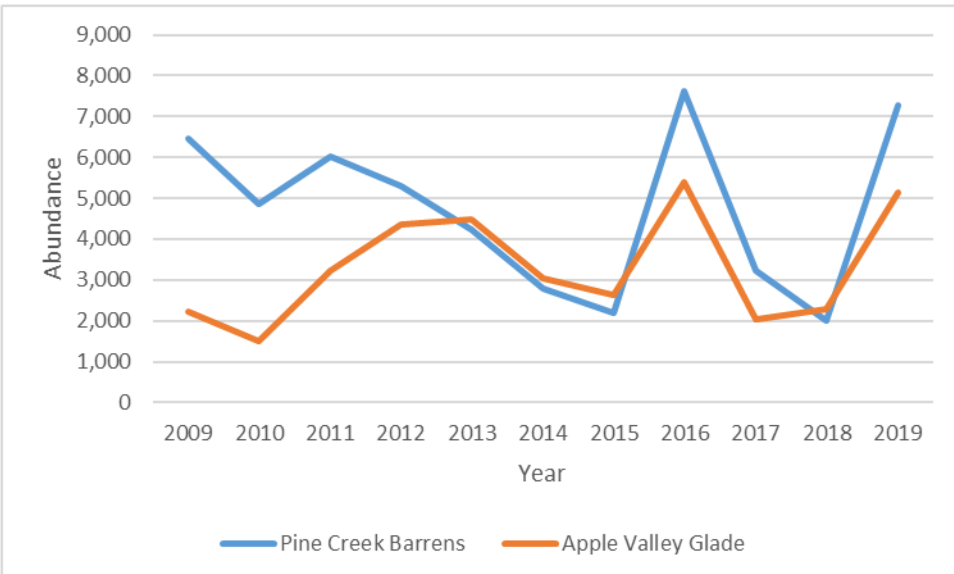

Figure 11. Annual survey data from two *L. exigua* var. *laciniata* populations that have been surveyed annually (OKNP 2019).

Population size was used in the resiliency assessment even though it represents only a snapshot in time. Population sizes naturally fluctuate (Figure 11), and the trend in population sizes (increasing, decreasing, stable) would provide more context to population resiliency than population sizes alone, but trend data were not available for all populations. Most populations are not surveyed annually or even every few years, surveys are often only partial surveys of an EO rather than a complete survey, and reported abundances from surveys vary in precision from exact counts of individuals to vague descriptions (e.g., “a few”, “several hundred”). For these reasons, only population size from the most recent survey was used to assess each population’s resiliency. Small population sizes often go hand in hand with low habitat quantity, which is discussed in the next section.

4.2.2 Habitat Quantity

Habitat quantity is an important component of population resiliency. *Leavenworthia exigua* var. *laciniata* has specialized habitat needs (e.g., shallow soils, no shading) and does not compete well with other species. Populations of *L. exigua* var. *laciniata* that are confined to very small areas can be totally eradicated by actions such as installation of utility lines, road construction, residential or commercial development, herbicide application, and forest succession or encroachment, because these threats are likely to affect the entirety of any given occurrence (see examples in Section 3.1). The majority of the extant populations of *L. exigua* var. *laciniata* are small, covering only a few square meters (KSNPC 2012, p. 1-108). Habitat quantity also goes hand in hand with population size; populations on larger areas of suitable habitat can support more individuals and maintain a larger seed bank than those with small habitat areas.

4.2.3 Habitat Quality

Element occurrence ranks also incorporated habitat quality, specifically natural vs. non-native habitat. Populations located in natural glade habitats received higher ranks than those in non-native habitats, like pastures, lawns, utility rights of way, and roadsides. Some of these populations in non-native habitats may have relatively large population sizes, especially where large open areas are maintained by periodic disturbance (e.g., mowing, grazing). However, *L. exigua* var. *laciniata* in these habitats are not filling their natural ecological role in a natural plant community and are highly vulnerable to changes in land management that could render the habitat unsuitable for the taxon. Habitat quality was assessed qualitatively by surveyors during site visits.

4.2.4 Combined Element Occurrence Ranking

Population size, habitat quantity, and habitat quality were combined to inform element occurrence ranks as shown in Littlefield (2019*c*, n.p.). In addition to the main ranks of A, B, C, and D (excellent, good, fair, and poor resiliency, respectively), EOs could be given an intermediate rank (e.g., AB, CD). For the assessment in this SSA, these intermediate ranks were collapsed to convert EO ranks into population resiliency ranks. Populations with an EO rank of A were assigned excellent resiliency, those with an EO rank of AB or B were assigned good resiliency, those with an EO rank of BC or C were assigned fair resiliency, and those with an EO rank of CD or D were assigned poor resiliency. We note that criteria for each rank have been similar over time, but have been refined. See Appendix B for comparison of rank criteria from 1994, 2004, and 2019. The current conditions of populations were assessed using the 2019 criteria.

Table 7. Element occurrence resiliency ranks.

	Habitat Quality		
EO Rank	**High** > 10 acres habitat, native vegetation, appropriate disturbance regime	**Medium** > 5 acres of habitat, generally natural but may be somewhat degraded, high potential for restoration	**Low** Degraded, fragmented habitat with non-native plants, low restoration potential, important seed source for restoration
A – Excellent Resiliency	> 2,500 (plants)		
AB	1,000 – 2,500		
B – Good Resiliency	100 – 1,000	> 2,500	
BC	< 100	500 – 2,500	
C – Fair Resiliency		100 - 500	> 5,000
CD		< 100	500 - 5,000
D – Poor Resiliency			< 500
F	**Failed to find:** failed to find the plants at the site		
O	**Obscure record**: directions not sufficient to determine accurate location		
X	**Extirpated**		

4.3 Species Needs - Redundancy and Representation

To be viable, *L. exigua* var. *laciniata* requires redundancy and representation of resilient populations. Redundancy of resilient populations distributed across the taxon's range is necessary to buffer the it against the effects of catastrophic events on any single population or group of populations. Potential catastrophic effects that could eliminate or severely reduce population resiliency include but are not limited to: residential or commercial development (including the construction of roads and utility lines), invasive species or forest encroachment, prolonged drought, and incompatible land management (e.g., mowing or herbicide application to plants prior to seed set or that impacts seed viability on the ground).

Representation refers to the breadth of genetic and environmental diversity within and among populations that contributes to the ability of the taxon to respond and adapt to changing environmental conditions over time. Maintaining resilient populations across the range of variation within the taxon will increase the amount of variation within the taxon on which natural selection can act, increasing the chances that it will persist in a changing world. *Leavenworthia exigua* var. *laciniata* has a very limited geographic range and virtually no genetic variation within or among populations. There is no evidence to support delineating multiple representative units for this taxon. Though there is very little genetic diversity and nearly all sampled populations were genetically identical, 5 of 21 sampled populations (EOs 17, 41, 24, 35, and 52) showed 1-2 private alleles, indicating that these populations might be good conservation targets for preserving what low levels of genetic variation exist within the taxon (Edwards 2018, p. 10, 16-17). We do not have data supporting that these few genetic differences warrant delineating separate representative units.

4.4 Current Resiliency

In the following section, we report the results of the resiliency assessment. All but four extant populations have been visited since 2004. Those that were last visited prior to 2004 were all of poor resiliency when last surveyed and are noted in the poor resiliency section. Resiliency was based directly on element occurrence ranks.

4.4.1 Excellent Resiliency

Three populations received a resiliency of “excellent” based on their element occurrence rank (population size, habitat quantity, habitat quality; Table 8). According to NatureServe’s application of element occurrence ranks, if current conditions prevail, these populations are “very likely to persist for the foreseeable future (i.e., at least 20-30 years) in their current condition or better” (Hammerson et al. 2008, n.p.). These three populations are all located in the southern third of the taxon’s range in Bullitt County, south of the Salt River. Two of these populations, Pine Creek Barrens and Apple Valley Glade, occur on protected lands owned by the Nature Conservancy and OKNP, respectively. The third, Rocky Run Glade, is privately owned but is registered as a Registered Natural Area, and the landowner has agreed not to alter the habitat and to allow access to OKNP personnel for monitoring. The occurrence on Rocky Run Glade extends outside of the RNA boundary, but landowner permission has not been granted to access those areas (Littlefield 2019*a*, pers. comm.).

Table 8. Populations with excellent resiliency.

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
2	Pine Creek Barrens	2019	A	Yes	7,264 plants, natural habitat with native plant communities
57	Apple Valley Glade	2019	A	Yes	5,134 plants, natural habitat with native plant communities
41	Rocky Run Glade	2012	A	Voluntary RNA	5,797 plants, population occurs on both high and low quality habitat

4.4.2 Good Resiliency

Four populations received a resiliency of "good" based on their element occurrence rank (Table 9). According to NatureServe's application of element occurrence ranks, if current conditions prevail, these populations are "likely to persist for the foreseeable future (i.e., at least 20-30 years) in their current condition or better" (Hammerson et al. 2008, n.p.). Three of these populations occur in the northern half of the taxon's range in Southern Jefferson or Northern Bullitt County, north of the Salt River. Only the Cedar Grove East site occurs south of the Salt River. McNeely Lake Park is publicly owned by the Louisville Metro Government, with a conservation easement held by OKNP that contains its *L. exigua* var. *laciniata* occurrences. The other populations occur on privately owned land, though the owners of the Cedar Grove East site are interested in an RNA or conservation easement (Littlefield 2019*a*, pers. comm.).

Table 9. Populations with good resiliency.

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
24	Cedar Grove East (Ratliff Glade Site)	2019	B	No	> 1,000 plants, flat glade with bedrock and bare gravelly soil, grazed but has glade flora, portion degraded by bulldozer and truck activity, portion has increase in woody native plants
72	McNeely Lake Park	2019	B	Yes	1,856 plants, impacted by construction, degraded glade/barren habitat with cedar encroachment and invasive species. Some sites treated with cedar/invasive removal and scraping.
64	Jefferson County Sportsmen's Club	2016	B	No	1,000s of plants, mowed areas along driveway
39	Mt. Washington Cedar Glade	2015	B	No	1,847 plants, in Dolomite glade and weedier area outside of glade

4.4.3 Fair Resiliency

These 22 populations received a resiliency of "fair" based on their element occurrence rank (Table 10). According to NatureServe's application of element occurrence ranks, persistence for these populations is uncertain under current conditions; the population may persist under current conditions dependent on appropriate protection or management, or these populations are likely to persist but in worse condition (e.g., lower population size, worse habitat quality) than the current condition (Hammerson et al. 2008, n.p.). While some of these populations have large population sizes (more than 1,000 plants), they occur on degraded habitat, which prevents them from having a higher resiliency score.

Table 10. Populations with fair resiliency.

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
68	Pennsylvania Run	2019	BC	Yes	> 247 plants, open gravelly soil around bedrock outcrops in degraded prairie/glade remnant, and on small outcrop along gravel road
37	Old Man's Run North	2018	BC	Yes	1,000s of plants, decline since 2011, over-grazed pasture and degraded prairie
96	Allen Farm	2018	BC	No	> 1,650 plants, medium quality areas with glade associated flora and low quality areas dominated by fescue
84	Cedar Creek North,	2015	BC	No	> 520 plants, one glade with native glade plants and one with natives present but more weeds
34	Knight Lane	2018	C	No	1,000s of plants, in lawn, along driveway, and in "beefalo" cattle pasture with native vegetation present
43	Pennsylvania Run NP	2018	C	Yes	21 plants, observed but not counted in 2019, gravelly soil around small outcrops in natural prairie/glade opening
60	Whitworth Glades	2018	C	No	> 300 plants, heavily grazed and trampled glade complex, has glade flora
16	Cedar Grove	2016	C	No	7,878 plants, house has eliminated western group, cemetery primarily weeds, open gravelly soil in mowed yards, one site in cedar glade
17	Solitude Northwest	2016	C	No	> 1,000 plants in rocky grazed pasture
22	Brownington South	2016	C	No	100s of plants, pasture
44	SR 480 South	2016	C	No	8,618 plants, rock outcrops in right-of-way, prairie vegetation, and bottom of small old rock quarry

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
45	Brooks/Floyd's Big Rock	2016	C	No	> 375 plants in 2015, observed but not counted in 2016, along road and mowed rocky fields and glade remnants, exposed rocks at edge of residential lawn
80	W of Bardstown Rd	2016	C	Yes	1,000s of plants, under powerline and in cedar glade remnants along roads
92	Highway 44 East	2016	C	No	> 1,000 plants, shallow soils within non-native lawn dominated by fescue and bluegrass
95	Cooper Chapel Glade	2016	C	No	> 5,350 plants, low quality glade remnant and lawn habitat
14	Ridge Road West	2015	C	No	> 196 plants, small prairie/barrens openings, portion is old road bed
76	Brooks	2015	C	No	1,000s of plants, rock outcropping in lawn
89	BULL078	2015	C	No	180 plants, dolomite glade, invasive plants present, likely benefitted by grazing in past
91	Edge of the Run	2015	C	No	> 230 plants, fields dominated by fescue, with rock outcrops where taxon occurs
19	Benchmark Glades	2012	C	No	150-250 plants, glade damaged by ORVs and associated erosion, flora intact
47	Floyds Fork at US 31E	2018	C	No	786 plants, limestone ledge in old pasture, some sites have been developed into subdivision
54	North Cedar Creek	2011	C	No	1,000s of plants, small open gravel areas in degraded prairie opening, thin soil areas in pasture, road, narrow opening next to recovering forest

4.4.4 Poor Resiliency

These 43 populations received a resiliency of "poor" based on their element occurrence rank (Table 11). These populations face a high risk of extirpation within 20-30 years (Hammerson et al. 2008, n.p.). Four populations in this category have not been surveyed since 1994 or earlier, and repeat surveys are recommended to determine if their condition has changed.

Table 11. Populations with poor resiliency.

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
11	Solitude West	2019	CD	No	large amount of plants in lawn (no exact count)
9	Jacksonhills Church	2016	CD	No	> 1,150 plants, lawn and formerly grazed pasture

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
35	Wells Run Glade	2016	CD	No	1,000s of plants, outcrops in degraded prairie/glade, grazed until 1986, cedar invasion, logging
52	Cedar Creek Road	2016	CD	No	1,000s of plants along driveway and in yard
56	Greens Branch Glades	2015	CD	No	> 435 plants, weedy pasture
61	North Greens Branch or Upper Greens Branch Barrens	2015	CD	No	> 211 plants, small outcrop in pasture mixed with remnant woodland
90	Backyard Barrens	2015	CD	No	> 64 plants, weedy power line right-of-way between higher quality glade habitat
46	NA	2014	CD	No	> 200 plants, outcrop in grazed pasture
58	Cedar Creek South	2012	CD	No	> 112 plants, medium size degraded glade, glade openings near pipeline, ORV tracks
82	Bardstown Rd at county line	2009	CD	No	100s of plants, pasture dominated by fescue
81	Low Cox Creek	2008	CD	No	100 plants, limestone slope glade, degraded by road use
27	Ridge Road West	2019	D	No	100s of plants, sprayed with herbicide in summer 2016 and 2019, not recovered
97	NA	2019	D	No	323 plants, no habitat notes
42	East of Lickskillet Creek south of KY 480	2016	D	No	3,624 plants, lawn outcrops
59	Pine Creek Road and SE of 480 and Pine Creek Road Junction	2016	D	No	980 plants, habitat ranges from degraded prairie/glade remnant to open gravely residential lawn
93	NA	2016	D	No	> 200 plants, roadside dolomite glade outcropping
86	NA	2015	D	No	About 350 plants, two small cedar glades
87	NA	2015	D	No	About 2,400 plants, mowed residential lawn
88	Cedar Creek Mini-Barren	2015	D	No	34 plants, glade remnants
94	Greens Branch Glades	2015	D	No	> 57 plants, no habitat notes
13	Cedar Grove Southeast	2014	D	No	100 plants, lawn along driveway

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
55	Ridge Road East	2011	D	No	> 35 plants, residential lawn
65	Big Run/ Floyds Fork	2010	D	No	100s of plants, sites in grazed glade remnant mostly converted to fescue, heavily grazed horse pasture, and power line right-of-way
83	E Rocky Run	2010	D	No	100 plants, scraped by bulldozer, highly eroded in places
78	NA	2005	D	No	< 100 plants, outcropping in lawn near road
1	Cedar Grove Cedar Glade	2004	D	No	< 150 plants in 1994, none found in 2004 but not all sites visited, lawn and trails through cedar thickets, degraded habitat
5	Ridge Road East	2004	D	No	32 plants, habitat converted to lawn
7	Bethel Church Road	2004	D	No	25 plants east of road, west of road converted to lawn but not visited
10	Automobile Road	2004	D	No	25 plants, rocky area in mowed lawn, rock outcrop in pasture, old field invaded with cedar, outcrop at telephone pole
12	Ridge Road East	2004	D	No	5 plants, limestone ledge in power line right-of-way
15	Solitude South	2004	D	No	35 plants, adjacent to gravel road, portion lost to residential development
21	Brownington East	2004	D	No	20 plants, pasture, no native flora
26	NA	2004	D	No	35 plants, along road and in lawn
30	Markwell Cemetery East	2004	D	No	< 10 plants, house built and lawn installed, plants persist in bare spots along lower slope
32	Bethel Church North	2004	D	No	None found at one site, other site not checked (2004). About 350 plants in 1994. Rock outcrops incorporated into new lawns
36	Oak Grove Church	2004	D	No	50 plants, rocky area in barn yard, gravel spread over site prior to 1990
50	Fairmount	2004	D	No	15 plants, lawn
51	Thixton	2004	D	No	5 plants, lightly grazed pasture, becoming overgrown with cedars
79	W of Ridge Road	2004	D	No	100s of plants, rocky areas along private road, area cleared for house but remnant outcroppings exist
18	Solitude Northwest	1994	D	No	80-100 plants, disturbed rocky area adjacent to dirt road
38	Mt Washington East	1994	D	No	< 200 plants, heavily eroded and disturbed glade area

EO Number	Site	Last Survey	EO Rank	Protected?	Notes (Abundance, Habitat)
69	NA	1994	D	No	100s of plants, rocky areas in degraded and eroded glade, trash piles throughout area
71	Ca 0.9 mi NW of Solitude.	1990	D	No	50 plants, rocky area in cow pasture

4.4.5 No Resiliency

These populations received an element occurrence rank of X or F. They are either currently extirpated (X: n = 16) or have not been located during the most recent surveys but need repeat surveys to confirm as extirpated (F: n = 7; Table 12).

Table 12. Populations that have been extirpated or were not found during the most recent surveys.

EO Number	Site	Last Survey	EO Rank	Protected?	Notes
3	Floyd's Fork	2019	F	Yes	Could not relocate population, habitat conditions have declined
75	SR61 West Side	2015	F	No	Failed to find, > 200 plants in 2005, lawn with rock outcropping
33	Mt Washington South	2004	F	No	Outcrops and open gravelly soil in degraded and overgrown prairie/glade complex. 200-300 feeble plants in 1994, none in 2004.
40	Hall Cemetery	2004	F	No	Field with rock outcrops that has become overgrown. Hundreds up to a thousand plants in 1994, none in 2004.
48	Thixton Lane Church	2004	F	No	Outcrop in old pasture, lawns. About 1,000 plants in 1994, none in 2004 after much of the habitat was degraded by development.
66	Markwell Cemetary Powerline	2004	F	No	Degraded glade in power line right-of-way, formerly a dump. 700-1,000 plants in 1994, not found in 2004.
8	Solitude	2000	F	No	Thin soil over flat limestone near running water. Collected in 1964 and 1977, not relocated in 1990.
67	McNeely South Park	2012	X	Yes	Glade remnant graded with fill for golf course/park construction. About 40 feeble plants in 1994, no plants found in 2004, 2005, or 2012, habitat shaded and successional.
74	NA	2011	X	No	Open field with small rocky areas. Hundreds of plants in 2000, but has since been developed, facility now on site.
20	Solitude South	2004	X	No	About 70 plants in 1994, not found in 2004

EO Number	Site	Last Survey	EO Rank	Protected?	Notes
23	Solitude West	2004	X	No	Small outcrop and gravelly area in pasture near road. No habitat remains. About 250 plants in 1994 and 1998, none in 2004.
25	Ridge Road West	2004	X	No	Rock outcrop on slope and gravel driveway, 30-40 plants observed in 1994, none in 2004.
28	NA	2004	X	No	Lawn. Few plants in 1998, none in 2004.
29	Ridge Road West	2004	X	No	Lawn. About 30 plants in 1994, converted to lawn, none found in 2004.
31	Simmons Lane	2004	X	No	Yard. One site destroyed by house, other site no plants observed in 2004.
49	Crenshaw	2004	X	No	Mapped in 1983, no suitable habitat found there in 1990 or 2004.
62	Clarks Lane	2004	X	No	Rock outcrop in pasture. About 100 plants in 1994, none in 2004.
63	Woodsdale Road	2004	X	No	Rock outcrop in pasture near road, house built, habitat now gone. About 250 plants in 1990.
73	NA	2004	X	No	Degraded gravel yard of quarry. About 100 plants in 1994, not found in 2004.
4	Mt Washington West	1994	X	No	Site destroyed by development.
53	Woodsdale Rd	1994	X	No	Narrow rock ledges along ravine in pasture. About 100 plants in 1990, destroyed by house destruction by 1994.
70	Ca 1.8 mi E of Cedar Grove and 0.2 mi N of KY 480.	1994	X	No	Bare gravelly soil along gravel road. About 100 plants in 1990, none found in 1994 or 2004.
6	Solitude Northwest	1990	X	No	Pasture. Collected in 1972, not relocated in 1990.

4.4.6 Current Resiliency Summary

Table 13. Summary of *L. exigua* var. *laciniata* populations in each resiliency category.

Resiliency	Number of Populations
Excellent	3
Good	4
Fair	22
Poor	43
No Resiliency (Failed to Find)	7
No Resiliency (Extirpated)	16

Overall, only seven populations (7 percent of populations) currently exhibit excellent or good resiliency (Table 13, Figure 12), indicating that they are likely to persist in their current condition or better for the foreseeable future (at least 20-30 years). Twenty-three percent of populations have fair resiliency, indicating that they will likely require conservation actions in order to remain in the current condition for the foreseeable future. Otherwise, they will be expected to decline. Nearly 70 percent of 95 known populations either have poor resiliency and face a high risk of extirpation (44 percent), or no resiliency (extirpated or unable to be located; 24 percent). Very few populations exist on natural habitat. Where populations do occur in natural glade habitats, those habitats are often degraded by invasive species or a legacy of previous land uses. The taxon has been able to flourish in non-glade habitats like pastures and lawns, where the land is managed consistent with *L. exigua* var. *laciniata* persistence (e.g., soils remain thin, or mowing/grazing keep competing plants at bay). While population sizes can be high in these habitats, the populations are not filling their natural ecological role in a natural plant community and are highly vulnerable to changes in land management. Nonetheless, these populations can serve as important seed sources for expanding or introducing other populations in natural or restored habitat.

4.5 Current Redundancy and Representation

Leavenworthia exigua var. *laciniata* is a narrow endemic known to occur only in northeastern Bullitt County and southeastern Jefferson County. A mapping of known occurrences shows this taxon to be restricted to an area less than 100 square miles. Within this area, *L. exigua* var. *laciniata* is restricted to the small patches of suitable habitat associated with shallow soils that are interspersed with flat-bedded Silurian dolomite and dolomitic limestones. This narrow range means that redundancy for the taxon is inherently low and places *L. exigua* var. *laciniata* at a higher risk for extinction from habitat loss or degradation associated with localized events (manmade or natural), change in land use, or industry than a species that occurs across a broader landscape.

Within this narrow range, the taxon has a broad distribution, but nearly half of the current extant populations exhibit poor resiliency (Figure 12). The seven populations with good or excellent resiliency are distributed throughout the taxon's range (i.e., not clustered close together), improving redundancy against catastrophic events because catastrophic events that affect one population (e.g., development) are unlikely to impact the others. The 22 populations with fair resiliency are similarly widely distributed within the taxon's range. Only seven populations occur on protected lands (including RNAs, private lands with voluntary conservation agreements). These populations are less susceptible to many of the types of catastrophes that could impact this *L. exigua* var. *laciniata* because they are less likely to experience changes in land use and management than those on privately owned lands.

Compared to the historical distribution, there has been a loss of redundancy. Twenty-three populations are either confirmed extirpated (n = 16) or have not been relocated during the most recent survey and may be extirpated (n = 7), leaving 72 confirmed extant populations out of 95 historical populations. The causes of these losses were typically development (i.e., houses, commercial facilities, lawns) and/or habitat degradation.

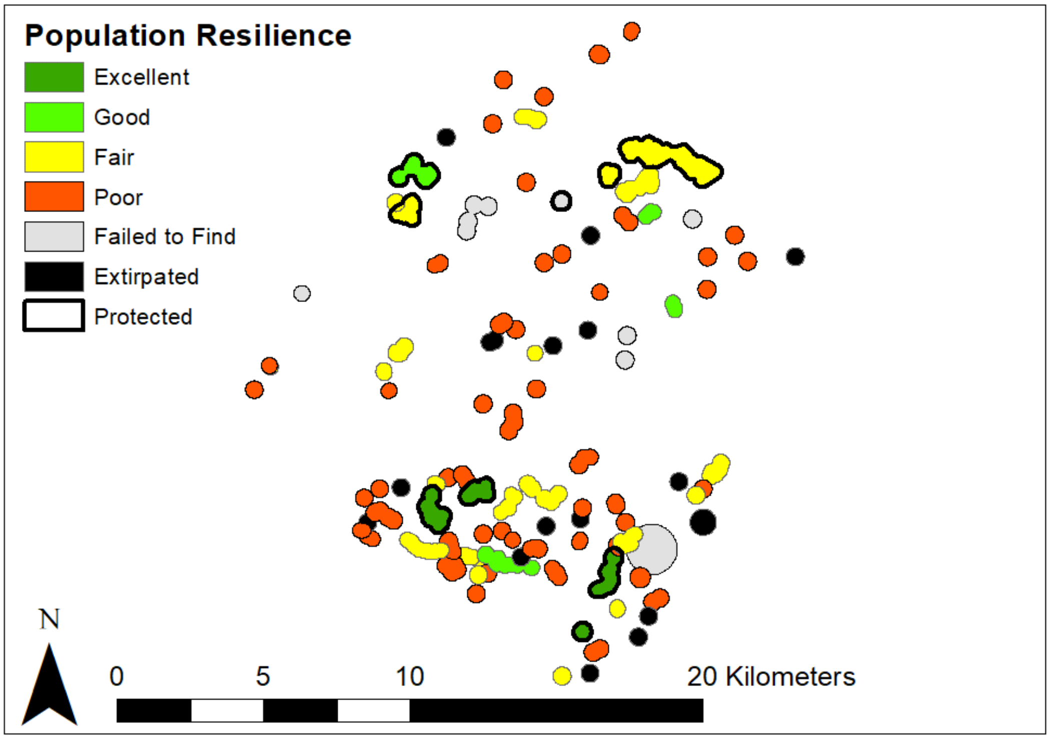

Figure 12. Distribution of *L. exigua* var. *laciniata* populations and resiliency scores. Populations bordered in bold indicate those on public land or with significant private ownership (see section 2.6.3).

As described earlier in this chapter, we did not delineate representative units for this taxon because all populations and individuals within populations have virtually identical genetic characteristics. This means that redundancy of genetic material is very high (given the low redundancy overall associated with having few resilient populations within a narrow range), as all individuals and populations are virtually genetically identical. For the five populations (of 21 sampled) that exhibited private alleles, resiliency was excellent (EO 41), fair (EO 24), and poor (EO 52, 17, and 35). The difference in genetic characteristics for these populations was still extremely small however, and might not have any functional implications for the adaptive capacity of the taxon.

CHAPTER 5 – FUTURE CONDITIONS AND VIABILITY

We developed multiple plausible scenarios to project the condition of *L. exigua* var. *laciniata* into the future. All scenarios were projected 20 and 40 years into the future. We used three assessment tiers for each scenario (Figure 13). In the first tier, populations were overlain with potential future development to identify those at risk. In the second tier, one of three conservation treatments was applied to populations meeting certain criteria (i.e., inclusion in critical habitat units, publicly owned, high-priority site). In the third tier, any populations that did not meet the criteria to be treated specifically by the conservation treatments were projected into the future using a probabilistic transition model based on past monitoring data. These three tiers are described in more detail in the following sections. We did not include the discovery of new populations in the scenarios; while several new occurrences have been discovered in recent years, these have mostly been in degraded habitats (e.g., lawns). The majority, approximately 95%, of high-quality glade habitat has been surveyed, and it is not likely that a substantial number of undiscovered populations exist in high-quality habitat (Littlefield 2020, pers. comm.).

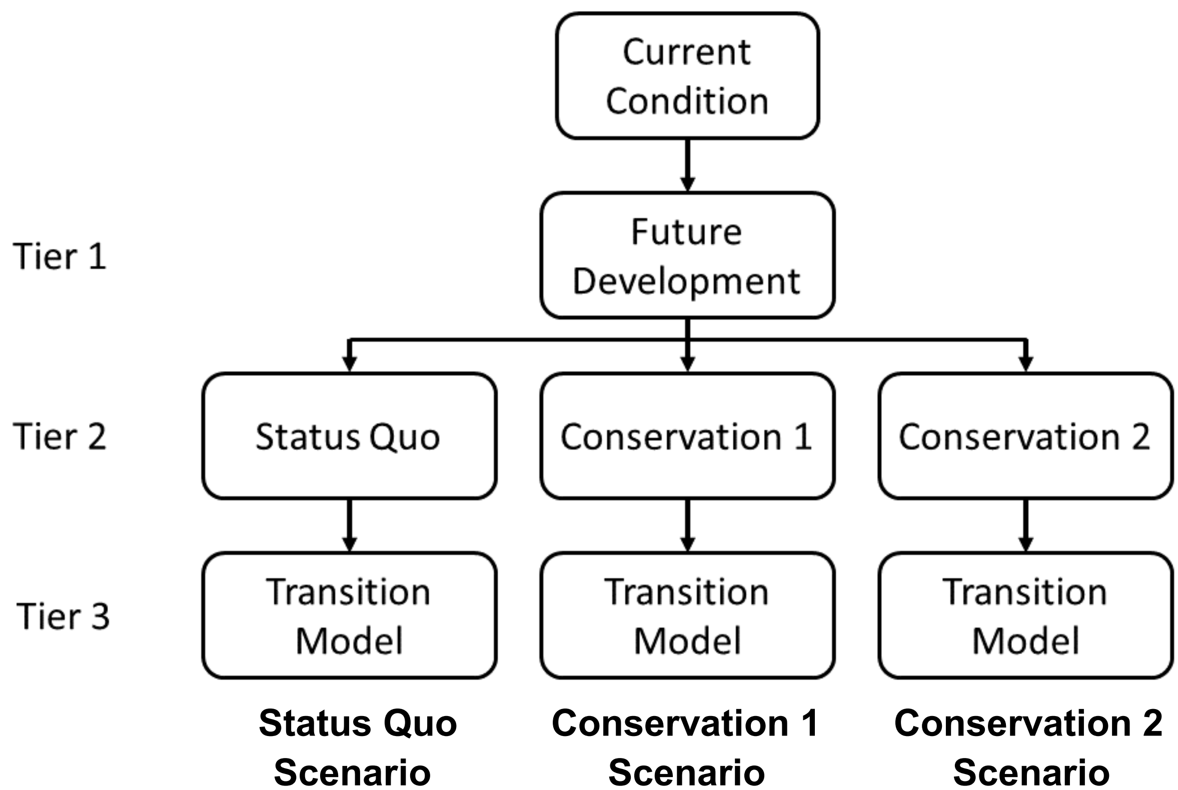

Figure 13. Conceptual diagram of the future condition assessment for *L. exigua* var. *laciniata*.

5.1 Tier 1 – Future Development

Development is not necessarily a death sentence for populations, as evidenced by extant populations with large numbers of plants in disturbed habitat. Because it is not possible to predict with much certainty how the resiliency of any given population exposed to any given development project will fare (e.g., extirpation, loss of resiliency, no change in resiliency, increase in abundance with a decline in natural habitat condition), we did not attempt to do so. Rather, we identified those populations that might be impacted. Using a Geographic Information System, we overlaid the proposed footprints of all three identified potential future development threats (general urbanization, a proposed interstate, and a proposed pipeline) over the current *L. exigua* var. *laciniata* populations.

5.1.1 Urbanization

To assess the risk of urbanization, we used the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH; Jantz et al. 2010, entire) model to determine areas predicted to be urbanized in the future. The SLEUTH model has previously been used to predict probabilities of urbanization across the southeastern US in 10-year increments, and the resulting GIS data are freely available (Belyea and Terando 2013, entire). Urbanization in this model includes low to medium-density residential and commercial development in addition to heavily developed areas (Terando et al. 2014, p. 2). For our future projections, we used the SLEUTH raster data sets from the years 2020, 2040 and 2060 (current, 20, and 40 years into the future), and examined the area predicted to be urbanized with 80% or higher probability. We identified those populations at risk from new urbanization after 2020. Populations existing in areas currently considered urbanized were not identified as being at further risk. Populations that currently occur entirely or partially on urbanized lands range from good resiliency to extirpated.

5.1.2 Interstate

As described in Section 3.1.3, preliminary plans are being explored for a new interstate to connect I-65 and I-71. The route has not yet been selected, but the proposed route will be based upon the results of a study that was due by the end of 2019 (KYTC 2019, n.p.). One alternative that the study will explore is a “no-build” scenario (KYTC 2019, n.p.). All of the route alternatives pass through the range of *L. exigua* var. *laciniata* (Figure 9). We overlaid all of the proposed routes over the *L. exigua* var. *laciniata* populations and identified those that intersect with any of the proposed routes. The mapped proposed routes are wide corridors, ~4,100 feet wide (1.25 km); any actual roadway would be approximately 200-250 feet wide (0.06-0.08 km; KYTC 2019, n.p.), but would also attract infrastructure and other development that typically concentrates around interstates. Because only one or none of the proposed routes will actually be constructed, including all of the proposed routes in our analysis overestimates the actual threat.

5.1.3 Pipeline

A new underground natural gas pipeline is being developed in the Cedar Grove area along KY 480 and will pass through or near existing *L. exigua* var. *laciniata* occurrences. The right-of-way for other pipelines in the area is ~164 feet (50 m) wide. To identify those populations that might be impacted by the installation of the pipeline and subsequent right-of-way maintenance, we identified populations within 328 feet (100 m) of the linear proposed pipeline route. After initial construction, long term impacts of the pipeline on *L. exigua* var. *laciniata* within or near the path are uncertain; open habitat maintained in the right-of-way could provide habitat for the taxon, but the disturbance could encourage encroachment by invasive species.

5.1.4 Future Development Summary

The threats of urbanization, interstate, and pipeline development are not spread uniformly throughout the range of *L. exigua* var. *laciniata*. Urbanization is concentrated in the northern and western parts of the range as the Louisville metro area continues to develop, while the proposed interstate and pipeline routes occur in the southern portion of the range (Figure 14).

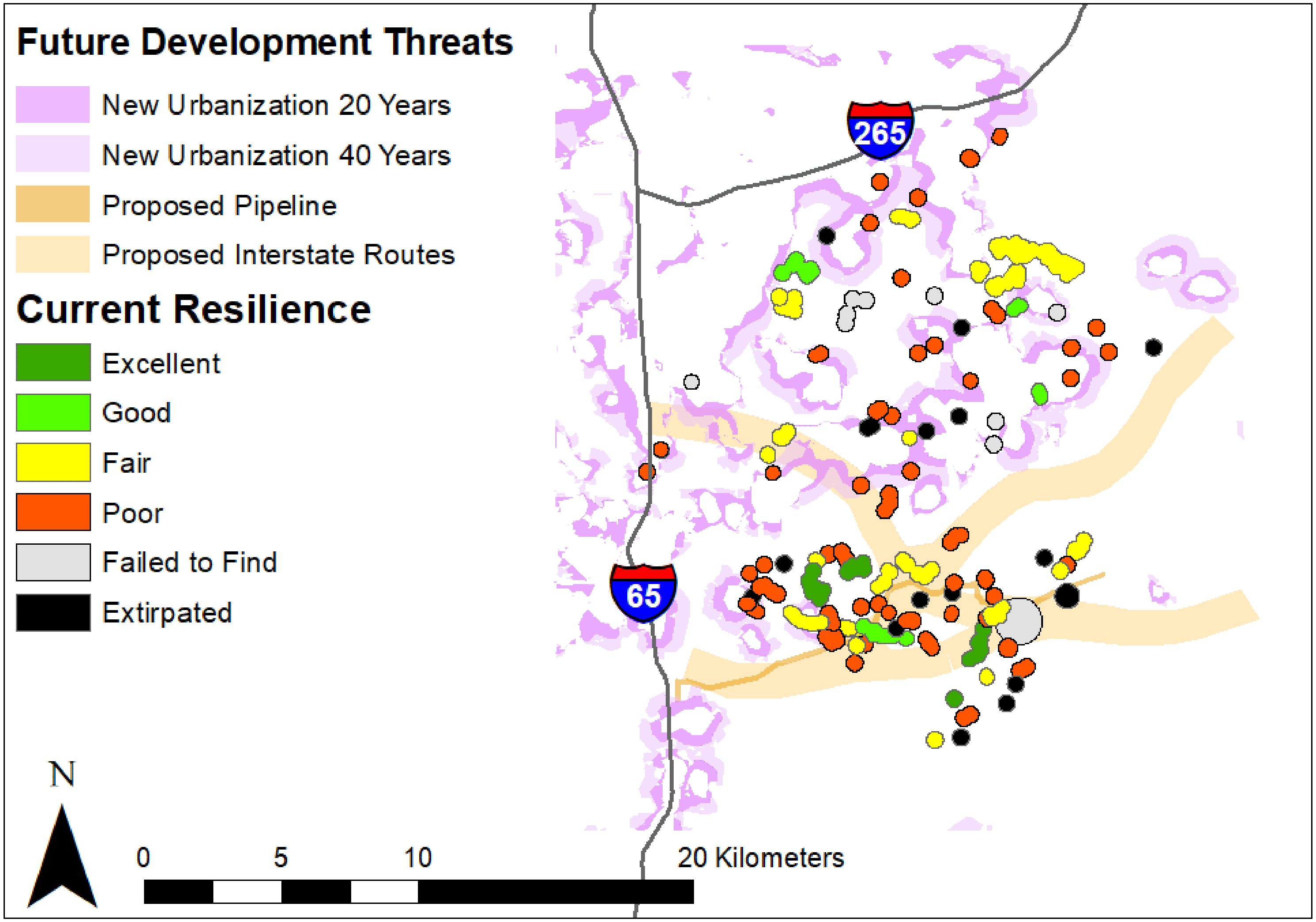

Figure 14. Locations of predicted future urbanization, possible interstate routes, and a proposed pipeline in relation to *L. exigua* var. *laciniata* populations.

A full table of the development risk (urbanization, interstate, and pipeline development) faced by each population can be found in Appendix C. Forty-two extant populations (out of 72) are at risk from at least one of the assessed development threats. Only one population (EO 1, Cedar Grove Cedar Glade, poor current resiliency) is at risk from all three development threats. Five populations are at risk from both the proposed pipeline and a potential interstate route (one good, three fair, one poor resiliency), and two populations are at risk from both urbanization and a potential interstate route (one fair, one poor resiliency). Thirty-four extant populations are at risk from a single development threat: 21 are at risk from urbanization (one excellent, two good, five fair, thirteen poor resiliency), 13 are at risk from a potential interstate route (one excellent, three fair, nine poor resiliency), and none are at risk from only the pipeline route, which largely overlaps with potential interstate routes. Thirty extant populations are not at risk from any of the three development threats (one excellent, one good, ten fair, eighteen poor resiliency).

5.2 Tier 2 – Conservation Treatments

We projected future resiliency of *L. exigua* var. *laciniata* under three conservation treatments: a status quo treatment, a treatment with targeted conservation in critical habitat (conservation 1), and a treatment with multiple conservation targets (conservation 2).

5.2.1 Status Quo Conservation Treatment

In the Status Quo conservation treatment, conditions were predicted to continue along present trajectories. Populations with excellent resiliency would maintain their excellent resiliencies. Populations that are currently presumed extirpated, remain extirpated. One population likely to experience development in the near future (EO 47) decreases in resiliency. There were no significant increases or decreases in management or recovery actions at *L. exigua* var. *laciniata* populations, except for increases in populations where conservation efforts are ongoing and recent progress has been made towards future conservation. Much of the ongoing conservation for *L. exigua* var. *laciniata* is associated with funding that is tied to its federal listing status. Thus, this scenario assumes no change in listing status that would alter the availability of conservation funding. The populations projected under the status quo conservation treatment are summarized in Table 14. Any populations not specifically addressed in this table were projected forward using a probabilistic transition model (Tier 3 of the assessment).

Table 14. Status Quo Conservation Treatment summary.

Population	Future
Currently ranked excellent resiliency	These populations are expected to retain excellent resiliency into the future. These populations occur on lands that are protected (to varying degrees) and are receiving conservation and management efforts beneficial to the taxon, and there is no reason to suspect that this will change and lead to declines in resiliency.
Currently ranked no resiliency	These populations are extirpated and are expected to have no resiliency into the future.
McNeely Lake Park (EO 72)	This population increases from good to excellent resiliency after 20 years based on a recent conservation easement and planned restoration and management actions. As a result, this population retains excellent resiliency at 40 years.
Cedar Grove East (EO 24) Knight Lane (EO 34) Cedar Creek South (EO 58)	There is a pending Registered Natural Area agreement for the property containing all or portions of these populations. These are currently ranked “good,” “fair,” and “poor,” respectively. We project each of these to increase by one resiliency class every 20 years.
Whitworth Glades (EO 60)	OKNP is actively working with the landowner on a possible Registered Natural Area, acquisition, or donation. We project this population will increase by one resiliency class after 20 years and remain in same class after 40 years. We do not project it to increase an additional resiliency class, like EOs 24, 34, and 58, because the potential conservation agreements are tentative at this early stage.
Floyd’s Fork at US 31E (EO 47)	Oakland Hills is slated for subdivision development by 21st Century Parks to help fund operation of the Parklands at Floyds Fork. As a result, this population decreases from fair to poor resiliency after 20 years and remains poor after 40 years.
All other populations	Future resiliency is projected by the transition model for all other populations not specifically listed in this table.

5.2.2 Conservation Treatment 1

This treatment represents a conservation focus on all populations that are in designated critical habitat units (79 FR 796800). Each of these critical habitat units contains the physical or biological features deemed essential to the conservation of the *L. exigua* var. *laciniata*, and each unit was occupied at the time of listing. This treatment builds off of the Status Quo Treatment; all rules applied to specific populations in that treatment apply to Conservation Treatment 1 as well, with the addition of targeted conservation in all critical habitat units (Table 15). Each population occurring entirely or partly in critical habitat was predicted to increase in resiliency by one step every 20 years as a result of targeted conservation in those populations. We chose the 20 year interval as a plausible average response time, recognizing that populations' response times will vary in reality due to prioritization, scheduling, funding availability, and site-specific conditions. The types of activities that would benefit *L. exigua* var. *laciniata* in these populations are described in Section 3.3 (Conservation and Management) and include disturbance (e.g., prescribed fire, mowing), invasive species control, cedar removal, population augmentation, and others. Any populations not specifically addressed by the Status Quo Treatment (section 5.2.1) or this Conservation 1 treatment (summarized in Table 15) were projected using the probabilistic transition model (Tier 3 of the assessment).

Table 15. Conservation 1 Treatment summary.

Critical Habitat Unit	**Subunit**	**EO Number**	**Current Resiliency**	**Future Resiliency**	
				20 years	**40 years**
1 – McNeely Lake	(NA)	EO 72	Good	Excellent	Excellent
2 – Old Mans Run*	2A	EO 80	Fair	Good	Excellent
	2B	EO 37	Fair	Good	Excellent
	2C	EO 82	Poor	Fair	Good
3 – Mount Washington	3A	EO 69	Poor	Fair	Good
	3B	EO 38	Poor	Fair	Good
	3C	EO 39	Good	Excellent	Excellent
4 – Cedar Creek	4A	EO 2	Excellent	Excellent	Excellent
	4B	EO 57	Excellent	Excellent	Excellent
	4C	EO 84	Fair	Good	Excellent
	4D	EO 54	Fair	Good	Excellent
	4E	EO 54	Fair	Good	Excellent
	4F	EO 58	Poor	Fair	Good
	4G	EO 24	Good	Excellent	Excellent
	4H	EO 60	Fair	Good	Excellent
5 – Cox Creek	5A	EO 81	Poor	Fair	Good
	5B	EO 19	Fair	Good	Excellent
6 – Rocky Run	(NA)	EO 41	Excellent	Excellent	Excellent

* EO 47 is in this critical habitat unit, but is projected under the Status Quo Conservation Treatment because of a pending subdivision development.

5.2.3 Conservation Treatment 2

It would be ideal to devote conservation resources to raise the resiliency of populations in all critical habitat units, as is modeled in Conservation Treatment 1, but a more moderate approach is likely more practicable given available resources (e.g., funds, personnel, access/partnering landowners, etc.). This treatment represents a future where targeted conservation in all critical habitat units is not feasible. Like Conservation Treatment 1, this treatment builds off of the Status Quo Treatment; all rules applied to specific populations in the Status Quo Treatment apply to Conservation Treatment 2 as well. However, the targeted conservation of all critical habitat units is replaced with targeted conservation efforts at the following locations: 1) critical habitat subunits on public lands or private lands with conservation easements or other agreements, 2) non-critical habitat sites on public/protected lands, and 3) EOs identified in Table 16 with high quality habitat or high restoration potential identified by OKNP as good conservation targets (Table 16). Any populations not specifically addressed by the Status Quo Treatment (section 5.2.1) or this treatment (summarized in Table 16) were projected using the probabilistic transition model (Tier 3 of the assessment).

Under Conservation Treatment 2 conservation efforts at the Floyd's Fork population (EO 3) increase its resiliency from "failed to find" to "fair" in 40 years through reintroduction/ augmentation. This treatment also includes a proposed introduction of the *L. exigua* var. *laciniata* at a currently unoccupied site at Bernheim Arboretum and Research Forest (Bernheim) for which we have no historical records. Bernheim has been a dedicated conservation partner with OKNP, and there are several glades there that appear to be suitable for *L. exigua* var. *laciniata*. For this assessment, we predicted good resiliency for the introduced population in both 20 and 40 years based on the apparent habitat quality and commitment from Bernheim for future targeted conservation at the site. However, *L. exigua* var. *laciniata* has not been introduced to new sites before, and it is unknown whether an introduction will be successful, how long it would take for an introduced population to reach a given population size, and what unforeseen challenges might arise. Before attempting an introduction, there must be careful thought and planning about the site selection and preparation, introduction strategy (e.g., how many plants or seeds introduced at how many sites over how many years), monitoring, and ongoing habitat maintenance if needed.

Table 16. Conservation 2 Treatment summary

Population	Justification	Current Resiliency	Future Resiliency	
			20 years	40 years
EO 72	Critical habitat (Unit 1), protected lands	Good	Excellent	Excellent
EO 80	Critical habitat (Unit 2a), protected lands	Fair	Good	Excellent
EO 37	Critical habitat (Unit 2b), protected lands	Fair	Good	Excellent
EO 2	Critical habitat (Unit 4a), protected lands	Excellent	Excellent	Excellent
EO 57	Critical habitat (Unit 4b), protected lands	Excellent	Excellent	Excellent
EO 60	Critical habitat (Unit 4h), protected lands (RNA pending)	Fair	Good	Excellent
EO 41	Critical habitat (Unit 6), protected lands (RNA)	Excellent	Excellent	Excellent
EO 68	Non-critical habitat, protected lands	Fair	Good	Excellent
EO 3	Non-critical habitat, protected lands	Failed to Find	Poor	Fair
EO 96	Restoration potential, conservation-minded landowner interested in RNA	Fair	Good	Excellent
Bernheim Forest	Conservation momentum with OKNP, would be new introduction	NA	-	Good

5.3 Tier 3 – Transition Model

For populations not explicitly addressed in the above scenarios, we projected population resiliency using a probabilistic transition model. A summary of the features of the model are provided here; more technical details and code to replicate the model in R (RStudio Team 2015, n.p.) are provided in Appendix D. The modeling effort was composed of two parts. First, we estimated transition probabilities between resiliency classes from past data (section 5.3.1 below). Second, we used those estimated probabilities in a simulation model to project the resiliency of extant populations into the future (see section 5.3.2 below).

5.3.1 Estimating Transition Probabilities

We estimated transition probabilities between resiliency classes using past EO rank data from 1990 to 2019. The most common interval between surveys in the data set was about four years, so we used those data to estimate the probability that a population in a given resiliency class will improve in rank, remain at the same rank, or decline after four years (we included the range of 2-6 years to include more transitions). While populations in the data set could improve or decline by more than one rank (e.g. transition from A to D), we collapsed the data for the model into just three possible transitions of improve, remain the same, or decline. Some of the transitions may have been influenced by differences in rank criteria during surveys in different years (see Appendix B). However, we did not have the survey information available to apply the same criteria to surveys from all years, and thus assumed that transitions due to differences in criteria application were rare. Transition probabilities are reported in Table 17.

Table 17. Transition probabilities and covariances, in parentheses, for 4-year resiliency transitions.

Initial Rank	Decline Rank	Remain at Initial	Improve Rank	Sample Size
Excellent	0.33 *(0.025)*	0.67 *(0.025)*	NA	9
Good	0.73 *(0.013)*	0.27 *(0.013)*	0 *(0)*	15
Fair	0.42 *(0.006)*	0.53 *(0.007)*	0.05 *(0.001)*	38
Poor	0.04 *(0.002)*	0.79 *(0.007)*	0.17 *(0.006)*	24

Each transition probability has a corresponding measure of uncertainty, the covariance. There is uncertainty in the probabilities because the true transition probabilities are not known; they were estimated from data. With a different subset of data (e.g., if surveys were conducted in different years), the estimated transition probabilities would differ from those shown here. Note that with higher sample sizes (i.e., 38 and 24 transitions for fair and poor-ranked populations compared to 9 and 15 transitions for excellent and good), the covariance declines. That is, uncertainty around the estimates decreases when there are more data informing the estimates.

For all populations, there was a low probability of improving a rank after four years. Populations ranked excellent were most likely to remain excellent, those ranked good were most likely to decline in status, and those ranked fair or poor were most likely to remain in the same status. Notably, the probability of a poor-ranked population declining to extirpation was fairly low at four percent. This could partly be contributed to the lack of recent survey data of several of these populations; some extirpations may not have been recorded. Overall, these results show a trend of declining population status.

5.3.2 Projecting Future Resiliency

We used the estimated transition probabilities to project forward the resiliency of the remaining populations that were not explicitly addressed in Tier 2 of the assessment. We constructed a model that predicted, in four-year intervals, the probability of a population improving a rank, remaining in the same rank, or declining a rank, based on the population's rank at the start of the four-year interval. We assumed that once a population declines from a poor resiliency rank, it is extirpated and will not regain resiliency.

Uncertainty was incorporated into the simulation model in two places:

1. *Uncertainty due to random process* – Because transition probabilities are probabilities, there is an element of randomness in which outcome will occur at each time step. Even if an outcome is 99% likely to occur, the opposite outcome is still expected to occur 1% of the time. We incorporated this uncertainty by running 5,000 replicates of the model. By running many replicates of the simulation model, we could simulate that random process and then summarize the results and determine which outcomes are more or less likely to occur without being influenced by uncommon random outcomes.
2. *Uncertainty in the transition probabilities* – Because transition probabilities between possible states were estimated from data, they have uncertainty associated with them (i.e., their covariance). Within each of the 5,000 simulation replicates, we selected a different value for each transition probability from a statistical distribution defined by the mean and covariance estimated from the transition data (Figure 15). This allowed the model to explore the range of plausible transition probabilities.

We summarized the results from the 5,000 replicates of the simulation to predict the expected number of populations in each resiliency class at each time point (median value from all replicates), with a focus on 20 and 40 years in the future.

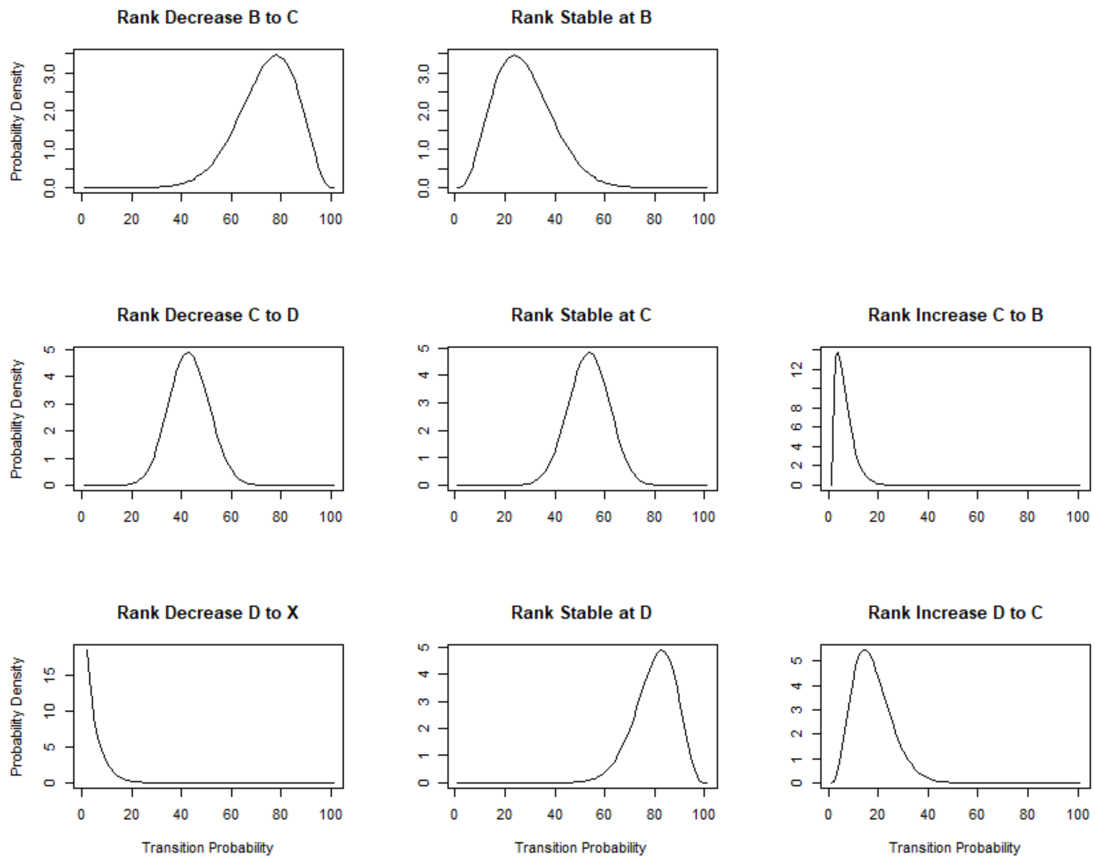

Figure 15. Statistical distributions showing the estimated transition probabilities and uncertainty for each transition between ranks. A different value was drawn from each distribution for each of 5,000 model replicates.

5.3.2.1 Status Quo Scenario

Under this scenario, we used the transition model to project the future status of 63 populations (those not specifically addressed in Tiers 1 and 2 of the assessment), two with good resiliency (B), 19 with fair resiliency (C), and 42 with poor resiliency (D) (Figure 16). After 20 years, we predicted that 1 (95% confidence interval: 0 - 5) population will have good resiliency, 17 (5 - 29) will have fair resiliency, 39 (24 - 54) will have poor resiliency, and 6 (0 - 27) will have become extirpated (X). After 40 years, we predicted that 1 (0 - 5) population will have good resiliency, 14 (3 - 53) will have fair resiliency, 36 (14 - 53) will have poor resiliency, and 11 (0 - 42) will have become extirpated. These values will be added to the numbers of populations of each rank determined in Tier 2 of the assessment.

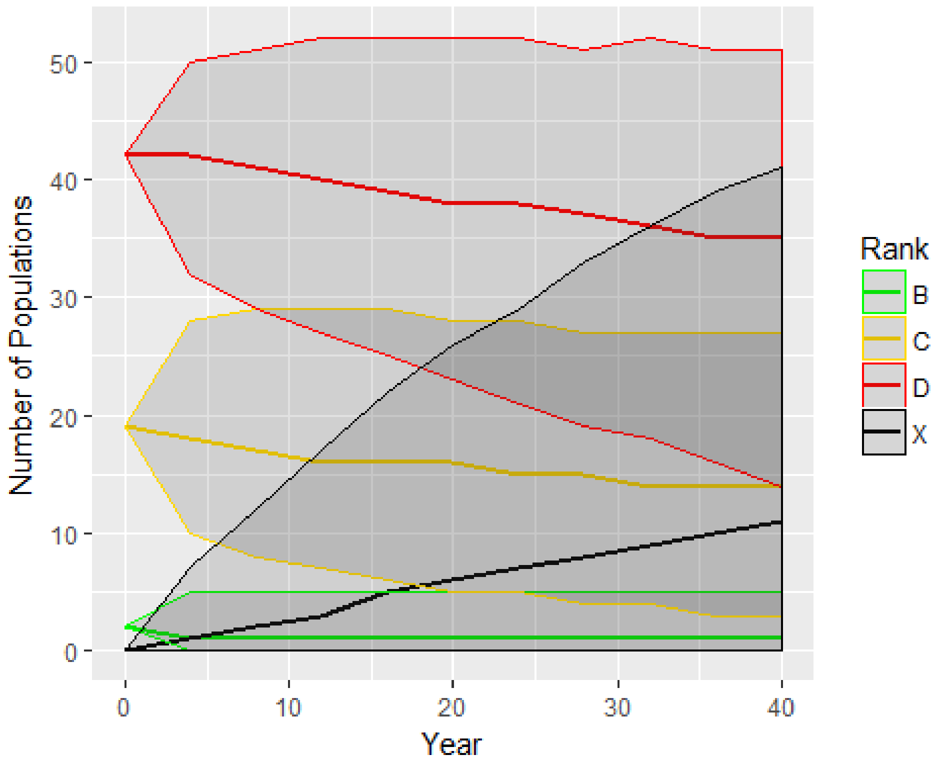

Figure 16. Transition model results for the Status Quo Scenario.

5.3.2.2 Conservation Scenario 1

Under this scenario, we used the transition model to project the future status of 53 populations (different from the Status Quo Scenario because different rules were applied to populations in Tiers 1 and 2 of the assessment), one with good resiliency (B), 14 with fair resiliency (C), and 38 with poor resiliency (D) (Figure 17). After 20 years, we predicted that 1 (95% confidence interval: 0 - 4) population will have good resiliency, 14 (4 - 25) will have fair resiliency, 33 (20 - 46) will have poor resiliency, and 5 (0 - 24) will have become extirpated (X). After 40 years, we predicted that 1 (0 - 4) population will have good resiliency, 11 (2 - 24) will have fair resiliency, 30 (12 - 45) will have poor resiliency, and 10 (0 - 37) will have become extirpated. These values will be added to the numbers of populations of each rank determined in Tier 2 of the assessment.

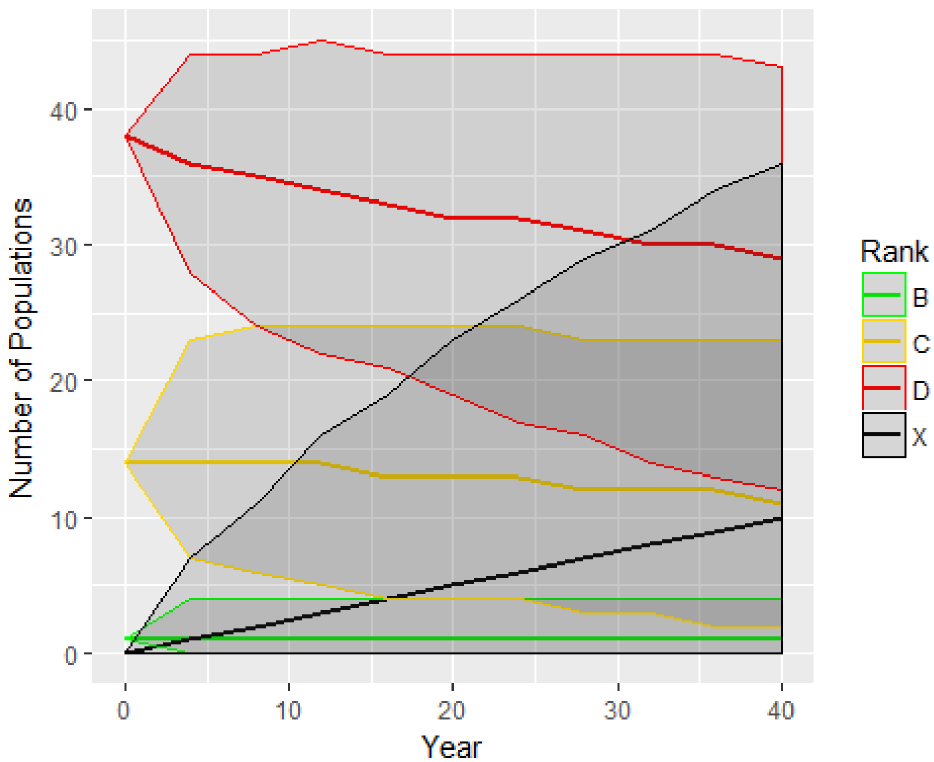

Figure 17.Transition model results for the Conservation Scenario 1.

5.3.2.3 Conservation Scenario 2

Under this scenario, we used the transition model to project the future status of 59 populations (different from the previous scenario because different rules were applied to populations in Tiers 1 and 2 of the assessment), two with good resiliency (B), 15 with fair resiliency (C), and 42 with poor resiliency (D) (Figure 18). After 20 years, we predicted that 1 (95% confidence interval: 0 - 7) population will have good resiliency, 14 (5 - 27) will have fair resiliency, 37 (22 - 51) will have poor resiliency, and 6 (0 - 26) will have become extirpated (X). After 40 years, we predicted that 1 (0 - 4) population will have good resiliency, 13 (3 - 26) will have fair resiliency, 33 (13 - 50) will have poor resiliency, and 11 (0 - 40) will have become extirpated. These values will be added to the numbers of populations of each rank determined in Tier 2 of the assessment.

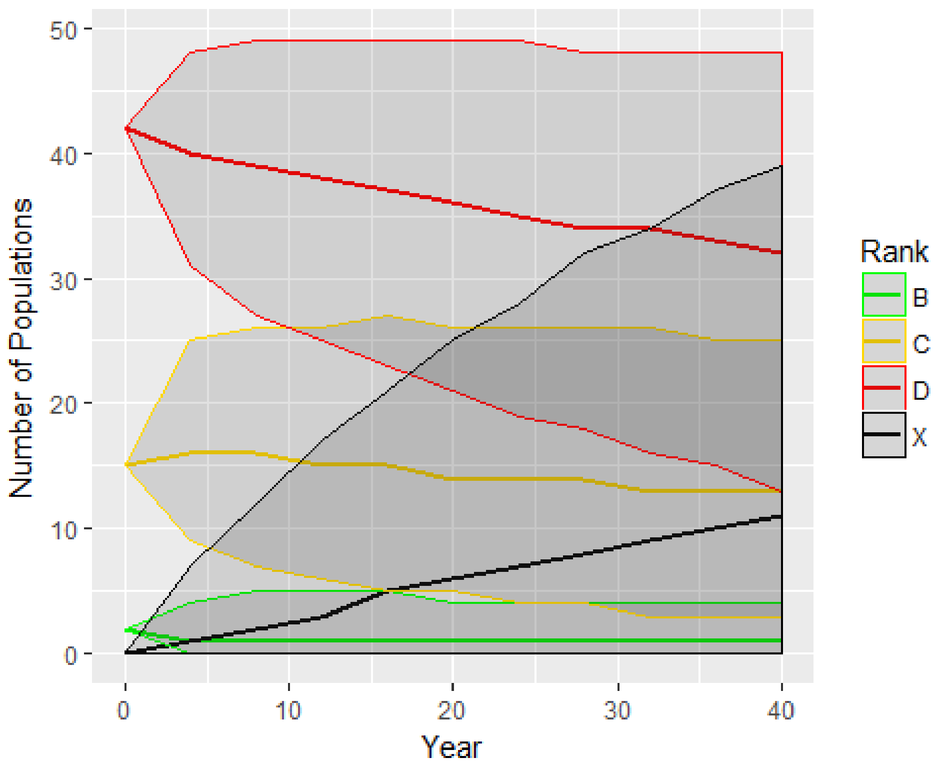

Figure 18. Transition model results for the Conservation Scenario 2.

5.4 Future Resiliency Results

We assessed future resiliency with a tiered approach, first assessing the risk of development threats on populations, then applying three different conservation treatments to populations meeting certain criteria, and finally applying a probabilistic transition model to the populations not explicitly addressed in the previous step (Tier 2).

The trajectory of populations predicted by the transition model is downwards, leading to overall declines in the number of extant populations, but the conservation measures applied to populations in the conservation treatments lead to increases in the number of extant populations with good or excellent resiliency (hereafter referred to as "highly resilient"). Even the Status Quo Scenario leads to modest increases in the number of highly resilient populations, from the current 7 to 9, because of existing conservation efforts by OKNP and partnering landowners that are likely to continue into the future. Further gains of highly resilient populations are predicted, to total 19 in Conservation Scenario 1 and 13 in Conservation Scenario 2, with targeted conservation efforts in those scenarios (Figure 19).

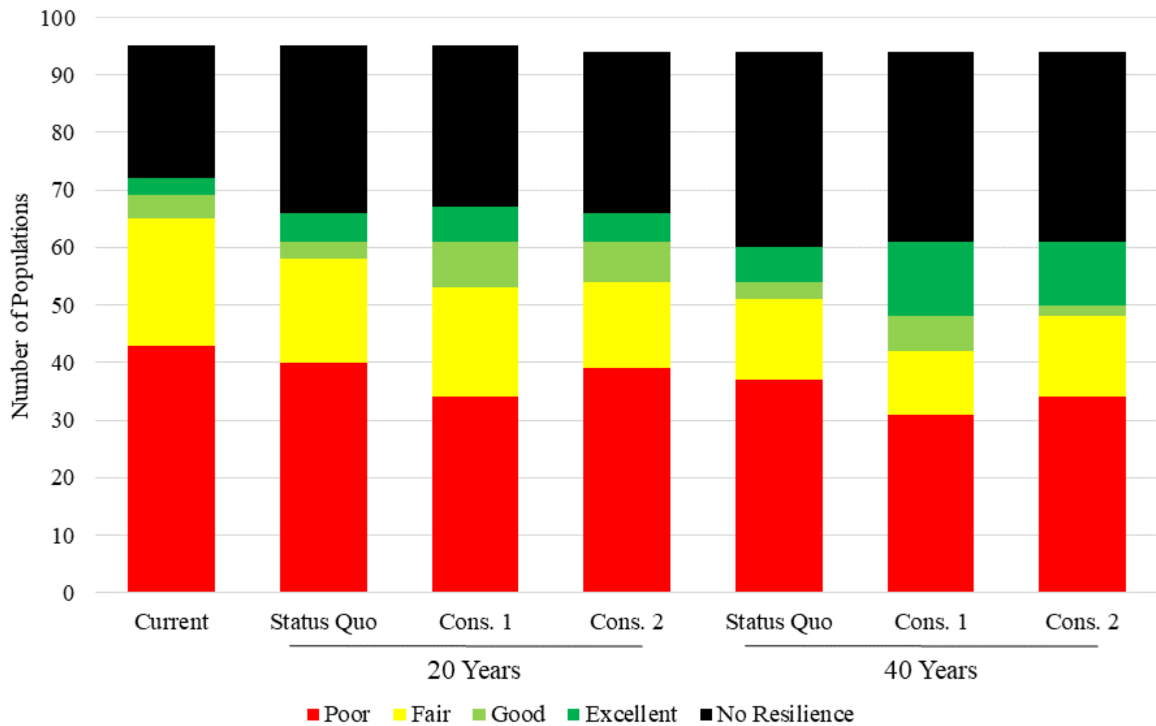

Figure 19. Current and predicted future resiliency in 20 and 40 years under three scenarios.

These predicted results are based on the assumption that populations currently ranked F (Failed to Find) or X (Extirpated) are extirpated and do not regain resiliency, with the exception of one population (Floyd's Fork, EO 3). It is possible that populations might regain resiliency, either because they had simply been missed in surveys despite persisting, or regrew from a seed bank. If this happens, the number of extant populations would be higher than those predicted here, but resiliency for those populations will likely remain low without significant conservation action.

5.5 Future Redundancy and Representation

Redundancy for *L. exigua* var. *laciniata* is inherently low due to its narrow historical range, and is expected to decline in the future. Under all three scenarios, the number of extant populations (currently 72) is predicted to decline (Table 18). Under the Status Quo Scenario, the number of extant populations is expected to decline to 66 in 20 years, and 60 in 40 years. In Conservation Scenario 1, the number of extant populations is expected to decline to 67 and 61 in 20 and 40 years, respectively. In Conservation Scenario 2, the number of extant populations is expected to decline to 66 and 61 in 20 and 40 years, respectively. Because our transition model was not spatially explicit, it did not predict which populations are most likely to be extirpated, but we achieved some insight on this issue by examining the spatial distribution of development threats

(Figure 20). Populations exposed to one or multiple development threats (e.g. where the proposed pipeline route intersects with a proposed interstate route) will likely have a higher risk of extirpation.

Table 18. Populations in each resiliency category in future scenarios. Not all columns sum to 95 due to rounding error from the transition model.

	Current	**Status Quo**		**Conservation Scenario 1**		**Conservation Scenario 2**	
Resiliency		**20 Years**	**40 Years**	**20 Years**	**40 Years**	**20 Years**	**40 Years**
Excellent	3	5	6	6	13	5	11
Good	4	3	3	8	6	7	2
Fair	22	18	14	19	11	15	14
Poor	43	40	37	34	31	39	34
No Resiliency	23	29	34	28	33	28	33

While redundancy of extant populations is expected to decline, redundancy of highly resilient populations is predicted to increase under all scenarios. Because of current conservation efforts that are expected to continue, even in the Status Quo Scenario, the number of highly resilient populations is expected to increase from 7 currently to 8 in 20 years and to 9 in 40 years. With additional targeted conservation on all critical habitat units (Conservation Scenario 1), we predict that there will be 14 and 19 populations with high resiliency in 20 and 40 years, respectively. Under Conservation Scenario 2, we predict that there will be 12 and 13 such populations in 20 and 40 years, respectively.

In the Status Quo Scenario, populations predicted to have high resiliency in the future are concentrated in the southern portion of the taxon's range (Figure 21), where the risk from pipeline and interstate construction are also concentrated. The two conservation scenarios include improvements to resiliency in the northern portion of the range. No scenarios lead to highly resilient populations in the central portion of the range.

As discussed in the Current Conditions section, we did not delineate representative units for this taxon because all populations and individuals within populations have virtually identical genetic characteristics. The taxon inherently exhibits low representation, and we expect the representation to remain low in the future.

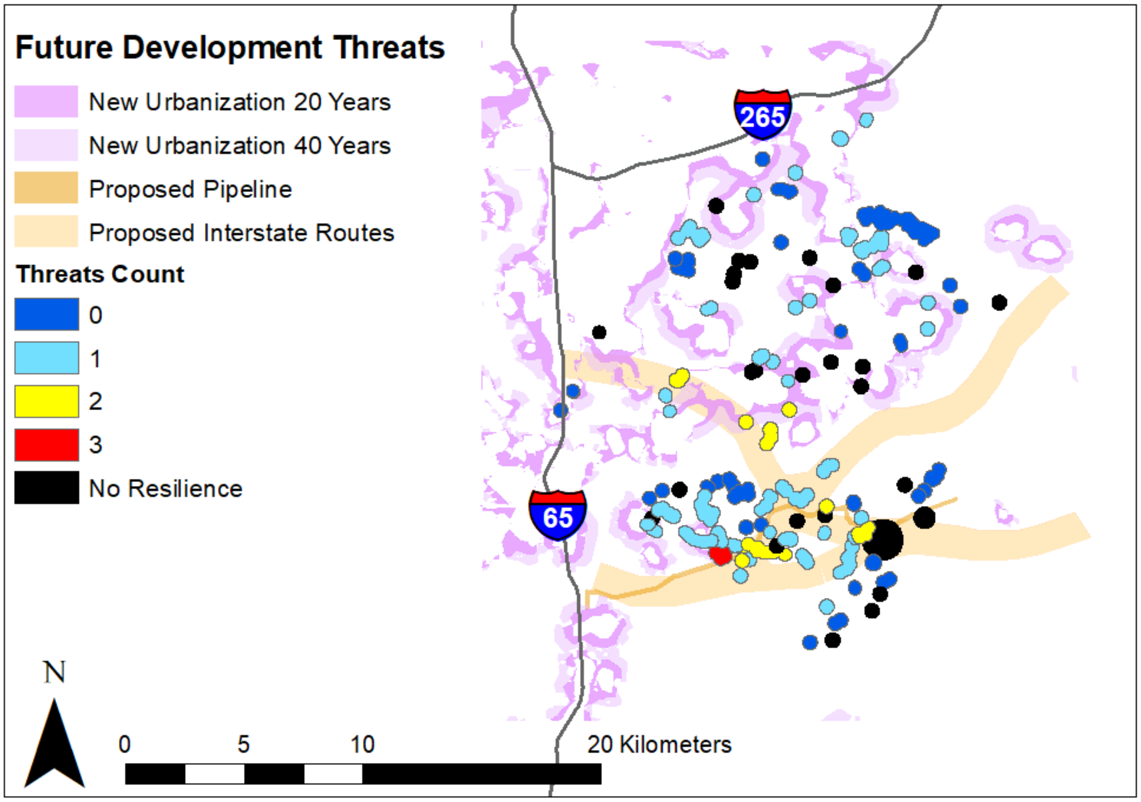

Figure 20. Distribution of populations and their risk from future development. Threats count refers to the number of development threats (urbanization, proposed pipeline, proposed interstate) the population is potentially exposed to. Counts are only given for extant populations.

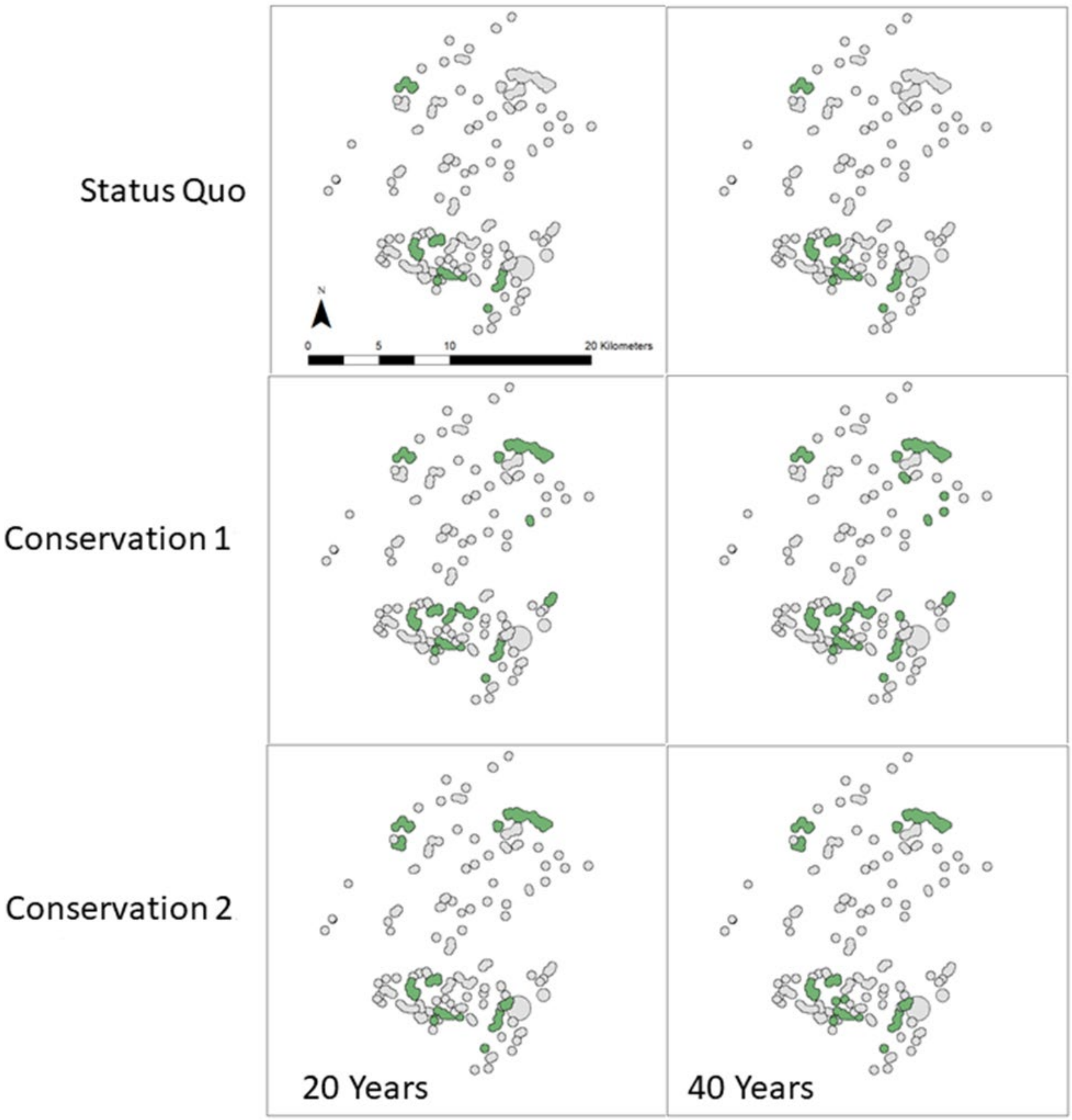

Figure 21. Spatial distribution of populations with good or excellent resiliency (green) based on conservation scenarios. NOTE: Does not include the one population predicted to have good resiliency in each scenario by the transition model because that model was not spatially explicit.

This concludes our assessment of *L. exigua* var. *laciniata* needs, current condition, and future condition. Viability for the taxon in the future will depend on targeted conservation actions to combat the declining trend. This SSA will support the functions of the Endangered Species Program, through recovery planning, consultations, and all policy-related decision-making until recovery and eventual delisting. This SSA will be updated as new information becomes available, including but not limited to information about seedbank viability, responses of the taxon to management, and the efficacy of population augmentation and introductions.

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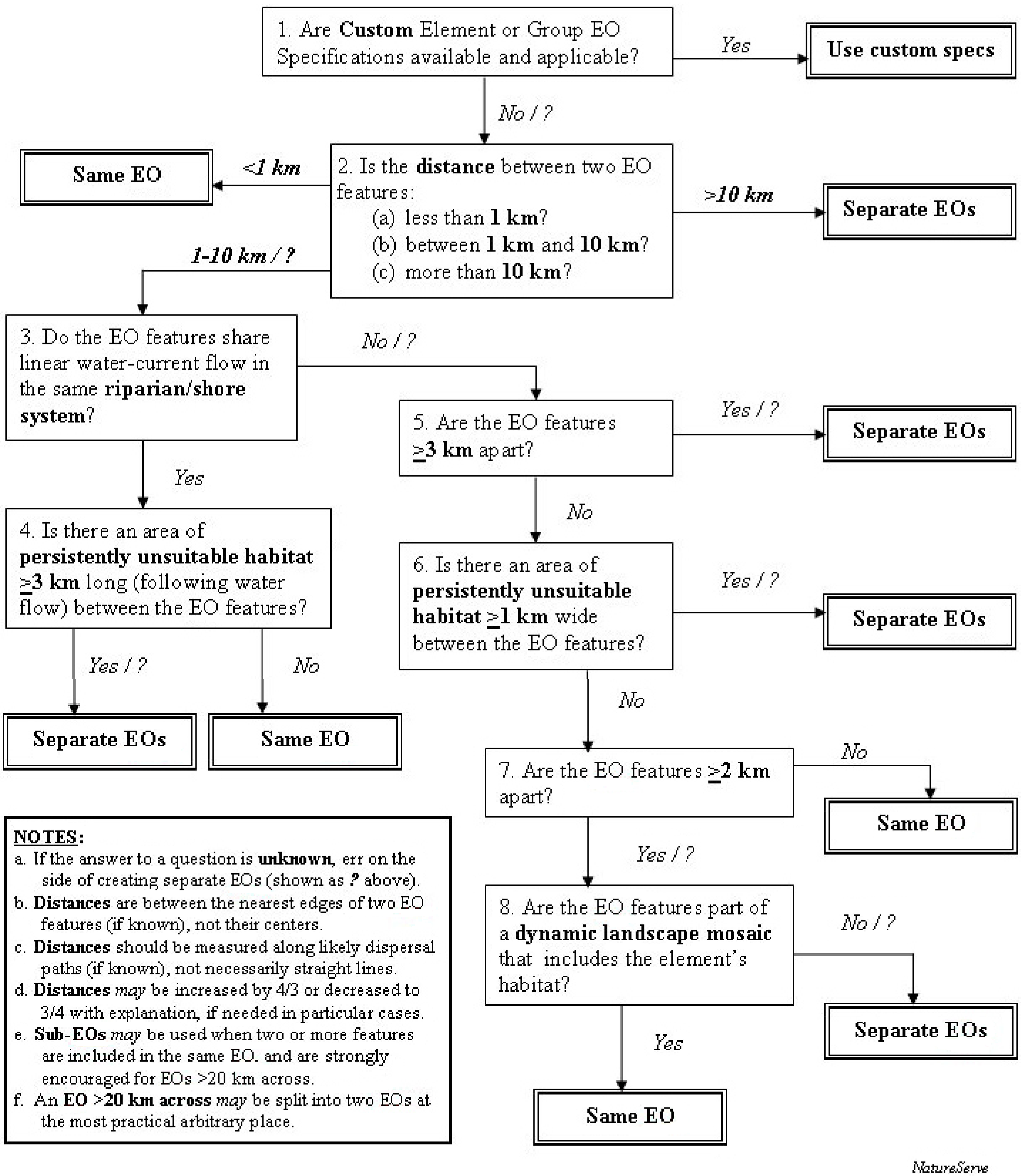
APPENDIX A - Element Occurrence Delineation

Habitat-based Plant Element Occurrence Delimitation Guidance, NatureServe, 1 October 2004



APPENDIX B - Element Occurrence Rank Criteria Over Time

Comparison of criteria for element occurrence ranks in 1994, 2004, and 2019 (White 1994, p. 2-3; White 2004, p. 1; Littlefield 2019*d*, n.p.).

EO Rank	1994	2004	2019
A – excellent resiliency	3,000 or more plants, at least 5 acres of habitat with native vegetation	1,000 or more plants, at least 5 acres of habitat with native vegetation	2,500 or more plants, at least 10 acres of high quality habitat
B – good resiliency	1,000 to 3,000 plants, fewer than 5 acres of habitat with native vegetation	500 to 1,000 plants, habitat generally natural but may be somewhat degraded OR many thousands of plants in highly degraded habitat	(B or AB rank) 100 to 2,500 plants in high quality habitat OR greater than 2,500 plants in habitat that is generally natural but may be degraded
C – fair resiliency	Several hundred plants, possible up to 1,000; although some native vegetation is present, most of the site has been degraded	100 or more plants, possibly up to 1,000; habitat may be degraded with non-native and undesirable plants present	(C or BC rank) 100 to 2,500 plants, habitat generally natural but may be somewhat degraded OR fewer than 100 plants in high quality habitat OR greater than 5,000 plants in highly degraded habitat
D – poor resiliency	Approximately 200 or fewer individuals; native vegetation has been removed (lawns, roadsides, pastures)	100 or fewer individuals and habitat need not have any native species (lawns, pastures, roadsides, etc.)	(CD or D rank) Up to 5,000 plants in highly degraded habitat with non-native plants OR fewer than 100 plants in somewhat degraded but generally natural habitat
F		Failed to find plants at the site	Failed to find plants at the site

APPENDIX C - Future Condition Results

The following table shows the results of the future condition projections by population. Populations are sorted by current resiliency, and then by EO number. Future resiliency was projected for three scenarios, Status Quo Scenario (SQ), Conservation 1 Scenario: Critical Habitat (C1), and Conservation 2 Scenario: Multiple Targets (C2) at 20- and 40-year time intervals. A score of "A" represents excellent resiliency; "B" represents good resiliency; "C" represents fair resiliency; "D" represents poor resiliency; and "F" (failed to find) and "X" (extirpated) represent no resiliency. If no future resiliency rank was given, that population was projected forward using a probabilistic transition model that was not spatially explicit. In the Development Risk columns, populations received a 1 if they were at risk in the future from urbanization, a proposed interstate route (route not yet finalized), or a proposed pipeline.

						Resiliency							Development Risk			
EO	Site	Last Survey	EO Rank	Protected Land	Critical Habitat	Curr.	SQ 20	SQ 40	C1 20	C1 40	C2 20	C2 40	Urbanization	Interstate	Pipeline	Total
2	Pine Creek Barrens	2019	A	Yes	Yes	A	A	A	A	A	A	A	1			1
41	Rocky Run Glade	2012	A	RNA	Yes	A	A	A	A	A	A	A		1		1
57	Apple Valley Glade	2019	A	Yes	Yes	A	A	A	A	A	A	A				0
24	Cedar Grove East (Ratliff Glade Site)	2019	B	No	Yes	B	A	A	A	A	A	A		1	1	2
39	Mt. Washington Cedar Glade	2015	B	No	Yes	B			A	A						0
64	Jefferson County Sportsmen's Club	2016	B	No	No	B							1			1
72	McNeely Lake Park	2019	B	Yes	Yes	B	A	A	A	A	A	A	1			1
14	Ridge Road West	2015	C	No	No	C										0
16	Cedar Grove	2016	C	No	No	C							1			1
17	Solitude Northwest	2016	C	No	No	C										0
19	Benchmark Glades	2012	C	No	Yes	C			B	A						0
22	Brownington South	2016	C	No	No	C										0
34	Knight Lane	2018	C	No	No	C	B	A	B	A	B	A		1	1	2
37	Old Man's Run North	2018	BC	Yes	Yes	C			B	A	B	A				0
43	Pennsylvania Run NP	2018	C	No	No	C										0
44	SR 480 South	2016	C	No	No	C							1			1
45	Brooks/Floyd's Big Rock	2016	C	No	No	C							1	1		2

						Resiliency							Development Risk			
EO	Site	Last Survey	EO Rank	Protected Land	Critical Habitat	Curr.	SQ 20	SQ 40	C1 20	C1 40	C2 20	C2 40	Urbanization	Interstate	Pipeline	Total
47	Floyds Fork at US 31E	2011/ 2018	C	No	Yes	C	D	D	D	D	D	D	1			1
54	North Cedar Creek	2011	C	No	Yes	C			B	A				1		1
60	Whitworth Glades	2018	C	No	Yes	C	B	B	B	A	B	A		1	1	2
68	Pennsylvania Run	2019	BC	No	No	C					B	A				0
76	Brooks	2015	C	No	No	C										0
80	W of Bardstown Rd	2016	C	Yes	Yes	C			B	A	B	A	1			1
84	Cedar Creek North	2015	BC	No	Yes	C			B	A				1		1
89	BULL078	2015	C	No	No	C								1		1
91	Edge of the Run	2015	C	No	No	C										0
92	Highway 44 East	2016	C	No	No	C							1			1
95	Cooper Chapel Glade	2016	C	No	No	C										0
96	Allen Farm	2018	BC	No	No	C					B	A		1	1	2
1	Cedar Grove Cedar Glade	2004	D	No	No	D							1	1	1	3
5	Ridge Road East	2004	D	No	No	D										0
7	Bethel Church Road	2004	D	No	No	D							1			1
9	Jacksonhills Church	2016	CD	No	No	D								1	1	2
10	Automobile Road	2004	D	No	No	D							1	1		2
11	Solitude West	2019	CD	No	No	D								1		1
12	Ridge Road East	2004	D	No	No	D										0
13	Cedar Grove Southeast	2014	D	No	No	D								1		1
15	Solitude South	2004	D	No	No	D										0
18	Solitude Northwest	1994	D	No	No	D										0
21	Brownington East	2004	D	No	No	D										0
26	NA	2004	D	No	No	D								1		1
27	Ridge Road West	2019	D	No	No	D							1			1
30	Markwell Cemetery East	2004	D	No	No	D										0
32	Bethel Church North	2004	D	No	No	D							1			1
35	Wells Run Glade	2016	CD	No	No	D							1			1
36	Oak Grove Church	2004	D	No	No	D										0

							Resiliency								Development Risk			
EO	Site	Last Survey	EO Rank	Protected Land	Critical Habitat		Curr.	SQ 20	SQ 40	C1 20	C1 40	C2 20	C2 40		Urbanization	Interstate	Pipeline	Total
38	Mt Washington East	1994	D	No	Yes		D			C	B				1			1
42	East of Lickskillet Creek south of KY 480	2016	D	No	No		D								1			1
46	NA	2014	CD	No	No		D											0
50	Fairmount	2004	D	No	No		D								1			1
51	Thixton	2004	D	No	No		D								1			1
52	Cedar Creek Road	2016	CD	No	No		D											0
55	Ridge Road East	2011	D	No	No		D									1		1
56	Greens Branch Glades	2015	CD	No	No		D									1		1
58	Cedar Creek South	2012	CD	No	Yes		D	C	B	C	B	C	B					0
59	Pine Creek Road and SE of 480 and Pine Creek Road Junction	2016	D	No	No		D								1			1
61	North Greens Branch or Upper Greens Branch Barrens	2015	CD	No	No		D									1		1
65	Big Run/ Floyds Fork	2010	D	No	No		D								1			1
69	NA	1994	D	No	Yes		D			C	B				1			1
71	~0.9 mi NW of Solitude	1990	D	No	No		D									1		1
78	NA	2005	D	No	No		D											0
79	W of Ridge Road	2004	D	No	No		D											0
81	Low Cox Creek	2008	CD	No	Yes		D			C	B							0
82	Bardstown Rd at county line	2009	CD	No	Yes		D			C	B							0
83	E Rocky Run	2010	D	No	No		D											0
86	NA	2015	D	No	No		D											0
87	NA	2015	D	No	No		D											0
88	Cedar Creek Mini-Barren	2015	D	No	No		D								1			1
90	Backyard Barrens	2015	CD	No	No		D								1			1
93	NA	2016	D	No	No		D									1		1

							Resiliency								Development Risk			
EO	Site	Last Survey	EO Rank	Protected Land	Critical Habitat		Curr.	SQ 20	SQ 40	C1 20	C1 40	C2 20	C2 40		Urbanization	Interstate	Pipeline	Total
94	Greens Branch Glades	2015	D	No	No		D									1		1
97	NA	2019	D	No	No		D											0
3	Floyd's Fork	2019	F	Yes	No		F	F	F	F	F	D	C					0
8	Solitude	2000	F	No	No		F	F	F	F	F	F	F			1		1
33	Mt Washington South	2004	F	No	No		F	F	F	F	F	F	F					0
40	Hall Cemetery	2004	F	No	No		F	F	F	F	F	F	F		1			1
48	Thixton Lane Church	2004	F	No	No		F	F	F	F	F	F	F					0
66	Markwell Cemetary Powerline	2004	F	No	No		F	F	F	F	F	F	F		1			1
75	SR61 West Side	2015	F	No	No		F	F	F	F	F	F	F					0
4	Mt Washington West	1994	X	No	No		X	X	X	X	X	X	X					0
6	Solitude Northwest	1990	X	No	No		X	X	X	X	X	X	X				1	1
20	Solitude South	2004	X	No	No		X	X	X	X	X	X	X					0
23	Solitude West	2004	X	No	No		X	X	X	X	X	X	X			1		1
25	Ridge Road West	2004	X	No	No		X	X	X	X	X	X	X					0
28	NA	2004	X	No	No		X	X	X	X	X	X	X			1		1
29	Ridge Road West	2004	X	No	No		X	X	X	X	X	X	X		1			1
31	Simmons Lane	2004	X	No	No		X	X	X	X	X	X	X		1			1
49	Crenshaw	2004	X	No	No		X	X	X	X	X	X	X					0
53	Woodsdale Rd	1994	X	No	No		X	X	X	X	X	X	X					0
62	Clarks Lane	2004	X	No	No		X	X	X	X	X	X	X					0
63	Woodsdale Road	2004	X	No	No		X	X	X	X	X	X	X					0
67	McNeely South Park	2012	X	Yes	No		X	X	X	X	X	X	X		1			1
70	Ca 1.8 mi E of Cedar Grove & 0.2 mi N of KY480.	1994	X	No	No		X	X	X	X	X	X	X			1		1
73	NA	2004	X	No	No		X	X	X	X	X	X	X		1			1
74	NA	2011	X	No	No		X	X	X	X	X	X	X		1			1

APPENDIX D - Transition Model Write-up

Kentucky Glade Cress Transition Model

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Initialization

This document was composed in R Studio using R Markdown (RStudio Team 2015).

Set working directory to location of input file and any desired output files. Load the etm package for empirical transition matrices of multi-state models.

```
setwd("...insert directory path here...")
library(etm)
library(ggplot2)
library(reshape2)
library(matrixStats)
```

First we read in a data file that contains four columns:

- *id* = rows labeled consecutively, arbitrary label
- *from* = initial state (EO rank)
- *to* = ending state (EO rank)
- *time* = amount of time between state changes, set to 1 for all rows, but represents 4 years in 1 time step

This data set was derived from a table from the Office of Kentucky Nature Preserves showing the Element Occurrence (EO) ranks for populations of Kentucky glade cress (*Leavenworthia exigua* var. *laciniata*) monitored in 1994 and 2004 and the element occurrence database for the species which included monitoring data up to 2019. Within the data set, the most common transition time (number of years between surveys) was about 4 years (2-6 years between surveys). We used this transition time to parameterize the transition model because it provided the most data. Initial states could be A (excellent resiliency), B (good resiliency), C (fair resiliency), or D (poor resiliency). Ending states included the same states, as well as X (extirpated).

While populations could transition by more than one rank in the 4-year time period (e.g., from A to D), we collapsed the data to indicate only whether a rank got better, worse, or stayed the same.

```
input26  <- read.csv("KYGCTransition_190925_2_6.csv", header=T)
head(input26)
```

```
##   id from to time
## 1 28    A  B    1
## 2 43    A  B    1
## 3 64    A  B    1
## 4 11    A  S    1
## 5 12    A  S    1
## 6 34    A  S    1
```

Then, we created an object (state.names) indicating what the different possible states are, and an object (tra) indicating what the possible state transitions are. In this R package, there cannot be "transitions" to the same state. Thus, the matrix object of possible transitions (tra) contains FALSE down the diagonal specifying to the program that transitions to the same state are not possible. If this step is omitted, the program will return an error. In our model, however, ranks can remain the same. Populations that remained in the same state (EO rank) after the time period were assigned a transition to "S" (for Same). For each initial state, possible final states were one rank above, one rank below, or the same rank.

```
state.names=c("A", "B", "C", "D", "X", "S")
tra <- matrix(FALSE, nrow= 6 , ncol= 6); colnames(tra)=state.names; rownames(
tra)=state.names
tra[1,2]=TRUE; tra[1,6]=TRUE; tra[2,1]=TRUE; tra[2,3]=TRUE; tra[2,6]=TRUE; tr
a[3,2]=TRUE
tra[3,4]=TRUE; tra[3,6]=TRUE; tra[4,3]=TRUE; tra[4,5]=TRUE; tra[4,6]=TRUE
tra
```

```
##       A     B     C     D     X     S
## A FALSE  TRUE FALSE FALSE FALSE  TRUE
## B  TRUE FALSE  TRUE FALSE FALSE  TRUE
## C FALSE  TRUE FALSE  TRUE FALSE  TRUE
## D FALSE FALSE  TRUE FALSE  TRUE  TRUE
## X FALSE FALSE FALSE FALSE FALSE FALSE
## S FALSE FALSE FALSE FALSE FALSE FALSE
```

Calculate Transition Matrix

We then used the etm() function to build the transition matrix for the 4-year transitions, including transition probabilities and covariances for each transition. The function used our input data object, list of state names, matrix of possible transitions, code for censored observations (NULL), starting time (0), and a command to compute the covariance matrix.

```
etm.out26= etm(input26,  state.names, tra, cens.name=NULL, s=0, covariance=TR
UE)
```

Then, we extracted from the model output the transition probabilities and covariance for each transition that appears in the data set.

Notice that the covariance for transitions from the A and B states are higher than those from the C and D states. There were only 9 and 15 populations, respectively, with an initial state of A and B, compared to 38 and 24 with an initial state of C and D. Lower sample sizes means less data to estimate transition probabilities from, leading to higher uncertainty around the transition estimates.

```
round(etm.out26$est,  digits=4)

## , , 1
##
##   A      B      C      D      X      S
## A 0 0.3333 0.0000 0.0000 0.0000 0.6667
## B 0 0.0000 0.7333 0.0000 0.0000 0.2667
## C 0 0.0526 0.0000 0.4211 0.0000 0.5263
## D 0 0.0000 0.1667 0.0000 0.0417 0.7917
## X 0 0.0000 0.0000 0.0000 1.0000 0.0000
## S 0 0.0000 0.0000 0.0000 0.0000 1.0000

trcov(etm.out26, "A S")

## [1] 0.02469136

trcov(etm.out26, "A B")

## [1] 0.02469136

trcov(etm.out26, "B A")

## [1] 0

trcov(etm.out26, "B S")

## [1] 0.01303704

trcov(etm.out26, "B C")

## [1] 0.01303704

trcov(etm.out26, "C B")

## [1] 0.001312145

trcov(etm.out26, "C S")

## [1] 0.006560723

trcov(etm.out26, "C D")
```

```
## [1] 0.006414929
trcov(etm.out26, "D C")
## [1] 0.005787037
trcov(etm.out26, "D S")
## [1] 0.006872106
trcov(etm.out26, "D X")
## [1] 0.001663773
```

Simulate Future Condition
Status Quo Scenario

In this scenario, select populations were projected into the future based on qualitative rules described in the SSA report. Briefly, populations with current conservation momentum were predicted to improve, and a population slated for subdivision development was predicted to decline. The remaining populations were projected using the transition probabilities calculated from the past monitoring data; specifically, the probability of each population improving a rank, falling a rank, or remaining at the same rank at 4-year intervals.

First we specified how many populations needing modeled were currently ranked good, fair, or poor (there were none ranked excellent that needed modeled), the number of time steps for the future simulation, and the number of replicates in the simulation. It was important that we run and combine the results from multiple replicates because of the stochastic (probabilistic) nature of the model, which will be described in more detail below.

```
n.B=2  # Number of populations to model  currently ranked 'good'
n.C=19 # Number of populations to model currently ranked 'fair'
n.D=42 # Number of populations to model currently ranked 'poor'
n.t=11 # Number of time steps including current, 0,4,8,12,16,20,24,28,32,36,4
0 years
n.sims=5000 # Number of replicates in simulation
```

We created a series of matrices where each row corresponds to one population. The first matrix contains the current rank, while the other matrices are empty, but of the same dimension, and will contain the projected rank of each population at 4-year intervals (i.e., Matrix #1 contains current rank, Matrix #2 will contain 4-year projection, Matrix #3 will contain 8-year projection, etc.).

Each matrix contains 5000 columns, corresponding to 5000 replicates of the future simulation. There are 2 populations ranked good, 19 populations ranked fair and 42 populations ranked poor that need modeled in this scenario.

```
Proj.frame= list()
Proj.frame[[1]]=data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hold
s aggregations at 0 years (Current)
    for (i in 1:n.B) Proj.frame[[1]][i,]="B"
    for (i in (n.B+1):(n.C+n.B)) Proj.frame[[1]][i,]="C"
    for (i in (n.B+n.C+1):(n.B+n.C+n.D)) Proj.frame[[1]][i,]="D"

Proj.frame[[2]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 4 years
Proj.frame[[3]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 8 years
Proj.frame[[4]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 12 years
Proj.frame[[5]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 16 years
Proj.frame[[6]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 20 years
Proj.frame[[7]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 24 years
Proj.frame[[8]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 28 years
Proj.frame[[9]] =data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 32 years
Proj.frame[[10]]=data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 36 years
Proj.frame[[11]]=data.frame(matrix(ncol = n.sims, nrow = (n.B+n.C+n.D))) #Hol
ds aggregations at 40 years
#View(Proj.frame[[1]]) # View first matrix to check dimensions and values
```

Uncertainty and probability were incorporated in two places:

1. Because transition probabilities between possible states were estimated from data, the estimated probabilities have uncertainty associated with them; we do not know the exact "true" transition probability. Within each of the 5000 replicates, we select a different value for each transition probability from a statistical distribution defined by the mean and covariance estimated from the transition data. This allows the model to explore the range of plausible transition probabilities.
2. Because transition probabilities are probabilities, there is an element of randomness in which outcome will occur at each time step. Even if an outcome is 99% likely to occur, the opposite outcome is still expected to occur 1% of the time. We incorporated this uncertainty by running `r n.sims` replicates of the model. By running many replicates of the simulation model, we can summarize the results and determine which outcomes are more or less likely to occur without being influenced by uncommon random outcomes.

Below, we defined the statistical distributions to incorporate the uncertainty in the transition probability estimates. A beta distribution was used rather than a normal distribution to bound the probability outcomes between 0 and 1. We generated figures showing what the resulting probability distributions look like for each transition.

```r
#First, a function to convert a mean and variance to the alpha and beta param
eters of a beta distribution
estBetaParams <- function(mu, var) {
  alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
  beta <- alpha * (1 / mu - 1)
  return(params = list(alpha = alpha, beta = beta))
}
BetaParms.BA=estBetaParams(trprob(etm.out26, "B A"), trcov(etm.out26, "B A"))
; BetaParms.BA# B improves a rank

## $alpha
## [1] NaN
##
## $beta
## [1] NaN

BetaParms.BS=estBetaParams(trprob(etm.out26, "B S"), trcov(etm.out26, "B S"))
; BetaParms.BS# B remains at rank

## $alpha
## [1] 3.733333
##
## $beta
## [1] 10.26667

BetaParms.BC=estBetaParams(trprob(etm.out26, "B C"), trcov(etm.out26, "B C"))
; BetaParms.BC# B falls a rank

## $alpha
## [1] 10.26667
##
## $beta
## [1] 3.733333

BetaParms.CB=estBetaParams(trprob(etm.out26, "C B"), trcov(etm.out26, "C B"))
; BetaParms.CB# C improves a rank

## $alpha
## [1] 1.947368
##
## $beta
## [1] 35.05263

BetaParms.CS=estBetaParams(trprob(etm.out26, "C S"), trcov(etm.out26, "C S"))
; BetaParms.CS# C remains at rank
```

```
## $alpha
## [1] 19.47368
##
## $beta
## [1] 17.52632
```

```
BetaParms.CD=estBetaParams(trprob(etm.out26, "C D"), trcov(etm.out26, "C D"))
; BetaParms.CD# C falls a rank
```

```
## $alpha
## [1] 15.57895
##
## $beta
## [1] 21.42105
```

```
BetaParms.DC=estBetaParams(trprob(etm.out26, "D C"), trcov(etm.out26, "D C"))
; BetaParms.DC# D improves a rank
```

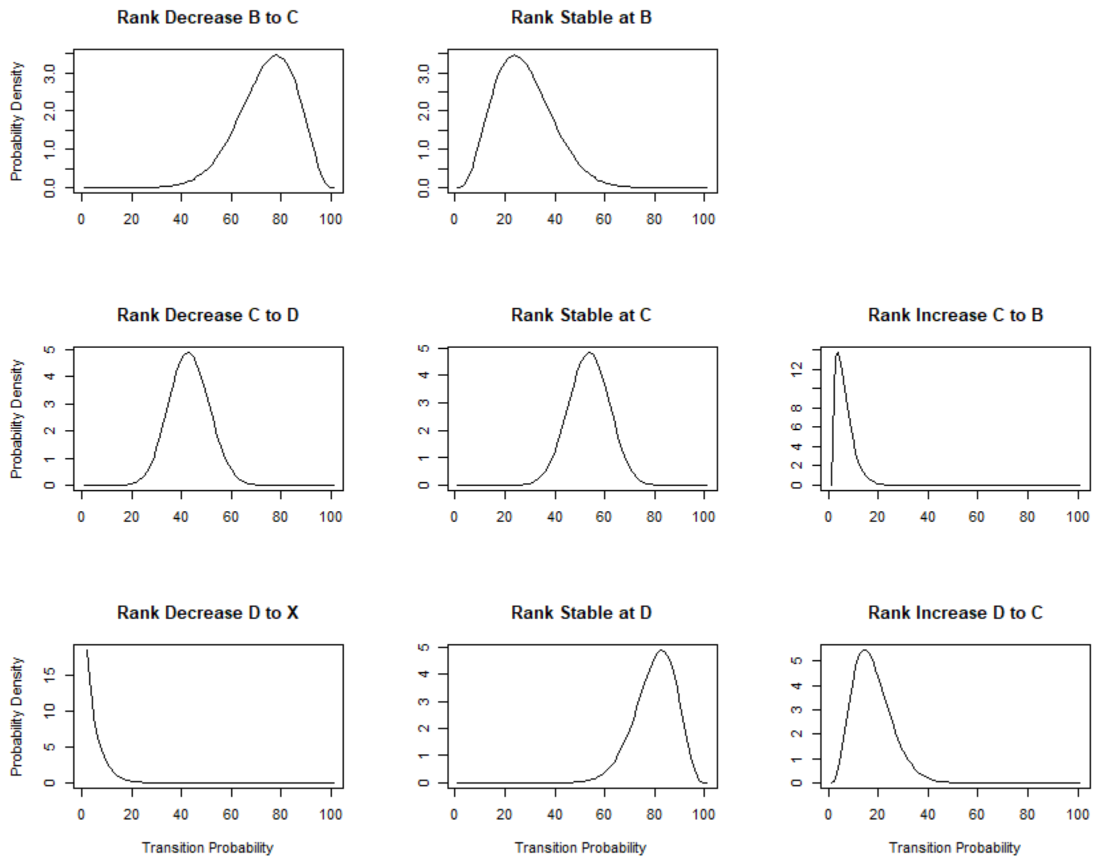
```
## $alpha
## [1] 3.833333
##
## $beta
## [1] 19.16667
```

```
BetaParms.DS=estBetaParams(trprob(etm.out26, "D S"), trcov(etm.out26, "D S"))
; BetaParms.DS# D remains at rank
```

```
## $alpha
## [1] 18.20833
##
## $beta
## [1] 4.791667
```

```
BetaParms.DX=estBetaParams(trprob(etm.out26, "D X"), trcov(etm.out26, "D X"))
; BetaParms.DX# D falls a rank
```

```
## $alpha
## [1] 0.9583333
##
## $beta
## [1] 22.04167
```



Then, we drew from these distributions to select one transition probability (one possible version of "the true probability") for each of the 5000 simulation replicates.

```
Prob.Trans=data.frame(matrix(ncol=8, nrow=n.sims)); colnames(Prob.Trans)=c( "
BStable", "BDecrease", "CIncrease", "CStable", "CDecrease","DIncrease", "DSta
ble", "DDecrease") # 6 columns, one each for the probability of rank increasi
ng, decreasing, or remaining stable
for (i in 1:n.sims) {Prob.Trans[i,]=c(rbeta(1, BetaParms.BS$alpha, BetaParms.
BS$beta), rbeta(1, BetaParms.BC$alpha, BetaParms.BC$beta),rbeta(1, BetaParms.
CB$alpha, BetaParms.CB$beta), rbeta(1, BetaParms.CS$alpha, BetaParms.CS$beta)
, rbeta(1, BetaParms.CD$alpha, BetaParms.CD$beta),rbeta(1, BetaParms.DC$alpha
, BetaParms.DC$beta), rbeta(1, BetaParms.DS$alpha, BetaParms.DS$beta), rbeta(
1, BetaParms.DX$alpha, BetaParms.DX$beta))}

head(Prob.Trans) # Take a look to make sure it worked

##     BStable BDecrease  CIncrease   CStable CDecrease  DIncrease   DStable
## 1 0.2404707 0.7287027 0.07339442 0.7126116 0.4848599 0.19434620 0.7399136
## 2 0.2498046 0.7386258 0.09152064 0.4649095 0.5208161 0.06569004 0.7374274
## 3 0.1855343 0.6200129 0.11880104 0.5181540 0.4122281 0.32907556 0.8206777
## 4 0.1375694 0.8859263 0.04792035 0.4706225 0.5747574 0.12146042 0.7224678
```

```
## 5 0.1328512 0.9706504 0.03591900 0.5472964 0.5149323 0.32150724 0.7971385
## 6 0.1294602 0.8411770 0.11599732 0.5761524 0.3827524 0.09215397 0.7581904
##      DDecrease
## 1 0.0118219893
## 2 0.0038131156
## 3 0.0557248598
## 4 0.0006770344
## 5 0.1740173074
## 6 0.0041632117
```

We now have generated 5000 different plausible versions of the "true" transition probabilities. Again, there is variation and uncertainty in what the true values are because they were estimated from data.

With those, we could then simulate future population ranks.

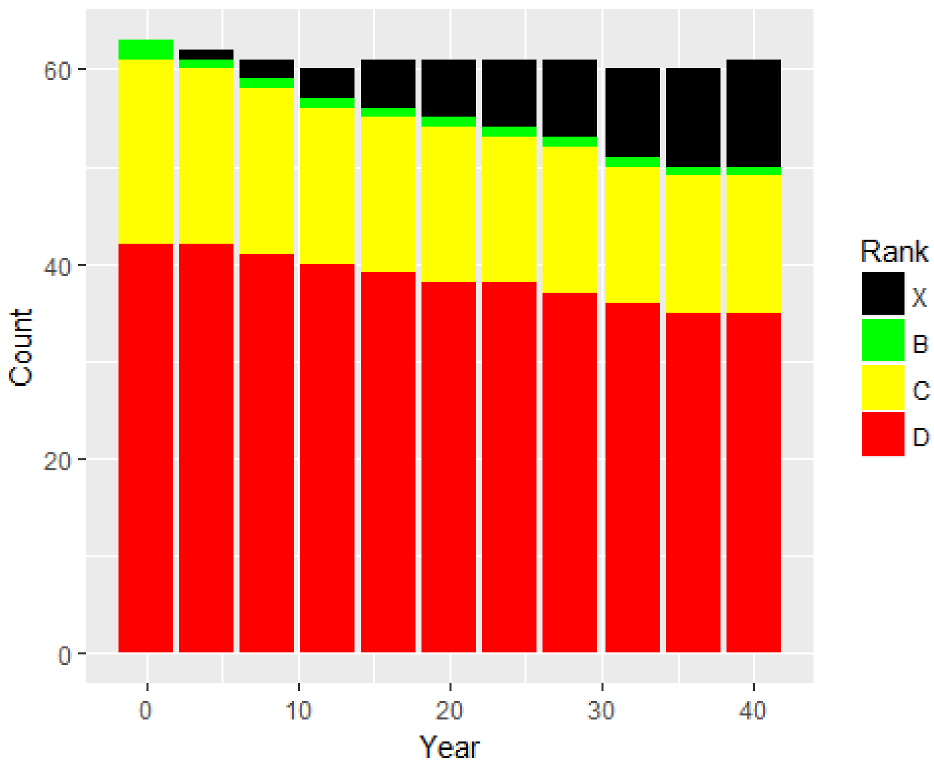
```
for (t in 2:n.t) { # projecting for time steps 2-11 (4-40 years, time step 1
= current condition)
  for(c in 1:n.sims) { # for each simulation replicate
    for(r in 1:nrow(Proj.frame[[1]])) { #for each population

if (Proj.frame[[t-1]][r,c]=="B") {
  temp.B=rmultinom(n=1, size=1, prob=Prob.Trans[c,1:2]); row.names(temp.B)=c(
"B", "C")
  Proj.frame[[t]][r,c]= rownames(temp.B)[which.max(temp.B)] }

if (Proj.frame[[t-1]][r,c]=="C") {
  temp.C=rmultinom(n=1, size=1, prob=Prob.Trans[c,3:5]); row.names(temp.C)=c(
"B", "C", "D")
  Proj.frame[[t]][r,c]= rownames(temp.C)[which.max(temp.C)] }

if (Proj.frame[[t-1]][r,c]=="D") {
  temp.D=rmultinom(n=1, size=1, prob=Prob.Trans[c,6:8]); row.names(temp.D)=c(
"C", "D", "X")
  Proj.frame[[t]][r,c]= rownames(temp.D)[which.max(temp.D)]  }

if (Proj.frame[[t-1]][r,c]=="X") {  Proj.frame[[t]][r,c]= "X"
 }



    }  }  }
```

The above model code produced a matrix for each 4-year time point with 5000 different possible outcomes for each population. The code below summarizes these results so we could work with them easier.

```
summary.1=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.1)= c("B
","C","D","X")
```

```
for (i in 1:n.sims) {summary.1[1,i]=sum(Proj.frame[[1]][,i]=="B")
                     summary.1[2,i]=sum(Proj.frame[[1]][,i]=="C")
                     summary.1[3,i]=sum(Proj.frame[[1]][,i]=="D")
                     summary.1[4,i]=sum(Proj.frame[[1]][,i]=="X")}
summary.2=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.2)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.2[1,i]=sum(Proj.frame[[2]][,i]=="B")
                     summary.2[2,i]=sum(Proj.frame[[2]][,i]=="C")
                     summary.2[3,i]=sum(Proj.frame[[2]][,i]=="D")
                     summary.2[4,i]=sum(Proj.frame[[2]][,i]=="X")}
summary.3=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.3)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.3[1,i]=sum(Proj.frame[[3]][,i]=="B")
                     summary.3[2,i]=sum(Proj.frame[[3]][,i]=="C")
                     summary.3[3,i]=sum(Proj.frame[[3]][,i]=="D")
                     summary.3[4,i]=sum(Proj.frame[[3]][,i]=="X")}
summary.4=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.4)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.4[1,i]=sum(Proj.frame[[4]][,i]=="B")
                     summary.4[2,i]=sum(Proj.frame[[4]][,i]=="C")
                     summary.4[3,i]=sum(Proj.frame[[4]][,i]=="D")
                     summary.4[4,i]=sum(Proj.frame[[4]][,i]=="X")}
summary.5=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.5)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.5[1,i]=sum(Proj.frame[[5]][,i]=="B")
                     summary.5[2,i]=sum(Proj.frame[[5]][,i]=="C")
                     summary.5[3,i]=sum(Proj.frame[[5]][,i]=="D")
                     summary.5[4,i]=sum(Proj.frame[[5]][,i]=="X")}
summary.6=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.6)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.6[1,i]=sum(Proj.frame[[6]][,i]=="B")
                     summary.6[2,i]=sum(Proj.frame[[6]][,i]=="C")
                     summary.6[3,i]=sum(Proj.frame[[6]][,i]=="D")
                     summary.6[4,i]=sum(Proj.frame[[6]][,i]=="X")}
summary.7=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.7)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.7[1,i]=sum(Proj.frame[[7]][,i]=="B")
                     summary.7[2,i]=sum(Proj.frame[[7]][,i]=="C")
                     summary.7[3,i]=sum(Proj.frame[[7]][,i]=="D")
                     summary.7[4,i]=sum(Proj.frame[[7]][,i]=="X")}
summary.8=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.8)= c("B
","C","D","X")
for (i in 1:n.sims) {summary.8[1,i]=sum(Proj.frame[[8]][,i]=="B")
                     summary.8[2,i]=sum(Proj.frame[[8]][,i]=="C")
                     summary.8[3,i]=sum(Proj.frame[[8]][,i]=="D")
                     summary.8[4,i]=sum(Proj.frame[[8]][,i]=="X")}
summary.9=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.9)= c("B
","C","D","X")
```

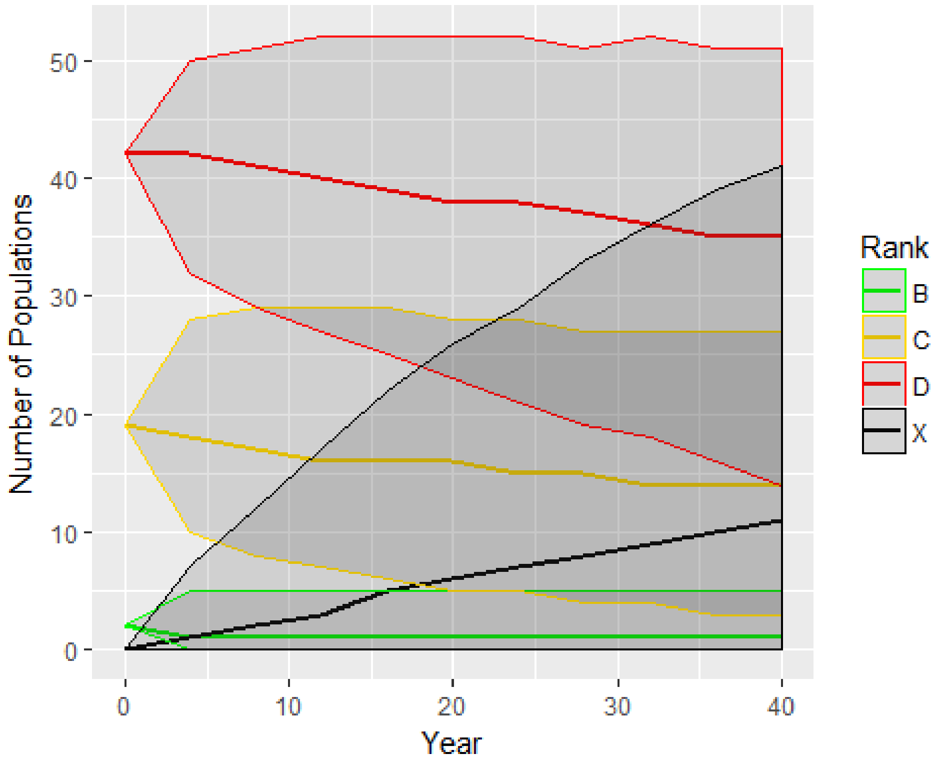
```
for (i in 1:n.sims) {summary.9[1,i]=sum(Proj.frame[[9]][,i]=="B")
                     summary.9[2,i]=sum(Proj.frame[[9]][,i]=="C")
                     summary.9[3,i]=sum(Proj.frame[[9]][,i]=="D")
                     summary.9[4,i]=sum(Proj.frame[[9]][,i]=="X")}
summary.10=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.10)= c(
"B","C","D","X")
for (i in 1:n.sims) {summary.10[1,i]=sum(Proj.frame[[10]][,i]=="B")
                     summary.10[2,i]=sum(Proj.frame[[10]][,i]=="C")
                     summary.10[3,i]=sum(Proj.frame[[10]][,i]=="D")
                     summary.10[4,i]=sum(Proj.frame[[10]][,i]=="X")}
summary.11=data.frame(matrix(ncol=n.sims, nrow=4)); row.names(summary.11)= c(
"B","C","D","X")
for (i in 1:n.sims) {summary.11[1,i]=sum(Proj.frame[[11]][,i]=="B")
                     summary.11[2,i]=sum(Proj.frame[[11]][,i]=="C")
                     summary.11[3,i]=sum(Proj.frame[[11]][,i]=="D")
                     summary.11[4,i]=sum(Proj.frame[[11]][,i]=="X")}

median.1=c(n.B,n.C, n.D, 0)
median.2= rowMedians(as.matrix(summary.2)); median.3= rowMedians(as.matrix(su
mmary.3))
median.4= rowMedians(as.matrix(summary.4)); median.5= rowMedians(as.matrix(su
mmary.5))
median.6= rowMedians(as.matrix(summary.6)); median.7= rowMedians(as.matrix(su
mmary.7))
median.8= rowMedians(as.matrix(summary.8)); median.9= rowMedians(as.matrix(su
mmary.9))
median.10= rowMedians(as.matrix(summary.10)); median.11= rowMedians(as.matrix
(summary.11))

medians=cbind(median.1, median.2, median.3, median.4, median.5, median.6, med
ian.7, median.8, median.9, median.10, median.11); colnames(medians)=c("0","4"
, "8", "12", "16", "20", "24", "28", "32", "36", "40"); rownames(medians)=c("
B", "C", "D", "X")
medians

##    0  4  8 12 16 20 24 28 32 36 40
## B  2  1  1  1  1  1  1  1  1  1  1
## C 19 18 17 16 16 16 15 15 14 14 14
## D 42 42 41 40 39 38 38 37 36 35 35
## X  0  1  2  3  5  6  7  8  9 10 11
```



Below, we show the estimates of the number of populations in each rank with 95% confidence intervals to capture the uncertainty. The 95% confidence intervals are calculated by capturing the envelope that contains the middle 95% of the `r n.sims` simulation replicates.

```
Quants.1= as.data.frame(rowQuantiles(as.matrix(summary.1), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.2= as.data.frame(rowQuantiles(as.matrix(summary.2), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.3= as.data.frame(rowQuantiles(as.matrix(summary.3), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.4= as.data.frame(rowQuantiles(as.matrix(summary.4), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.5= as.data.frame(rowQuantiles(as.matrix(summary.5), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.6= as.data.frame(rowQuantiles(as.matrix(summary.6), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.7= as.data.frame(rowQuantiles(as.matrix(summary.7), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.8= as.data.frame(rowQuantiles(as.matrix(summary.8), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.9= as.data.frame(rowQuantiles(as.matrix(summary.9), probs=c(0.025, 0.2
5, 0.5, 0.75, 0.975)))
Quants.10= as.data.frame(rowQuantiles(as.matrix(summary.10), probs=c(0.025, 0
```

```
.25, 0.5, 0.75, 0.975)))
Quants.11= as.data.frame(rowQuantiles(as.matrix(summary.11), probs=c(0.025, 0
.25, 0.5, 0.75, 0.975)))
```



More summarization here.

```
numpops=n.B+n.C+n.D
B20.med=(Quants.6t[1,3])/sum(Quants.6t[,3])*100; B20.low=(Quants.6t[1,1])/sum
(Quants.6t[,3])*100; B20.upp=(Quants.6t[1,5])/sum(Quants.6t[,3])*100
C20.med=(Quants.6t[2,3])/sum(Quants.6t[,3])*100; C20.low=(Quants.6t[2,1])/sum
(Quants.6t[,3])*100; C20.upp=(Quants.6t[2,5])/sum(Quants.6t[,3])*100
D20.med=(Quants.6t[3,3])/sum(Quants.6t[,3])*100; D20.low=(Quants.6t[3,1])/sum
(Quants.6t[,3])*100; D20.upp=(Quants.6t[3,5])/sum(Quants.6t[,3])*100
X20.med=(Quants.6t[4,3])/sum(Quants.6t[,3])*100; X20.low=(Quants.6t[4,1])/sum
(Quants.6t[,3])*100; X20.upp=(Quants.6t[4,5])/sum(Quants.6t[,3])*100

B20.medN=B20.med/100*numpops; B20.lowN=B20.low/100*numpops; B20.uppN=B20.upp/
100*numpops
C20.medN=C20.med/100*numpops; C20.lowN=C20.low/100*numpops; C20.uppN=C20.upp/
100*numpops
D20.medN=D20.med/100*numpops; D20.lowN=D20.low/100*numpops; D20.uppN=D20.upp/
100*numpops
X20.medN=X20.med/100*numpops; X20.lowN=X20.low/100*numpops; X20.uppN=X20.upp/
100*numpops
```

```
B40.med=(Quants.11t[1,3])/sum(Quants.11t[,3])*100; B40.low=(Quants.11t[1,1])/
sum(Quants.11t[,3])*100; B40.upp=(Quants.11t[1,5])/sum(Quants.11t[,3])*100
C40.med=(Quants.11t[2,3])/sum(Quants.11t[,3])*100; C40.low=(Quants.11t[2,1])/
sum(Quants.11t[,3])*100; C40.upp=(Quants.11t[2,5])/sum(Quants.11t[,3])*100
D40.med=(Quants.11t[3,3])/sum(Quants.11t[,3])*100; D40.low=(Quants.11t[3,1])/
sum(Quants.11t[,3])*100; D40.upp=(Quants.11t[3,5])/sum(Quants.11t[,3])*100
X40.med=(Quants.11t[4,3])/sum(Quants.11t[,3])*100; X40.low=(Quants.11t[4,1])/
sum(Quants.11t[,3])*100; X40.upp=(Quants.11t[4,5])/sum(Quants.11t[,3])*100

B40.medN=B40.med/100*numpops; B40.lowN=B40.low/100*numpops; B40.uppN=B40.upp/
100*numpops
C40.medN=C40.med/100*numpops; C40.lowN=C40.low/100*numpops; C40.uppN=C40.upp/
100*numpops
D40.medN=D40.med/100*numpops; D40.lowN=D40.low/100*numpops; D40.uppN=D40.upp/
100*numpops
X40.medN=X40.med/100*numpops; X40.lowN=X40.low/100*numpops; X40.uppN=X40.upp/
100*numpops
```

In the above figures, the populations do not necessarily add up to the original 63 during each year of the simulation because the values are taken from medians of 5000 simulation replicates. We want to translate the results back into the original 63 populations, and do so by calculating the percentage of the populations predicted to be at each rank in 20 and 40 years, and multiplying that percentage by the number of original populations.

After 20 years, out of 63 original populations modeled, 1.6393443 percent (0 - 8.1967213 percent) are predicted to have good resiliency, 26.2295082 percent (8.1967213 - 45.9016393 percent) are predicted to have fair resiliency, 62.295082 percent (37.704918 - 85.2459016 percent) are predicted to have poor resiliency, and 9.8360656 percent (0 - 42.6229508 percent) are predicted to be extirpated. This translates to 1.0327869 populations (0 - 5.1639344) predicted to have good resiliency, 16.5245902 populations (5.1639344 - 28.9180328) predicted to have fair resiliency, 39.2459016 populations (23.7540984 - 53.704918) predicted to have poor resiliency, and 6.1967213 populations (0 - 26.852459) predicted to be extirpated.

After 40 years, out of 63 original populations modeled, 1.6393443 percent (0 - 8.1967213 percent) are predicted to have good resiliency, 22.9508197 percent (4.9180328 - 44.2622951 percent) are predicted to have fair resiliency, 57.3770492 percent (22.9508197 - 83.6065574 percent) are predicted to have poor resiliency, and 18.0327869 percent (0 - 67.2131148 percent) are predicted to be extirpated. This translates to 1.0327869 populations (0 - 5.1639344) predicted to have good resiliency, 14.4590164 populations (3.0983607 - 27.8852459) predicted to have fair resiliency, 36.147541 populations (14.4590164 - 52.6721311) predicted to have poor resiliency, and 11.3606557 populations (0 - 42.3442623) predicted to be extirpated.

Conservation 1 Scenario

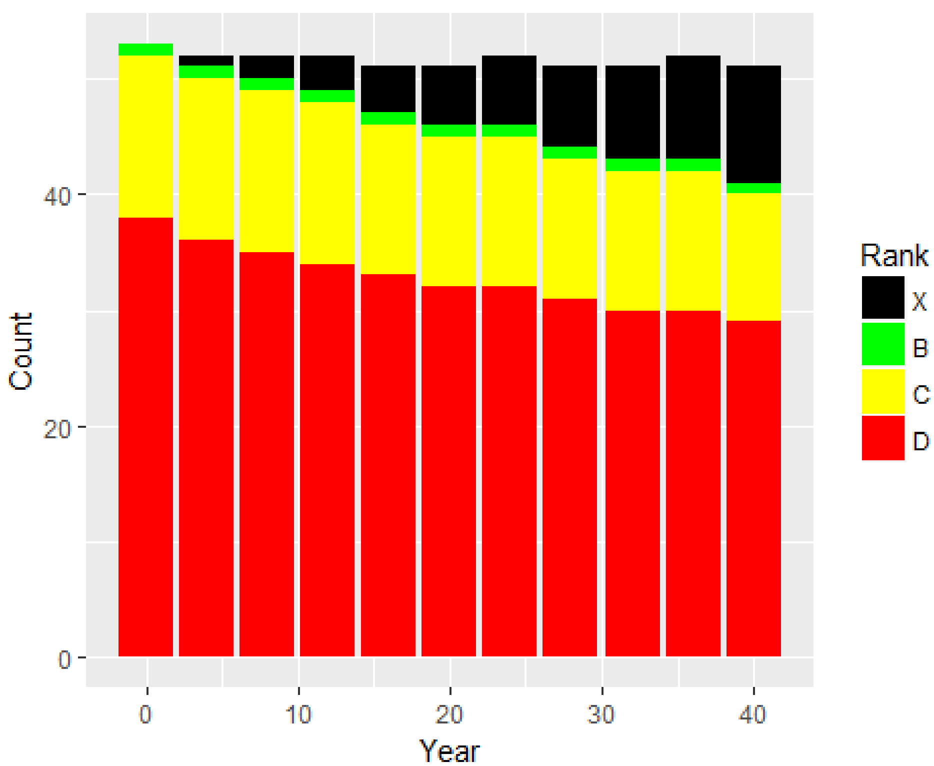
In the two Conservation treatments, the model and code remain the same, but the initial number of populations in each rank changed according to the scenarios.

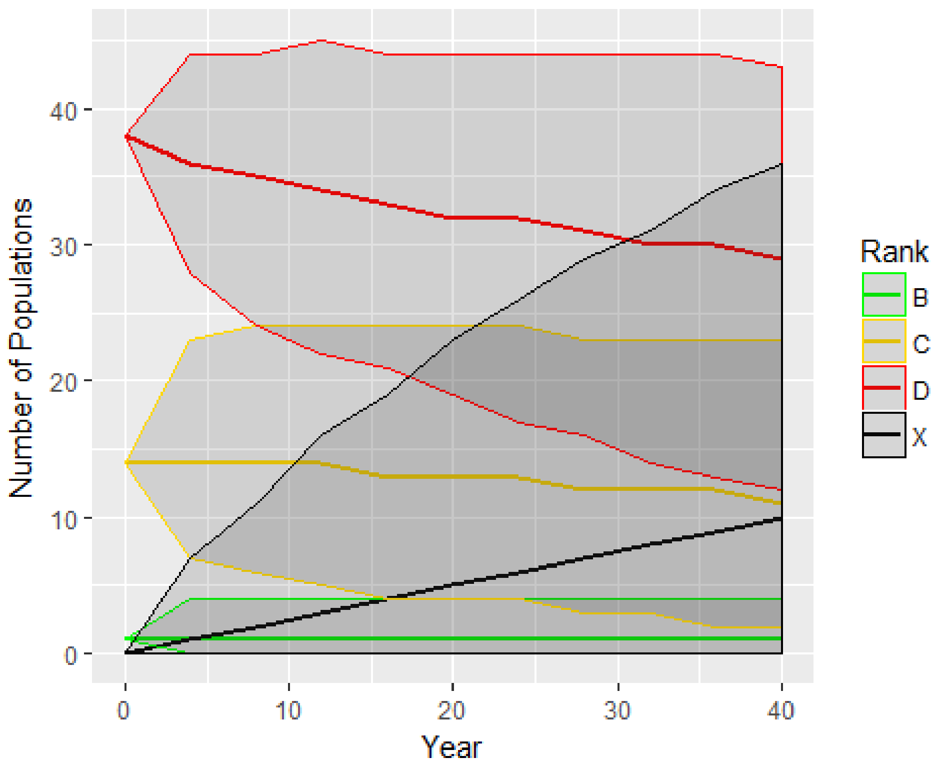
```
n.B=1  # Number of populations to model  currently ranked 'good'
n.C=14 # Number of populations to model currently ranked 'fair'
n.D=38 # Number of populations to model currently ranked 'poor'
n.t=11 # Number of time steps including current, 0,4,8,12,16,20,24,28,32,36,4
0 years
```

There was 1 population ranked good, 14 populations ranked fair, and 38 populations ranked poor that need modeled in this scenario.

The median number of populations in each rank at each time step are summarized below.

```
##     0  4  8 12 16 20 24 28 32 36 40
## B   1  1  1  1  1  1  1  1  1  1  1
## C  14 14 14 14 13 13 13 12 12 12 11
## D  38 36 35 34 33 32 32 31 30 30 29
## X   0  1  2  3  4  5  6  7  8  9 10
```





In the above figures, the populations do not necessarily add up to the original 53 during each year of the simulation because the values are taken from medians of 5000 simulation replicates. We want to translate the results back into the original 53 populations, and do so by calculating the percentage of the populations predicted to be at each rank in 20 and 40 years, and multiplying that percentage by the number of original populations.

After 20 years, out of 53 original populations modeled, 1.9607843 percent (0 - 7.8431373 percent) are predicted to have good resiliency, 25.4901961 percent (7.8431373 - 47.0588235 percent) are predicted to have fair resiliency, 62.745098 percent (37.254902 - 86.2745098 percent) are predicted to have poor resiliency, and 9.8039216 percent (0 - 45.0980392 percent) are predicted to be extirpated. This translates to 1.0392157 populations (0 - 4.1568627) predicted to have good resiliency, 13.5098039 populations (4.1568627 - 24.9411765) predicted to have fair resiliency, 33.254902 populations (19.745098 - 45.7254902) predicted to have poor resiliency, and 5.1960784 populations (0 - 23.9019608) predicted to be extirpated.

After 40 years, out of 53 original populations modeled, 1.9607843 percent (0 - 7.8431373 percent) are predicted to have good resiliency, 21.5686275 percent (3.9215686 - 45.0980392 percent) are predicted to have fair resiliency, 56.8627451 percent (23.5294118 - 84.3137255 percent) are predicted to have poor resiliency, and 19.6078431 percent (0 - 70.5882353 percent) are predicted to be extirpated. This translates to 1.0392157 populations (0 - 4.1568627) predicted to have good resiliency, 11.4313725 populations (2.0784314 - 23.9019608) predicted to have fair resiliency, 30.1372549 populations (12.4705882 - 44.6862745) predicted to have poor resiliency, and 10.3921569 populations (0 - 37.4117647) predicted to be extirpated.

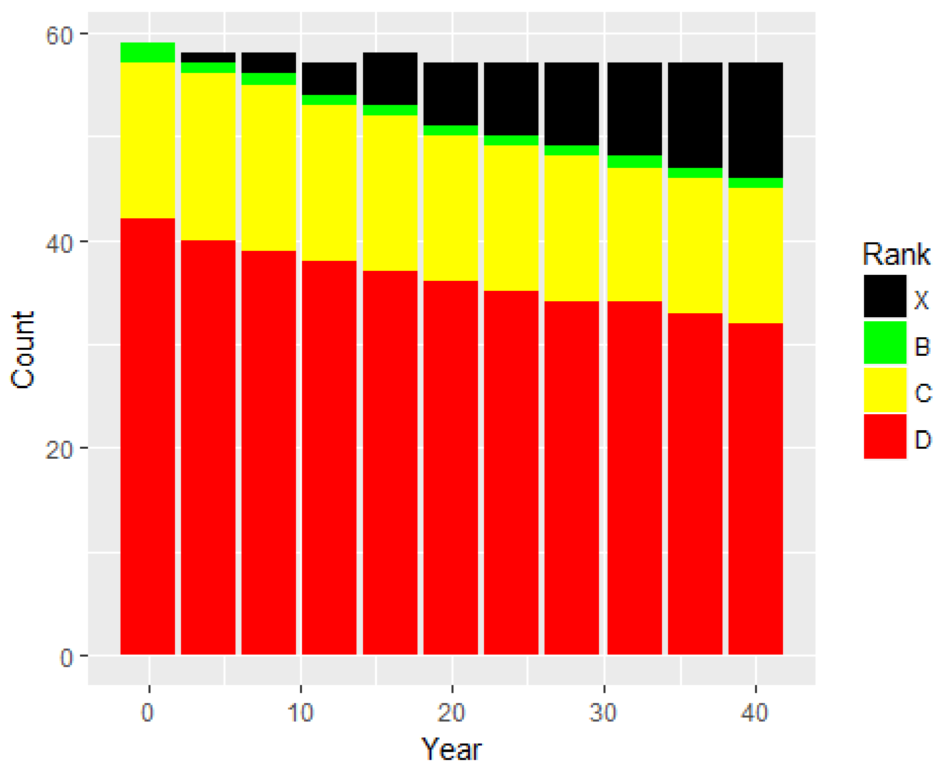
Conservation 2 Scenario

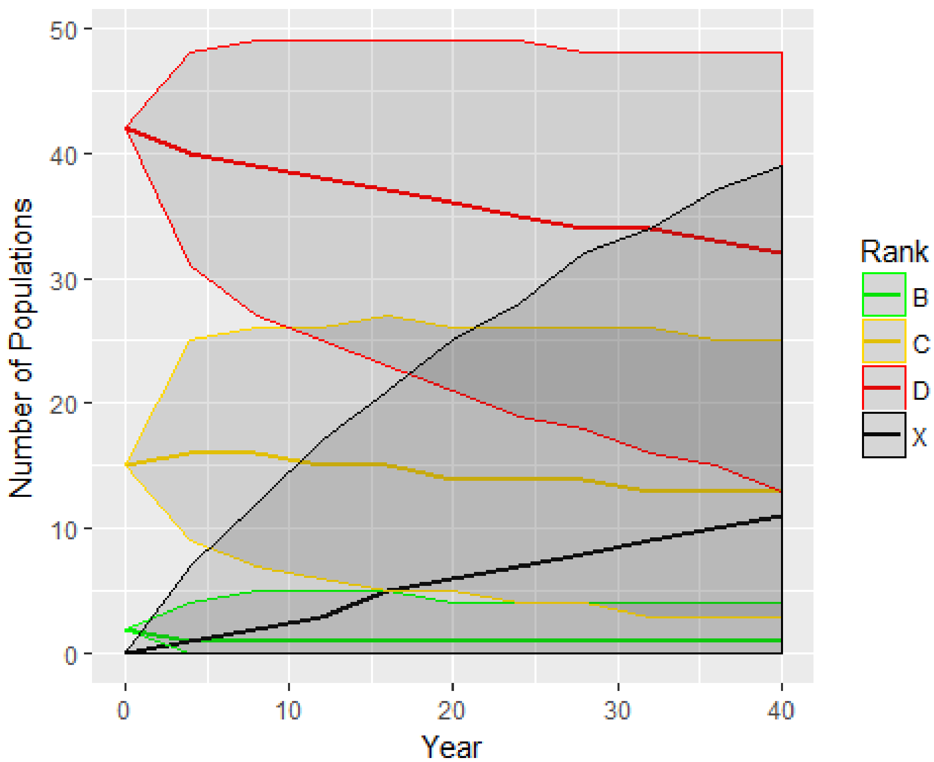
```
n.B=2  # Number of populations to model  currently ranked 'good'
n.C=15 # Number of populations to model currently ranked 'fair'
n.D=42 # Number of populations to model currently ranked 'poor'
n.t=11 # Number of time steps including current, 0,4,8,12,16,20,24,28,32,36,4
0 years
```

There were 2 populations ranked good, 15 populations ranked fair and 42 populations ranked poor that need modeled in this scenario.

The median number of populations in each rank at each time step are summarized below.

```
##     0  4  8 12 16 20 24 28 32 36 40
## B   2  1  1  1  1  1  1  1  1  1  1
## C  15 16 16 15 15 14 14 14 13 13 13
## D  42 40 39 38 37 36 35 34 34 33 32
## X   0  1  2  3  5  6  7  8  9 10 11
```





In the above figures, the populations do not necessarily add up to the original 59 during each year of the simulation because the values are taken from medians of 5000 simulation replicates. We want to translate the results back into the original 59 populations, and do so by calculating the percentage of the populations predicted to be at each rank in 20 and 40 years, and multiplying that percentage by the number of original populations.

After 20 years, out of 59 original populations modeled, 1.754386 percent (0 - 7.0175439 percent) are predicted to have good resiliency, 24.5614035 percent (8.7719298 - 45.6140351 percent) are predicted to have fair resiliency, 63.1578947 percent (36.8421053 - 85.9649123 percent) are predicted to have poor resiliency, and 10.5263158 percent (0 - 43.8596491 percent) are predicted to be extirpated. This translates to 1.0350877 populations (0 - 4.1403509) predicted to have good resiliency, 14.4912281 populations (5.1754386 - 26.9122807) predicted to have fair resiliency, 37.2631579 populations (21.7368421 - 50.7192982) predicted to have poor resiliency, and 6.2105263 populations (0 - 25.877193) predicted to be extirpated.

After 40 years, out of 59 original populations modeled, 1.754386 percent (0 - 7.0175439 percent) are predicted to have good resiliency, 22.8070175 percent (5.2631579 - 43.8596491 percent) are predicted to have fair resiliency, 56.1403509 percent (22.8070175 - 84.2105263 percent) are predicted to have poor resiliency, and 19.2982456 percent (0 - 68.4649123 percent) are predicted to be extirpated. This translates to 1.0350877 populations (0 - 4.1403509) predicted to have good resiliency, 13.4561404 populations (3.1052632 - 25.877193) predicted to have fair resiliency, 33.122807 populations (13.4561404 - 49.6842105) predicted to have poor resiliency, and 11.3859649 populations (0 - 40.3942982) predicted to be extirpated.