Species Status Assessment Report

for the

Rattlesnake-Master Borer Moth (*Papaipema eryngii*)

Version 1.1

Papaipema eryngii moth in Jim Wiker collection

Photo credit Jon Rapp

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Summary of Changes from Version 1.0

This version of the SSA report includes minor typographical corrections. The Literature Cited section was also updated to include all personal communications.

Suggested Reference

U.S. Fish and Wildlife Service. 2020. Species status assessment report for the rattlesnake-master borer moth (*Papaipema eryngii*). Version 1.1. Bloomington, MN.

Executive Summary

This report summarizes the results of a species status assessment (SSA) for the rattlesnake-master borer moth (*Papaipema eryngii*) to assess the species' viability, using the conservation biology principles of resiliency, representation, and redundancy (collectively, the 3Rs). In conducting the SSA, we compiled the best available scientific information regarding rattlesnake-master borer moth biology; individual, population, and species-level needs; and the factors that influence its viability. We used this information to evaluate and describe the current and projected future conditions of the species in terms of the 3Rs.

The rattlesnake-master borer moth inhabits primarily high quality remnant prairies and also some grassland, savanna, barrens, glades, and open woodland habitats in Arkansas, Illinois, Kansas, Kentucky, Missouri, and Oklahoma. The only host plant for the moth is rattlesnake-master (*Eryngium yuccifolium*) on which the moth larvae develop and eggs overwinter. Within known populations, the species relies on presence of its host plant and connectivity to other sites with host plant presence to have resilient populations. Rattlesnake-master borer moth populations may be positively or negatively influenced by land management activities that affect the host plant, including grazing, mowing, or fire (prescribed or naturally occurring), and negatively influenced by conversion of prairie, and herbicide or pesticide treatments.

We inferred some aspects of the species' historical distribution and population dynamics due to an incomplete record of its occurrence before massive conversion of its habitat took place. It is assumed that rattlesnake-master habitat was once widespread and, as a result, populations likely ebbed and flowed across the landscape in response to transient factors. These factors may have included grazing by bison, fire, and local weather conditions, including drought and flooding. Current knowledge of the species is primarily limited to presence/absence surveys with abundance and demographic information lacking.

To assess and compare resiliency of each rattlesnake-master borer moth population, we developed a semi-quantitative model that produced a "resiliency score" for each population. The model relies on three categories of interrelated metrics, including habitat parameters (number of stems of host plant, patch size or acres of suitable habitat with known host plant presence) and connectivity between known populations. To evaluate the degree to which the rattlesnake-master borer moth may be able to adapt to novel changes in its environment (representation), we used U.S. Department of Agriculture/Forest Service-defined plant hardiness zones to delineate areas with potential sources of unique adaptive diversity (referred to as representation units). We evaluated the rattlesnake-master borer moth current and future distribution within the representation units (RUs) to assess the degree of genetic and environmental diversity.

Increasing surveys over the last ten years have resulted in additional known population occurrences. Currently, the rattlesnake-master borer moth is known from 55 sites or populations in six states or three representation units. Of these 55 populations, 17 are highly resilient, 21 have medium resiliency, and 17 have low resiliency under current conditions. The 17 highly resilient populations represent 89 percent of the acreage where the species is known to occur. Populations in private ownership and management are characterized by smaller site size, lower host plant stem count, and resultant lower resiliency compared to sites in public ownership and management.

To assess the species' future viability, we evaluated how and to what extent those influences are expected to affect the species in three plausible future scenarios. Influences on species' viability include loss of suitable habitat (*i.e.*, habitat containing the obligate host plant, rattlesnake-master) from one of two factors: 1) from inappropriate management or lack of management of a site leading to succession of the vegetation, and 2) land use changes through urbanization and development. The three scenarios differ in intensity of management, highlighting the largest influence on the species, and are informed by land use change under predictive environmental/economic storylines. In all scenarios, plant hardiness zones are predicted to shift northward with an overwinter low temperature increase of 10°F. The warmer temperatures are not expected to affect the host plant or moth, as both are historically or currently found in the predicted plant hardiness zones.

Under scenario A, the 3Rs improved with increased host plant density to increase carrying capacity and resiliency within sites, and no loss of populations. Under scenario B, management is the same as the current condition, leading to the extirpation of three populations and a slight reduction in the 3Rs. We see the largest loss of resiliency in scenario C, with a loss of half of the populations in the southern RU and the same loss of three additional populations across the middle and northern RUs by 2039 as in scenario B. This loss of 12 populations results in the largest decline in representation and redundancy with resulting reduced viability for the species. In all scenarios, no loss of range is predicted to occur. We expect rattlesnake-master borer moth to persist in all future scenarios.

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Chapter 1. Introduction

1.1 Background

This report summarizes the results of a species status assessment (SSA) conducted for the rattlesnake-master borer moth (*Papaipema eryngii*). We, the U.S. Fish and Wildlife Service, were petitioned to list rattlesnake-master borer moth as either threatened or endangered with critical habitat on June 25, 2007 by Forest Guardians (now WildEarth Guardians). On August 14, 2013, we published a 12-month finding that listing of the rattlesnake-master borer moth is warranted, but precluded by higher priority actions (78 FR 49422).

1.2 Analytical Framework

The SSA is intended to be a concise review of the best scientific and commercial data available regarding the species' biology and factors that influence the species, 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 easily updated as new information becomes available and to provide the best available information for comparison to standards and policy to guide ESA decisions in regard to this species. The SSA will serve as the basis for listing, recovery planning, consultation, and conservation measures, but does not result in a decision. For development of the SSA, we utilized the latest version of the framework: SSA Framework version 3.4 (USFWS 2016), illustrated in Figure 1. The Service now uses this framework to inform all new candidate assessments, listing determinations and recovery plans, and encourages its use in other ESA decisions.

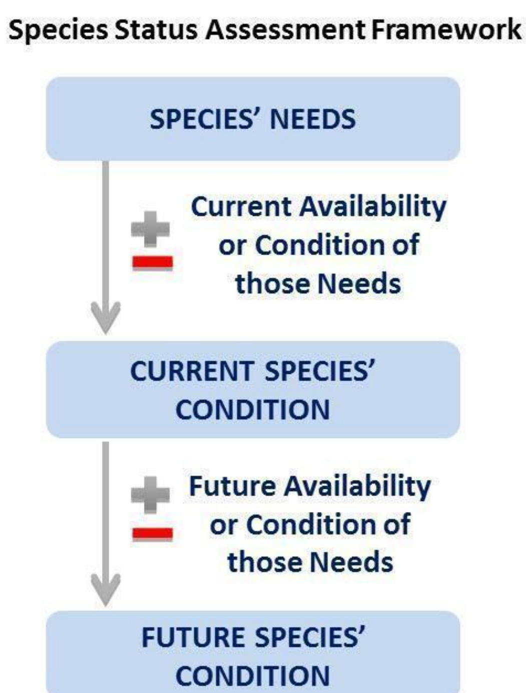


Figure 1. SSA framework in three iterative assessment stages.

For the purpose of this SSA, we define viability as the ability of a species to maintain populations in the wild over time. "Over time" means time periods as long as possible given the ability to predict future conditions that are biologically meaningful to the life history of the species. The SSA framework uses the conservation biology principles of resiliency, representation, and redundancy (collectively, the 3Rs) (Wolf *et al.* 2015, entire; Shaffer *et al.* 2002, pp. 139-140; Shaffer and Stein 2000, pp. 308-311). These are summarized below:

- Resiliency is defined as the ability of the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size, if that information is available. Healthy populations are more resilient and better able to withstand stochastic disturbances, such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall or temperature (environmental stochasticity), or the effects of human activities.

- Representation is defined as the ability of a species to adapt to changing environmental conditions over time. Changing environmental conditions may include physical factors of climate or habitat characteristics or biological factors of disease, pathogens, or predators. Representation can be measured through the breadth of genetic diversity within and among populations, if known, and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the greater the ability to adapt to changes (natural or human caused) and stochastic events in its environment.

- Redundancy is defined as the ability of a species to withstand catastrophic events, rare destructive natural events or episodes involving many populations and occurring suddenly or unexpectedly. Redundancy is about spreading the risk and can be measured through the duplication and distribution of resilient populations across the range of the species. The greater the number of resilient populations a species has distributed over a larger landscape, the better it can withstand catastrophic events. Redundancy guards against irreplaceable loss of representation (Tear *et al.* 2005, p. 841; Redford *et al.* 2001, p. 42) and minimizes the effect of localized extirpation on the range-wide persistence of a species (Shaffer and Stein 2000, p. 308).

1.3 Methodology

To inform this assessment of rattlesnake-master borer moth current and future viability, we first reviewed and assessed all known survey records for the species to infer population structure and delineate populations. We then identified the ecological requirements for survival and reproduction at the individual, population, and species levels and the past and ongoing factors expected to influence the species' current and future conditions. In coordination with species experts, we elicited input on the accuracy of our potential influences and the magnitude of effect such influences are likely to have on rattlesnake-master borer moth. We used all of these factors to describe the current condition in terms of the 3Rs. Supporting information, calculations, and additional reference information related to current and future conditions is provided in Appendix A to this document.

The future biological status was then analyzed using a range of plausible future scenarios informed by the primary factors affecting the species in terms of the 3Rs. These scenarios do not include all possible futures, but rather include specific plausible scenarios that assess demographic risks, threats, and limiting factors in the context of determining the future viability of the species. These scenarios represent examples from the continuous spectrum of possible futures. The species' ecology is summarized in Chapter 2, the historical and current conditions in Chapter 3, and the future condition in Chapter 4.

Chapter 2. Species Ecology

In this section, we provide basic biological information about the rattlesnake-master borer moth, including taxonomic history, morphological description of life stages, reproductive and life history traits, species' needs (Table 2-1), and habitat requirements. This is not an exhaustive review of the species' natural history; rather, it provides the ecological basis for the SSA analysis.

2.1 Species Taxonomy and Description

Taxonomy

The rattlesnake-master borer moth (*Papaipema eryngii*) is a member of the family Noctuidae (owlet moths) and was first described in 1917 from individuals collected near Chicago, Illinois (Bird 1917, pp. 125-128). The genus *Papaipema* contains 47 described and several undescribed species, all of which are found in North America and are root- or stem-boring (Schweitzer *et al.* 2011, p. 349; Lafontaine and Schmidt 2010, p. 79-80; Panzer 1998, p. 48).

Description

The adult rattlesnake-master borer moth measures 3.5–4.8 centimeters (cm) (1.4–1.9 inches) in wingspan (Bird 1917, p. 125). Both sexes are purple-brown with small, scattered yellow and white spots (Bird 1917, p. 125). Flight-worn moths appear lighter in color after darker scales have fallen away after a few nights of flying and crawling through vegetation, although the large white spots typically remain distinctive. Males have distinctive genitalia that allow distinction from other *Papaipema* (Wiker 2017a, p. 13; Forbes 1954, p. 193; Bird 1917, p. 126). Rattlesnake-master borer moth larvae appear similar to other *Papaipema* larvae, but retain longitudinal white and purplish-striped markings until the last instar, when the purple fades and the larvae become mostly dull yellowish-white with scattered, raised, dark-brown spots.

2.2 Individual-level ecology

Life History

Rattlesnake-master borer moth has a single flight per year, with adults emerging from mid-September to early October and flying through mid-October or until killing frosts (Bess 2018b, pers. comm.; Wiker 2017a, pp. 19, 24; Hessel 1954, p. 59; Forbes 1954, p. 198; Bird 1917, p. 128). Larvae in southern populations emerge in mid-April to early May, up to a month before those in Illinois, but adults emerge from their pupae about a month later than northern populations, likely reflective of local temperature regimes and length of growing season (Bess 2019, pers. comm.). The adult flight period and breeding period is approximately 10 days of peak flight, with the greatest concentration of adults noted the last week of September (Wiker 2018, pers. comm.; Wiker 2017a, p. 37). *Papaipema* females seldom fly before breeding, and rattlesnake-master borer moth is expected to follow this pattern (Wiker 2018, pers. comm.). Adult moths live 10-14 days (Wiker 2017a, p. 19). Milder weather conditions in the southern part of the species' range may allow the flight period to extend into November (Bess 2018b, pers. comm.).

Adult rattlesnake-master borer moth feeding habits are largely unknown. Based on their short flight period, general scarcity of seasonal nectar sources in the fall, and large fat stores in adults, researchers postulate that adult moths likely do not feed much from nectar sources and likely use dew, puddles, aphid residue, or oozing sap for moisture and nutrients (Bess 2018b, pers. comm.; Wiker 2018, pers. comm.). Adults will drink from sugar water when held in captivity (Wiker 2017a, p. 40; LaGesse 2013, pers. comm.), extending the adult moth lifespan by several days (Wiker 2018, pers. comm.). Based on their coloring, adult moths likely spend their days camouflaged and attached to plants or on the bottoms of leaves (Wiker 2018, pers. comm.).

Mating occurs during the flight period after which females lay eggs in creases or folds on dead, dying, or green leaves of rattlesnake-master (*Eryngium yuccifolium*) (Wiker 2017a, p. 3), where the eggs overwinter. Eggs darken a few days before larvae emerge between early May (southern portion of range) and early June (Wiker 2017a, p. 3; Derkovitz 2013, pers. comm.; LaGesse *et al.* 2009, p. 4; Bird 1917, p. 126). Rattlesnake-master is the only food source for the larvae (Panzer 2003, p. 18; Hessel 1954, p. 59; Forbes 1954, p. 198; Bird 1917, p. 124), which are internal plant feeders, boring into stems and root of the host plant. The first larval instar often feeds behind new growth of a leaf or stem until capable of chewing into the harder growth and then enters the stem. Subsequent instars bore into the leaf whorl and burrow down to the root (Bess 2018a, p. 13; Wiker 2017a, p. 3). Larvae generally finish feeding by mid- to late July after reaching the root crown and then begin to burrow into the bulb or root. The fifth instar will then stay in the root chamber and aestivate for several weeks before triggered to pupate in mid-August to mid-September (Wiker 2017a, p. 8; Derkovitz 2013, pers. comm.; LaGesse *et al.* 2009, p. 4; Bird 1917, p. 127). Pupation appears to take place either inside the feeding chamber in the root or in the soil next to the root and lasts 3-4 weeks (Wiker 2017a, p. 8; Derkovitz 2013, pers. comm.; LaGesse *et al.* 2009, p. 4; Bird 1917, p. 127). Before pupation, larvae may construct a short silken tube to the soil surface to allow the emerging moth to reach the surface (Wiker 2017a, p. 36).

During the time of actively boring into the host plant, some larvae exhibit competitive behavior by moving into already occupied bore holes, killing the occupant and consuming it or pushing it back out (LaGesse *et al.* 2009, p. 4). Multiple larvae may occur in a single stem early in the season, but by early June, only one larva remains. Those not killed and eaten by cannibalistic larvae move to another plant (Wiker 2018, pers. comm.). When an older larva is located in a host plant insufficient for its needs, the larva can move to a different host plant on which it continues to develop normally, although this plant-to-plant movement is uncommon (Wiker 2017a, p. 8). One rattlesnake-master clump may contain multiple stems and multiple larvae.

Although there are no specific data on their home range, rattlesnake-master borer moths are not thought to disperse widely and have been described as "relatively sedentary" (LaGesse *et al.* 2009, p. 4; Panzer 2003, p. 18). Panzer (2003, p. 19) found that female rattlesnake-master borer moths dispersed up to 120 meters (m) (394 feet (ft)) from where they were released and some traversed a 25-m (82-ft) gap that was devoid of host plants. Rattlesnake-master borer moths appear to be capable of dispersal of up to 2 miles (3.2 kilometers (km)) if the number of host plants is limiting (Wiker 2018, pers. comm.; LaGesse *et al.* 2009, p. 4). Recolonization of sites after prescribed fires in Missouri show that adult moths are able to fly at least two miles to seek out new breeding habitat (Wiker 2017a, p. 34). Farther dispersal may be aided by wind or severe weather events, and some females appear to disperse more widely just before death (Wiker 2018, pers. comm.).

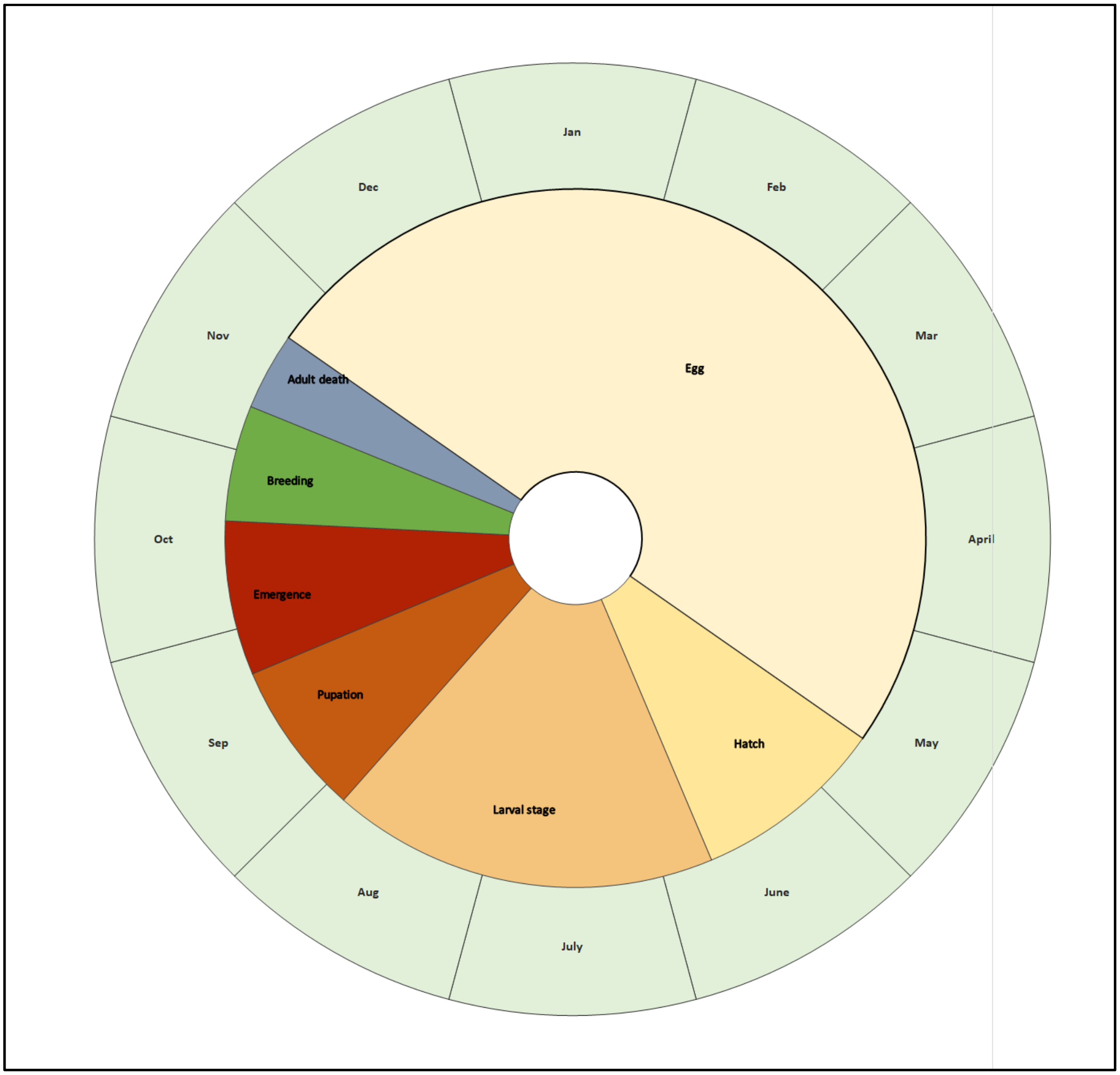


Figure 2-1. Rattlesnake-master borer moth single year life cycle.

Habitat

Rattlesnake-master borer moths are obligate residents of undisturbed prairie, barrens, savanna, and woodland openings that contain rattlesnake-master, the sole larval food plant (Bess 2018a, pp. 11-13; Schweitzer *et al.* 2011, p. 351; LaGesse *et al.* 2009, p. 4; Panzer 2002, p. 1298; Molano-Flores 2001, p. 1; Panzer *et al.* 1995, p. 115; Mohlenbrock 1986, p. 34; Forbes 1954, p. 198; Hessel 1954, p. 59; Bird 1917, p. 124). Rattlesnake-master borer moth was thought not to occur outside of a true prairie or prairie remnant; however, populations in Missouri and Arkansas were found in roadsides, savannahs, glades, and woodland openings with moist, well-drained soils (Wiker 2018, pers. comm.; AGFC 2017, p. 1; Wiker 2017a, pp. 47-102). The term “prairie” will be used in this report as the primary habitat type for rattlesnake-master borer moth, but it is understood that other habitat types are also suitable to support the species and host plant.

Prairie habitat that support populations of rattlesnake-master borer moth have evolved with and been maintained by three primary disturbance factors: periodic drought, fire, and grazing (Robertson *et al.* 1997, pp. 56-59). Without periodic disturbance, prairies are subject to expansion of woody plant species (secondary succession), litter accumulation, or invasion by nonnative plant species (*e.g*., smooth brome) (Schweitzer *et al*. 2011, p. 40; Skadsen 2003, p. 52; Higgins *et al*. 2000, p. 21; Panzer and Schwartz 2000, p. 363; Dana 1997, p. 5; McCabe 1981, p. 191).

Although rattlesnake-master is found in remnant prairies, it occurs in low densities and is considered a conservative species, which is characterized by resistance to environmental stressors such as fire, drought, and low soil fertility (Maracahipes *et al.* 2018, p.18). Rattlesnake-master has been found to have relative frequencies in restored and relict prairies of less than 1 percent (Danderson and Molano-Flores 2010, p. 235; Molano-Flores 2001, p. 1) to approximately 5 percent in some managed prairie sites (Fowler 2018, pers. comm.; Scheiman 2018, pers. comm.). The range of rattlesnake-master covers much of the eastern United States and spans from Minnesota south to Texas, east to Florida and back north to Connecticut (USDA 2018).

Plant hardiness zones have been developed by the U.S. Department of Agriculture (USDA) (Matthews *et al*. 2019, entire; Matthews *et al*. 2018, entire) to identify environmental conditions under which a species or variety of plant can successfully survive and grow and a general indication of the extent of overwinter stress experienced by plants. Plant hardiness zones are based on the average annual extreme minimum temperatures and are used to evaluate the cold hardiness of plants (Daly *et al.* 2012, p. 242; Cathey 1990, p. 4) and are delineated by 10°F (5.56°C) increments. Zone designations are associated with growing season length, but this information is not used to develop plant hardiness zones. Because they reflect cold tolerance for many plant species, hardiness zones are most likely to reflect plant range limits. Rattlesnake-master is found in twenty-six states from Minnesota in zone three in the north to Florida in zones nine and ten in the south (Figure 2-2), although rattlesnake-master borer moth is currently known from a more restricted range (zones 5 to 7).

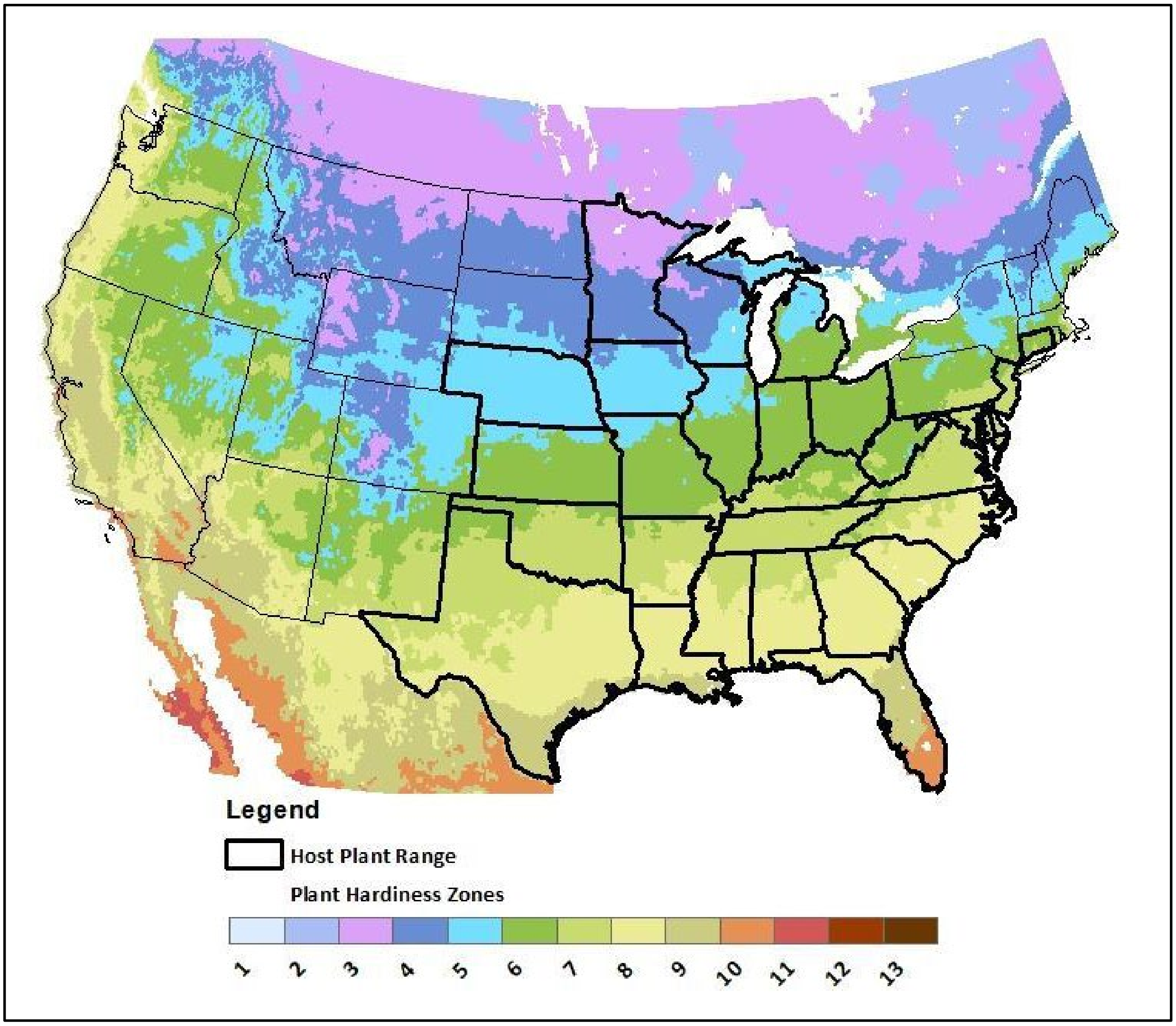


Figure 2-2. Rattlesnake-master plant range by 2009 plant hardiness zone (Matthews *et al*. 2019, Matthews *et al*. 2018).

Although the plant has an expansive range, the loss of tallgrass prairie is estimated to be between 82 to 99 percent, with most estimates at greater than 98 percent loss (Noss *et al.* 1995, Appendix A; Samson and Knopf 1994, p. 418). Most high-quality prairies that remain are small and scattered across the landscape (Robertson *et al.* 1997, p. 63). In Missouri, approximately 0.63 percent of the presettlement tallgrass prairie remains and is primarily confined to southwest Missouri (Solecki and Toney 1986, p. 169). Of the 253 high-quality prairies identified in Illinois, 83 percent were smaller than 10 acres (4 hectares) and 30 percent were smaller than 1 acre (0.4 hectare) (Robertson *et al.* 1997, p. 63). Most prairie destruction occurred between 1840 and 1900 (Robertson *et al.* 1997, p. 63), prior to the description of rattlesnake-master borer moth.

Although rattlesnake-master is relatively common in remaining prairie and other suitable habitat, rattlesnake-master borer moth is found only in a subset of the available habitat. Surveys have been conducted in prairies of similar quality and size that contain rattlesnake-master in Indiana, Iowa, Florida, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee (Bess

2018a, p. 107; Wiker 2017b, p 20; Casebere 2012, pers. comm.); however, no additional populations have been found. Wiker (2017a, p. 20) surveyed 25 sites in 17 counties in Iowa without detecting the moth. From 2016 to 2018, 209 sites were surveyed in Florida, Louisiana, Mississippi, North Carolina, South Carolina, Arkansas, and Tennessee (Bess 2018a, p. 15). Although suitable habitat was searched in each state, the only new populations of rattlesnake-master borer moth were found in Arkansas where eight new populations were discovered (Bess 2018a, p. 16). Many sites with suitable habitat for the moth have been surveyed in Indiana since the early 1990s (Casebere 2012, pers. comm.); however, the species has never been found in the state. We know of surveys conducted in 14 states in suitable habitat with healthy populations of rattlesnake-master since the early 1900s. Rattlesnake-master borer moth is currently extant in 6 of those states, and it is unknown what other factors may make habitat unsuitable if the host plant is present.

Table 2-1. Life history and primary resource requirements of rattlesnake-master borer moth.

Life stage	Resource requirements
Egg	Host plant dead lower leaves
Larva	Growing host plant
Pupa	Undisturbed host plant root chamber and surrounding soil
Adult	Host plant within flight distance (≤2 miles)
Adult	Sufficient population size to allow breeding

2.3 Population-level ecology

For the purposes of this assessment, a population is considered to be those rattlesnake-master borer moths in a patch (discrete occupied area) of suitable habitat (containing rattlesnake-master) greater than two miles away from another patch with known rattlesnake-master borer moth presence such that dispersal or genetic exchange is reasonably unlikely to occur. These isolated prairie areas may be connected by smaller unoccupied habitat patches or isolated rattlesnake-master plants and occur within a matrix of suitable and unsuitable habitat across the landscape. Rattlesnake-master generally exhibits an uneven distribution within habitat patches based on microhabitat variables and past and ongoing management practices. A healthy rattlesnake-master borer moth population is characterized by a large patch size supporting a high number of rattlesnake-master stems connected to another healthy population via suitable habitat (Table 2-2). Populations may be limited by dispersal barriers, including large rivers, urban areas and areas greater than two miles with no host plant occurrence.

As population sizes have not been reported in presence/absence surveys for rattlesnake-master borer moth and no population viability analysis has been attempted, comparison to minimum viable population sizes are not possible.

Table 2-2. Rattlesnake-master borer moth population requirements affecting viability.

Population parameter	**Resource requirement**
abundance	number of stems of host plant
demographics	host plant required for all stages
emigration/immigration	connectivity to another population within 2-mile dispersal distance
habitat condition	management of succession
area occupied	larger patch size increases viability

Demographic and Habitat Considerations

The number of rattlesnake-master plants and the size and connectivity of habitat patches needed to ensure population viability is unknown. Suitable habitat must include the rattlesnake-master host plant. Due to the behavior of rattlesnake-master borer moth at the larval stage, a maximum of one adult is produced per rattlesnake-master root (Bess 2018a, p. 13; Wiker 2017a, p. 4). Thus, we can infer a potential maximum population size, based on stem count. However, this potential maximum is not reflective of actualized carrying capacity on a site, as not all stems are infested and not all impacted stems contain a rattlesnake-master borer moth larva. In addition, the presence, relative frequency and density of the plant or overall patch size do not necessarily correlate to likelihood of occurrence of the moth (Wiker 2018, pers. comm.; Wiker 2017a, pp. 48-102). Patches of host plants within one to two miles of occupied patches allow for potential dispersal and colonization (Wiker 2017a, p. 4; LaGesse *et al.* 2009, p. 4). Dispersal over greater distances with no host plant may be possible when flight is aided by wind or weather events (Wiker 2017a, pp. 24, 30). Larvae in occupied patches of host plant, particularly small patches, are likely the offspring of one female. If offspring from this small patch do not disperse to breed, the negative effects of inbreeding may occur, decreasing fitness. The specific optimal amount of habitat and its spatial distribution are not known; more research is needed on optimal distances between habitat patches, as well as optimal patch sizes.

Persistence of a population after disturbance is dependent on connectivity to occupied patches. Small "stepping stone" patches of rattlesnake-master may link populations, allowing dispersal and gene flow. For example, the occupied habitats in Arkansas are more diverse than other states and may be reliant on these small woodland, glade, or roadside patches to connect larger areas of suitable habitat (Wiker 2018, pers. comm.). Population viability is also dependent on connectivity among occupied patches to ensure mating of unrelated individuals and connectivity among populations to maintain within-population genetic diversity. Lack of suitable dispersal habitat across a landscape may limit recolonization of previously occupied patches.

Dispersal of individuals from these small, isolated populations avoids the negative effects of inbreeding depression, including potential extirpation or extinction (Frankham 2005, p. 133; Saccheri *et al.* 1998, p. 491). Small, isolated populations are likely to become unviable over time due to lower genetic diversity resulting in a decrease in the ability to adapt to environmental change (Frankham *et al.* 2009, pp. 309-335). Populations also depend on appropriate management of occupied patches to promote host plant occurrence and rattlesnake-master borer moth continued presence. Site management through setback of succession is strongly related to sustainability and likelihood of presence (Bess 2018a, pp. 125-126; Wiker 2017a, pp. 28-29). Management as an influence on viability is further discussed in Chapter 3.

Very little is known about the demographics and age structure of rattlesnake-master borer moth populations. Management actions (*e.g.*, prescribed fire or mowing/grazing) or naturally-occurring fires during the overwintering period may drastically reduce or eliminate eggs within a population (Figure 2-1). High mortality of first instar larvae is expected due to exposure to predation and lack of suitable host plants; later stage larval mortality is also due to intraspecific and congeneric competition with other borers in the host plant. Mortality related to cold temperatures is expected in adult moths with a late fall flight period.

Rattlesnake-master borer moth is thought to be less sensitive to environmental conditions other than conditions affecting the host plant. Repeated presence/absence surveys conducted on the same site observe that rattlesnake-master borer moth does not appear to exhibit large swings in population numbers year-to-year (Wiker 2017a, p. 29).

2.4 Species-level ecology

The ecological needs for the rattlesnake-master borer moth at the species level include sufficient number, health, and distribution of populations to ensure it can withstand stochastic events (resiliency), novel biological and physical changes in its environment (representation), and the ability to withstand catastrophic events (redundancy).

Resiliency

Rattlesnake-master borer moth resiliency is a function of the number and distribution of healthy populations. Healthy populations are better able to recover from stochastic events and withstand variation in the environment. Generally speaking, the greater the number of healthy populations and spatial heterogeneity occupied by the species, the greater likelihood of sustaining populations through time. Connectivity among healthy populations is an important factor for rattlesnake-master borer moth, especially for small populations. Connectivity of populations helps ensure gene flow and recolonization of populations impacted by stochastic events.

Representation

In the absence of species-specific genetic and ecological diversity information, we can evaluate representation based on the extent and variability of environmental conditions within the species' geographic range. We delineated areas with potential sources of unique adaptive diversity (referred to as representation units, described in Chapter 3). Representation units are used to express the adaptive potential of the species that results from the range of environmental conditions. To ensure the breadth of diversity is preserved, healthy populations should be maintained in the representation units with connectivity between populations to ensure genetic exchange.

Redundancy

Redundancy for rattlesnake-master borer moth is characterized by having multiple resilient populations distributed across the breadth of its geographical variation (*i.e.*, representation units), thereby reducing the likelihood that all populations are exposed simultaneously to the effects of catastrophic events. We considered drought and fire as potential catastrophic events for rattlesnake-master borer moth. Widespread, prolonged (multi-state, multi-year) drought that diminishes host plant occurrence could be catastrophic for the species. In addition, an increase in catastrophic fire as a result of increased drought was considered as a potential catastrophic scenario. Based on input from site managers and prescribed fire professionals, we expect that climate change may affect the number of burn days, but not necessarily rotation or frequency or the severity of burn temperature on a site managed with prescribed fire. Further, the species does not occur in areas experiencing wildfire. An out-of-control fire may burn an entire site, but the risk of catastrophic wildfire is less in the landscapes where the species is found. Therefore, the risk of a fire-related catastrophic event to the species was not considered further.

Recolonization or immigration is directly related to connectivity and the availability of the host plant. Populations should maintain natural or high levels of connectivity to allow for immigration and emigration. This increases the likelihood of recolonization should a population become extirpated. Patchy distribution of the host plant and moth across a large site gives some redundancy and resiliency at a population level within a site. Large sites often contain separate distinct patches of rattlesnake-master occupied by the moth. These patches do not contribute to redundancy at a species level as these patches are within two miles of each other, within contiguous habitat, and are considered to be one interbreeding population.

Chapter 3. Historical and Current Condition

3.1 Historical Condition

The historically occupied range and species condition of rattlesnake-master borer moth is not known. The species was described in 1917, and only occasional collection records exist until the 1990s. At the time of the original 12-month finding in 2013, 16 known extant populations had been discovered since 1993. Additional surveys between 2013 and 2018 brought the total number of extant populations to 55. Species occurrence historically is unknown; however, we may infer its historical range from its reliance on rattlesnake-master and prairie habitats. With more than a 98 percent decline of prairie landscapes across the U.S., it may be assumed that the currently occupied range is less than the historically occupied range. Conversion of grasslands began in the 1800s; it is feasible the species may have been lost from large parts of its historical range before the limits of its former distribution were recorded. The consequences of the loss or fragmentation of habitat is a direct influence on species viability via the loss of host plant and loss of connectivity.

Four small populations discovered since 1990 are currently presumed extirpated. A single adult rattlesnake-master borer moth was found on State-owned and managed pine barrens in North

Carolina in 1994 (Hall 2013, pers. comm.; Hall 2012, pers. comm.; Schweitzer *et al.* 2011, p. 351). Following a prescribed burn in 1994, a subsequent survey resulted in location of one larva during the summer of 1995 (Hall 2012, pers. comm.; Schweitzer *et al.* 2011, p. 351). Surveys in 2000, 2002, and 2018 revealed no larvae (Bess 2018a, pp. 72-82; Hall 2012, pers. comm.). One site in Illinois was lost to development, and a site in Arkansas was lost due to development and habitat loss and degradation. Another small site in Arkansas may have been lost when the right-of-way was mowed, but will be resurveyed to determine if the site is extirpated or merely not found during the second survey year. There is also one historic record from Iowa from 1928 (Wiker 2017b, p. 2), indicating the species was once extant in the state. Rattlesnake-master borer moth has been considered extirpated in Iowa and during a 2017 survey of 25 sites across 17 Iowa counties, no rattlesnake-master borer moths were found (Wiker 2017b, p. 2).

We assume the resiliency, representation, and redundancy were greater historically due to greater acreage of prairie with suitable or potentially suitable habitat containing the host plant and increased connectivity. Rattlesnake-master borer moth is a relatively cryptic species with a long larval stage and is typically found in low numbers, if at all, on species-specific surveys. Lepidopteran surveys typically occur in the summer when the rattlesnake-master borer moth larvae is in the plant stem. Species-specific techniques are needed to find both larvae and adults. Although experts in Missouri examined numerous *Papaipema* specimens before 2012 without finding any collections of rattlesnake-master borer moth, 20 populations have since been identified in the state (Wiker 2017a, p. 1; McKenzie 2012, pers. comm.).

3.2 Factors Influencing Viability

Incorporating the species life history needs and in coordination with species experts, we identified potential positive and negative influences and the contributing sources of those influences likely to affect species' viability (Figure 3-1). The primary factors expected to influence the viability of the species include management actions (*e.g.*, grazing, mowing, prescribed fire), natural fire regime, and habitat loss and fragmentation. We evaluated the potential influence of herbicide/pesticide use and collection, but do not believe they will impact population viability. Herbicide use will cause the loss of some host plants, but is typically not employed over widespread areas where the species is found. However, small populations along linear corridors experience an increased effect of herbicide application, as rattlesnake-master appears highly susceptible to herbicides (Coffin and Pfannmuller 1988, p. 184). Suitable habitat with infestations of difficult-to-eradicate invasive species (*e.g.*, sericea lespedeza) may be impacted on a larger scale with persistent herbicide use. Pesticide use is expected to have limited, if any, effect on adults due to the very short time (10-14 days) and seasonality of the flight period (fall). Pesticide use, particularly neonicotinoids, may have negative effects on larvae as they accumulate in plant tissue. This class of pesticides has been found in wild plants near agricultural fields (Wood and Goulson 2017, pp. 17291, 17298-17303). Rattlesnake-master plants found within the agricultural matrix could be susceptible to these impacts. Collection of individual larvae or adults is minor, and we have no evidence collection has influenced a population.

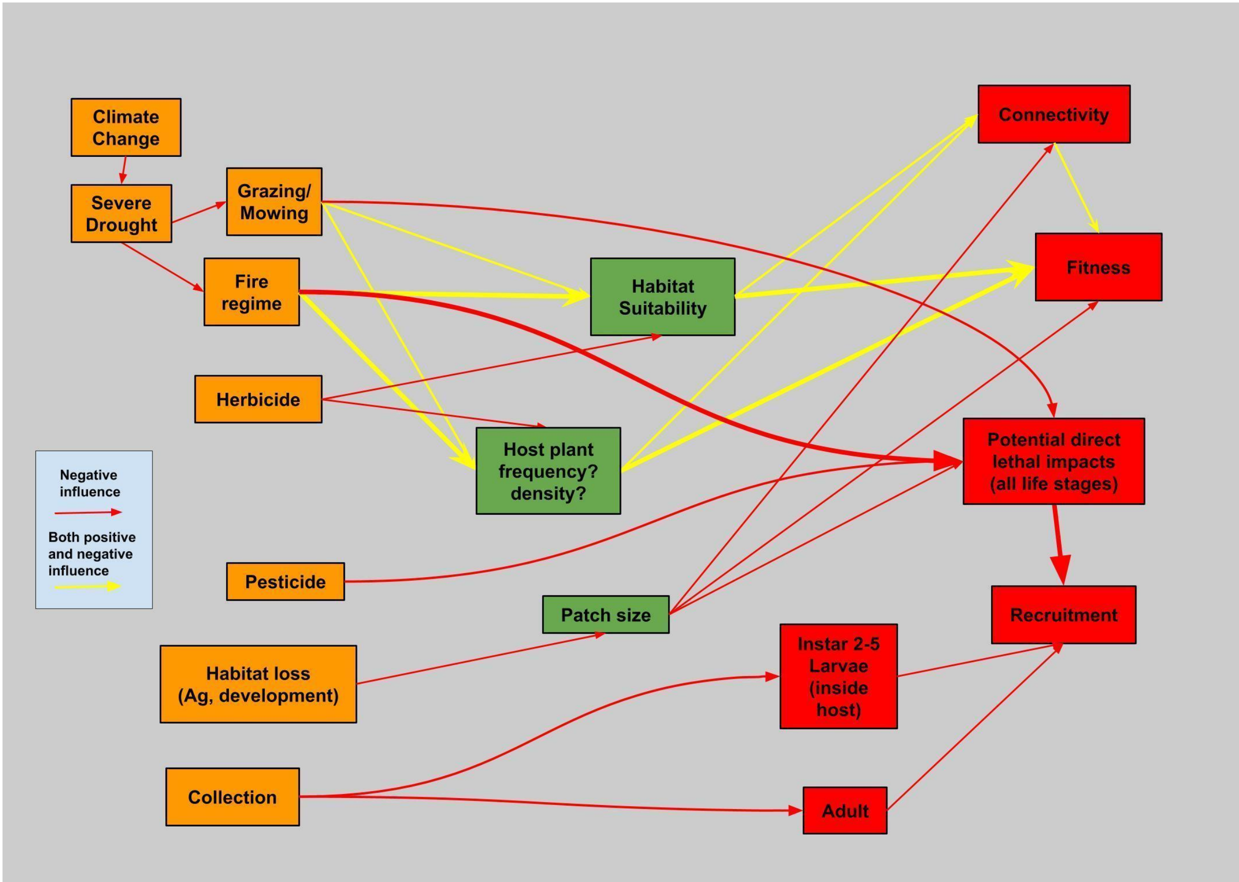


Figure 3-1. Influence diagram for rattlesnake-master borer moth.

Management

Management of the vegetation in an area occupied by rattlesnake-master borer moth can positively or negatively affect the species. Timing, intensity, type, frequency, and spatial rotation through a site are components of a land management strategy that have the potential to affect the species' persistence and viability on a site through the effects on the rattlesnake-master host plant. Each rattlesnake-master plant is typically clonal with clumps of roots found together and each root producing a main stem, resulting in one to dozens of stems in one large clump. Only one larva will pupate from each root; therefore, the carrying capacity of a site is determined by the number of stems or roots on a site. The number of stems on a site is directly related to the management of the site. Types of management actions that may affect the species are further discussed below.

Grazing/Mowing

Grazing, mowing, or any reduction in rattlesnake-master plant height during the early larval stage of the borer moth may remove some larvae. Grazing or mowing while rattlesnake-master is in flower is expected to stress the plant by decreasing the potential for accumulation of energy reserves during the growing season, particularly if repeated annually. After rattlesnake-master borer moth bores lower into the stem, mowing is not expected to have a detrimental effect. Grazing or haying after late June provides land management tools, with minimal effects to the moth as larvae should be low in the stem or in the root at this time. Mowing rattlesnake-master plants low to the ground in September (or just prior to adult flight) may be detrimental to a population by removing egg-laying sites. Mowing to a height of 6-10 inches in fall and winter is not expected to negatively affect the moth in any life cycle stage. Repeated heavy grazing degrades native plant communities, disturbs and compacts the soil, and can kill the original flora, providing germination sites for invasive weeds, shrubs and young trees (Tester and Marshall 1962, p. 271); however, no sites are currently subjected to heavy grazing. Low stocking-rate grazing or mowing of an occupied area may have a positive effect by setting back succession on the site and a benefit to rattlesnake-master borer moth if the timing of the action is coordinated with the moth life cycle and the site is grazed or mowed on a rotational basis.

Lack of Habitat Management

Lack of a management regime affects habitat suitability directly by allowing succession to proceed unimpeded. Succession is detrimental to the sustainability of suitable habitat by allowing the development of woody species that compete with rattlesnake-master for resources and, if unchecked, may lead to the loss of the host plant from the site.

Leaving habitat idle does not affect rattlesnake-master borer moth survival directly, but prairie and other habitats that lack periodic disturbance become unsuitable for the species due to expansion of woody plant species (secondary succession), litter accumulation, or invasion of non-native species. The succession to woody plants changed the composition of the plant community on one Kentucky site, resulting in the likely extirpation of rattlesnake-master borer moths (Laudermilk 2012, pers. comm.). Woody species encroachment in remnant prairie, savanna, and glade habitats is suggested as one of the greatest threats to suitable habitat types (Briggs *et al.* 2005, p.1; Heikens 1999, p. 226).

Fire

Fire, either naturally occurring or as a prescribed land management tool, is expected to influence species' viability either positively or negatively, depending on a variety of factors. Rattlesnake-master borer moths lay their eggs in the fall on the host plant where they overwinter. In the spring after they emerge, the first instars eat the host plant and eventually burrow into the stem and root. The species is protected from fire after burrowing into the root chamber before emerging as an adult in the fall. All other life stages are susceptible to the negative effects of fire (Bird 1934, p. 555). Although prairie insects are adapted to fire in some ways, prescribed burns that are conducted frequently and cover entire insect populations can be detrimental (Bess 2018a, p. 103; Schweitzer *et al*. 2011, p. 42). The rattlesnake-master borer moth is restricted in population size and distribution and thus is sensitive to management activities, such as fire, that are implemented across an entire site (Panzer 2002, p. 1298). Four life history traits of duff-dwelling insects, such as rattlesnake-master borer moth, are good predictors of a negative response to fire: (1) remnant dependence (occurring as small, isolated populations); (2) upland inhabitance (dry uplands burn more thoroughly than wetter habitats); (3) nonvagility (low recolonization rate); and (4) univoltine (slower recovery rates for species with only one generation per year) (Panzer 2002, p. 1306). Species exhibiting one or more traits should be considered fire-sensitive, and species with all four traits should be considered "hypersensitive" to fire (Panzer 2002, p. 1306). The rattlesnake-master borer moth exhibits all four of these traits and thus, according to these criteria, is hypersensitive to fire. Univoltine (having one generation per year) duff-inhabiting species like *Papaipema* moths should be considered especially susceptible to extirpation from fire (Panzer 2002, p. 1298). The use of prescribed fire during overwintering is recommended as an effective control and extermination method for pest borer *Papaipema* moths in agricultural fields (Bird 1934, p. 556; Decker 1931, p. 3).

At Tucker prairie in Missouri, rattlesnake-master borer moth was not found in the area of a prairie burned in spring, but was noted in areas with a late summer burn (Wiker 2017a, p. 68). However, summer surveys in Arkansas and Kentucky noted larvae in areas burned the preceding summer or spring, respectively (Bess 2019 pers. comm.; Bess 2018a, pp. 21-23, 94-95). Rotational use of prescribed fire in late summer (August to mid-September), taking into account the presence of rattlesnake-master borer moth in addition to the host plant, should provide the most protective benefit for the species (Bess 2018a, p. 105; Wiker 2018, pers. comm.; Wiker 2017a, p. 34). Late summer burns allow rattlesnake-master plants time to recover and put out leaves for oviposition sites by the flight period.

Habitat Loss or Fragmentation

The obligate host plant is found primarily in high-quality remnant or restored prairie and, to a lesser extent, in savannah, woodland, glade, and right-of-way habitat (Bess 2018a, p.101). Loss of suitable habitat to development or urbanization or through conversion to agricultural land directly and negatively influences the species through loss of the host plant. Loss of areas or patches of rattlesnake-master, with or without borer moth presence, increases the fragmentation of potentially suitable habitat on a landscape level and reduces connectivity between populations. This loss of connectivity influences the resiliency, representation, and redundancy of the species. Habitat loss and fragmentation through urbanization and development of prairie lands for agriculture has reduced suitable habitat for rattlesnake-master borer moth in the past. These land use changes are expected to be less of an influence now and in the future compared to the historical influence.

Due to loss or fragmentation of prairie habitat, many of the remaining known populations are more widely separated than the demonstrated dispersal distance. These isolated sites would not experience immigration and emigration and prairie remnant sites would not be recolonized. These demographic alterations result in species-level effects.

3.3 Current Condition: Resiliency, Representation, and Redundancy

No consistent, rangewide assessment of the rattlesnake-master borer moth is available, although survey efforts have increased in the last decade. The unstandardized presence data used in this SSA comprises the extent of the best available scientific and commercial data regarding the species, but key uncertainties remain. Population numbers, phenology, site conditions, plant density or frequency, extent of suitable habitat within dispersal distance, and other parameters have not been completely quantified. In order to address current and future conditions in terms of resiliency, representation, and redundancy, we made assumptions about demographics and dispersal, based on patches of habitat with species occurrence. In our analyses, we use presence/absence data as a surrogate for abundance as most surveys have no measure of abundance (*e.g.*, catch per unit effort) as part of the methodology or analysis.

Our analyses rely on available data, expert and site manager knowledge and judgment, and our assessment of future conditions. Models are unable to predict future state conditions with certainty, and our analyses are necessarily predicated upon numerous assumptions, which could lead to over- and underestimates of viability. We identify the fundamental assumptions used and discuss the implications of these assumptions in relevant sections.

A preliminary predictive model was developed for use in the southern portion of the range (Arkansas). This model included sixteen environmental, habitat classification, and ownership parameters. The model was not found to have positive predictive value and will not be included in the SSA.

Resiliency

To assess and compare resiliency of each rattlesnake-master borer moth population, we developed a semi-quantitative model that produced a "resiliency score" for each population (Table 3-2). The model relies on three categories of interrelated metrics, including habitat parameters (number of stems of host plant, patch size or acres of suitable habitat with known host plant presence) and connectivity between known populations. Only current populations are included in this model. Because empirical data relating these metrics to the species' life history and needs are sparse, we consulted species experts who generally agreed that, for the purpose of this SSA, the selected metrics were appropriate for assessing the viability of rattlesnake-master borer moth populations across the species range (Bess 2018b, pers. comm.; Wiker 2018, pers. comm.). The individual metrics were ranked and scored based on defined criteria, then combined to produce a unitless resiliency score for each population (Table 3-2).

We qualitatively assessed and assigned resiliency scores to the rattlesnake-master borer moth populations utilizing several habitat metrics (Table 3-1). We utilized the number of rattlesnake-master stems per site as reported by site managers and species surveyors (reflecting host plant density, distribution, and patch size), the acreage of suitable habitat under the same site management, and whether a site was considered to be connected (within 2 miles of another known occupied site). Although each of the habitat metrics was scored individually, none are mutually exclusive. Stem count for a site is reflected by the patch size as the total number of stems possible on a site is limited by the amount of suitable habitat. Although there is a wide range of stems per acre within the extant sites, small sites will be able to support a smaller number of stems. However, large sites exhibit a range of stem counts from very low on sites with poor-quality habitat to very high on sites that have high quality. Patch size and connectivity are also intrinsically linked.

Connectivity was assessed by evaluating the proximity of one known population or patch to another to allow for dispersal and recolonization (*i.e.*, occupied patch proximity). The suitability of intervening habitat within the two-mile buffer around sites representing the expected dispersal and recolonization distance was not included in the connectivity analysis because rattlesnake-master borer moths, particularly egg-laying females near senescence, will fly through unsuitable habitat (habitat lacking the rattlesnake-master plant) to disperse in search of oviposition sites. (Wiker 2017a, p. 24; Panzer 2003, p. 19). Barriers to this connectivity include: large bodies of water; large, busy highways; agricultural fields; dense forest; and unsuitable habitat of greater than two miles. Unsuitable habitat is defined as habitat lacking in the host plant or containing characteristics not conducive to moth flight. Rattlesnake-master is not uniformly distributed across large sites but has a patchy distribution. These patches of habitat likely sustain metapopulations of the moth that exhibit connectivity in the same way smaller individual populations do when they are within 2 miles of each other.

The current extant populations range widely in size (0.5 – 35,000 acres) and stem count (30 – >100,000), with approximately half the populations exhibiting connectivity to other populations. The metrics were broken into categories based on natural breaks in size and stem count and then all factors within the model were weighted to reflect their overall contribution to species viability.

Rangewide, 30 percent of populations are within the low resiliency category; however, this makes up only 0.32 percent of the total acreage, reflecting the relatively small patch size in the low category (see Appendix A for all calculation tables). Approximately 89 percent of the total acreage is represented by populations with high resiliency and 10 percent by populations with medium resiliency. Inferring that large patch size and large stem count correlates to larger populations, the majority of rattlesnake-master borer moth individuals are located within high resiliency populations.

Table 3-1. Description of conditions for parameters used to assess population resiliency.

Host plant stems in patch	Score		Patch size	Score		Connectivity	Score
very large: >100,000	5		100+ acres	3		Within 2 miles of another occupied patch	2
large: 10,000-100,000	4		10-100 acres	2		Greater than 2 miles from another occupied patch	0
medium: 1,000-10,000	3		0.1-10 acres	1			
small: 100-1,000	2						
very small: <100	1						

Resiliency Score = (Stem * Patch) + Connectivity

We categorized the final condition scores as "high" (population generally resilient), "moderate" (population marginally resilient), or "low" (population generally insecure). These categories are reflective of current condition only and do not represent the species condition in a historical or an ideal situation. We based these categories primarily on our understanding of rattlesnake-master borer moth habitat needs, known influence factors, and principles of conservation biology. We acknowledge that there is uncertainty associated with this model and some of the supporting data, but consider the methodology suitable for assessing the status of the species across its range.

In general, we found that sites with lower resiliency scores were smaller sites and/or sites with low stem counts and were less likely to exhibit connectivity. Conversely, higher resiliency scores reflect larger sites or sites with very high stem count and connectivity or a combination of factors. Resiliency scores range from 1 to 17 and have been grouped into low/medium/high categories, reflecting scores 1-4 for the low resiliency group, 5-9 for the medium resiliency group, and 10-17 for the high resiliency group. This tabular information is presented as it occurs across the landscape in Figure 3-2.

Table 3-2. Resiliency scores for all current, known rattlesnake-master borer moth populations. Darker shading represents a higher score. Low resiliency scores are shaded red, medium resiliency scores yellow, and high resiliency scores green.

Occupied Populations	Site Stem Score	Patch Size	Connectivity	Resiliency Score
Arkansas				
Arkansas 1	2	1	0	2
Arkansas 2	3	3	2	11
Arkansas 3	3	3	2	11
Arkansas 4	3	3	2	11
Arkansas 5	4	3	2	14
Arkansas 6	2	1	0	2
Arkansas 7	2	1	0	2
Arkansas 8	3	3	2	11
Arkansas 9	2	1	0	2
Arkansas 10	1	1	0	1
Arkansas 11	1	1	0	1
Arkansas 12	2	1	2	4
Arkansas 13	2	1	0	2
Arkansas 14	3	1	0	3
Arkansas 15	4	3	2	14
Arkansas 16	1	3	2	5
Arkansas 17	3	1	0	3
Arkansas 18	1	1	2	3
18 Extant Populations				
Illinois				
Illinois 1	4	3	0	12
Illinois 2	3	3	0	9
Illinois 3	2	2	2	6

Illinois 4	2	2	2	6
Illinois 5	3	3	0	9
Illinois 6	3	2	2	8
Illinois 7	2	2	2	6
Illinois 8	2	2	2	6
Illinois 9	2	1	0	2
Illinois 10	3	2	2	8
Illinois 11	3	3	2	11
Illinois 12	2	3	2	8
Illinois 13	3	3	2	11
Illinois 14	3	3	2	11
Illinois 15	1	3	2	5
Illinois 16	4	3	0	12
16 Extant Populations				
Kansas				
Kansas 1	3	2	0	6
1 Extant Population				
Kentucky				
Kentucky 1	4	3	0	12
Kentucky 2	3	2	0	6
2 Extant Populations				
Missouri				
Missouri 1	2	3	0	6
Missouri 2	3	3	0	9
Missouri 3	2	3	2	8
Missouri 4	5	3	0	15
Missouri 5	3	3	0	9
Missouri 6	1	1	2	3
Missouri 7	3	3	0	9
Missouri 8	2	2	0	4
Missouri 9	4	3	0	12
Missouri 10	3	3	0	9
Missouri 11	1	2	2	4
Missouri 12	1	2	2	4
Missouri 13	1	2	2	4
Missouri 14	3	3	0	9
Missouri 15	5	3	2	17
Missouri 16	2	2	2	6

Missouri 17	3	3	2	11
17 Extant Populations				
Oklahoma				
Oklahoma 1	5	3	0	15
1 Extant Population				

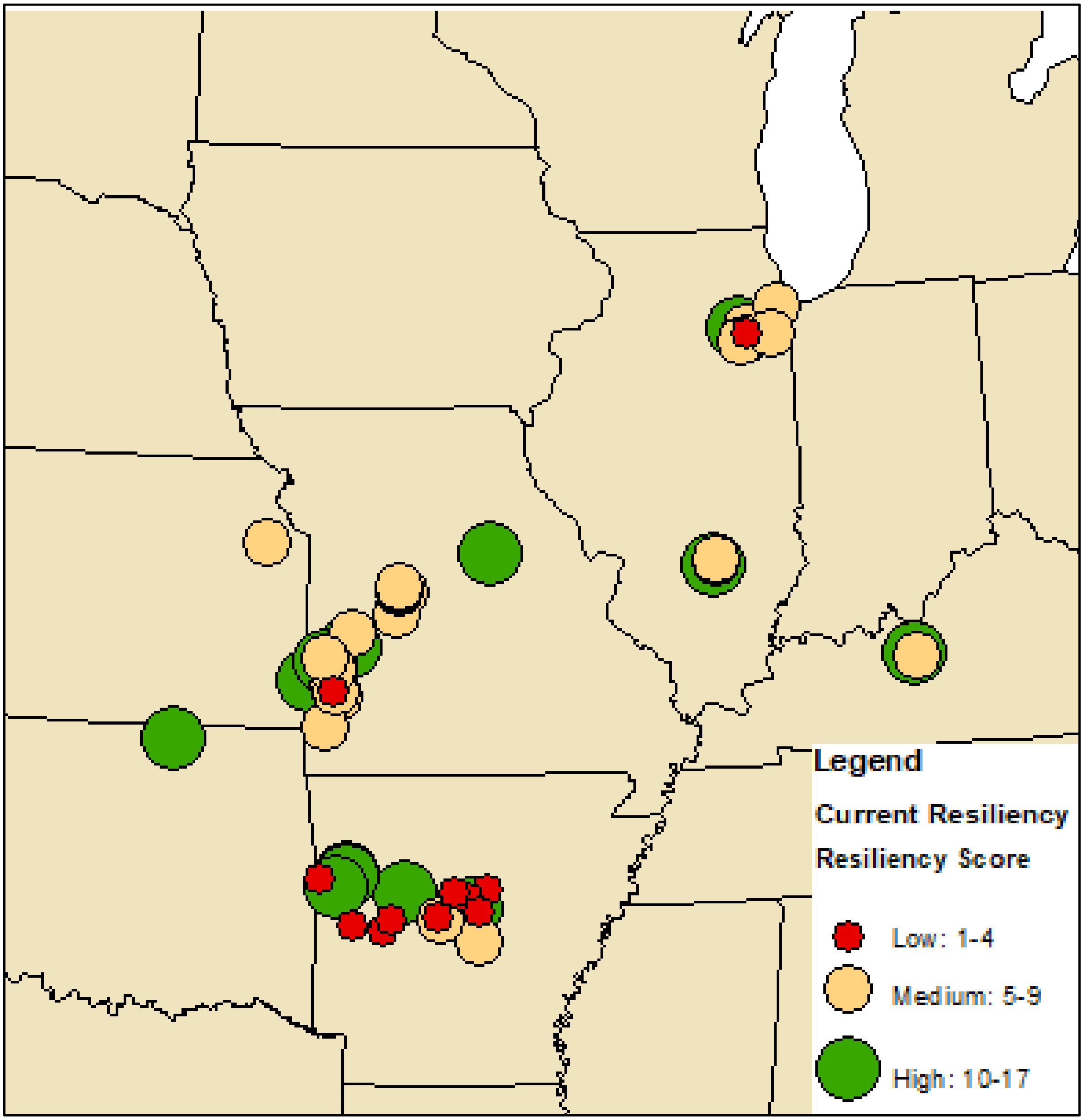


Figure 3-2. Current condition resiliency score for each known extant population. Presumed extirpated populations are not shown. Relative sizes of populations based on site stem scores are represented by relative symbol sizes and are strongly correlated to resiliency scores.

Table 3-3. Percentage of rangewide acreage and number of acres in each representation unit characterized by low, medium, or high resiliency scores.

Resiliency Score	Total Acres	% Range	Acres South	% South	Acres Middle	% Middle	Acres North	% North
Low (1-4)	328	0.32%	49	0.10%	268	0.5%	10	0.20%
Medium (5-9)	10993	10.8%	4000	8.3%	4482	9.2%	2511	49.6%
High (10-17)	90640	88.9%	43916	91.6%	48937	90.3%	2537	50.2%

Representation

Rattlesnake-master borer moth has no apparent phenotypic differences among populations (Wiker 2018, pers. comm.). A temperature-related behavioral difference is noted as larvae of the southern populations hatch in early to mid-May, while the Illinois populations appear to hatch from their eggs in late May to early June (Bess 2019, pers. comm.). In the absence of species-specific genetic information, we can use proxies, such as geographical or ecological variation to evaluate representation across the range of the species. This evaluation assumes adaptation to local conditions, reflecting the latitudinal differences across the range.

We used USDA/Forest Service-defined plant hardiness zones (Matthews *et al*. 2019, entire; Matthews *et al*. 2018, entire) to divide known populations into three roughly latitudinally-defined regions. These were adopted as the Southern (Zone 7), Middle (Zone 6), and Northern (Zone 5) Representation Units (RU). The extirpated North Carolina and Pine Bluff Arsenal populations may be considered as the Deep Southern Unit (Zone 8) (Figure 3-3). These representation units reflect differences in environmental conditions and represent the adaptive potential of the species for the purposes of this SSA but have not been confirmed or supported by genetic differences or other characteristics of the species.

When viewed by RU (Southern, Middle, and Northern), the species currently maintains representation in 3 of the 4 historic units (Table 3-4). Low resiliency scores characterize 61 percent of populations in the Southern RU, 18 percent of sites in the middle RU, and none of the Northern RU populations (Table 3-3). Populations in the Southern RU express a more bimodal distribution overall, with few medium resiliency scores. As reflected by the restricted condition of prairies, although local connectivity may occur between preserved and managed sites, there is currently little connectivity between representation units across the range.

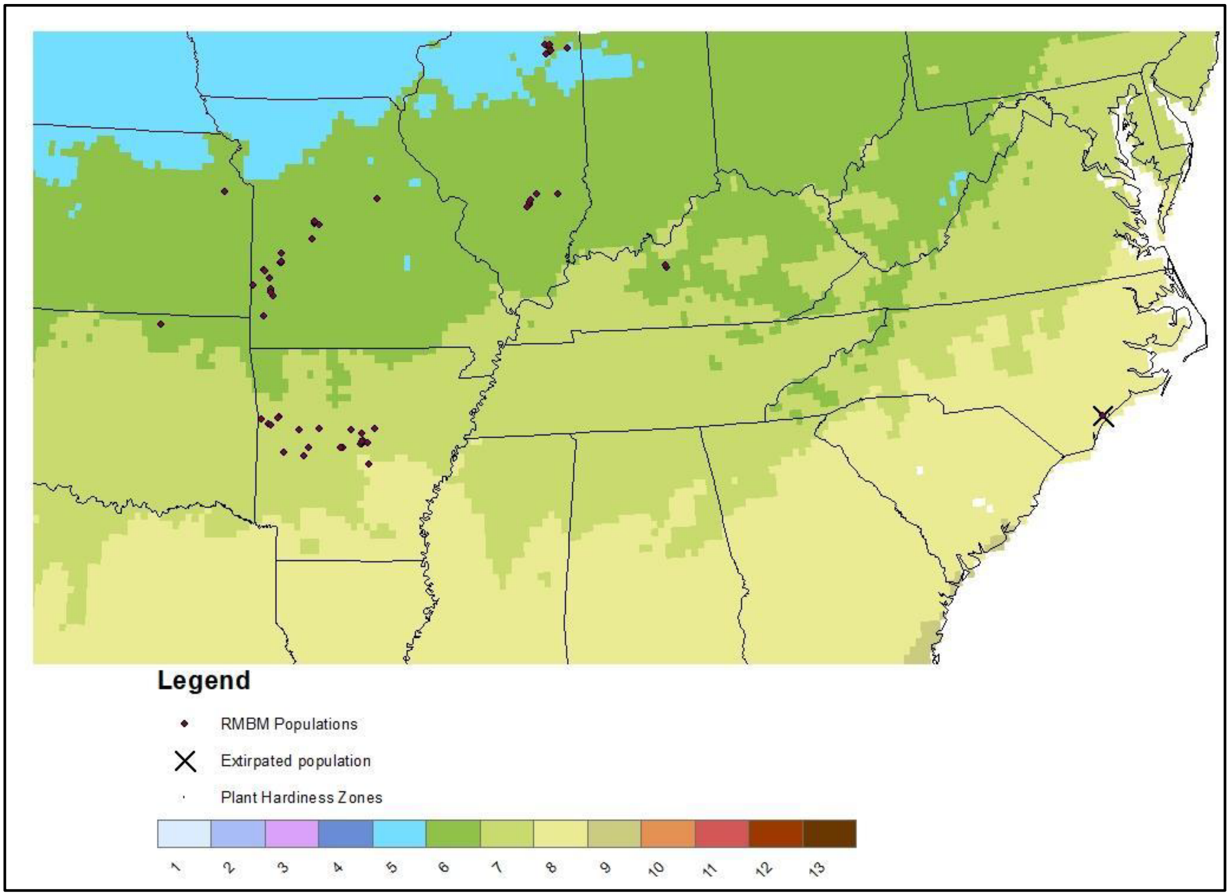


Figure 3-3. Baseline (2009) plant hardiness zones in relation to known rattlesnake-master borer moth populations (Matthews *et al*. 2019; Matthews *et al*. 2018).

Table 3-4. Percentage of populations in each representation unit characterized by low, medium, or high resiliency scores.

	Southern	**Middle**	**Northern**	**Rangewide**
Resiliency Score				
Low (≦4) or (1-4)	61.1%	17.9%	11.1%	30.9%
Medium (5-9)	5.5%	46.4%	77.8%	38.1%
High (≧10) or (10-17)	33.3%	35.7%	11.1%	30.9%

Redundancy

Viewing redundancy by representation unit, nine populations in the Southern RU exhibit connectivity (within the two-mile dispersal distance) to another known population. The Northern RU exhibits lower connectivity with 5 sites and the Middle RU shows the highest degree of connectivity with 14 sites. Each RU's contribution to rangewide connectivity is roughly equal with approximately half of all populations occurring within two miles of another current population (Table 3-5).

Table 3-5. Number of populations within dispersal distance (two miles) of another known population in each representation unit and relative contribution to the total percentage of sites exhibiting connectivity.

Representation Unit	Populations	% Connectivity
South	9	32.1%
Middle	14	50.0%
North	5	17.9%
Rangewide	28	50.9%

Although the species' current redundancy is likely lower than historical redundancy, the species' viability benefits from the variety of ecological conditions in which it has survived and the geographic extent of its distribution. The species' current widespread distribution may provide some buffer against rangewide catastrophic events.

Overall, rattlesnake-master borer moth has multiple, resilient populations across the breadth of its environmental variation, and roughly half of current populations have connectivity to another population. This assessment assumes that additional populations or suitable habitat do not occur between known populations. We acknowledge that this is likely an underestimate of host plant occurrence in some areas and potentially an underestimate of rattlesnake-master borer moth occurrence.

Chapter 4. Future Condition: Resiliency, Representation, and Redundancy

In this chapter, we describe our analysis of the future viability of rattlesnake-master borer moth. Here we describe three plausible future scenarios and project potential changes from current conditions under each scenario. Our future scenarios consider plausible variations in management and land use.

Specifically, we forecast the condition of populations and RUs based on influences on viability over a period of 80 years under multiple scenarios. These future scenarios represent the species' risk profile in plausible, timeframe-based scenarios. The time frame chosen reflects the extent of the model used to assess influences on viability and is biologically significant to the species through long-term effects on the host plant. The three selected future scenarios do not represent the breadth of all potential or possible scenarios, but those that are plausible based on input from site managers, verified and vetted models, and expert input. We considered a range of potential scenarios that may be important influences on the status of the species, and our results describe this range of possible conditions in terms of the 3Rs for rattlesnake-master borer moth.

The dependence of the rattlesnake-master borer moth on the host plant is reflected in the influences chosen to carry through in future scenarios. Parameters included are those expected to affect host plant density, abundance, and occurrence and thus rattlesnake-master borer moth. The shift in host plant occurrence may occur in the short-term or long-term, depending on the influence. For example, conversion of suitable prairie habitat with host plant occurrence to agricultural lands represents a short-term change while lack of active and appropriate management to maintain host plant occurrence on an occupied site leads to woody encroachment and succession and represents a long-term shift in habitat suitability.

4.1 Analysis Factors for Future Condition

Management

Land management actions, including those actions that set back succession, include prescribed fire, herbicide treatment, grazing, and mechanical treatment (mowing, bush hogging). Land management actions (management) conducted on a site are one of the primary influences to the viability and persistence of rattlesnake-master borer moth populations (Bess 2018a, pp. 102-126; Wiker 2018, pers. comm.; Wiker 2017a, pp. 27-31). Suitable habitat must be managed to remain suitable and retain the host plant within the site. The density of host plants and the subsequent carrying capacity of a site (one larva matures per plant stem) is strongly influenced by management. Plant surveys for rattlesnake-master have been conducted on only a few sites, but one site in Kentucky includes yearly host plant surveys. This site has had habitat management, including prescribed fire, for over 30 years, resulting in a density of 84 plants/acre. In contrast, a site not managed for rattlesnake-master has a density of only 25 plants/acre (Fulton 2019, pers. comm.). We used this first site as a basis for calculating an optimal stem count of rattlesnake-master. This site has received approximately 30 years of management of varying intensity designed to reduce succession and sustain open prairie habitat. In 2014, more intense site management, including spot spraying with herbicide and mechanical removal of woody and invasive plants, was added to the rotational prescribed fire, resulting in a stem count of approximately 84 stems/acre. An annual stem count is conducted on this site and represents an accurate assessment of host plant density on an occupied site. We assume this level of intensive and intentional management for rattlesnake-master plant results in an optimal stem count.

Lack of management influences host plant density and species' occurrence in the short-term and long-term through the process of succession. Some forms of management may be beneficial to the host plant, but may result in loss of individual rattlesnake-master borer moths, for example when all suitable habitat within a site is burned at one time. Unless this widespread prescribed fire is conducted when the species is pupating underground or in the lower leaf litter, mortality may be expected. Rotational management of sites is beneficial to the rattlesnake-master borer moth by ensuring that only a portion of the population is impacted by the event.

Succession has been shown to reduce the number of rattlesnake-master plants in an area; at least one site with the moth has been presumed extirpated due to increase in woody habitat on a site (Laudermilk 2012, pers. comm.). This succession and woody encroachment is expected to begin to affect habitat suitability in as few as five years (in the Southern representation unit) and is expected to substantially decrease host plant density in approximately ten years without site management (Baxter 2019, pers. comm.; Archer *et al.* 2017, pp. 62-63; Ratajczak *et al.* 2012, p. 697).

For the purposes of this assessment, sites under public ownership are considered to be State or Federal lands, lands owned by non-governmental organizations (*e.g.*, The Nature Conservancy), or private lands with a permanent conservation easement. Rangewide, over 99 percent of currently occupied acreage is publicly owned or managed. Lands in public ownership are considered to contain a substantial portion of suitable habitat within the managed area and are currently managed appropriately to ensure maintenance or restoration of quality habitat. Private lands are sites under private ownership with no conservation easement and rights-of-way under departments of transportation or private railroad company management.

To assess likely management actions on public lands, individual site managers were requested to describe current and predicted management actions (*e.g.*, rotational prescribed fire, herbicidal or mechanical treatment of woody encroachment, full site prescribed fire, no management). Private landowners were not queried. Responses were obtained for all public lands. The answers from current site managers have been used to assess the current management of habitat for the populations on public land and forecast management in the future. It is possible that management priorities could change from what is currently predicted on some sites, depending on shifts in funding, staffing, priorities, or other factors.

Rotational management of a site (often prescribed fire, some mechanical treatment) was commonly listed as the planned management tool. If a site is known to have multiple areas occupied by rattlesnake-master borer moth, management conducted on all areas at the same time may be detrimental to the species and require greater time before recolonization can occur, if a suitable population is within dispersal distance. If rattlesnake-master occurs on multiple areas on a management site, rotational treatments (*e.g.*, one-fourth of a site annually for four years) allows the possibility of more rapid recolonization. We recognize that some individuals may be lost when management actions take place if the timing of the action is not precisely aligned with the species' life history (due to competing goals, availability of resources, weather conditions, and other factors). However, the longer-term benefit of this setback of succession to the habitat, continued host plant occurrence, and sustainability of the species justifies the shorter-term loss in all but the most dire situations. The negative influence of secondary succession of a site was discussed in *Factors Influencing Viability*.

Urbanization and Development

Urbanization and land use change associated with development may influence the species directly as suitable habitat containing the host plant is lost due to land use change. Urbanization may influence the species indirectly, as patches of suitable habitat with the host plant become farther away from other patches due to fragmentation of potentially suitable habitat. If a patch of rattlesnake-master occurring less than the 2-mile dispersal distance is lost, the next patch may be farther than the flight distance for the species, decreasing the likelihood the farther patch will be colonized. This resultant loss of connectivity could reduce dispersal between known and unknown interconnected populations if patches of suitable habitat are lost. No model was found that allows assessment of predicted land use change on the fine scale necessary to make predictions within populations and the two-mile dispersal distance with any certainty of effects to the species. Therefore, the model chosen addresses landscape-level changes due to development pressure in different emissions scenarios.

Due to the need for multiple time steps over a large geography, we evaluated the USGS Earth Resources Observation Science Center FORE-SCE (FOREcasting SCEnarios), which projects land use changes for each land use type. The FORE-SCE model develops a range of land use projections to 2100 and incorporates multiple datasets related to growth, including climate change, urban development, agriculture development, and other socioeconomic pressures. These factors are evaluated in relation to four scenarios (from the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (SRES) 2000). No available model provided the scale or resolution required to evaluate future conditions of land use in a biologically meaningful site-specific application.

Within the FORE-SCE model, 17 land cover types are evaluated. Grassland and hay/pasture types were chosen as most representative of potentially suitable habitat for rattlesnake-master borer moth, although prairie habitat, suitable habitat, or presence of rattlesnake-master cannot be inferred from habitat classification tools at available scales and requires ground-truthing outside the scope of this analysis or previous studies.

The FORE-SCE model develops annual projections from 2009 to 2100. We evaluated projected changes predicted by the FORE-SCE model at 2039, 2069, and 2099 for similarity of comparison with the projected changes in hardiness zone (see section 4.5 Implications for Representation). The land use changes projected by the model were not used in calculations due to the limitations of scale and resolution, but did provide underlying support for the management-related changes to population viability.

The FORE-SCE models are not explicitly linked to representative concentration pathways but incorporate these general predictions within the storyline. Three FORE-SCE projection storylines are described below.

- The **A1B** storyline is characterized by very rapid economic growth, moderate global population growth, and rapid technology innovation with a balance use of fossil-intensive and non-fossil energy source. It may be considered to be roughly reflective of RCP 6. (Economic/Global)
- The **B1** storyline is characterized by high economic growth in service and clean industries, moderate global population growth, with an emphasis on non-fossil energy sources but without additional climate initiatives. It may be considered roughly reflective of RCP 4.5. (Global/Environmental)
- The **B2** storyline is characterized by intermediate levels of economic growth, moderate global population growth, and less rapid and more diverse technological change. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional economic solutions. It may be considered roughly reflective of RCP 4.5. (Regional/Environmental).

When viewing future conditions though the FORE-SCE model in all scenarios, we assume that land use on publicly owned and managed sites is unlikely to undergo land use change; however, privately owned sites may be impacted. Calculations of land use change percentages (Table 4-1) were performed using all known sites and the flight distance/connectivity 2-mile buffer.

Table 4-1. Rangewide land use change predicted by FORE-SCE model in varying scenarios through time. Percentages reflect loss of hay/pasture and grassland land types in site acreage and a 2-mile dispersal buffer.

Land Use Change Influences			
Loss by year	**Scenario A**	**Scenario B**	**Scenario C**
2039	-18%	-23%	-31%
2069	-24%	-35%	-58%
2099	-28%	-40%	-85%

Although the FORE-SCE model predicts an overall loss of suitable habitat, it is difficult to utilize the results to predict the loss of any of the extant populations. For example, a site and surrounding 2-mile buffer is predicted to have a 30 percent loss in grassland and hay/pasture land use, but it cannot be determined where within the site that loss will occur. The loss may occur on the occupied portion of the site and the population is lost, or it may occur on another area with no host plant occurrence and the species is unaffected. Further confounding the results is the assumption that only private sites will be lost in the future scenarios. In all scenarios, we assume that public sites will be protected into the future and will be protected from development or conversion to agriculture. The remaining private sites make up only a small percentage of the total projected suitable habitat within the range of the moth. The baseline calculation of grassland habitat in the FORE-SCE model is 331,543 acres. Currently, private extant rattlesnake-master borer moth sites total 122 acres, which is 0.04 percent of the total acreage. This small acreage size makes using the FORE-SCE results to directly analyze the likelihood of a loss of populations even more difficult. The sensitivity of the species to the effects of land use change on a fine scale cannot be determined. Therefore, the FORE-SCE model results are used to support the analysis in the future scenarios, but are not used to determine if individual populations will be directly impacted or lost to future development.

Although we cannot use the FORE-SCE model results to pinpoint direct effects from land use change, we can assume there may be indirect effects to the species through loss or fragmentation of unknown and unsurveyed suitable habitat containing the host plant that may or may not be occupied by rattlesnake-master borer moth. These patches of suitable habitat could act as stepping stones for species dispersal and gene flow. The extent of this effect is unknown and not possible to quantify for this SSA.

4.2 Description of Three Future Scenarios

We have identified three scenarios characterized by a reasonable degree of confidence (Table 4-2).

Table 4-2. Brief description of three plausible future condition scenarios with management actions and land use change components.

Scenario	Management	Land Use Change
A	increased beneficial management of all sites	B2 scenario

B	future management at current levels on all sites	B1 scenario
C	No future management on private sites	A1B scenario

Scenario A

This scenario incorporates increased beneficial land management actions and land use changes as expected in the Regional/Environmental (B2) model. Private sites that currently receive only incidental management from mowing or grazing will be changed under Scenario A to beneficial management specific to the habitat or moth, and we project all public sites will continue to receive beneficial management. For public sites that are already implementing rotational management, we predict that ongoing optimal management prescribed specifically to benefit the rattlesnake-master borer moth will increase habitat suitability for the moth by increasing the stem count of rattlesnake-master. Constraints to improved management and optimal host plant density was considered in this model based on on-the-ground knowledge of sites and management.

This scenario also assumes continued population surveys on known, occupied sites to inform adaptive management practices and species surveys on additional suitable habitat. Additional populations may be discovered as a result of expanded survey efforts, although only eight new populations were found on a survey of 209 sites in southeastern states (Bess 2018a, p. 29). For example, only two populations were known from Arkansas since 1998 until survey efforts in 2017 and 2018 discovered 19 additional populations, and all known populations in Missouri were identified since 2016.

The lowest emissions scenario B2 of the FORE-SCE model predicts land use changes across the range of 18 percent of potentially suitable habitat by 2039, 24 percent by 2069, and 28 percent by 2099. The greatest change in land use occurs in the Northern RU, with a 17 percent loss of potentially suitable habitat by 2039 and 24 percent by 2099. A slight increase (0.6-1.5 percent) in hay/pasture and grassland habitat types is predicted in the Middle RU.

Scenario B

In this scenario, management continues with directed rotational habitat management on public sites, incidental management of some private sites, including mowing in rights-of-way and grazing on some sites, and no management at all on three private sites. Land managers for public sites consistently reported continuing the current level of management as the expected implementation over the next 10 years. This scenario assumes that the reported management will continue through the timeframe snapshots of 2039, 2069, and 2099. Rattlesnake-master borer moth occurrence on publicly managed sites would continue to persist at current levels. Private sites that currently receive incidental management through mowing, grazing or other means that has maintained prairie habitat (avoiding woody invasives) and allowed rattlesnake-master to persist on the site will continue. These sites with incidental management will persist into 2039 because they have persisted to this point. Any sites that include no intentional or incidental management will no longer have suitable habitat in 2039 based on woody encroachment and progression of succession.

Based on the B1 emissions scenario from the FORE-SCE model, this scenario predicts a loss of hay/pasture and grassland acres within known populations sites and a 2-mile buffer of 23 percent of suitable habitat by 2039, 35 percent by 2069, and 40 percent by 2099. The highest projected loss is in the Northern RU across all time spans.

Scenario C

In this scenario, sites without structured management plans to maintain prairie habitat or projected management (out 10 years) will no longer have suitable habitat in 2039. Private sites with incidentally appropriate management (populations in rights-of-way with Departments of Transportation or other small sites with private landowners) are not predicted to maintain this level of management. Without management, the habitat will become unsuitable and all private populations are considered lost due to the negative influence of secondary succession (see *Factors Influencing Viability*) before the first timeframe snapshot in 2039.

As with Scenarios A and B, current habitat management on public sites to maintain prairie habitat will continue but only at current levels (not increasing or enhanced management specific to the moth). This scenario assumes that the reported management will continue through the timeframe snapshots of 2039, 2069, and 2099. Based on that management, rattlesnake-master borer moth occurrence on publicly managed sites would continue to persist at current levels. Reversion of publicly owned and managed sites to private ownership is possible, but is not considered plausible in any of the scenarios.

This environmental/economic scenario (A1B; higher emissions scenario) predicts a loss of hay/pasture and grassland acres within known populations and a 2-mile buffer of 31 percent of suitable habitat by 2039, 58 percent by 2069, and 85 percent by 2099.

4.3 Implications for Resiliency

Scenario A: Improved management and limited land use change

In this scenario, management on private sites that currently receive no or only incidental management will improve. Public sites that already receive directed management to control woody invasives would either maintain management at current levels or change the design to be more beneficial to the moth and its host plant.

We assumed it is plausible for increased or improved management to result in optimal rattlesnake-master stem counts of 84/stems per acre where possible. When calculating increases in resiliency for this scenario, increases in stem count is limited by the acreage of a site. Some higher acreage sites increased in resiliency due to increases in total stem counts (Table 3.1). For example, one 140-acre site has an estimated stem count in the 100s giving it a site stem score of 2 and an overall resiliency score of 8 (medium). When calculated with an optimal stem count, the new stem score is 4 (140 x 84 = 11,760 stems/acre), which results in a new resiliency score of 14 (high). Stem scores were unchanged for some smaller sites when the projected stem count could not be raised due to the small size of the habitat patch. For example, a 5-acre site is estimated to have 840 stems which is a stem score of 2. Using our optimal stem score, the new calculation would still yield a stem score of 2 (84 x 5 + 420 stems/acre), resulting in no change to the resiliency score.

Changing the stem scores yielded a rangewide increase in resiliency of over half (54 percent; 30 sites) of populations (Figure 4-3). Resiliency in the high category (scores 10-17) increases from 18 populations to 36 populations. The number of populations in the low category (scores 1-4) decreases from 17 to 13.

This increase in resiliency is expected to occur by 2039, the earliest snapshot of comparison to the FORE-SCE urbanization and land use scenarios, and continue through the forecasted time period to 2099. The FORE-SCE model predicts the lowest potential land use change with projected possible increase in grassland habitat in the Middle RU, supporting the management-based resiliency changes.

Table 4-3. For scenario A, rangewide resiliency scores categorized by high (H:score 10-17), medium (M:score 5-9), low (L:score 1-4) in current condition and future condition scenarios for 2039, 2069, and 2099. Decreases in resiliency from current conditions are shown in red and increases in resiliency are shown in green. Equivalent resiliency scores across time are not shaded.

			Future Conditions								
Current Condition			**2039**			**2069**			**2099**		
L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
17	**21**	**17**	**13**	**9**	**33**	**13**	**9**	**33**	**13**	**9**	**33**

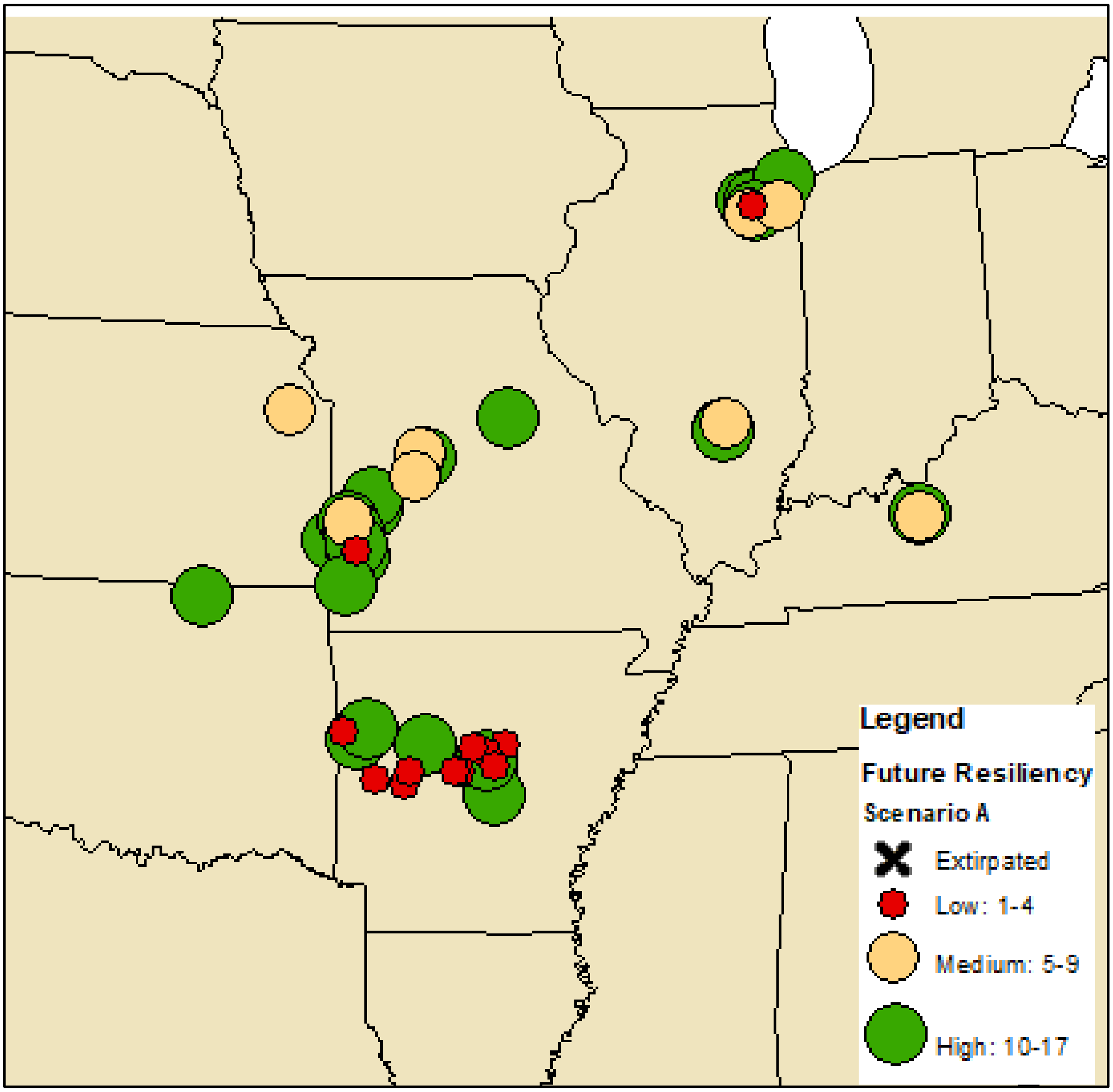


Figure 4-1. Current populations shown by predicted resiliency score in future scenario A in 2039.

Scenario B: Continued current management and moderate land use change

Scenario B is characterized by the continuation of current management at the same level; this is the overwhelming response public site managers predicted when surveyed regarding expected future management. We also assume the current incidental management of some private sites through mowing or grazing will continue into the future. Although these sites do not receive specific management actions designed to maintain prairie habitat, the current mowing or grazing on these sites has continued to keep woody plants from invading the sites, and the species persists. We predict the loss of three sites in private ownership that contain no management of the site either directed or incidental (Figure 4-2; Table 4-4). These extirpated populations are all smaller populations with low resiliency scores. This loss of three private populations (two in the northern RU and one in the middle RU) results in a small decrease in the overall resiliency of the species.

Projected land use change will have no impact on the calculations for this scenario. We have assumed that lands in public ownership will continue to remain public and protected from development into the future through 2099. The loss of three populations due to lack of appropriate management will occur earlier in time (approximately ten years) than the potential loss of suitable habitat due to land use change (2039). Based on expected loss of three private populations and stability of public site land use and management, the effects of urbanization and development are negligible in this scenario.

Table 4-4. For scenario B, rangewide resiliency scores categorized by high (H:score 10-17), medium (M:score 5-9), low (L:score 1-4) in current condition and future condition scenarios for 2039, 2069, and 2099. Changes in resiliency are expected to occur by 2039, with no further changes predicted. Decreases in resiliency from current conditions are shown in red. Equivalent resiliency scores across time are not shaded.

			Future Conditions								
Current Condition			**2039**			**2069**			**2099**		
L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
17	**21**	**17**	**15**	**20**	**17**	**15**	**20**	**17**	**15**	**20**	**17**

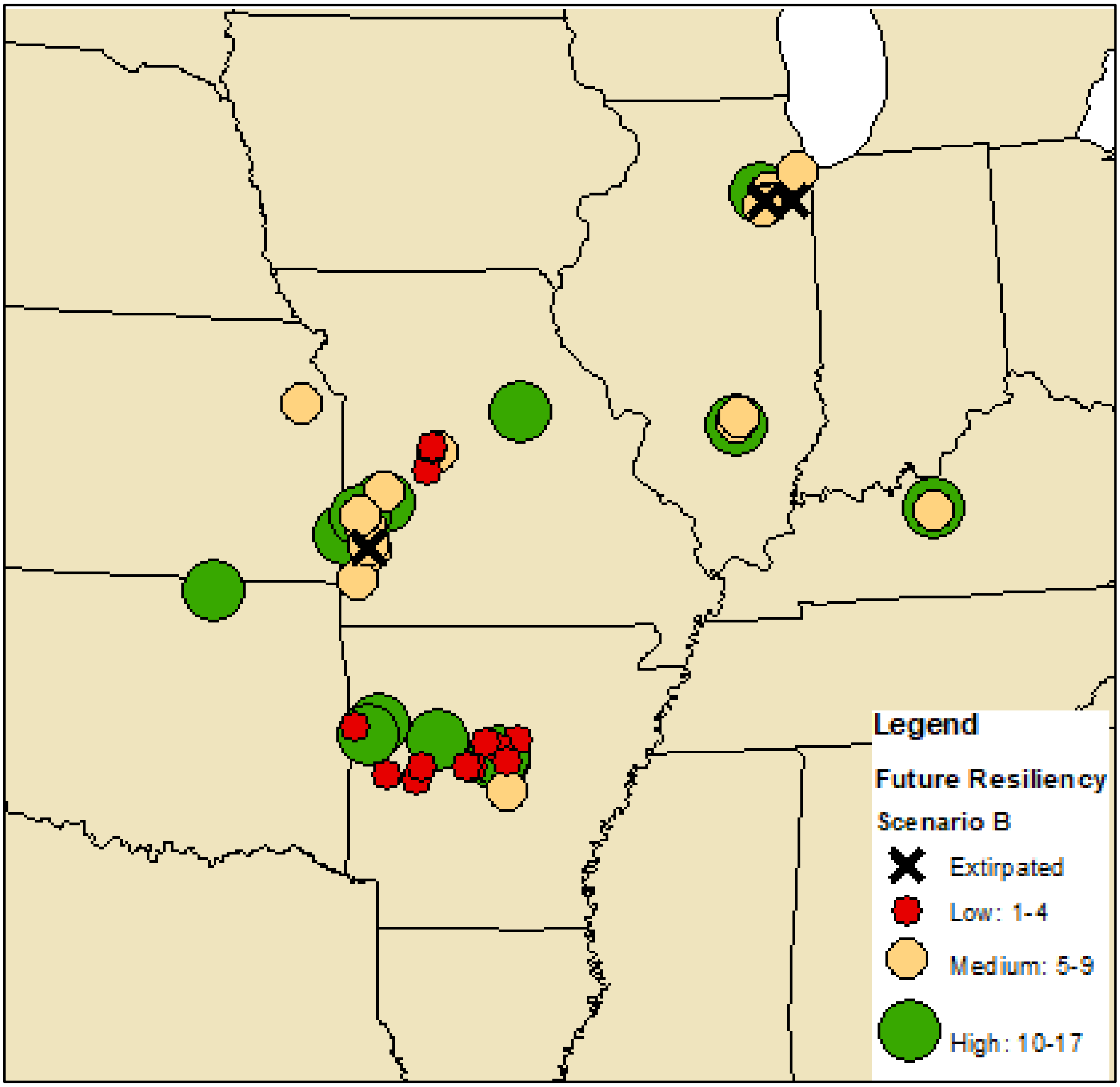


Figure 4-2. Current populations shown by predicted resiliency score in future scenario B in 2039.

Scenario C: No habitat management and increased land use change

The third future scenario is characterized by continued management of public sites at current levels and a cessation of management on all non-public sites. Lack of management will result in progression of succession of vegetation types, including woody encroachment and invasives on private sites. This is expected to result in the loss or extirpation of nine sites, in addition to the three lost in Scenario B (nine sites in the Southern RU, one population in the Middle RU, and two in the Northern RU) by 2039 (Figure 4-3; Table 4-5). The loss of populations is not expected to continue after 2039, as public sites are assumed to remain public with the current level of management. Land-use change will not impact populations in this scenario because all populations vulnerable to this influence are considered extirpated prior to 2039.

Table 4-5. For scenario C, rangewide resiliency scores categorized by high (H:score 10-17), medium (M:score 5-9), low (L:score 1-4) in current condition and future condition scenarios for 2039, 2069, and 2099. Loss of resiliency is expected to occur by 2039, with no further changes predicted. Decreases in resiliency from current conditions are shown in red. Equivalent resiliency scores across time are not shaded.

			Future Conditions								
Current Condition			**2039**			**2069**			**2099**		
L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
17	**21**	**17**	**6**	**20**	**17**	**6**	**20**	**17**	**6**	**20**	**17**

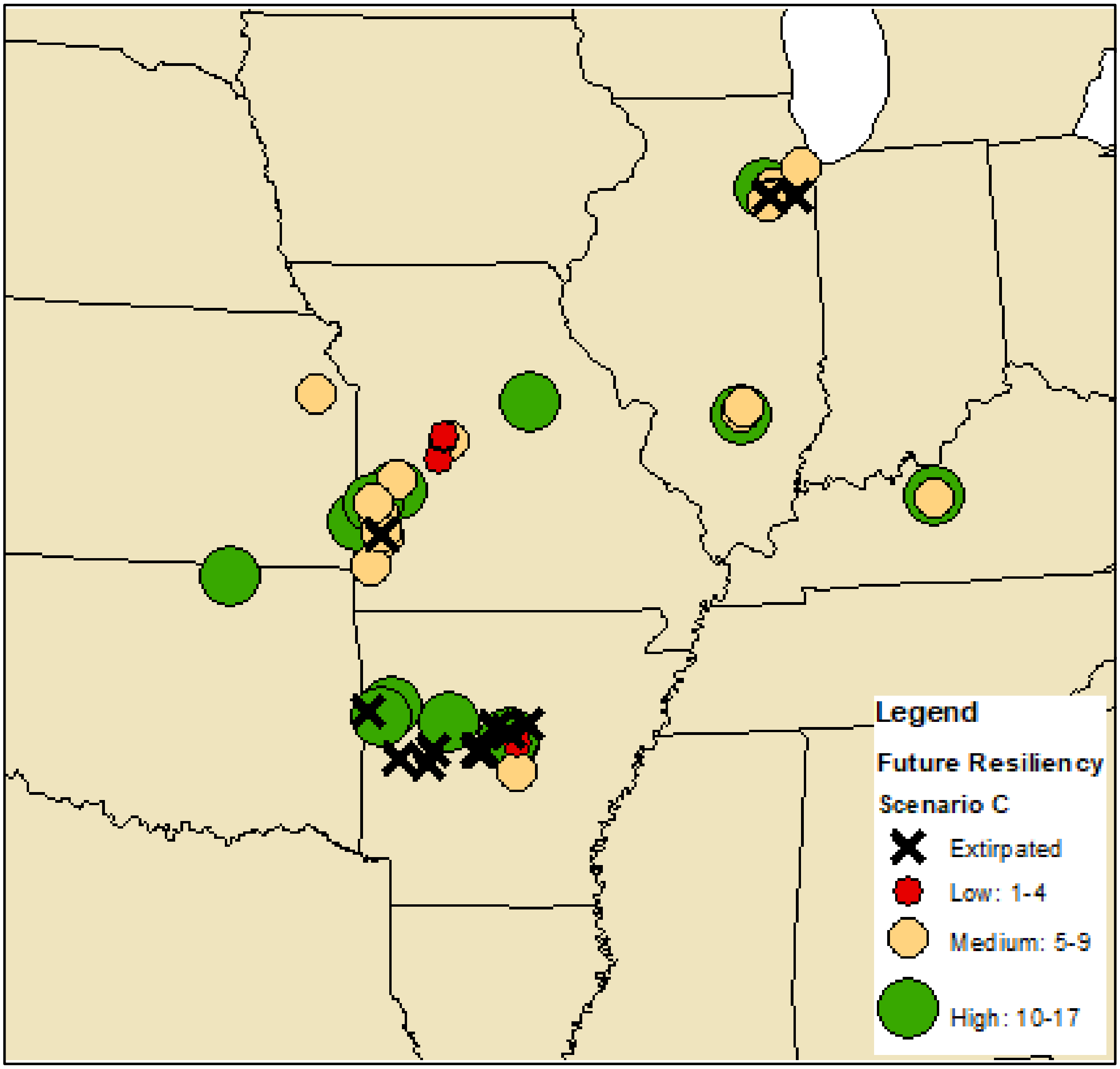


Figure 4-3. Current populations shown by predicted resiliency score in future scenario C in 2039.

In two scenarios (B and C), resiliency of populations is expected to decrease in varying degrees due to lack of management. In no scenario does predicted land use change benefit the rattlesnake-master borer moth.

4.4 Implications for Representation

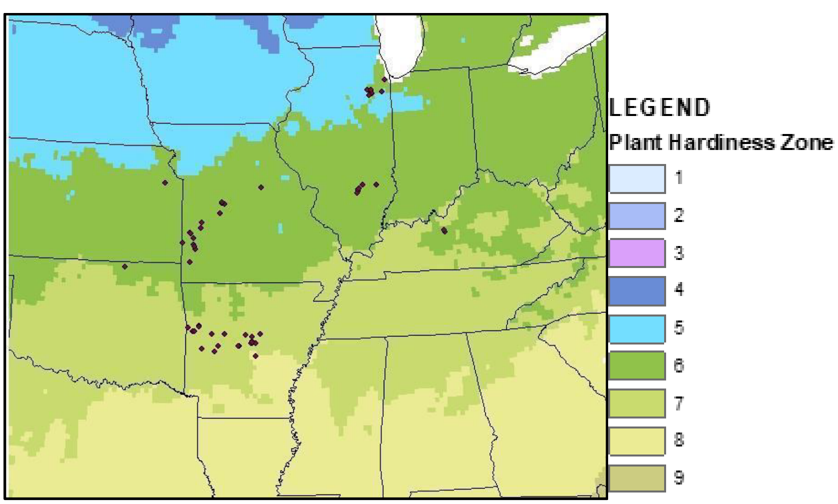
The U.S. Forest Service projected shifts in plant hardiness zones in response to modeled climate data for two representative concentration pathways (RCP) (4.5 and 8.5) at three 30-year intervals beginning from a baseline in 2009 (Matthews *et al*. 2019, entire; Matthews *et al.* 2018, pp. 11-15). These models were developed to evaluate multiple signals of climate change across the conterminous United States, including growing degree days, plant hardiness zones, heat zones, and cumulative drought severity. Models of projected plant hardiness zones used in our future scenarios show a continued shift northward over the 90-year timeframe (up to 200 miles from present) (Matthews *et al*. 2019, entire; Matthews *et al.* 2018, p. 13). Each population will experience a change in zone representing a shift to approximately 10°F warmer lowest winter temperature (Figures 4-4 a-g).

In the RCP 4.5 emissions pathway, each population will experience an upward shift in plant hardiness zone with the Southern RU populations shifting from Zone 7 to Zone 8 in 2069, Middle RU populations shifting from Zone 6 to a mix of Zone 6 and Zone 7 in 2069, and all Middle RU populations in Zone 7 by 2099 (Table 4-6). Northern RU populations currently in Zone 6 in this scenario stay in Zone 6, with one population found in Zone 7 in 2099.

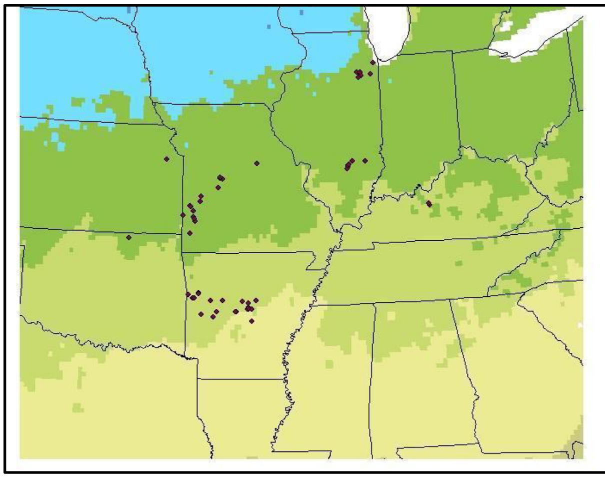
In the RCP 8.5 emissions pathway, each population will experience an upward plant hardiness zone shift with Southern and Middle RU populations undergoing this shift by 2039 and Northern RU populations by 2069. Southern RU populations in Zone 7 will end in Zone 8, while Middle and Northern RU populations in Zone 6 end in Zone 7 in the timeframes previously discussed.

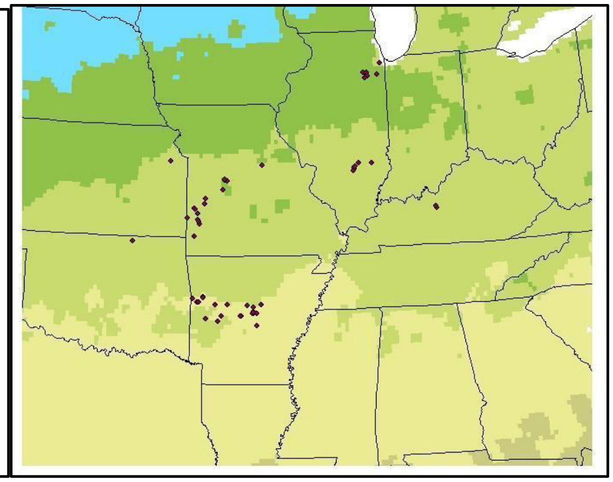
Table 4-6. The shift in plant hardiness zones for populations in each RU are expected in each representative concentration pathways from baseline (2009) to 2039, 2069, and 2099 (Matthews *et al.* 2019; Matthews *et al.* 2018). The three plant hardiness zones (6, 7, and 8) are represented in light, medium, and dark green, respectively.

RCP	RU	2009	2039	2069	2099
4.5	Southern	7	7, one site in 8	8, very close to 7	8
	Middle	6	6	6 and 7	7
	Northern	6, few sites in 5	6	6	6, one in 7
8.5	Southern	7	8	8	8
	Middle	6	7	7	7
	Northern	6, few sites in 5	6	7	7
	Key	Zone 5	Zone 6	Zone 7	Zone 8



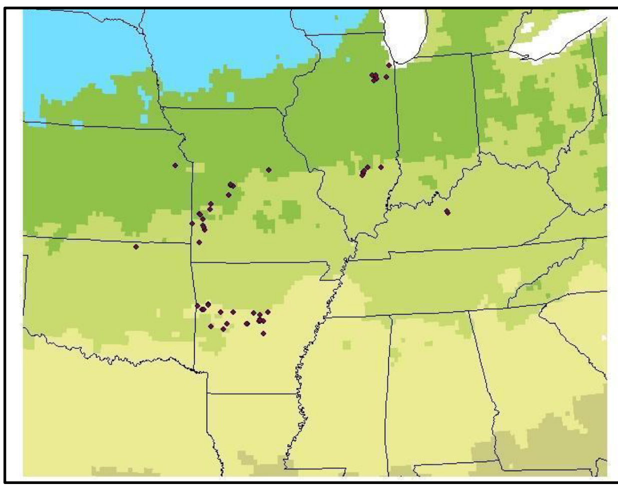
a) Baseline PHZ 2009

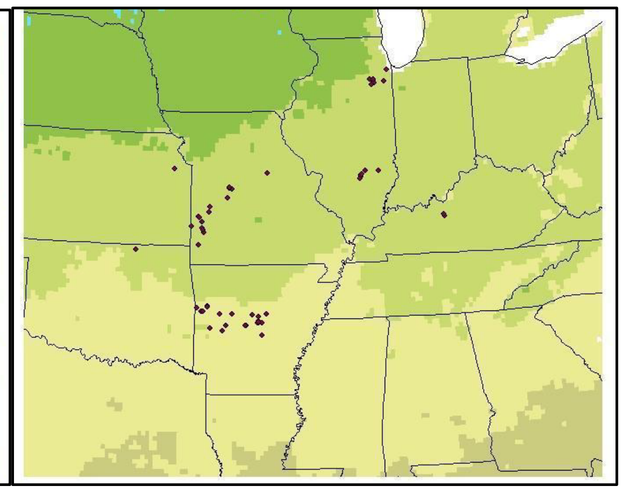




b) PHZ 2039 RCP 4.5

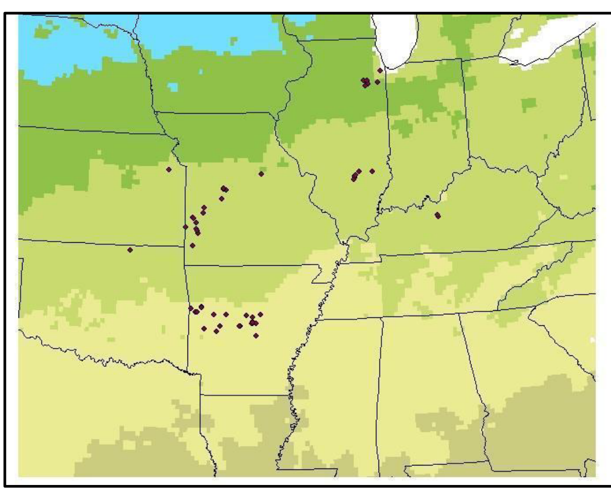
c) PHZ 2039 RCP 8.5

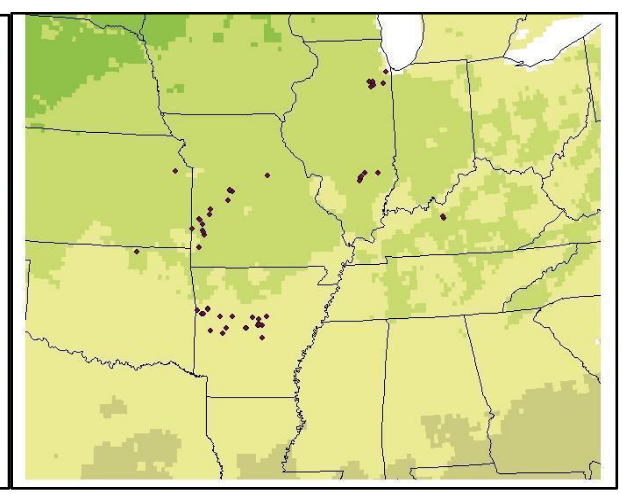




d) PHZ 2069 RCP 4.5

e) PHZ 2069 RCP 8.5





f) PHZ 2099 RCP 4.5

g) PHZ 2099 RCP 8.5

Figures 4-4 a-g. Rattlesnake-master borer moth populations in current and predicted plant hardiness zones (PHZ): a) PHZ baseline in 2009; b) 2039 plant hardiness zones as predicted in emission scenario RCP 4.5; c) 2039 plant hardiness zones as predicted in emission scenario RCP 8.5; d) 2069 plant hardiness zones as predicted in emission scenario RCP 4.5; e) 2069 plant hardiness zones as predicted in emission scenario RCP 8.5; f) 2099 plant hardiness zones as predicted by emission scenario RCP 4.5; and g) 2099 plant hardiness zones as predicted in emission scenario RCP 8.5.

Although there is predicted to be a full shift into the next warmer hardiness zone for all RUs by 2099, there is no evidence the shift will adversely impact the occurrence or density of rattlesnake-master in any of the extant rattlesnake-master borer moth populations. Plant hardiness zones identify the range of environmental conditions under which a species of plant can survive. The current range of rattlesnake-master occurs from Zone 3 to Zone 10, which encompasses the projected shift in hardiness zones for all extant moth populations; therefore, the plant is expected to have low sensitivity to the gradually changing climatic conditions as reflected by plant hardiness zones.

The predicted shift in hardiness zone represents an increase of 10°F (5.56 °C) in overwintering temperatures within each zone. Extant populations of the rattlesnake-master borer moth currently occur or have been known to occur across all hardiness zones represented in the future projections (see Table 4.1). Although the moth is capable of inhabiting the range of predicted environmental conditions, our choice of representation units assumes local adaptation for surviving colder overwinter temperatures from south to north. Based on surveys of the species from all three RUs, larval emergence in the Southern RU is up to a month earlier than that in the Northern RU, and adults in the Southern RU emerge from their pupae about a month later than those in the Northern RU (Bess 2019, pers. comm.).

Although the gradual 10-degree change may result in shorter, milder winters in all the RUs that could result in adult activity later in the fall and earlier egg hatch in the spring, it is not expected to be outside the current date ranges for these activities as outlined in Section 2.2 *Life History*. The temperature shift is not expected to impact the relationship of emerging first instar larvae with host plant emergence. Although the adaptive plasticity of the species is unknown, the rattlesnake-master borer moth may have the capacity to adapt its behavior to correspond with local temperature and timing of emergence. If the moth does not have the capacity to shift larval and adult emergence timing, the shift in zones to warmer conditions is not expected to limit conditions (temperature at larval emergence) or resources (oviposition sites on host plant at adult emergence). The species is not expected to be impacted locally from slow change in conditions from one zone to another. The rattlesnake-master borer moth previously occurred in North Carolina and Arkansas in Zone 8, and one extant population in Arkansas is in Zone 8. The extirpated populations in Arkansas and North Carolina are assumed to be lost due to development and inappropriate management, not environmental conditions. There is no evidence the climatic conditions experienced in Zone 8 prevent rattlesnake-master borer moth occurrence.

With host plant abundance stable and no evidence that the changes in environmental conditions will impact rattlesnake-master borer moth populations, we do not expect the viability of rattlesnake-master borer moth will be affected by changing plant hardiness zones.

In our analysis of representation, we assume an increased risk of extirpation or loss of the population with low resiliency scores. Loss of populations and decreasing resiliency scores reduce the ability of the species to adapt to novel change due to the consequences of isolation. Isolation of populations occurs when areas or small patches of suitable habitat containing the host plant are lost. This may create a gap in suitable habitat greater than the species' flight distance, resulting in a functional barrier to immigration, emigration, gene flow, and dispersal. Fragmentation of the landscape and decrease in potentially suitable habitat with resulting loss of connectivity expressed in the FORE-SCE model potentially further impedes gene flow between populations and impairs adaptation.

Resiliency scores are not expected to change after 2039; therefore, Table 4-7 presents only the 2039 expected resiliency score shifts. With the loss of nine populations in the Southern RU in scenario C, representation is greatly decreased. The Middle and Northern populations are not expected to experience this degree of loss of representation as these RUs have fewer sites with no long-term management plans (fewer private sites).

A fragmented landscape is expected to impede gene flow between populations and impair adaptation. This has likely occurred to some unknown extent in the past given the loss of prairie habitat across the species' presumed historic range and continues to affect the species.

Table 4-7. Number of populations with resiliency scores categorized by low (L), medium (M), high (H) by Representation Unit (RU) in future condition scenarios for 2039.

	Current Condition Resiliency Scores Low, Medium, High			**Scenario A** Resiliency Scores Low, Medium, High			**Scenario B** Resiliency Scores Low, Medium, High			**Scenario C** Resiliency Scores Low, Medium, High		
RU	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
North	1	7	1	1	1	7	0	6	1	0	6	1
Middle	5	13	10	1	8	19	4	13	10	4	13	10
South	11	1	6	11	0	7	11	1	6	2	1	6
Total	17	21	17	13	9	33	15	20	17	6	20	17

4.5 Implications for Redundancy

Predicted changes to resiliency scores affecting redundancy under each future scenario are shown in Table 4-7. Under scenario A, overall redundancy is not reduced as no populations are lost with improved resiliency of many sites managed by State or Federal agencies or conservation-focused NGOs. Under scenario B, overall redundancy is reduced with the loss of three populations and further reduced in scenario C with the loss of 12 populations.

4.6 Implications for Overall Viability

Currently, the rattlesnake-master borer moth is known from 55 sites or populations in six states. Of these 55 populations, 17 are highly resilient and 21 have medium resiliency under current conditions. The 17 highly resilient populations represent 89 percent of the acreage where the species is known to occur. Influences on species' viability include loss of suitable habitat (*i.e.*, habitat containing the obligate host plant, rattlesnake-master) from one of two factors: 1) inappropriate management or lack of management of a site leading to succession of the vegetation, and 2) land use changes through urbanization and development.

Our future scenarios assessment considered the current viability of the species to project future viability given plausible scenarios of intensity of management and land use change under predictive environmental/economic storylines. While habitat loss and fragmentation likely influenced the species current condition and may affect some individual populations in the future, land management actions are expected to have the greatest influence on rattlesnake-master borer moth populations and its overall species' viability within the projected timeframes.

Under scenario A, the 3Rs improved with increased host plant density to increase carrying capacity and resiliency within sites and no loss of populations. Under scenario B, three populations (two in the Northern RU and one in the Middle RU) are lost due to lack of management by 2039 before land use change has an effect. Representation and redundancy are also slightly reduced under this scenario. We see the largest loss of resiliency in scenario C with a loss of half of the populations in the southern RU and the same loss of three additional populations across the middle and northern RUs by 2039 as in scenario B. This loss of 12 populations results in the largest decline in representation and redundancy with resulting reduced viability for the species. Although scenario B and C predict the loss of populations, these are all small private sites. The overall impact to the species is low as the 17 highly resilient populations, representing 89% of the acreage for the species, remain in each of these scenarios. In all scenarios, no loss of range is predicted to occur. We expect rattlesnake-master borer moth to persist as a species in all future scenarios.

Literature Cited

Archer, S.R., E.M. Andersen, K.I. Predick, S. Schwinning, R.J. Steidl, S.R. Woods. 2017. Woody plant encroachment: causes and consequences. In: Briske, D.D. (ed.), *Rangeland Systems: Processes, Management and Challenges* (pp. 25-84). Springer Series on Environmental Management.Cham, Switzerland: Springer International Publishing AG.

Arkansas Game and Fish Commission (AGFC). 2017. Surveys for the rattlesnake-master borer moth (*Papaipema eryngii*) in Arkansas. Section 6 Interim Report to U.S. Fish and Wildlife Service. Little Rock, AR.

Baxter, J. 2019. Conversation with J. Baxter, Partners for Fish and Wildlife biologist, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office and M. Lombardi, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office (July 15, 2019).

Bess, J. 2018a. A report on status surveys for the rattlesnake master borer moth (*Papaipema eryngii* Bird) in the southeastern United States. Final report to Southeastern Association of Fish and Wildlife Agencies. Hancock, MI.

Bess, J. 2018b. Email from J. Bess, President, Northland Environmental Services (February 21, 2018).

Bess, J. 2019. Email from J. Bess, President, Northland Environmental Services (July 9, 2019).

Bird, H. 1917. New species and histories in Papaipema SM. (Lepidoptera.) No. 19. The Canadian Entomologist 49(4): 121-128.

Bird, H. 1934. Decline of the noctuid genus *Papaipema* (Lepidoptera). Annals of the Entomological Society of America, 27(4): 551-556.

Briggs, J.M., A.K. Knapp, J.M. Blair, J.L. Heisler, G.A. Hock, M.S. Lett, and J.K. McCarron. 2005. An ecosystem in transition: Causes and consequences of the conversion of mesic grassland to shrubland. Bioscience 55(3): 243-254.

Cathey, H.M. 1990. USDA plant hardiness map. Misc. Publ. 1475. Washington, DC: U.S. Department of Agriculture, Agriculture Research Service. Retrieved from https://archive.org/details/usdaplanthardine1475unit (accessed April 2019).

Casebere, L. 2012. Email from L. Casebere, Division of Nature Preserves, Indiana Department of Natural Resources (August 8, 2012).

Coffin, B. and L. Pfannmuller. 1988. *Minnesota's Endangered Flora and Fauna*. Minneapolis, MN: University of Minnesota Press.

Dana, R. 1997. Characterization of three Dakota skipper sites in Minnesota. Minnesota Department of Natural Resources, Natural Heritage and Nongame Research Program, St. Paul, MN.

Danderson, C.A. and B. Molano-Flores. 2010. Effects of herbivory and inflorescence size on insect visitation to *Eryngium yuccifolium* (Apiaceae) a prairie plant. The American Midland Naturalist 163(1): 234-246.

Daly, C., M.P. Widrlechner, M.D. Halbleib, J.I. Smith, and W.P. Gibson. 2012. Development of a new USDA plant hardiness zone map for the United States. Journal of Applied Meteorology and Climatology 51(2): 242-264.

Decker, G.C. 1931. The biology of the stalk borer *Papaipema nebris* (Gn.). Research Bulletin - Iowa Agriculture and Home Economics Experiment Station 11: 143.

Derkovitz, G. 2013. Telephone conversations with G. Derkovitz, Restoration Specialist, The Nature Conservancy, Illinois and K. Lundh, U.S. Fish and Wildlife Service, Illinois-Iowa Ecological Services Field Office (April 8 and May 1, 2013).

Forbes, W.T.M. 1954. *Lepidoptera of New York and Neighboring States: Noctuidae, Part III.* Cornell University Agricultural Experiment Station Memoir Volume 329. Ithaca, NY: Cornell University.

Fowler, A. 2018. Field site visit with A. Fowler, Wildlife Diversity Coordinator, Arkansas Game and Fish Commission and M. Lombardi, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office (July 17, 2018).

Frankham, R. 2005. Genetics and extinction. Biological Conservation 126(2): 131-140.

Frankham, R., J.D. Ballou, D.A. Briscoe. 2009. *Introduction to Conservation Genetics*, 2nd ed. New York, NY: Cambridge University Press.

Hall, S. 2012. Email from S. Hall, Landscape Ecologist, Natural Heritage Program, North Carolina Department of Environment and Natural Resources (October 17, 2012).

Hall, S. 2013. Telephone conversation with S. Hall, Landscape Ecologist, Natural Heritage Program, North Carolina Department of Environment and Natural Resources and K. Lundh, U.S. Fish and Wildlife Service, Illinois-Iowa Ecological Services Field Office (May 30, 2013).

Heikens, A.L. 1999. Savanna, barrens, and glade communities of the Ozark plateaus province. In: R.C. Anderson, J.S. Fralisch, and J.M. Baskin (eds.), *Savannas, barrens, and rock outcrop plant communities of North America* (pp. 220-230). New York, NY: Cambridge University Press.

Hessel, S.A. 1954. A guide to collecting the plant-boring larvae of the genus *Papaipema* (Noctuidae). The Lepidopterists News 8(3-4): 57-63.

Higgins, J.J., G.E. Larson, and K.F. Higgins. 2000. Floristic comparisons of tallgrass prairie remnants managed by different land stewardships in eastern South Dakota. In: N.P. Bernstein and L.J. Ostrander (eds.), *Proceedings of the seventeenth North American Prairie Conference: Seeds for the future, roots of the past* (pp. 21-31) Mason City, IA: North Iowa Area Community College.

Lafontaine, J.D., and B.C. Schmidt. 2010. Annotated check list of the Noctuoidea (Insecta, Lepidoptera) of North America north of Mexico. ZooKeys 40: 1-239.

LaGesse, V.L., T.L. Esker, and J.W. Walk. 2009. 2009 Monitoring of *Papaipema eryngii*, the rattlesnake master borer moth at Prairie Ridge State Natural Area and Twelve Mile

Prairie. Report prepared for the Illinois Department of Natural Resources and the Illinois Endangered Species Protection Board. Springfield, IL.

LaGesse, V. 2013. Telephone conversation with V. La Gesse, LaGesse & Associates Inc., Springfield Illinois and M. Lombardi, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office (April 15, 2013).

Laudermilk, E. 2012. Telephone conversation with E. Laudermilk, Zoologist, Kentucky Natural Heritage Program and M. Lombardi, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office (December 17, 2012).

Matthews, S.N., L.R. Iverson, R. Louis, M.P. Peters, and A.M. Prasad. 2018. Assessing potential climate change pressures across the conterminous United States: Mapping plant hardiness zones, heat zones, growing degree days, and cumulative drought severity throughout this century. Res. Map NRS-9. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Matthews, S.N., L.R. Iverson, R. Louis, M.P. Peters, and A.M. Prasad. 2019. Climate change pressures for the conterminous United States: Plant hardiness zones, heat zones, growing degree days, and cumulative drought severity. Fort Collins, CO: Forest Service Research Data Archive.

Maracahipes, L., M.B. Carlucci, E. Lenza, B.S. Marimon, B.H. Marimon, Jr., F.A.G. Guimarães, and M.V. Cianciaruso. 2018. How to live in contrasting habitats? Acquisitive and conservative strategies emerge at inter-and intraspecific levels in savanna and forest woody plants. Perspectives in Plant Ecology, Evolution and Systematics 34: 17-25.

McCabe, T.L. 1981. The Dakota skipper, *Hesperia dacotae* (Skinner): Range and biology, with special reference to North Dakota. Journal of the Lepidopterists' Society 35: 179-193.

McKenzie, P. (2012). Email from P. McKenzie, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service, Missouri Ecological Services Field Office (October 11, 2012).

Mohlenbrock, R.H. 1986. *Guide to the Vascular Flora of Illinois*. Carbondale and Edwardsville, Illinois: Southern Illinois University Press.

Molano-Flores, B. 2001. Reproductive biology of *Eryngium yuccifolium* (Apiaceae), a prairie species. Journal of the Torrey Botanical Society 128(1): 1-6.

Noss, R.F., E.T. LaRoe, and J.M. Scott. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation (Vol. 28). Washington, DC, USA: US Department of the Interior, National Biological Service.

Oswalt, C., J. Cooper, D. Brockway, H. Brooks, J. Walker, K. Connor, S. Oswalt, and R. Conner. 2012. History and current condition of longleaf pine in the southern United States. Southern Research Station, General Technical Report SRS–166. Asheville, NC: Southern Research Station.

Panzer, R.J. 1998. Insect conservation within the severely fragmented eastern tallgrass prairie landscape. (Master's Thesis). University of Illinois at Urbana-Champaign, Urbana, Illinois.

Panzer, R.J. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. Conservation Biology 16(5): 1296-1307.

Panzer, R.J. 2003. Importance of in situ survival, recolonization, and habitat gaps in the postfire recovery of fire-sensitive prairie insect species. Natural Areas Journal 23(1): 14-23.

Panzer, R.J., and M. Schwartz. 2000. Effects of managing burning on prairie insect species richness within a system of small, highly fragmented reserves. Biological Conservation 96: 363-369

Panzer, R.J., D. Stillwaugh, K. Gnaedinger, and G. Derkovitz. 1995. Prevalence of remnant dependence among the prairie- and savanna-inhabiting insects of the Chicago region. Natural Areas Journal 15(2): 101-116.

Ratajczak, Z., J.B. Nippert, and S.L. Collins. 2012. Woody encroachment decreases diversity across North American grasslands and savannas. Ecology 93(4): 697-703.

Robertson, K.R., R.C. Anderson, and M.W. Schwartz. 1997. The tallgrass prairie mosaic. In: M.W. Schwartz (ed.), *Conservation in Highly Fragmented Landscapes* (pp. 55-87). New York, NY: Chapman and Hall.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44(6): 418-421.

Scheiman, S. 2018. Email from S. Scheiman, Biologist and Aid Coordinator, Arkansas Natural Heritage Commission (July 30, 2018).

Schweitzer, D.F., M.C. Minno, and D.L. Wagner. 2011. Rare, declining, and poorly known butterflies and moths (Lepidoptera) of forests and woodlands in the eastern United States. U.S. Forest Service Technology Transfer Bulletin, FHTET-2011-1. Morgantown, WV: U.S. Department of Agriculture Forest Service.

Shaffer, M.L., and M.A. Stein. 2000. Safeguarding our precious heritage. In: B.A. Stein, L.S. Kutner, and J.S. Adams (eds.), *Precious heritage: The status of biodiversity in the United States* (pp. 301-321). New York: Oxford University Press.

Shaffer, M., L.H. Watchman, W.J. Snape III, and I.K. Latchis. 2002. Population viability analysis and conservation policy. In: S.R. Beissinger, and D.R. McCullough (eds.), *Population viability analysis* (pp. 123-142). Chicago, IL: The University of Chicago Press.

Skadsen, D.R. 2003. Dakota skipper population surveys for CCAA development in the State of South Dakota. South Dakota Department of Game, Fish, and Parks, Pierre, SD.

Solecki, M.K. and T. Toney. 1986. Characteristics and management of Missouri's public prairies. In: G.K. Clambey and R.H. Pemble (eds.), *The prairie: Past, present, and future: Proceedings of the ninth North American Prairie Conference* (pp. 168-171). Fargo, ND: Tri-College University Center for Environmental Studies.

Tester, J.R., and W.H. Marshall. 1962. Minnesota prairie management techniques and their wildlife implications. In: J.B. Trefethen (ed.), *Transactions of the twenty-seventh North American Wildlife Natural Resources Conference* (pp. 267-287).

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service. 2018. PLANTS Database. Retrieved from https://plants.usda.gov/core/profile?symbol=ERYU

Wiker, J. 2017a. Final report on the search for the rattlesnake master borer moth *Papaipema eryngii* Bird (Lepidoptera: Noctuidae) in the state of Missouri. Final Report to Missouri Department of Conservation, Contract No. SFS S14-152.

Wiker, J. 2017b. Final report on the search for the rattlesnake master borer moth *Papaipema eryngii* Bird (Lepidoptera: Noctuidae) in the state of Iowa. Final Report to the Iowa Department of Natural Resources.

Wiker, J. 2018. J. Wiker, species expert, in-person interview with M. Lombardi, U.S. Fish and Wildlife Service, Arkansas Ecological Services Field Office (July 17, 2018).

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience 65: 200-207.

Wood, T.J., and D. Goulson. 2017. The environmental risks of neonicotinoid pesticides: A review of the evidence post 2013. Environmental Science and Pollution Research, 24(21): 17285-17325.

Appendix A.

Population Resiliency by Representation Unit for Current Condition and Scenarios A, B, and C

Current Condition	**Population Resiliency Scores**																		
State	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**	**Representation Unit**
AR:	2	5	3	1	1	0	0	0	0	0	4	0	0	2	0	0	0	18	South
IL (Northern populations):	0	1	0	0	0	4	0	1	2	0	0	1	0	0	0	0	0	9	North
IL (Southern populations):	0	0	0	0	1	0	0	2	0	0	3	1	0	0	0	0	0	7	Middle
KS:	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	
KY:	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2	
MO:	0	0	1	4	0	3	0	0	5	0	1	1	0	0	1	0	1	17	
OK:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
Representation Unit*																		**Total**	
South:	2	5	3	1	1	0	0	0	0	0	4	0	0	2	0	0	0	18	
North:	0	1	0	0	0	4	0	1	2	0	0	1	0	0	0	0	0	9	
Middle:	0	0	1	4	1	5	0	2	5	0	4	3	0	0	2	0	1	28	
Range (entire)	2	6	4	5	2	9	0	3	7	0	8	4	0	2	2	0	1	55	

Scenario A	Population Resiliency Scores																		
State	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**	**Representation Unit**
AR:	2	5	3	1	0	0	0	0	0	0	0	0	0	4	0	0	3	18	South
IL (Northern populations):	0	1	0	0	0	0	0	1	0	4	0	2	0	0	1	0	0	9	North
IL (Southern populations):	0	0	0	0	0	0	0	1	0	0	0	1	0	5	0	0	0	7	Middle
KS:	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	
KY:	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2	
MO:	0	0	1	0	0	1	0	4	0	0	0	6	0	2	2	0	1	17	
OK:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
Representation Unit*																		**Total**	
South:	2	5	3	1	1	0	0	0	0	0	4	0	0	2	0	0	0	19	
North:	0	1	0	0	0	4	0	1	2	0	0	1	0	0	0	0	0	9	
Middle:	0	0	1	0	0	3	0	5	0	0	0	8	0	7	3	0	1	28	
Range (entire)	2	6	4	1	1	7	0	6	2	0	4	9	0	9	3	0	1	55	

Scenario B	Population Resiliency Scores																		
State	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**	**Representation Unit**
AR:	2	5	3	1	1	0	0	0	0	0	4	0	0	2	0	0	0	18	South
IL (Northern populations):	0	0	0	0	0	3	0	1	2	0	0	1	0	0	0	0	0	7	North
IL (Southern populations):	0	0	0	0	1	0	0	2	0	0	3	1	0	0	0	0	0	7	Middle
KS:	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	
KY:	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2	

MO:	0	0	0	4	0	3	0	0	5	0	1	1	0	0	1	0	1	16	
OK:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
Representation Unit*																		**Total**	
South:	2	5	3	1	1	0	0	0	0	0	4	0	0	2	0	0	0	18	
North:	0	0	0	0	0	3	0	1	2	0	0	1	0	0	0	0	0	7	
Middle:	0	0	0	4	1	5	0	2	5	0	4	3	0	0	2	0	1	27	
Range (entire)	2	5	3	5	2	8	0	3	7	0	8	4	0	2	2	0	1	52	

Scenario C	**Population Resiliency Scores**																		
<u>State</u>	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**	**Representation Unit**
AR:	1	1	0	0	1	0	0	0	0	0	4	0	0	2	0	0	0	9	South
IL (Northern populations):	0	0	0	0	0	3	0	1	2	0	0	1	0	0	0	0	0	7	North
IL (Southern populations):	0	0	0	0	1	0	0	2	0	0	3	1	0	0	0	0	0	7	Middle
KS:	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	
KY:	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2	
MO:	0	0	0	4	0	3	0	0	5	0	1	1	0	0	1	0	1	16	
OK:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
Representation Unit*																		**Total**	
South:	1	1	0	0	1	0	0	0	0	0	4	0	0	2	0	0	0	9	
North:	0	0	0	0	0	3	0	1	2	0	0	1	0	0	0	0	0	7	
Middle:	0	0	0	4	1	5	0	2	5	0	4	3	0	0	2	0	1	27	
Range (entire)	1	1	0	4	2	8	0	3	7	0	8	4	0	2	2	0	1	43	

Populations by Resiliency Scores in each of the Representation Units

Current Condition	Populations by Resiliency Scores in each of the Representation Units.							
Score	**Count Range**	**% Range**	**Count South**	**% South**	**Count Middle**	**% Middle**	**Count North**	**% North**
Low (1-4)	17	30.91%	11	61.11%	5	17.86%	1	11.11%
Medium (5-9)	21	38.18%	1	5.56%	13	46.43%	7	77.78%
High (10-17)	17	30.91%	6	33.33%	10	35.71%	1	11.11%
total	55		18		28		9	

Scenario A	Populations by Resiliency Scores in each of the Representation Units.							
Score	**Count Range**	**% Range**	**Count South**	**% South**	**Count Middle**	**% Middle**	**Count North**	**% North**
Low (1-4)	13	23.64%	11	61.11%	1	3.57%	1	11.11%
Medium (5-9)	9	16.36%	0	0.00%	8	28.57%	1	11.11%
High (10-17)	33	60.00%	7	38.89%	19	67.86%	7	77.78%
Totals	55		18		28		9	

Scenario B	Populations by Resiliency Scores in each of the Representation Units.							
Score	**Count Range**	**% Range**	**Count South**	**% South**	**Count Middle**	**% Middle**	**Count North**	**% North**
Low (1-4)	15	28.85%	11	61.11%	4	14.81%	0	0.00%
Medium (5-9)	20	38.46%	1	5.56%	13	48.15%	6	85.71%
High (10-17)	17	32.69%	6	33.33%	10	37.04%	1	14.29%
Totals	52		18		27		7	

Scenario C	Populations by Resiliency Scores in each of the Representation Units.							
Score	**Count Range**	**% Range**	**Count South**	**% South**	**Count Middle**	**% Middle**	**Count North**	**% North**
Low (1-4)	6	13.95%	2	22.22%	4	14.81%	0	0.00%
Medium (5-9)	20	46.51%	1	11.11%	13	48.15%	6	85.71%
High (10-17)	17	39.53%	6	66.67%	10	37.04%	1	14.29%
Totals	43		9		27		7	

Populations with Connectivity by State and Representation Unit for Current Condition and Scenarios A, B, and C

Current Condition

State	Number of populations with Connectivity by state	% Populations with Connectivity of Rangewide Total	Total Isolated by state	% Isolated	Percent of populations within each State with connectivity	Percent of total populations range-wide with connectivity
AR:	9	32.14%	9	33.33%	50.00%	**50.91%**
IL (North):	5	17.86%	4	14.81%	55.56%	
IL (South):	6	21.43%	1	3.70%	85.71%	
KS:	0	0.00%	1	3.70%	0.00%	
KY:	0	0.00%	2	7.41%	0.00%	
MO:	8	28.57%	9	33.33%	47.06%	
OK:	0	0.00%	1	3.70%	0.00%	
	28		**27**			

Scenario A

State	Number of populations with Connectivity by state	% Populations with Connectivity of Rangewide Total	Total Isolated by state	% Isolated	Percent of populations within each State with connectivity	Percent of total populations range-wide with connectivity
AR:	9	32.14%	9	33.33%	50.00%	**50.91%**
IL (North):	5	17.86%	4	14.81%	55.56%	
IL (South):	6	21.43%	1	3.70%	85.71%	
KS:	0	0.00%	1	3.70%	0.00%	
KY:	0	0.00%	2	7.41%	0.00%	
MO:	8	28.57%	9	33.33%	47.06%	
OK:	0	0.00%	1	3.70%	0.00%	
Totals	**28**		**27**			

Scenario B

State	Number of populations with Connectivity by state	% Populations with Connectivity of Rangewide Total	Total Isolated by state	% Isolated	Percent of populations within each State with connectivity	Percent of total populations range-wide with connectivity
AR:	9	36.00%	9	33.33%	50.00%	**50.91%**
IL (North):	4	16.00%	3	11.11%	57.14%	
IL (South):	6	24.00%	1	3.70%	85.71%	
KS:	0	0.00%	1	3.70%	0.00%	
KY:	0	0.00%	2	7.41%	0.00%	
MO:	6	24.00%	10	37.04%	37.50%	
OK:	0	0.00%	1	3.70%	0.00%	
Totals	**25**		**27**			

Scenario C

State	Number of populations with Connectivity by state	% Populations with Connectivity of Rangewide Total	Total Isolated by state	% Isolated	Percent of populations within each State with connectivity	Percent of total populations range-wide with connectivity
AR:	7	30.43%	2	10.00%	77.78%	**53.49%**
IL (North):	4	17.39%	3	15.00%	57.14%	
IL (South):	6	26.09%	1	5.00%	85.71%	
KS:	0	0.00%	1	5.00%	0.00%	
KY:	0	0.00%	2	10.00%	0.00%	
MO:	6	26.09%	10	50.00%	37.50%	
OK:	0	0.00%	1	5.00%	0.00%	
Totals	**23**		**20**			

Current and Future Management by State and Representation Unit for Current Condition and Scenarios A, B, and C

Current Condition	Current Management					Future management (next 10 years)			
State	**No management for prairie, may include incidental mowing**	**Rotational management (beneficial)**	**Burn entire site**	**Totals**		**None**	**Rotational**	**Entire**	**Totals**
AR:	8	10	0	18		8	10	0	18
IL (North):	2	7	0	9		2	7	0	9
IL (South):	0	7	0	7		0	7	0	7
KS:	0	1	0	1		0	1	0	1
KY:	0	2	0	2		0	2	0	2
MO:	1	16	0	17		1	16	0	17
OK:	0	1	0	1		0	1	0	1
_	11	44		55					55
Representation Unit									
North:	2	7	0	9		2	7	0	
Middle:	1	27	0	28		1	27	0	
South:	8	10	0	18		8	10	0	
Range (entire)	11	44	0	55		11	44	0	55

Scenario A	Current Management					Future management (next 10 years)			
State	**No management for prairie, may include incidental mowing**	**Rotational management (beneficial)**	**Burn entire site**	**Totals**		**None**	**Rotational**	**Entire**	**Totals**
AR:	8	10	0	18		8	10	0	18
IL (North):	2	7	0	9		2	7	0	9

IL (South):	0	7	0	7		0	7	0	7
KS:	0	1	0	1		0	1	0	1
KY:	0	2	0	2		0	2	0	2
MO:	1	16	0	17		1	16	0	17
OK:	0	1	0	1		0	1	0	1
	11	44		55		11	44	0	55
Representation Unit									
North:	2	7	0	9		2	7	0	9
Middle:	1	27	0	28		1	27	0	28
South:	8	10	0	18		8	10	0	18
Range (entire)	11	44	0	55		11	44	0	55

Scenario B	**Current Management**					**Future management (next 10 years)**			
State	**No management for prairie, may include incidental mowing**	**Rotational management (beneficial)**	**Burn entire site**	**Totals**		**None**	**Rotational**	**Entire**	**Totals**
AR:	8	10	0	18		8	10	0	18
IL (North):	0	7	0	7		0	7	0	7
IL (South):	0	7	0	7		0	7	0	7
KS:	0	1	0	1		0	1	0	1
KY:	0	2	0	2		0	2	0	2
MO:	0	16	0	16		0	16	0	16
OK:	0	1	0	1		0	1	0	1
				52					52

Representation Unit									
North:	0	7	0	7		0	7	0	7
Middle:	0	27	0	27		0	27	0	27
South:	8	10	0	18		8	10	0	18
Range (entire)	8	47	0	52		8	47	0	52

Scenario C	**Current Management**					**Future management (next 10 years)**			
State	**No management for prairie, may include incidental mowing**	**Rotational management (beneficial)**	**Burn entire site**	**Totals**		**None**	**Rotational**	**Entire**	**Totals**
AR:	0	9	0	9		0	9	0	9
IL (North):	0	7	0	7		0	7	0	7
IL (South):	0	7	0	7		0	7	0	7
KS:	0	1	0	1		0	1	0	1
KY:	0	2	0	2		0	2	0	2
MO:	0	16	0	16		0	16	0	16
OK:	0	1	0	1		0	1	0	1
				43					43
Representation Unit									
North:	0	7	0	7		0	7	0	7
Middle:	0	27	0	27		0	27	0	27
South:	0	9	0	9		0	9	0	9
Range (entire)	0	43	0	43		0	43	0	43

Public and Private Ownership by State and Representation Unit for Current Condition and Scenarios A, B, and C

Current Condition	Public/Private Ownership and Management of Populations					
State	**Total Public**	**% Public**	**Total Private**	**% Private**	**Mixed ownership**	**% Mixed ownership**
AR:	9	50.00%	9	50.00%	0	0.00%
IL (North):	7	77.78%	2	22.22%	0	0.00%
IL (South):	6	85.71%	0	0.00%	1	14.29%
KS:	1	100.00%	0	0.00%	0	0.00%
KY:	2	100.00%	0	0.00%	0	0.00%
MO:	16	95.00%	1	5.00%	0	0.00%
OK:	1	100.00%	0	0.00%	0	0.00%
	42		12		1	
Public/Private by ACU (# sites)						
South:	9	50.00%	9	50.00%	0	0.00%
North:	7	77.78%	2	22.22%	0	0.00%
Middle:	26	96.67%	1	3.33%	1	3.23%
Range (entire)	42	75.51%	12	24.49%	1	2.38%

Scenario A	Public/Private Ownership and Management of Populations					
State	**Total Public**	**% Public**	**Total Private**	**% Private**	**Mixed ownership**	**% Mixed ownership**
AR:	9	50.00%	9	50.00%	0	0.00%
IL (North):	7	77.78%	2	22.22%	0	0.00%
IL (South):	6	85.71%	0	0.00%	1	14.29%
KS:	1	100.00%	0	0.00%	0	0.00%
KY:	2	100.00%	0	0.00%	0	0.00%

MO:	16	95.00%	1	5.00%	0	0.00%
OK:	1	100.00%	0	0.00%	0	0.00%
	45		12		1	
Public/Private by ACU (# sites)						
South:	9	50.00%	9	50.00%	0	0.00%
North:	7	77.78%	2	22.22%	0	0.00%
Middle:	29	93.55%	0	0.00%	1	3.23%
Range (entire)	45	77.59%	11	18.97%	1	1.72%
Scenario B	**Public/Private Ownership and Management of Populations**					
State	**Total Public**	**% Public**	**Total Private**	**% Private**	**Mixed ownership**	**% Mixed ownership**
AR:	9	50.00%	9	50.00%	0	0.00%
IL (North):	7	100.00%	0	0.00%	0	0.00%
IL (South):	6	85.71%	0	0.00%	1	14.29%
KS:	1	100.00%	0	0.00%	0	0.00%
KY:	2	100.00%	0	0.00%	0	0.00%
MO:	16	100.00%	0	5.00%	0	0.00%
OK:	1	100.00%	0	0.00%	0	0.00%
	42		9		1	
Public/Private by ACU (# sites)						
South:	9	50.00%	9	50.00%		0.00%
North:	7	100.00%	0	0.00%		0.00%
Middle:	26	96.67%	0	0.00%	1	3.23%
Range (entire)	42	81.82%	9	16.36%	1	1.82%

Scenario C	Public/Private Ownership and Management of Populations					
State	**Total Public**	**% Public**	**Total Private**	**% Private**	**Mixed ownership**	**% Mixed ownership**
AR:	9	100.00%	0	0.00%	0	0.00%
IL (North):	7	100.00%	0	11.11%	0	0.00%
IL (South):	6	85.71%	0	0.00%	1	14.29%
KS:	1	100.00%	0	0.00%	0	0.00%
KY:	2	100.00%	0	0.00%	0	0.00%
MO:	16	100.00%	0	0.00%	0	0.00%
OK:	1	100.00%	0	0.00%	0	0.00%
	42		0		1	
Public/Private by ACU (# sites)						
South:	9	100.00%	0	0.00%	0	0.00%
North:	7	100.00%	0	0.00%	0	0.00%
Middle:	26	96.67%	0	0.00%	1	3.23%
Range (entire)	42	97.83%	0	0.00%	1	2.17%

Total acreage of populations for the current condition

Acreage by Resiliency Score, State, and Representative Unit

State	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	total acreage
AR:	1.5	25	13	10	4,000	0	0	0	0	0	23,279	0	0	20,637	0	0	0	47965.5
IL (Northern populations):	0	10	0	0	0	1235	0	315	961	0	0	2537	0	0	0	0	0	5058.0
IL (Southern populations):	0	0	0	0	280	0	0	220	0	0	727.5	550	0	0	0	0	0	1777.5
KS:	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	22.0
KY:	0	0	0	0	0	54	0	0	0	0	0	119	0	0	0	0	0	173.0
MO:	0	0	0.25	268	0	489	0	126	3,291	0	615	146	0	0	4,000	0	3,030	11965.3
OK:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35,000	0	0	35000.0
Representation Unit																		
South:	1.5	25	13	10	4000	0	0	0	0	0	23279	0	0	20637	0	0	0	47965.5
North:	0	10	0	0	0	1235	0	315	961	0	0	2537	0	0	0	0	0	5058.0
Middle:	0	0	0.25	268	280	565	0	346	3291	0	1342.5	815	0	0	39000	0	3030	48937.8
Range (entire)	1.5	35.0	13.3	278.0	4280.0	1800.0	0.0	661.0	4252.0	0.0	24621.5	3352.0	0.0	20637.0	39000.0	0.0	3030.0	101961.3

Potentially suitable habitat change projected by the FORE-SCE Model

	2009 Baseline Acres				Projected Percent Change											
					A1B			A2			B1			B2		
	A1B	A2	B1	B2	2009-2039	2009-2069	2009-2099	2009-2039	2009-2069	2009-2099	2009-2039	2009-2069	2009-2099	2009-2039	2009-2069	2009-2099
Southern RU																
Grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hay/Pasture Land	93134.08	94786.16	93041.44	93520.08	-1.89	0.75	0.93	-0.55	4.69	8.73	-4.51	-2.95	-2.90	-2.54	-4.44	-5.63
Middle RU																
Grassland	86278.72	85969.92	86232.40	86078.00	-3.19	-9.90	-22.17	-1.53	-5.24	-25.40	-0.41	-2.26	-3.87	-1.00	-0.47	-0.50
Hay/Pasture Land	136412.40	136335.20	136288.88	136227.12	0.20	2.97	9.02	-0.59	-1.20	6.01	0.88	-0.35	-1.08	1.65	2.03	1.93
Northern RU																
Grassland	4076.16	4107.04	4107.04	4153.36	-16.67	-40.15	-56.44	-22.56	-60.90	-62.78	-15.41	-23.31	-23.68	-13.01	-16.36	-17.84
Hay/Pasture Land	11379.28	11471.92	11502.80	11564.56	-9.63	-12.62	-16.82	-6.46	-11.71	-18.57	-3.89	-6.85	-8.86	-4.01	-4.94	-6.54
Total Rangewide Combined	331280.64	332670.24	331172.56	331543.12	-31.17	-58.95	-85.49	-31.69	-74.36	-92.01	-23.35	-35.72	-40.39	-18.91	-24.18	-28.59