

Kirtland's Snake (*Clonophis kirtlandii*) Species Status Assessment



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Executive Summary

This report summarizes the results of a species status assessment (SSA) completed for the Kirtland's snake, *Clonophis kirtlandii*, to assess the species' overall viability. Historically, this secretive species was sporadically distributed across areas of Illinois, Missouri, Indiana, Michigan, Kentucky, Tennessee, Ohio, Pennsylvania, and Wisconsin.

The intent of our analysis was to characterize Kirtland's snake viability over time. To assess the species' viability, we used the three conservation biology principles of resiliency, representation, and redundancy. Specifically, we identified the species' ecological requirements for survival and reproduction at the individual, population, and species levels, and described the beneficial and risk factors influencing Kirtland's snake viability.

Kirtland's snake spends most of its time underground in moist soil, using crayfish and other animal burrows. When above ground, it is often found under natural and artificial cover objects. It preys primarily on worms and slugs. Data on home range, movement, population structure and viability, and demographics are extremely limited or unavailable. At the species level, Kirtland's snake needs a sufficient number and distribution of healthy populations to withstand environmental stochasticity (resiliency), catastrophes (redundancy), and biological and physical changes in its environment (representation), but because of lack of data, we were unable to develop specific parameters for number and size of populations or to make more than general statements about the distribution across the range.

We compiled all available scientific and commercial data in hopes to evaluate the changes in representation, resiliency, and redundancy from historical to the current time and to project future conditions. Survey data are sporadic and typically limited to presence/absence level information. There are 139 counties that have historically supported populations of Kirtland's snake, and 60 of these contain records determined to be extant. Spatial data were provided by the States within the range of the species, and of the 415 records, 194 are extant, 17 are extirpated and 204 are unknown. There are 21 natural habitat areas that have detected multiple Kirtland's snakes in multiple years and are owned by conservation organizations or agencies; however, no population estimates are available for these sites.

We considered stressors that may be acting on the Kirtland's snake, and these included habitat loss due to development, road mortality, snake fungal disease, and climate change, but again, we lack data on how any populations of Kirtland's snake may respond to any of these stressors. Thus we were unable to predict future conditions.

The most basic data—where do our populations exist and what is their status—are very limited, and thus, we were unable to credibly assess the current and future conditions of Kirtland's snake. Additional research on demographics, population size and distribution, responses to stressors, and genetic diversity and gene flow are necessary to inform future analyses.

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Chapter 1. Introduction & Analytical Framework

This report summarizes the results of a species status assessment (SSA) conducted for the Kirtland's snake (*Clonophis kirtlandii*). We, the U.S. Fish and Wildlife Service, were petitioned to list 404 aquatic, riparian, and wetland species, including Kirtland's snake, as endangered or threatened under the Endangered Species Act of 1973, as amended (ESA) on April 20, 2010, by the Center for Biological Diversity, Alabama River Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald. In September of 2011, the Service found that the petition presented substantial scientific or commercial information indicating that the listing of 374 species, including Kirtland's snake, may be warranted. A subsequent complaint for not meeting the statutory petition finding deadlines was filed on June 17, 2014. Per a settlement agreement, we agreed to publish a 12-month finding by September 30, 2017. Thus, we conducted a SSA to compile the best available data regarding the species' biology and factors that influence the species' viability. The SSA will be the biological underpinning of the Service's forthcoming decision on whether Kirtland's snake warrants protection under the ESA.

The SSA assesses the ability of Kirtland's snake to maintain populations over time (*i.e.*, viability). To assess Kirtland's snake viability, we used the three conservation biology principles of resiliency, representation, and redundancy (or the "3Rs", Shaffer & Stein, 2000). These principles are generally described later in this chapter, and more specifically for Kirtland's snake in Chapter 2. We began by describing the species' ecology in terms of the 3Rs. Specifically, we identified the ecological requirements for survival and reproduction at the individual, population, and species levels. We then evaluated the species' historical and current condition in relation to the 3Rs and identified past and ongoing factors (beneficial and risk factors) that led to the species' current condition. We did not have sufficient data to develop future scenarios that may affect Kirtland's snake or to characterize Kirtland's snake viability over time.

1.1 Analytical Framework

To assess the viability of Kirtland's snake, we applied the conservation biology principles of resiliency, representation, and redundancy (henceforth, 3Rs). Viability is the ability to sustain populations over time; to do this, a species must have a sufficient number and distribution of healthy populations to withstand changes in its biological (*e.g.*, novel diseases, predators) and physical (*e.g.*, climate change) environment, environmental and demographic stochasticity (*e.g.*, wet or dry, warm or cold years), and catastrophes (*e.g.*, severe and prolonged droughts). Viability is not a single state—viable or not viable; rather, there are degrees of viability—less to more viable or low to high viability. Generally speaking, the more resiliency, representation, and redundancy a species has, the more protected it is against the vagaries of the environment, the more it can tolerate stressors (one or more factors that may be acting on the species or its habitat, causing a negative effect), the better able it is to adapt to future changes, and thus, the more viable it is. The 3Rs framework (assessing the health, number, and distribution of Kirtland's snake populations relative to frequency and magnitude of environmental stochasticity, catastrophic events, and exposure to stressors across its historical range of adaptive diversity) is useful for describing a species' degree of viability through time.

1.2.1 Resiliency

Resiliency is the ability to sustain populations in the face of environmental variation and transient perturbations. Environmental variation includes normal year-to-year variation in rainfall and temperatures, as well as unseasonal weather events. Perturbations are stochastic events such as fire, flooding, and storms. Simply stated, resiliency is having the means to recover from “bad years” and disturbances. Generally speaking, resiliency means populations are able to sustain themselves through good and bad years (*i.e.*, having healthy vital rates). The healthier the populations and the greater the number of healthy populations, the more resiliency a species possesses. For many species, resiliency is also affected by the degree of connectivity among populations. Connectivity among populations increases the genetic health of individuals (heterozygosity) within a population and bolsters a population’s ability to recover from disturbances via rescue effect (immigration).

1.2.2 Representation

Species-level representation is the ability of a species to adapt to near and long-term changes in the environment; it’s the evolutionary capacity or flexibility of a species. Representation is the range of variation found in a species; this variation, called adaptive diversity, is the source of species’ adaptive capabilities. Representation can, therefore, be measured through the breadth of adaptive diversity of the species. The greater the adaptive diversity, the more responsive and adaptable the species will be over time. Maintaining adaptive diversity includes conserving both the phenotypic diversity and genetic diversity of a species. By maintaining these two sources of adaptive diversity across a species’ range, the responsiveness and adaptability of a species over time is preserved. Phenotypic diversity is the physiological, ecological, and behavioral variation exhibited by a species across its range. Genetic diversity is the number and frequency of unique alleles within and among populations.

In addition to preserving the breadth of adaptive diversity, maintaining evolutionary capacity requires maintaining the evolutionary processes that drive evolution, namely gene flow, genetic drift, and natural selection. Gene flow is expressed through the physical transfer of genes or alleles from one population to another through immigration and breeding. The presence or absence of gene flow can directly affect the size of the gene pool available. Gene flow will generally increase genetic variation within populations by bringing in new alleles from elsewhere, but decrease genetic variation among populations by mixing their gene pools (Hendry *et al.*, 2011). Genetic drift is the change in the frequency of alleles in a population due to random, stochastic events. Genetic drift always occurs but is more likely to negatively affect populations that have a smaller effective population size and populations that are geographically spread and isolated from one another. Natural selection is the process by which heritable traits can become more (selected for) or less (not selected for) common in a population based on the reproductive success of an individual with those traits. Natural selection influences the gene pool by determining which alleles are perpetuated in particular environments. This selection process generates the unique alleles and allelic frequencies, which reflect specific ecological, physiological, and behavioral adaptations that are optimized for survival in different environments.

1.2.3 Redundancy

Species-level redundancy is the ability of a species to withstand catastrophic events. Redundancy protects species against the unpredictable and highly consequential events for which adaptation is unlikely. In short, it is about spreading the risk. Generally speaking, redundancy is best achieved by having multiple populations widely distributed across the species' range. Having multiple populations reduces the likelihood that all populations are affected simultaneously, while having widely distributed populations reduces the likelihood of populations possessing similar vulnerabilities to a catastrophic event. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species. Thus, the greater redundancy a species has, the more viable it will be. Furthermore, the more populations and the more diverse or widespread that these populations are, the more likely it is that the adaptive diversity of the species will be preserved. Having multiple populations distributed across the range of the species will help preserve the breadth of adaptive diversity, and hence, the evolutionary flexibility of the species.

Chapter 2. Species Ecology

In this chapter, we briefly describe the Kirtland's snake taxonomy and discuss the species' life history characteristics at the individual, population, and species levels. This is not an exhaustive review of the species natural history; rather, it provides the ecological basis for the 3Rs analyses.

2.1 Species taxonomy

Kirtland's snake was first described by Kennicott in 1856 as *Regina kirtlandii*, but a new monotypic genus *Clonophis* was assigned by Cope in 1888 (Cope, 1888). In 1892, Hay assigned it to the genus *Natrix*, and it continued with that assignment until it was re-assigned to *Clonophis* in 1963 (Rossman 1963). It is currently recognized as *Clonophis kirtlandii* (Crother, 2012) (Figure 2.1).



Figure 2.1 Ventral surface of Kirtland's snake with characteristic reddish scutes with black dots on both lateral edges.

Photo: Todd Pierson

2.2 Genetics

Only one study to date has evaluated the genetic diversity of Kirtland's snake. Ray (2009) analyzed genetic sequences from two mitochondrial genes, ND2 and CytBc, from 24 individual snakes in 5 states. These sequences differed by at most five base pairs, indicating low levels of variation. Snakes from the western portion of the range (Missouri, Illinois, and southern Michigan, Figure 4.1) were genetically separated from eastern snakes (Indiana and Ohio) by a single base pair, which was not significant (Ray, 2009).

At a site-specific level, four sites had three or more individual samples available for analysis, so these sites were analyzed independently to look at the geographic distribution of genetic variation. Little variation was present among most sites with the exception of southwestern

Ohio, where five haplotypes were identified, indicating high regional haplotype diversity at this site (Ray, 2009).

Ray's (2009) results indicate that genetic patterns likely reflect historical evolutionary lineages and not more recent selection. Thus, it appears that all populations of Kirtland's snake comprise a single ecological unit (Ray, 2009).

Kirtland's snake has relatively low genetic diversity of the ND2 and CytBc mitochondrial genes compared to other sympatric snakes of the Midwest, such as *Nerodia sipedon*, *Storeria dekayi*, and *Storeria occipitomaculata* (Ray, 2009). This may be due to small population size and lack of gene flow, or it could reflect a restricted geographic distribution compared to other more widely distributed species (Ray, 2009).

Bavetz (1994) and Tucker (1977) both considered morphological diversity of Kirtland's snake as a surrogate for genetic variation. Bavetz (1994) considered snout-vent length, lateral spots, and scale counts on specimens collected in Illinois. While the results indicated that there were significant differences in mean number of supralabial scales, postocular scales, anterior temporal scales, and lateral blotches between northern and southern populations in Illinois, results of Principal Components Analysis did not suggest more than a single taxon (Bavetz, 1994).

2.3 Geographic variation in morphology

Tucker (1977) evaluated 331 preserved specimens of Kirtland's snake range-wide for 34 different morphological characteristics. He found that western populations have relatively longer heads while eastern populations of the snake have relatively wider heads (Tucker, 1977). Tucker postulated that Kirtland's snake from the eastern part of the range may be more fossorial but caveated that the effects of local environments could also be causing these differences (Tucker, 1977). He also found an increasing number of supralabial and ventral scale counts and blotch counts toward the western portion of the range, with the Louisville, KY population supporting unusually high blotch counts (Tucker, 1977). Based on ventral scale counts, Tucker (1977) suggested there were two morphological, phenotypic groups of Kirtland's snake, one in the western and southern part of the range and one in the eastern and northern part of the range.

2.4 Reproduction

Kirtland's snake breeding has been documented in spring (February-May) (Brown, 1987; Minton, 1968, 1972; Smith, 1961; D. Wynn, unpublished data) and fall (Anton *et al.*, 2003). Females give birth to between 4-15 neonates between late July and late September (Brown, 1987; Conant, 1943, 1951; Pope, 1964; Tucker, 1976; D. Wynn, unpublished data). Sex ratios at birth are 1:1 (Conant, 1943). The smallest sexually mature females documented were 36-37 cm total body length (TBL) (Conant, 1951; D. Wynn unpublished data), while the smallest sexually mature male documented was 35 cm TBL (Wright & Wright, 1957, as cited in Ernst & Ernst, 2003).

2.5 Survival and Longevity

No estimate of survival has been generated for Kirtland's snake. Little information on longevity is available in the literature. D. Wynn (unpublished data) indicates that the same marked individual female was captured in 2001 and again in 2003 at the same site in Ohio. During this time her snout-vent length increased from 290 mm to 380 mm, and her tail length increased from 75 mm to 82 mm (D. Wynn, unpublished data). Thus, she was likely a young adult when collected the first time, and at least 4 years old when recaptured in 2003. When captured in July, she was gravid and was kept in captivity until she gave birth in August to three live and one stillborn neonates (D. Wynn, unpublished data). Minton (1972) documented survival of three marked snakes at the same location over two field seasons.

2.6 Habitat

Kirtland's snake is "fossorial" meaning it spends much of the time underground. It requires moist-soil environments to survive and is always found in close proximity to a permanent or seasonal water source, including wetlands, streams, reservoirs, lakes, or ponds (Wilsmann & Sellers, 1988). It is often found in or near crayfish burrows (Anton *et al.*, 2003; Bavetz, 1993; Briggler, 2015; Capparella *et al.*, 2012; Davis, 2012; J. MacGregor, Kentucky Division of Fish and Wildlife, pers. comm. 2017; Tucker, 1994; Wilsmann & Sellers, 1988; T. Wilson, University of Tennessee at Chattanooga, pers. comm. 2017). MacGregor (pers. comm. 2017) indicated that two Kirtland's snakes were accidentally excavated in April 2011 at a construction site. These snakes were found in crayfish burrows at a depth of 12-15 inches. The species of crayfish that have been found to co-occur with Kirtland's snake include *Fallicambarus fodiens*, *Procambarus gracilis* (Anton *et al.*, 2003), and *Cambarus diogenes* (Wilsmann & Sellers, 1988). Infrequently, Kirtland's snake has been documented using other animal burrows, such as "rodent holes" (Dreslik *et al.*, 2015). A laboratory study found that Kirtland's snake would not dig its own holes, but would readily use artificial burrows and cover if provided (Tucker, 1994).

When Kirtland's snake is above ground, it is almost always found under natural or artificial cover objects instead of basking or moving through open areas (Figures 2.2, 2.3) (Anton, 2016; Anton *et al.*, 2003; Brown, 1987; Capparella *et al.*, 2012; Conant, 1943; Davis, 2012; J. Davis, Herpetologist, pers. comm. 2015; Dreslik *et al.*, 2015; Maranto, 2007; Minton, 1972, 2001; Mott & Meretsky, 2005; Shulse, 2006; Tucker, 1994; Wilsmann & Sellers, 1988; D. Wynn, The Ohio State University, pers. comm. 2015). The species is also nearly always found in moist conditions even when above ground, for example under cover boards that are partially submerged (Davis, pers. comm. 2015; Wynn, pers. comm. 2015), adjacent to streams (Capparella *et al.*, 2012) or during and after rainy periods (Conant, 1943). During dry periods, the species retreats underground and may aestivate (Conant, 1943).

In Illinois, Kirtland's snakes are typically found in areas that have high water tables and clay soils intermixed with grassy areas and crawfish burrows (Wilson, pers. obs.). Minton (2001) indicated that urban populations are usually in open grassy places with clay soil and a water source. Wilsmann and Sellers (1988) indicate they are found in areas with mesic Alfisols that pond seasonally or with Mollisols that have excellent water retaining capability.



Figure 2.2 Vacant lot in Cincinnati, OH. Four Kirtland's snakes were found at this site in one day under cover objects including a board, a piece of cloth, and a couch. Photo: Greg Lipps



Figure 2.3 One Kirtland's snake was found under this rock on a hillside in Cincinnati, OH. Photo: Greg Lipps

Kirtland's snake hibernates underground in winter but may emerge during warm days to bask (Conant, 1943). Little is known about the habitat in which it hibernates, but Wilsmann and Sellers (1988) speculate that Kirtland's snake may hibernate in crayfish burrows. Some evidence supports speculation that Kirtland's snake hibernates in or near wetlands. Minton (1972) reported finding Kirtland's snake caked in mud in early spring on an embankment near a wetland where they were found in the summer; Conant (1943) found sluggish, muddy snakes in a meadow in early spring; and Hay (1892, as cited in Conant, 1943) dug an individual out of the mud near a pond in March.

In recent times, Kirtland's snake occurs in a variety of habitats, including wet meadow/prairie, forested riparian areas of streams, reservoirs, and urban and suburban habitats. While there are numerous references in the literature to Kirtland's snake being a species of the "prairie peninsula" (Conant, 1943, 1951; Wilsmann & Sellers, 1988) or primarily occurring in prairie habitats (Bavetz, 1994; Garman, 1892) or wet grasslands (Briggler, 2015), a large number of records also occur in distinctly non-prairie areas. Some of the more dense populations of Kirtland's snake, namely the populations around Indianapolis, IN, Louisville, KY, and Cincinnati, OH, occur outside of the prairie peninsula, and historically consisted of deciduous forest. Similarly, sites in Pennsylvania also occurred in a deciduous forest region. A common element among all sites is a seasonal water component for habitat.

A large number of historical and extant Kirtland's snake records occur in urban areas, particularly Toledo and Cincinnati, OH, Indianapolis, IN, and Louisville, KY (Conant, 1943; Davis, pers. comm. 2015; Indiana Division of Fish and Wildlife, unpublished data; Kentucky Department of Fish and Wildlife Resources, unpublished data; Minton *et al.*, 1982; Wilsmann & Sellers, 1988). These accounts report local Kirtland's snake abundance in vacant lots, remnant wetlands, and even trash dumps. In urban areas, Kirtland's snake also occurs in parks, cemeteries, vacant lots (G. Lipps, The Ohio State University, pers. comm. 2016; Wilsmann & Sellers, 1988), along railroad rights-of-way (Wilsmann & Sellers, 1988), and in neighborhood yards (Davis, pers. comm. 2015; Indiana Division of Fish and Wildlife, unpublished data; Kentucky Department of Fish and Wildlife Resources, unpublished data). Among disturbed sites in Illinois, the only habitat components that were the same between sites were mowed grass, crayfish burrows, and a temporary or permanent source of water (Bavetz, 1993).

2.7 Feeding Habits

Several studies report on the diet of Kirtland's snake, indicating that it feeds primarily on earthworms and slugs (Conant, 1943, 1951; Harding, 1997; Minton, 1972; Tucker, 1977). It may also feed on crayfish (Bavetz, 1993), leeches (Bavetz, 1993; Tucker, 1977), small fish (Minton, 1944), insects (Thurrow, 1993), and grubs (V. Meretsky, unpublished report).

2.8 Site Fidelity, Movement Patterns and Home Range

Both within-year and between-year site fidelity has been documented in a number of instances. One individual snake was tracked daily from April 23-May 13 in Illinois and was consistently found under the same tuft of grass or in the adjacent rodent hole (Dreslik *et al.*, 2015). In

another study, one marked female was found under the same artificial cover panel on 25, 26, 27, and 30 April (Anton *et al.*, 2003). A gravid female was found under the same cover board at an Ohio site on five occasions between July 24 and August 21, 2016 (Cross & Bekker, 2017). D. Wynn (unpublished data) indicates that the same marked individual female was captured in May 2001 and again in July 2003 at the same site in Ohio. Minton (1972) reported that three snakes were captured, marked, and recaptured in virtually the same spot on multiple occasions over two field seasons.

Little quantitative data are available on Kirtland's snake movement patterns. Incidental observations of 253 Kirtland's snakes (mostly road-kill) over 25 years along 2.5 miles of lake-front road in central Indiana indicate that snakes are crossing or basking on roads (Indiana Division of Fish and Wildlife, unpublished data). The total number of observations of Kirtland's snake per month is as follows: March=16; April=19; May=34, June=21, July=17, August=25, September=63, October=55, November=3. While these are opportunistic observations, they were provided over many years and throughout all seasons and seem to indicate movement beginning in March and ending in November, with a peak in activity between August and October. Several papers report that Kirtland's snake is active at night (Brown, 1987; Holman, 2012).

No home range studies have been completed. Wilsmann and Sellers (1988) postulate that repeated observations of individuals near and under the same cover objects indicate this species may have a very small home range.

2.9 Climate

Two models were completed to assess climatic features that may influence habitat suitability for Kirtland's snake. Both used BIOCLIM variables, which are derived from monthly temperature and rainfall values to describe annual and seasonal measures of climate within a given area over time (WorldClim, undated). Ray (2009) used a maximum entropy model and found that precipitation of the driest quarter, annual temperature range, and temperature seasonality were the top three BIOCLIM variables that described the current climate within the range of Kirtland's snake. King and Niirio (2013) conducted a similar analysis but attempted to address potential bias more so than in the Ray (2009) model (R. King, Northern Illinois University, pers. comm. 2017). They found that annual mean temperature, mean diurnal temperature range, annual precipitation, and temperature seasonality were the BIOCLIM variables that described the current climate within the Kirtland's snake's range.

Chapter 3. Ecological Requisites

This chapter will assess the ecological requisites at the individual, population, and species level. These requisites inform the analysis of resiliency, representation, and redundancy.

3.1 Individual-level ecology

Using the known life history characteristics of Kirtland's snake, we identified the specific ecological needs for individuals to survive and reproduce (Table 3.1). As explained above, the habitat needs of Kirtland's snake appear diverse and varied across the range. Five elements, however, appear to be essential to the survival and reproductive success of individuals: moist soils, burrows, prey, cover, and hibernation habitat.

Table 3.1 The ecological requisites for survival and reproductive success of Kirtland's snake individuals.

Survival & Reproduction Requisites	Description	Source
Moist soil	Moist soil in close proximity to water source	Wilsmann & Sellers, 1988
Burrows	Often found in crayfish or other animal burrows	Anton <i>et al.</i> , 2003; Bavetz, 1993; Briggler, 2015; Capparella <i>et al.</i> , 2012; Davis, 2012; Tucker, 1994; Wilsmann & Sellers, 1988
Prey	Primarily worms and slugs, few other prey items identified	Bavetz, 1993; Conant, 1943, 1951; Harding, 1997; Meretsky, unpublished report; Minton, 1944, 1972; Thurow, 1993; Tucker, 1977
Cover	Usually found under cover objects, natural and artificial	Anton, 2016; Anton <i>et al.</i> , 2003; Brown, 1987; Capparella <i>et al.</i> , 2012; Conant, 1943; Davis, 2012; J. Davis, pers. comm. 2015; Dreslik <i>et al.</i> , 2015; Maranto, 2007; Minton, 1972, 2001; Mott & Meretsky, 2005; Shulse, 2006; Tucker, 1994; Wilsmann & Sellers, 1988; Wynn, pers. comm. 2015
Hibernation habitat	Undefined. Thought to be burrows in soil in or near wetlands. May use crayfish burrows.	Conant, 1943; Minton, 1972; Wilsmann & Sellers, 1988

3.2 Population-level ecology

The specific needs for population sustainability are unknown for Kirtland's snake, but generally speaking, population viability requires healthy demographics and sufficient habitat (including patch size and connectivity) to support a healthy demography (Table 3.2). Healthy demography is a function of population size (N) and its population growth rate (λ). Lambda is a function of reproductive capacity and survival rates of individuals of various age classes. For a population to be growing, λ must be >1 . The size of a population influences population viability through the processes of demographic and environmental stochasticity. No population ecology or viability studies of Kirtland's snake have been published (Gibson & Kingsbury, 2004; Wilsmann & Sellers, 1988). We know that females can produce 4-15 offspring per year (Conant, 1943, 1951; Tucker, 1976; D. Wynn, unpublished data), and one report indicates that an adult female survived to at least 4 years of age (D. Wynn, unpublished data), but we do not have sufficient data on juvenile or adult survival rates or reproductive capacity necessary to understand population ecology for this species.

We suspect that individuals have fairly small home ranges based on recaptures of the same individuals at the same locations within and between years, but we have no data on how many individuals occur within any extant populations or how much habitat is needed to support a viable population. Further, we do not know how mobile individuals are, or how connected sites must be to have sufficient genetic exchange. We assume that, at a minimum, populations would require a sufficient amount of quality habitat that provides moist soils close to a water source, burrows, cover, prey, and hibernation habitat to support a viable population size.

Table 3.2 The requisites for Kirtland's snake population viability.

	Requisites for Population Health	Description
Demography	Population growth	Need $\lambda \geq 1$, which is a function of: survivorship, recruitment, and population structure, all of these are unknown
	Population size	Minimum N required, but unknown
Suitable Habitat	Sufficient suitable habitat	Moist soil near water source, prey, burrows, cover objects, and hibernation sites. Sufficient patch size unknown, connectivity between sites unknown.

3.3 Species-level ecology

In this section, we describe the ecological requirements at the species-level in terms of the 3Rs (Table 3.3).

3.3.1 Resiliency

Resiliency is the ability to sustain populations in the face of environmental variation and transient perturbations. In Kirtland's snake, resiliency is a function of the number of healthy populations and the distribution of these populations relative to degree and spatial extent of environmental stochasticity. Generally speaking, the greater the number of healthy populations and spatial heterogeneity occupied by the species are, the greater the likelihood of sustaining populations is through time. Healthy populations are better able to recover from stochastic events and withstand variation in the environment. Thus, the greater the number of healthy populations is, the more resiliency the species possesses.

We have no demographic data that would allow us to evaluate the health of any of the Kirtland's snake populations throughout the range of the species. We have anecdotal information indicating that populations at some sites have persisted over multiple years and likely still persist today (Chapter 4.3). The site for which we have the most available demographic data is in Ohio. This site has had incidental captures of Kirtland's snakes every year since 1996 (though only a small number of individuals were marked), has documented reproduction in several years, and has documented snakes ranging from 9-38 cm snout-vent length, indicating the presence of various age classes of individuals (D. Wynn, unpublished data). But even for this site, data is insufficient to determine if the available habitat, population growth rate, or population size are sufficient to maintain the population over time. Thus, for sites with even less data, we cannot evaluate population health.

Environmental stochasticity acts at local and regional scales, and thus, populations sensitive to environmental conditions can fluctuate in synchrony over broad geographical areas (Hanski & Gilpin, 1997). Additionally, over longer periods, landscape and habitat changes can be synchronized over large areas, leading to correlated extinction risks among populations at a larger regional scale (Hanski & Gilpin, 1997). Thus, having populations distributed across a diversity of environmental conditions helps guard against concurrent losses of populations at local and regional scales by inducing asynchronous fluctuations among populations. Kirtland's snake's sensitivity to environmental conditions is unknown. We do know that Kirtland's snake requires moist soils near a water source, and thus it is reasonable to assume that seasonal and annual precipitation patterns may be an important driver of habitat suitability. We suspect that Kirtland's snake can aestivate during dry periods (Conant, 1943), but we do not know how long it can maintain this behavior in the case of an extended drought, and what the biological costs to individuals are of prolonged aestivation; if Kirtland's snake's demography is influenced by environmental conditions, such as drought, spatial heterogeneity (specifically, the diversity of temperature and precipitation conditions occupied by Kirtland's snake) will influence the species resiliency.

Lastly, resiliency is often influenced by connectivity among populations; movement among populations is essential for genetic health via gene flow and demographic rescue. Limited

genetic analysis of Kirtland's snake did not identify high levels of variation among individuals or sites, with the exception of one site in southwestern Ohio. This may be due to small population size and lack of gene flow, or it could reflect a restricted geographic distribution (Ray, 2009). This result could also be due to a past bottleneck, driven by habitat conversion from mesic-grasslands to agrarian and exurban development in the early to mid-1900's (T. Wilson, pers. comm. 2017). As explained above, we have no data on Kirtland's snake movement ability, home range size, patch size needed to support a population, or to what extent it can move across unsuitable areas, and thus, it is unknown whether connectivity among populations influences the resiliency of the species.

Given the above, beyond general principles, we do not have a solid understanding of needs for Kirtland's snake resiliency.

3.3.2 Representation

Representation is the ability of the species to adapt to physical (*e.g.*, climate conditions, habitat conditions or structure across large areas) and biological (*e.g.*, novel diseases, pathogens, predators) changes in its environment presently and into the future; it is the evolutionary capacity or flexibility of the species. Representation is the range of variation found in a species, and this variation—called adaptive diversity—is the source of species' adaptive capabilities. By maintaining these two sources of adaptive diversity across a species' range, the responsiveness and adaptability of the species is preserved.

Genetic diversity is the primary fuel for adapting to changing environmental conditions (Hendry *et al.*, 2011); for adaptation to occur, there must be variation upon which to act (Lankau *et al.*, 2011). The genetic diversity of Kirtland's snake is determined by its allele diversity (size of its gene pool), which is influenced by the level of gene flow among populations and the rates of genetic drift within populations. There is little genetic information for Kirtland's snake. Ray (2009) did not find a significant difference in mitochondrial genes in 24 individual snakes from five states. Thus we did not further evaluate genetic diversity.

Phenotypic diversity (the physiological, ecological, and behavioral variation expressed by Kirtland's snake) is also important for adapting to changes in environmental conditions. Phenotypic variation determines how organisms interact with their environment and how they respond to selection pressures (Hendry *et al.*, 2011). The degree of phenotypic variation is determined by the diversity of physical and biological pressures to which organisms are exposed, which vary across spatial and temporal scales. As such, species that span environmental gradients are expected to harbor the most phenotypic and genetic variation (Lankau *et al.*, 2011). Thus, preserving the breadth of phenotypic diversity of Kirtland's snake requires maintaining populations across historical latitudinal, longitudinal, and elevational gradients, as well as climatic gradients; doing so increases the likelihood that the species will retain the potential for adaptation over time.

We assessed the variation in morphology, and climate/habitat use across the range of Kirtland's snake. Only one study of morphological variation rangewide has been completed (Tucker, 1977). This study suggested there were two phenotypic groups of Kirtland's snake, one in the western and southern part of the range and one in the eastern and northern part of the range,

based on head shape and ventral scale counts (Tucker, 1977). We do not know whether these morphological differences provide adaptive benefits.

To get a sense of the range of climates occupied by Kirtland's snake, we looked at Bailey (1995) ecoregions. The largest ecosystems are domains, which are groups of related climates and which are differentiated based on precipitation and temperature. The entirety of the Kirtland's snake range lies within the humid temperate domain. This domain is characterized by four distinct seasons, with strong annual cycles of temperature and precipitation (Bailey, 1995). Divisions represent the climates within domains and are differentiated based on precipitation levels and patterns as well as temperature.

Kirtland's snake occurs in three ecoregional divisions: Hot Continental, Prairie, and Warm Continental Divisions (Figure 3.1). The core of the Kirtland's snake range is in the Hot Continental Division. This division is characterized by deciduous forest habitat, hot summers and cool winters (Bailey, 1995). The westernmost portion of Kirtland's snake's range is in the Prairie Division. This area is composed primarily of grassland habitat, and is drier and warmer than other portions of the range. A small number of Kirtland's snake records occur in the Warm Continental Division. These records are found at the northern extent of the range in Michigan and the eastern extent of the range in Pennsylvania. The Warm Continental Division is characterized by needle leaf and mixed needle leaf-deciduous forest vegetation, cold and snowy winters, warm summers, and ample precipitation (Bailey, 1995).

Kirtland's snake's range includes a diverse range of temperature conditions. Average annual temperatures range from 40°F (4°C) in the North to 65°F (18°C) in the south. Likewise, populations that occur in the northern portion of the range are subject to colder, snowier winters and significantly shorter frost-free period (3-5 months) than populations that occur in the southern portion of the range, where the frost-free period ranges from 5-6 months (Bailey, 1995).

The range of Kirtland's snake incorporates distinctly different vegetative communities (prairie vs. deciduous forest) in the western and eastern extents of its range, seasonal temperature extremes and frost-free days in the northern and southern extent of its range, and different elevation and topographic landscapes from the northeast to the southwest extent of its range. These differing environmental conditions can influence species evolution over time. Without further information, it seems prudent to maintain populations of Kirtland's snake across the breadth of environmental conditions.

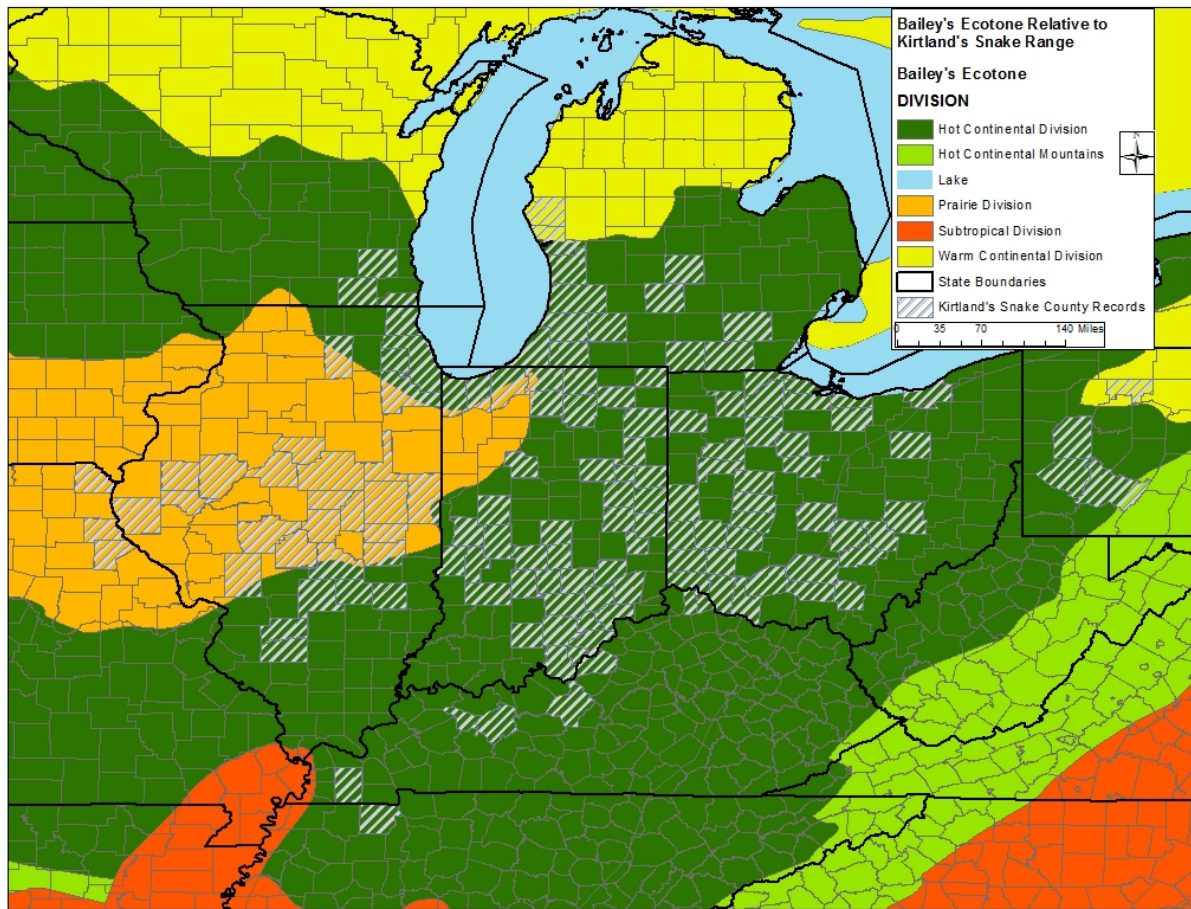


Figure 3.1 Range map of Kirtland's snake (hashed counties) relative to ecoregions (Bailey, 1995). Prairie Division is found in the westernmost portion of the range (orange), Hot Continental Division is found in the core of the range (dark green), and Warm Continental is found in the northernmost (Michigan) and easternmost (Pennsylvania) extent (yellow) (Bailey, 1995).

3.3.3 Redundancy

Species-level redundancy reflects the ability of a species to withstand catastrophic events and is best achieved by having multiple, widely distributed populations relative to the spatial occurrence of catastrophic events. In addition to guarding against a single or series of catastrophic events extirpating all populations of Kirtland's snake, redundancy is important to protect against losing irreplaceable sources of adaptive diversity. Having multiple populations distributed across the range of the species will help preserve the breadth of adaptive diversity, and hence, the evolutionary flexibility of the species. Thus, Kirtland's snake redundancy is described as having multiple, healthy populations widely distributed across the spatial occurrence of catastrophic events.

We identified prolonged drought as the most likely potential catastrophic event of relevance to Kirtland's snake. Because Kirtland's snake is dependent on permanent and seasonal water sources for habitat, we assume that precipitation has a significant influence on habitat availability. According to Bailey (1995), the normal range of precipitation per year within the Hot Continental and Prairie Divisions is 510 mm (20 in.) to 1280 mm (50 in.). The U.S. Drought Monitor (2017) classifies general drought categories by intensity, with D1 being the least intense drought and D4 being the most intense drought. Droughts categorized as D3-D4 would result in vegetation losses and water shortages (U.S. Drought Monitor, 2017), and thus, may impact Kirtland's snake.

Table 3.3 General ecological requirements for species-level viability

3 Rs	Requisites for long-term viability	Description
Resiliency (able to withstand stochastic events)	Healthy populations	Insufficient data available to discern the requirements needed to support healthy populations (no data on λ , minimum viable population size, habitat patch size, connectivity).
Representation (to maintain adaptive capacity)	Maintain adaptive diversity of the species	Sufficiently large populations maintained across the species' genetic and phenotypic variation. Generally, maintain populations across the latitudinal, longitudinal, and elevational distribution, particularly southwest Ohio region which appears to have highest diversity.
	Maintain evolutionary processes	Insufficient data available to discern what is necessary to maintain evolutionary drivers—gene flow, natural selection, genetic drift—to mimic historical patterns (no data on gene flow, population connectivity, movement capabilities)
Redundancy (to withstand catastrophic events)	Sufficient number and distribution of populations to spread risk	Insufficient data available to determine sufficient number and distribution of populations to guard against catastrophic events, such as drought, wiping out portions of the species adaptive diversity (no data on drought response, distribution of healthy populations).

Chapter 4. Analysis of Historical and Current Conditions

In this Chapter, we describe the historical and current conditions of Kirtland's snake. For the purposes of our analyses, the historical condition is the reference condition; it provides the context for the current and future conditions. That is, historical condition is the baseline from which the current and future degrees of resiliency, representation, and redundancy are measured.

4.1 Methods

We reviewed all available literature for occurrence data of Kirtland's snake. Literature included published papers, unpublished survey reports and the web-based platform HerpMapper (2017). Historic occurrence data were primarily gleaned from Conant (1943), which included a thorough inventory of museum specimens throughout the range of the species.

We queried the state wildlife agencies in the range of the species (IN, IL, KY, MI, MO, OH, PA, TN, WI) for data on distribution of Kirtland's snake. We requested the following data from each state:

- Kirtland's snake occurrence data including latitude/longitude, county, ownership of parcel, date of most recent observation, number of individuals observed, and ongoing management
- Data or reports for surveys that targeted Kirtland's snake (*e.g.*, historical location, suitable habitat), but during which no Kirtland's snake was found
- Identification of species experts—individuals with expertise in critical biology aspects and habitat needs of this species
- Rationale for assigning a state-listing status to Kirtland's snake in each state
- Literature or unpublished reports that describe the species habitat, behavior, or life history

Each state responded to our request with spatial and/or narrative data. We compiled all available species occurrence data from the above sources and created a geographic information system database. Where point data were available, they were included in the database. Where point data were not available (*e.g.*, museum records), we mapped only the county of occurrence.

4.2 Historical Condition

Based on all compiled records, Kirtland's snake occurrence is documented from 9 states: Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, Pennsylvania, Tennessee, and Wisconsin (Figure 4.1). GIS data are available for at least some records in all states with the exception of Wisconsin, where the species has not been detected since 1926 (Cahn, 1929).

Various documents include discussion of records that we do not include in our range. Two late 1800s museum specimens exist from a disjunct area far east of all other records: Trenton, New Jersey and Delaware County, Pennsylvania (Conant, 1943; Gibson & Kingsbury, 2004). While Conant (1943) thought these may be valid, others have called them into question (Brandon & Bavetz, 1992; Gibson & Kingsbury, 2004; Wilsmann & Sellers, 1988); thus, we do not include

these in the range. Specimens originally reported from West Virginia and Alabama in the 1930s were determined to be in error (Conant, 1943); thus, we do not include these in the range.

Ray's (2009) ecological niche model suggested that the range of climatically suitable conditions for Kirtland's snake may extend beyond the historically documented range, and given the species' fossorial nature, it is likely that the species' range is not fully delineated. Nonetheless, records indicate that Kirtland's snake's historical range includes nine states extending from the northeastern edge of Missouri, east through Illinois, Indiana, Ohio, and western Pennsylvania, north into southeastern Wisconsin and the southern half of Michigan's lower peninsula, and south through northern and western Kentucky to the northwestern border of Tennessee (Figure 4.1).

The fossorial nature of Kirtland's snake makes it difficult to find, and thus it is difficult to know how many populations may have existed historically. Wilsmann and Sellers (1988) note that Kirtland's snake had been found at 230 sites, but do not specify how they arrived at this number. While point data were not available for all records, we were able to glean county-level information from nearly all records, and thus we summarize the number of historical populations by county. Our assessment indicates that Kirtland's snake has been documented in 139 counties (Figure 4.1).

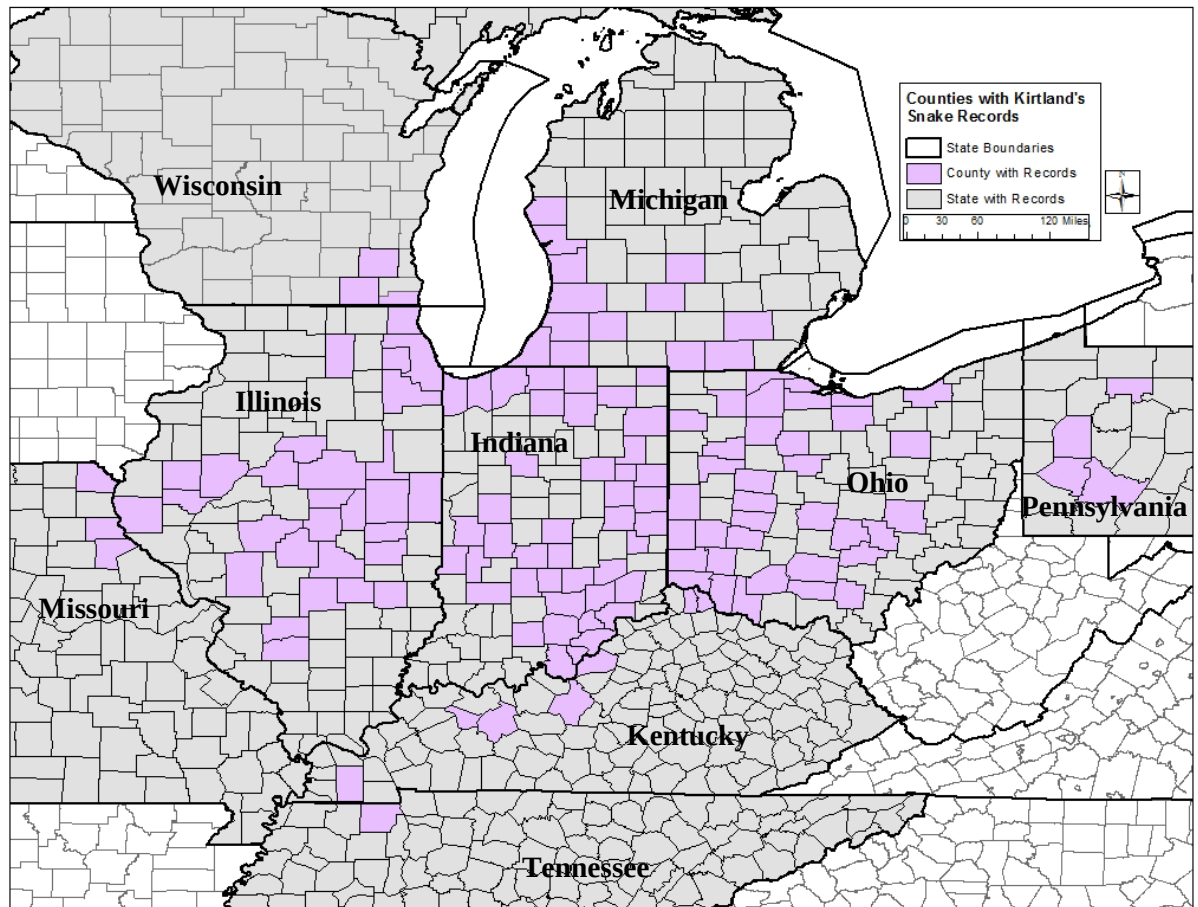


Figure 4.1 Historical range map of Kirtland's snake

4.3 Current Condition

In this section, we describe our analysis of the current condition of Kirtland's snake.

4.3.1 Methods

Determining the status of Kirtland's snake populations is confounded by the inordinate difficulty in detecting the species, even with targeted surveys using reliable methods. At a site in Illinois where Kirtland's snakes are widely distributed and have been detected regularly since the mid-1900s, observations are inconsistent and sometimes separated by periods of years (Anton & Mauger, 2007). Bavetz (1994) states that successive visits are often necessary to detect Kirtland's snake. Briggler (2015) required repeated, intensive sampling to find Kirtland's snake in Missouri. Wilsmann and Sellers (1988) noted that "failure to locate it on any particular visit, or even on several visits, does not necessarily mean that population is extirpated." For example, the species was recently detected in three townships in Missouri, where it had not been seen in over 50 years (Briggler, 2015; Shulse, 2006). Thus, assessing status and health of populations based on current data is difficult.

To assess the current condition of Kirtland’s snake, we considered all the spatial occurrence data provided by the states, in the published and unpublished literature, and on the web-based platform HerpMapper, and assigned each record to a category of “extant,” “unknown,” or “extirpated,” based on three broad criteria: the last date of observation (LDO); presence of suitable habitat within 100 m; and thoroughness of surveys (Table 4.1). The status criteria were devised based on input from species’ experts.

Table 4.1 Criteria used to determine current status of Kirtland’s snake records.

Status	Criteria
Extant	Last date of observation (LDO) is within 15 years, and no evidence that habitat has been destroyed since LDO.
Unknown	LDO is greater than 15 years but less than 100 years and habitat is still present. Data are insufficient to determine whether the population is extant or extirpated.
Extirpated	LDO is greater than 15 years and extensive surveys completed with negative results; or LDO is greater than 100 years; or habitat is completely unavailable (regardless of LDO).

Our first step was to assign each record to a status category, based on LDO. We assigned records less than 15 years old to the “extant” category because we know that Kirtland’s snake can live for at least 4 years, and that populations have the ability to persist at a given site for decades, even in areas where habitat appears disturbed. Conversely, we know they are difficult to detect even with focused surveys. Thus, we selected 15 years as a reasonable time frame within which to assume that records may still be persisting if suitable habitat is still available (see habitat suitability discussion below). This was similar to the timeframe (14 years) used by Gibson and Kingsbury (2004) in their assessment. We assigned records that have not been documented for more than 100 years to the “extirpated” category, as it seems reasonable that if the species was still extant in the area, it would have been documented again at least once in this amount of time. All other records (*e.g.*, less than 100 years but greater than 15 years), were considered “unknown.” To get a sense of the number of populations that may be trending toward extirpation, we also quantified the number of records that are between 50 and 100 years old, (1966-1916).

Our second step was to evaluate the habitat suitability at each record and factor that information into the status category. We defined suitable habitat as any water resource or non-farmed vegetative cover within 100 meters (m) of the Kirtland’s snake record. We applied a 100 m buffer around points to account for inaccuracy and to account for limited movements within a home-range. If no suitable habitat existed within 100 m of the record no matter what the LDO, the record was assigned “extirpated” status. As site-specific habitat assessments are lacking for nearly all records, we used aerial photos in ArcGIS (accessed July-October 2016) to assess habitat suitability. If water resources were visible, we assumed that habitat was suitable. While the presence of water resources or moist soils is believed to be essential, this element was not

always visible in aerial photographs or other remote broad-scale mapping (*e.g.*, National Land Cover Database, National Wetlands Inventory). This is particularly true for small areas and seasonally wet areas or moist soils and in urban or suburban areas. In these instances, we used the presence of non-farmed vegetative cover (*e.g.*, trees, grass, and herbaceous cover) as a surrogate for presence of small pockets of habitat where they could still persist, and assumed that this habitat was suitable. We assumed that Kirtland's snake would not persist in tilled fields because tilling would disrupt the fossorial habitat on which they depend; thus if the area was entirely agricultural, we assumed it was unsuitable. We also classified each record as "natural," "urban/suburban," or "agricultural" based on the majority of habitat within the 100 m buffer. This was similar to the classification used by Wilsmann and Sellers (1988). Because suitable habitat is so broadly defined, only a small number of "extirpated" status records were assigned using this component.

Lastly, we used survey effort to help inform whether sites were extirpated. As described earlier, the fossorial behavior of Kirtland's snake makes them difficult to detect. Thus, we assume that surveys to confirm presence or absence must be "extensive," which we loosely defined as multiple visits to a specific location during spring-fall over multiple years. If "extensive surveys" were completed at a record with subsequent negative results, the record was assigned a status of "extirpated," regardless of LDO or suitable habitat. Because most records did not have this level of survey intensity, only a small number of "extirpated" status records were assigned using this component.

Information and presentation of data varied considerably among states. Some states provided point data while others provided township data or large polygon data. Some states provided individual points for each snake in their database while others provided summary data per parcel (*e.g.*, 5 Kirtland's snakes collected at one park represented by one point). This variability in the data complicated our analysis. We considered each point, polygon, or township to be one "record." Where metadata existed to inform the record, we used that to help derive additional information if useful. Some states provided only township-level data or large polygons, and we could not complete a habitat analysis for those. We used LDO and survey effort to rank these sites.

If a record was available only at the county level, we assigned the county to either "extant" if the record's LDO was within 15 years, or "other" if the record was older than 15 years. This was primarily relevant to museum specimens and data obtained from HerpMapper (2017).

4.3.2 Distribution, Number, and Health of Populations

The spatial data included a total of 415 Kirtland's snake records. Using our status criteria, 194 (47%) records are classified as "extant," 17 (4%) are classified as "extirpated" and 204 (49%) are classified as "unknown" (Table 4.2, Appendix A). The "extant" records occur in 60 counties in 7 states (Figures 4.2, 4.3). Pennsylvania and Wisconsin were the only states with no "extant" records. Thus, 43% of the historical counties have had Kirtland's snake documented within the last 15 years. While some states (*e.g.*, Pennsylvania and Missouri) have been actively looking for Kirtland's snakes in historic locations recently, other states' recent records are primarily opportunistic. Several states indicated that they consider specific locations to have "extant" populations even though the records are older than our 15-year criterion, for example Mclean

County, KY (J. MacGregor, pers. comm. 2017), Allegan and Berrien Counties, MI (Lee, Michigan Natural Features Inventory, pers. comm. 2017); but unless we had capture records within the last 15 years, we did not include these locations as extant. Other states indicated that they had not done broad surveys necessary for a true status assessment for the species (A. Holtrop, Illinois Department of Natural Resources, pers. comm. 2017). Thus, our analysis is conservative in that there are likely to be other extant populations that are not accounted for here.

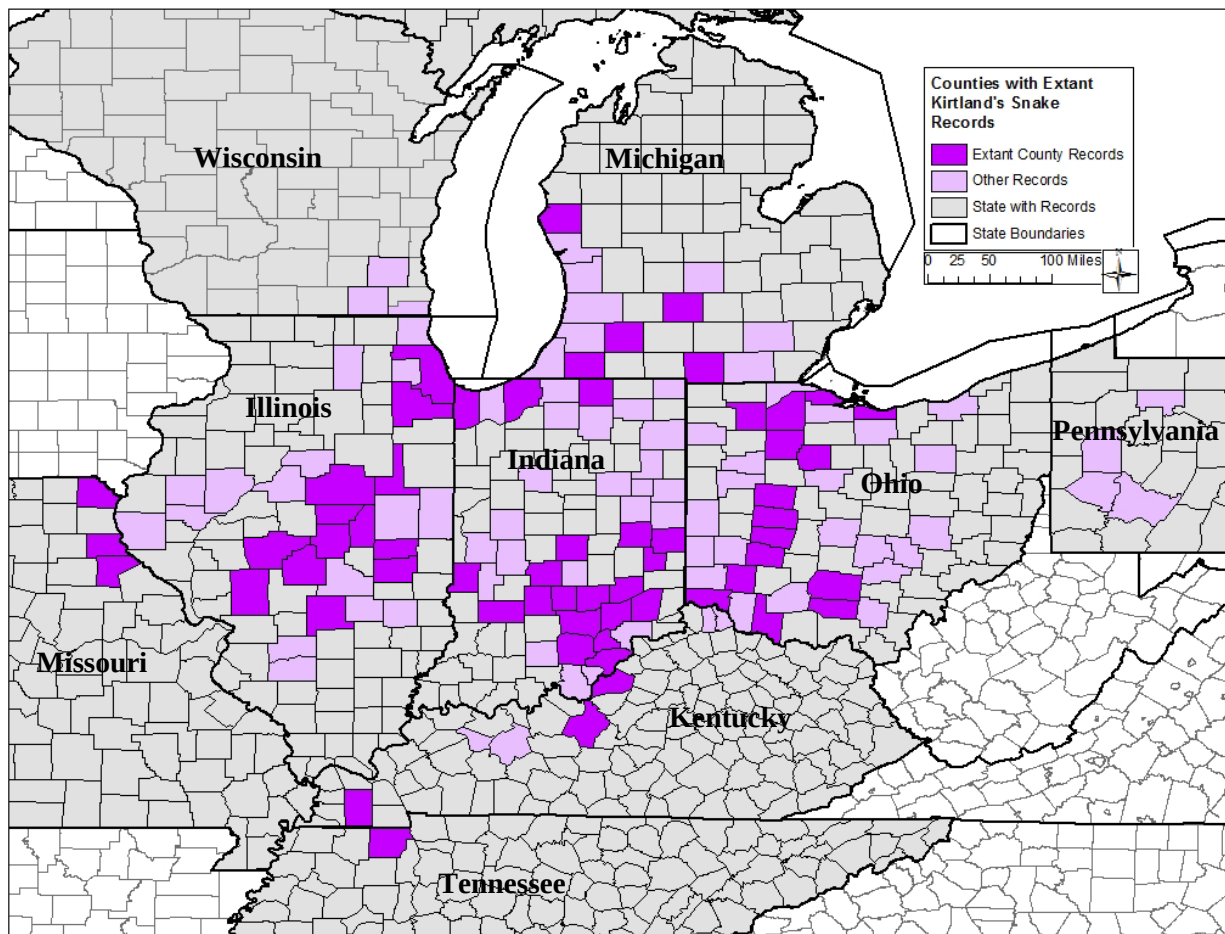


Figure 4.2 Counties with extant Kirtland's snake records.

Table 4.2 Summary of status of Kirtland's snake records by state

State	Counties		Records							Extant Natural Areas, Captures in Multiple Years
	Counties with Records	Counties with Extant Records	Definition	Total Records	Extant Records		Unknown Records		Extirpated Records	
					Single	Multi	Pre-1966	Post-1966		
IL	29	13	One record per site	41	5	12	2	19	3	5
IN	43	20	One record per individual	150	18	58 (in 7 areas)	20	51	3	6
KY	7	3	One record per individual; one record per polygon	136	1	73 (in 2 areas)	13	48	1	1
MI	13	5	One record per site	22	3	2	2	8	7	1
MO	3	3	One record per township	4	2	1	1	0	0	1
OH	36	15	One record per township	51	11	7	25	8	0	6
PA	4	0	One record per site	10	0	0	7	0	3	0
TN	1	1	One record per site	1	0	1	0	0	0	1
WI	3	0	One record per county	0	0	0	0	0	0	0
Total	139	60	-	415	40	154	70	134	17	21

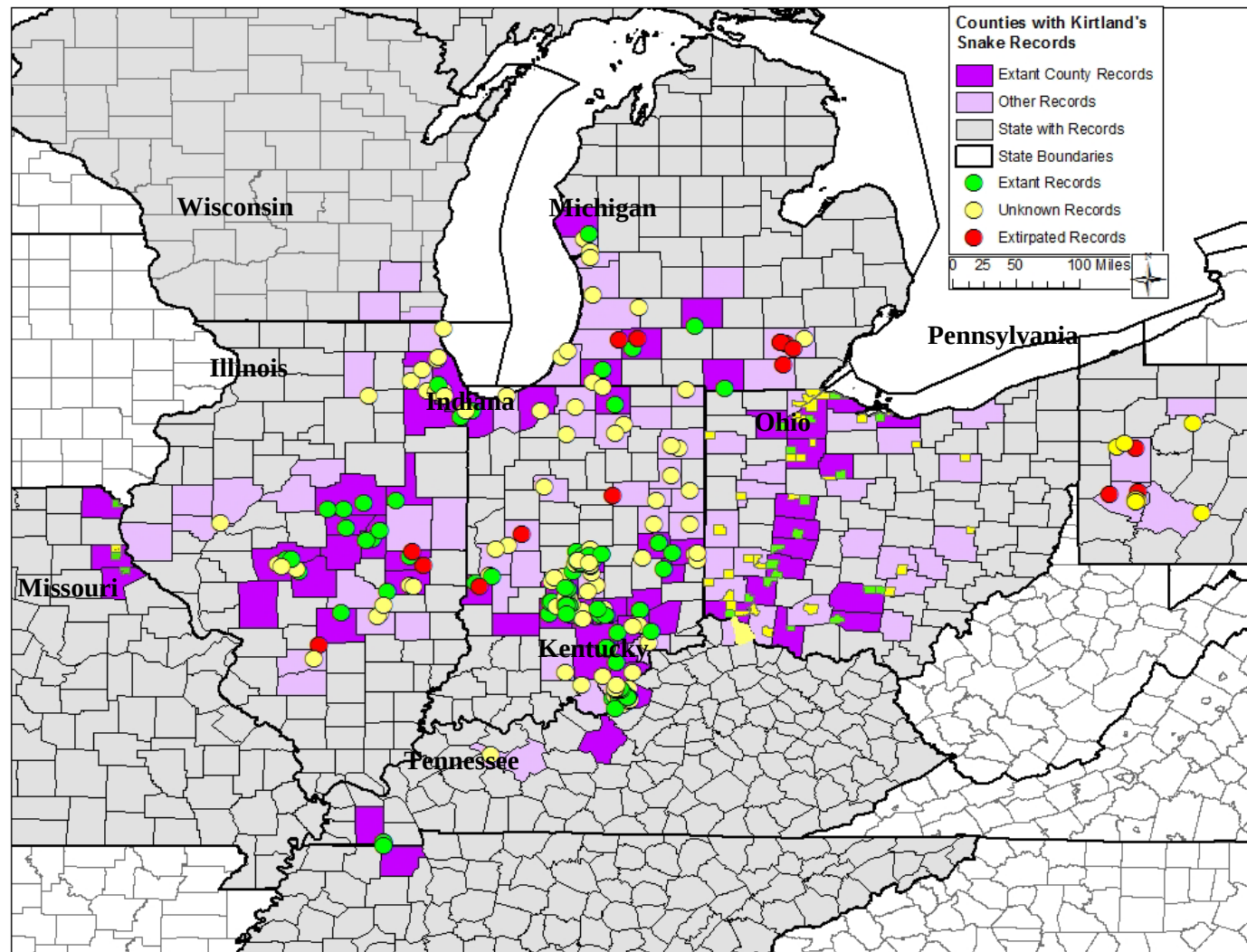


Figure 4.3 Results of ranking exercise for all Kirtland's snake records.

To assess the health of the extant populations, we first examined the number of captures representing each of the records. Of the 194 extant records, 40 are documented by a single individual Kirtland's snake detected in a single year. For these populations, the population health is unknown. The remaining 154 records occur within 31 distinct areas.

We examined these "extant" records to see how many of these occur in natural habitat areas and include captures of multiple Kirtland's snakes in more than one year. Sixty-eight records met these criteria, comprising 21 different natural habitat areas: five in Illinois, six in Indiana, one in Kentucky, one in Michigan, one in Missouri, and six in Ohio. These areas generally provide natural habitat, and most are owned or managed by a conservation organization or government agency, although only one of the states indicated that one site was managed specifically *with* Kirtland's snake habitat needs in mind. Data available for each site vary. Reproduction has been documented on nine of these sites; information on reproduction is lacking on all others. However, given that individuals have been observed at these sites over multiple years, it is likely that these populations are reproducing.

Eight sites have multiple Kirtland's snake detected or detections in multiple years, but did not meet the criteria to be in natural habitat areas managed by a conservation organization.

The remaining 85 records (44%) are clustered in the four urban areas of Indianapolis, IN, New Albany, IN, Louisville, KY, and Cincinnati, OH. The heavily urban area of Louisville, KY (adjacent New Albany, IN), for example, has consistently supported Kirtland's snake. There are 127 records documented from this area from 1935-2013.

At a site within this area, Kirtland's snake occurs on a 0.67 acre undeveloped plot. From 2011 to 2013, 24 Kirtland's snakes were detected, including as many as eight individuals in one day (Kentucky Department of Fish and Wildlife Resources, unpublished data). This site is located in an extremely urbanized area that has been developed for a long period of time.

Other records indicate that Kirtland's snake persists in residential communities too. Extant records exist in established urban neighborhoods in Louisville, KY, Indianapolis, IN, and Cincinnati, OH.

Relative to urban populations, Minton and others (1982) hypothesize that, "undoubtedly these are remnants of what once were much larger populations that have been reduced by urbanization and now may be rapidly dying out." However, individuals continue to persist in these areas and have done so for decades. Wilsmann and Sellers (1988) speculated that it may be easier to detect and collect individuals in urban sites because populations are confined in small patches of habitat and there is debris for cover. It is uncertain why so many Kirtland's snake records are in urban areas; it may be a function of more observers, populations confined in small areas, long-lived individuals, or other factors. Some experts suggest that fewer predators and lower competition in urban areas may allow populations to become large (M. Lodato, pers. comm. 2017; J. MacGregor, pers. comm. 2017). These seemingly unsuitable areas apparently still provide key habitat features (such as moist soil and cover). Given that Kirtland's snakes have been found repeatedly over 80 years, these populations seem adept at persisting in highly urbanized areas, although population size and health remain unknown.

Not all urban populations have persisted as successfully at those described above. The Toledo Zoo population that Conant studied and published on extensively was probably eliminated during construction of a large road project (Conant, 1951). A site in the outskirts of Chicago known as Edison Park was turned into a residential development in the 1950s (Edgren, 2000). A known site in northeast Indianapolis was developed in the mid-1990s after a large number of Kirtland's snakes were relocated to a nearby park (Brown, 1994). Thus, urban sites that currently persist may be vulnerable to habitat loss or modification from development or collection.

"Unknown" records account for 49% of all records. For these records, we are unsure of the status of Kirtland's snake, but suitable habitat remains in the area, so the species may still persist. For nearly all of these sites, information on recruitment is unavailable. Sixty-seven percent of the "unknown" records are less than 50 years old. At least 44% of the unknown records are in urban areas (though we could not categorize habitat within "unknown" sites in Ohio and Missouri, so this figure may be higher), primarily concentrated in Indianapolis, IN and Louisville, KY, where we also have many extant records. Whether these "unknown" records are simply "hanging on," "one event away from extirpation," or "recruiting populations" is unknown.

4.3.3 Trends

Some have reported that Kirtland's snake is declining (Gibson & Kingsbury, 2004; Harding, 1997; Minton *et al.*, 1982; Natureserve, 2015; Wilsmann & Sellers, 1988). Indeed, most of the states within which it occurs list it as endangered or threatened (Table 4.3), and substantial wetland habitat has been lost throughout the species' range in the Midwest over the past century.

Table 4.3 State listing status of Kirtland's snake

State	Status	Rationale	Protection Afforded
Illinois	Threatened	Likely to become endangered in the wild in Illinois within the foreseeable future.	It is unlawful to possess, take, transport, sell, offer for sale, give or otherwise dispose threatened species.
Indiana	Endangered	Monotypic genus, relatively small range, occurs spottily at low population density except in urban or suburban sites where it is vulnerable.	A person may not take, possess, transport, export, process, sell or offer for sale, or ship endangered species.
Kentucky	Threatened	Likely to become endangered within the foreseeable future throughout all or a significant part of its range in Kentucky.	Five or fewer individuals may be taken per year for personal use without a permit.

Michigan	Endangered	Small number of known sites/populations of this species in the state. Species has not been well-surveyed in the state.	Activities including taking, possession, transport, import, export, buying and selling are prohibited.
Missouri	Species of Conservation Concern, S1 (critically imperiled)	Rarity in the state (fewer than 5 occurrences), but lack of information on species, and state is at periphery of range.	None
Ohio	Threatened	A species whose survival in Ohio is not in immediate jeopardy, but to which a threat exists. Continued or increased stress will result in its becoming endangered.	Buying, selling, or offering any part of wild animals for sale or transport without a permit is prohibited.
Pennsylvania	Endangered	Extremely or very high risk of extirpation throughout all or a significant portion of its range within the state.	Activities including taking, possession, transport, import, export, buying and selling are prohibited.
Tennessee	Extremely rare and critically imperiled	Five or fewer occurrences or very few remaining individuals, or because a special condition where the species is particularly vulnerable to extirpation.	None
Wisconsin	None	--	None

Prior status assessments have considered number and distribution of extant populations by county when describing the status of the species, similar to the approach we used (Table 4.4). Wilsmann and Sellers (1988) conducted a rangewide survey for Kirtland's snake from 1980-1987 and found them to be extant in 28 counties in 5 states (Illinois, Indiana, Kentucky, Michigan, and Ohio). Gibson and Kingsbury (2004) conducted a status assessment and determined them to be extant within 39 counties in the same 5 states over a 15-year period from 1990-2004 and extant within 58 counties if including a 24-year timeframe. Our assessment found Kirtland's snake to be extant in 60 counties in seven states in the past 15 years (2001-2016), based on mostly opportunistic data. Thus, it appears that the number of counties within which the species still persists has not declined in recent times. It is also notable that new records of Kirtland's snake continue to be documented. For example, five new county records in Ohio have been added since 2003 (Davis, 2008, 2012; Ohio Department of Natural Resources, Division of Wildlife, unpublished data), and the Tennessee population was not documented until 2006 (Frymire & Scott, 2012). Certainly the difficulty in detecting Kirtland's snake contributes to the difficulty in identifying the status of populations, and there are likely undocumented populations (Wilsmann & Sellers, 1988).

Table 4.4 Distribution of Kirtland's snake by state and county in recent status assessments.

Analysis	Years	Extant States	Number of extant Counties
Wilsmann and Sellers (1988)	1980-1987	5 (IL, IN, KY, MI, OH)	28
Gibson and Kingsbury (2004)	1990-2004	5 (IL, IN, KY, MI, OH)	39
Gibson and Kingsbury (2004)	1980-2004	5 (IL, IN, KY, MI, OH)	58
This assessment (2017)	2001-2016	7 (IL, IN, KY, MI, MO, OH, TN)	60

4.3.4 Catastrophic Events

We evaluated the vulnerability of Kirtland's snake to catastrophic D3+ level drought. In the Midwest, D3 and D4 level droughts are typically rare and usually cover only a small portion of the region. For example, only two periods of D4 drought have occurred in the Midwest since 2000. One D4 drought occurred in 2007, and covered at most 1.19% of the Midwest Region, while the D4 drought in 2012-2013 covered at most 8.17% (<http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx>). Although we believe that Kirtland's snake could be affected by drought, we don't know how individuals or populations would respond. Further, we were unable to define where healthy populations of Kirtland's snake exist, and thus, to what extent the occurrence of prolonged drought events might spatially and temporally overlap with those populations.

Chapter 5. Risk and Conservation Factors

In this chapter, we review the negative and beneficial factors affecting Kirtland's snake. Factors that have a negative impact on Kirtland's snake individuals are referred to as risk factors (also as stressors or threats); factors that have a beneficial effect are referred to as conservation factors.

5.1 Risk Factors

5.1.1 Habitat Loss and Modification

Habitat loss, modifications, and degradation have occurred across the range of Kirtland's snake. Habitat loss is the most common stressor, with urbanization (Bavetz, 1994; Edgren, 2000; Minton *et al.*, 1982) and wetland modification (Garman, 1892; Wilsmann & Sellers, 1988) most commonly reported. Habitat fragmentation can lead to population isolation, which is cited as a threat by some (Bavetz, 1993; Gibson & Kingsbury, 2004; Wilsmann & Sellers, 1988). Disturbance of the soil when Kirtland's snakes are underground may cause injury or mortality of individuals. It is unclear to what extent habitat modification may impact Kirtland's snake because as noted, it can persist in seemingly degraded environments for decades, so long as certain key features (*e.g.*, moist soils) are present.

5.1.2 Disease and Predation

In reptiles, stress can lead to immune suppression which can further lead to an increase in mortality from infectious disease or parasitic infections (Allender, 2006). Many factors, such as habitat loss or alteration (degradation), environmental contamination, or human harassment (research, collection, persecution), can induce stress in reptiles (Allender, 2006). The prevalence of disease within a snake population can cause differences in the health and body condition of snakes in the population. For example, the inadequate condition of female snakes in a population due to disease can also affect reproductive rates of that population and eventually negatively affect the viability of that population (Allender, 2006).

Fungal infections in reptiles are described as opportunistic pathogens, infecting animals with depressed immune systems (Wylie *et al.*, 2014). Snake fungal disease (SFD) is an emerging disease found in certain populations of wild snakes in the eastern and Midwestern United States (Sleeman, 2013). There has been a substantial increase in the reported incidence of skin infections caused by the fungus *Ophidiomyces ophiodiicola* in wild snake populations in the past decade (Lorch *et al.*, 2016). *O. ophiodiicola* has been detected in wild snakes from most states in the eastern U.S. and the pathogen is thought to be widely distributed in eastern North America (Lorch *et al.*, 2016). In some cases the fungal infection may spread from the skin and epidermis to other areas, including the bones, eyes, and lungs, or snakes may develop secondary infections (Lorch *et al.*, 2016). Complications of the fungal infection may lead to impairment of vision or sense of smell, and may impact a snake's ability to feed (Lorch *et al.*, 2016).

Our understanding of SFD is still in its early stages. Some snakes that have tested positive have developed external symptoms and experienced high mortality, but conversely other snakes that have tested positive remained asymptomatic at some sites. Researchers are unsure if the primary

vector is direct contact with an infected individual or contact with fungal spores in the soil (Wylie *et al.*, 2014). Wylie *et al.* (2014) found that *O. ophiodiicola* can be transferred between mothers and neonates.

Ophidiomyces ophiodiicola may also indirectly cause mortality through behavioral changes. When infected with a pathogen, many reptile species induce fever through basking (Burns, 1996) which is thought to increase their immune response. Increased basking time leads to an increase in the amount of time spent exposed to visual predators and thus increased mortality (Webb, Whiting, & Benton, 2005). In addition, increased overall basking time increases the snake's metabolic rate resulting in faster utilization of resources but reducing the amount of time the individual can spend on foraging. Increased metabolic rate with less time spent foraging can lead to declines in body condition or death (Wylie *et al.*, 2014).

To date, samples from 7 Kirtland's snakes have been provided for SFD testing. Four were clearly negative using quantitative polymerase chain reaction (qPCR) methods and three were positive; however, two had very low scores that should be re-analyzed (M. Allender, University of Illinois, pers. comm. 2017). Thus it appears that Kirtland's snake is susceptible to SFD, but further investigation is needed to determine its potential impact on populations (Allender, pers. comm. 2017). At this time it is uncertain how the species will respond, how susceptible the species will be, or to what extent the disease may spread within the population.

Only a few accounts of predation have been documented, and include cats (HerpMapper, 2017; J. MacGregor in Kentucky Department of Fish and Wildlife, 2015), a goose (Wilsmann & Sellers, 1988) and a Black king snake (Minton, 2001).

5.1.3 Collection

Collection for the pet trade is cited as a potential threat in several papers and is of particular concern at urban sites where Kirtland's snake populations may be dense and easily found (Harding, 1997; Wilsmann & Sellers, 1988). Anton (2016) recently documented an occasion where a visitor to a protected area was looking under cover boards and posting pictures of Kirtland's snake on social media, which could lead to collection. Some state laws may limit collection (*e.g.*, states where the species is listed as endangered), but illegal collection may still occur.

5.1.4 Road Mortality

Vehicles may pose a risk to some extant populations of Kirtland's snake. There are multiple references in the literature documenting road-killed snakes (Bavetz, 1993, 1994; Gibson & Kingsbury, 2004; Minton, 1972, 2001; Wilsmann & Sellers, 1988). Most noteworthy are data we have for a site in Indiana. An Indiana resident engaged in citizen science annually reported to Indiana Division of Fish and Wildlife on live and road-killed Kirtland's snakes incidentally found along approximately 2.5 miles of shoreline around a large lake in central Indiana from 1989-2014 (Indiana Division of Fish and Wildlife, unpublished data). These results were compiled by Indiana Division of Fish and Wildlife and provided for this analysis (Table 5.1). Data indicate that 235 Kirtland's snakes were found as road-kill out of a total of 255 observations from 2003-2014 (Table 5.1). Based on the sheer number of road-killed specimens

documented each year, it is apparent that there is a large population of Kirtland's snake that persists in this area. It is noteworthy that road mortality has been implicated in population declines of other wildlife, including snakes at some sites (Roe *et al.*, 2006; Rudolph *et al.*, 1999; Shepard *et al.*, 2008), but because we have no data on the population size at this site, we are unable to determine to what extent road kill may be affecting this population.

Table 5.1 Kirtland's snake records from a lake shoreline in central Indiana.
Source: Indiana Division of Fish and Wildlife, unpublished data.

Year	# Road kill	# Alive	# Predated	Yearly Totals
2003	39	1	1	41
2004	27	2	1	30
2005	21	2		23
2006	21	1		22
2007	27	1	1	29
2008	14	2		16
2009	11	1		12
2010	13	3		16
2011	12			12
2012	14	1	3	18
2013	6			6
2014	30			30
Total	235	14	6	255

Similarly, a long-term monitoring project at a natural site in Ohio has resulted in over 200 incidental captures of Kirtland's snake between 1996 and 2015 (Wynn, unpublished data). On a single day in mid-October 2016, a visitor to this area reported nine dead Kirtland's snakes on the road (K. Lott, U.S. Fish and Wildlife Service, pers. comm. 2016). It is uncertain to what extent road mortality may be affecting this population.

5.1.5 Management

Controlled burning and mowing are sometimes used as management tools to maintain open habitats and manage for early successional habitats such as prairie. During certain times of year and under certain conditions, Kirtland's snake may be exposed to these activities and could be injured or killed. One Kirtland's snake mortality was documented during a controlled burn at a site in Illinois (Anton & Mauger, 2007). One record from HerpMapper (2017) photo-documented a Kirtland's snake killed by a mower.

5.1.6 Climate Change

The U. S. Global Change Research Program (USGCRP, 2014) indicates that within the Midwest, average temperatures are expected to increase between 3.8 and 4.9°F by 2065 and by 5.6-8.5°F by 2100, compared to average temperatures from 1979-2000. Further, increases in winter and spring precipitation are expected particularly in the northern portion of the Midwest, while drier

summers are predicted in the southern portion (USGCRP, 2014). More intense and frequent precipitation events are expected to occur region-wide (USGCRP, 2014).

Two reports modeled potential climate change impacts on Kirtland's snake. One is a master's thesis by Ray (2009), which was overseen by Dr. Richard King at Northern Illinois University. The second is a report by Dr. King and M. Niiri (2013) that evaluated the sensitivity of various Great Lakes region reptiles to climate change impacts. These reports used similar methods: a maximum entropy model to determine BIOCLIM variables that characterize the temperature and rainfall conditions within the species' current range based on a subset of occurrence records; similar number and distribution of Kirtland's snake occurrence points; climate change impacts projected from the Intergovernmental Panel on Climate Change from 2007 (both modeled A2A, a high emission prediction; King and Niiri also modeled B2a, a lower emission prediction); and mapping of the projected areas where the BIOCLIM variables that characterize the current range will occur in 2050 (King and Niiri also modeled 2080). However, the two reports had divergent findings. Ray (2009) found that the suitable climatic range of the Kirtland's snake would not change significantly by 2050 under A2A emissions, while King and Niiri (2013) found a significant shift to the northeast under A2A emissions by 2050, and that potentially large portions of the current range would fall outside of current climate conditions.

Dr. King (pers. comm. 2017) described that the Ray (2009) analysis was a naïve (simplistic) application using default settings for the maximum entropy software used in ecological niche modeling. Methods used in King and Niiri (2013) applied a more refined approach to avoid overfitting the model. For example, they spatially filtered occurrence records to reduce the effects of sampling effort, regularized the response function, and looked at multiple thresholds of greater or lesser climatic suitability (King, pers. comm. 2017). These processes resulted in a selection of different BIOCLIM variables that predicted future climatic suitability for Kirtland's snake, and overall led to a more robust analysis than Ray's (2009) approach. Thus, we more carefully evaluated the King and Niiri (2013) model results.

Under the King and Niiri (2013) model, using the A2A high emissions scenario, in 2050, the worst-case threshold predicts that 14% of the known locations used in the model will be located in climatically similar areas, while the best-case threshold predicts that 72% remain. By 2080, in the worst-case threshold, only 3% of known locations used in the model will be located in climatically similar areas, while the best-case threshold predicts that 33% will remain (King & Niiri, 2013). Climatic suitability changes begin in the south and western portions of the range and spread north and east over time. The model also shows steadily declining areas of high climatic suitability, whether those areas are occupied or not. Remaining areas of climatic suitability within the current range occur along the edges of the Great Lakes, and in Michigan, Ohio, and Pennsylvania. Suitable climatic conditions are projected to expand into areas not currently occupied, including Ontario and New York.

Overall, the King and Niiri (2013) findings indicate that Kirtland's snake will see greater declines in climatic suitability than other reptiles in the Great Lakes region. However, the predicted climatic suitability maps are only a portion of the analysis. We also must consider how Kirtland's snake will respond to changes in temperature and precipitation patterns, but we do not have any information to inform this analysis. Further, we do not know if other factors beyond climate change, such as biotic or physical components of habitat, influence distribution and

persistence of Kirtland's snake, or if micro-habitat may ameliorate or exacerbate impacts from climate change (King, pers. comm. 2017). Finally, we do not know if Kirtland's snake will be able to colonize new climatically suitable areas, as we know very little about its movement capabilities. Kirtland's snake would not be likely to move hundreds of miles to inhabit climatically suitable areas distant from their current range (*e.g.*, large portions of Ontario, Canada and western New York state are predicted to be climatically suitable in King and Niiro (2013), but these areas are well outside the current range), especially considering the species site fidelity and the degree of habitat fragmentation in these areas. There is no data available to indicate if they are able to expand their range locally (*e.g.*, within a watershed) to take advantage of favorable microclimates or shift population distribution if a site became climatically unsuitable. Thus, the impact of climate change on this species is unknown.

5.2 Conservation Factors

State listing status affords a limited amount of protection to Kirtland's snake in some states (Table 4.3). For example, because Kirtland's snake is listed as endangered in Michigan, activities including taking, possession, transport, import, export, buying and selling are prohibited (MCL § 324.36505). Conversely, where the species has no listing status or a status other than "endangered," these activities may still be legal. The State of Indiana lists the species as "endangered" and has developed guidelines intended to avoid take of Kirtland's snake in construction areas where the species may occur.

Some of the sites where Kirtland's snake is extant are owned or managed by conservation organizations or agencies, including the 21 natural sites with multiple Kirtland's snake captures over multiple years. However, only one state indicated that one of these sites was specifically managed with consideration of Kirtland's snake. Other sites may be managed for specific communities (*e.g.*, prairie habitat), other species (*e.g.*, eastern massasauga (*Sistrurus catenatus*)), or other uses (*e.g.*, recreation). These management foci may be compatible with persistence of Kirtland's snake if the species' needs are considered when implementing management activities.

Chapter 6. Synthesis

This Chapter is intended to synthesize the results from our historical and current analyses and discusses the consequences for the future viability of Kirtland's snake.

We compiled all available scientific and commercial data to evaluate the changes in representation, resiliency, and redundancy from historical to the current time and to project future conditions.

Historic and current survey data are sporadic and typically limited to presence/absence level information. There are 139 counties that have historically supported populations of Kirtland's snake and 60 of these contain records determined to be "extant" with records collected within the past 15 years. Spatial data were provided by the States within the range of the species, and of the 415 records, we determined 17 (4%) are "extirpated," based on conservative criteria. Further, multiple accounts in the literature describe former Kirtland's snakes sites being destroyed by urbanization or development (Bavetz, 1994; Edgren, 2000; Minton *et al.*, 1982; A. Resetar, Field Museum of Natural History, pers. comm. 2017). Thus, there has been a decline in the number of populations over time. "Extant" populations are still distributed throughout most of the range, with the exception of Pennsylvania (eastern extent of the range) and Wisconsin, which have not documented "extant" populations in over 50 years; thus, there may be range contraction in the northwest and east, though Pennsylvania still continues to search for the species.

Habitat degradation is also clearly occurring, as grassland and wetlands are converted to agriculture, residential sites, or other uses. However, at a number of urban and suburban sites Kirtland's snakes are able to persist in these seemingly degraded habitats for decades; thus, we cannot equate habitat degradation to extirpation without survey effort. Kirtland's snakes are notoriously difficult to detect, even with focused survey effort, because they are primarily fossorial; so survey effort must be robust to document absence. Negative survey data available for most sites are not rigorous enough to document whether the species is extirpated. Some sites have only one opportunistic record with no follow-up survey effort. Several states have indicated that they believe some of these records to still be extant, but recent survey effort is lacking. Thus, the status of 204 records (49%) out of 415 total records is "unknown."

One hundred-ninety-four records (47%) out of 415 total records provided by the states were determined to be "extant" (less than 15 years old and suitable habitat still exists). Some of these records represent all snakes captured at one site, while other records represent individual snakes. Thus we have tried to further evaluate these "extant" records by site. There are 21 natural habitat areas that have detected multiple Kirtland's snakes in multiple years and are owned by conservation organizations or agencies. There are four urban areas with many "extant" records (Louisville, KY, New Albany, IN, Indianapolis, IN, and Cincinnati, OH) and Kirtland's snake appears to be persisting in these areas despite seemingly marginal habitat. An additional 48 locations support "extant" records that are comprised of natural habitat, agricultural areas, or urban/suburban development, most of which are single records. While Kirtland's snake is "extant" in these areas, we have no demographic information that would allow us to evaluate the health of the populations that exist at these sites.

Due to lack of survey data, detection difficulties, and uncertainty regarding habitat requirements, the status of 49% of the Kirtland's snake records is "unknown." Even for the records that we know are "extant," we have no baseline population or demographic data with which to evaluate population health. Thus, we were unable to credibly assess the current condition of Kirtland's snake.

It is unclear what stressors might be threatening the health of "extant" Kirtland's snake populations because no population estimates exist for any sites. Although urban development has certainly reduced natural habitat for Kirtland's snake, the species persists in some urban areas for decades in seemingly high densities. At one location in Indiana where road-kill is frequently observed, Kirtland's snakes continue to be documented annually; thus, it is unclear how this stressor may be impacting this population. Other sources of mortality have been documented infrequently; so it is unclear what stressors drive the population dynamics at extant sites. While SFD may have broad-scale implications for some species of snakes, the impact of the fungus on Kirtland's snake has not been determined. While climate change projections indicate that the climatic conditions within the Kirtland's snake range are likely to change and the current climatic conditions within which it occurs will shift north and east, we have no data to indicate how snakes might respond to these changes. For an analysis of future threats, we could have projected future scenarios of drought or development or population growth, but it is unclear how the species would respond to these stressors, nor what the baseline population conditions are. For these reasons, we were unable to reasonably assess the current and future viability of Kirtland's snake.

In order to better inform future analyses, many data gaps must be addressed.

The following information would help to inform our resiliency analysis: the number and distribution of extant populations and the health of these populations. This entails collecting information such as population estimates, home range estimates, age at first reproduction, age-specific survival, hibernation needs, minimum patch size to support a population, connectivity needed among sites necessary for genetic exchange, viability of urban populations, and stressors on populations (*e.g.*, road mortality).

Collection of the following information would help to inform representation: additional genetic studies to further elucidate any significant genetic diversity among distinct populations and variation of potentially adaptive traits.

Collection of the following information would help to inform redundancy: thermal and moisture limits during different seasons (*e.g.*, summer versus hibernation), and susceptibility and response to SFD.

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Appendix A

State Analysis

Below we summarize the data for each state:

Illinois: Illinois provided one record for each site (*e.g.*, park, preserve); thus, a single record may represent more than one Kirtland's snake individual or records over more than one year (Illinois Department of Natural Resources, unpublished data). Illinois has conducted ongoing focused survey effort over the past 20 years or so. Seventeen of their records are extant, but of these, five are single individuals in single years. Five extant sites are natural habitat areas that have multiple individuals detected in multiple years. Twenty-one sites are unknown, but only two are prior to 1966. Some of these sites were subject to recent survey events which did not find Kirtland's snake but did not meet our rigorous criteria for determining "extirpated." Other sites were surveyed in the 1990s and documented Kirtland's snake, but were older than 15 years old so were categorized as "unknown." Three sites were determined to be extirpated based on survey effort.

Indiana: Indiana provided one record for each Kirtland's snake observed (Indiana Division of Fish and Wildlife, unpublished data). Thus, some of the points are overlapping for individuals found at the same site. Seventy-six records were classified as "extant." Of these, 22 were in the Indianapolis area. There are six additional natural habitat areas that support multiple "extant" records of Kirtland's snake over multiple years. Eighteen extant records are single individuals in single years. Seventy-one records were classified as "unknown," and 20 of these were prior to 1966. Three records were classified as "extirpated," based on being greater than 100 years old.

Kentucky: Kentucky State Nature Preserves Commission (unpublished data) provided one record for each individual Kirtland's snake, and the Kentucky Department of Fish and Wildlife Resources (unpublished data) provided polygons which represented sites. Thus the polygons may represent more than one Kirtland's snake individual or records over more than one year. Kentucky has a large number of records, but they are restricted to only seven counties. Seventy-four records were classified as "extant," but 63 of these records are in the Louisville area, which is very urbanized. There is an area in southwest Kentucky in natural habitat that supports multiple records over multiple years. One "extant" record is for a single individual in a single year. Of the 61 unknown records, most of these are also in the Louisville area, and 13 are prior to 1966. One record in the Louisville area was classified as "extirpated," based on lack of suitable habitat.

Michigan: Michigan provided one record for each site (*e.g.*, park, preserve); thus, a single record may represent more than one Kirtland's snake individual or records over more than one year (Michigan Natural Features Inventory, unpublished data). Five records are extant, and of these three records are for a single individual in a single year. One record includes multiple captures of Kirtland's snakes over multiple years at a natural site. Ten records are unknown; two of these are prior to 1966. Seven records are extirpated, some based on age and others based on survey effort.

Missouri: Missouri provided one record for each township; thus, a single record may represent more than one Kirtland's snake individual or records over more than one year (Missouri Department of Conservation, unpublished data). Three townships were categorized as extant, and all of these were discovered since 2007. Two townships have single records, and one has multiple records over multiple years in a natural habitat area. Only one township is unknown, with records prior to 1966. No township met the criteria for "extirpated."

Ohio: Ohio provided one record for each township; thus, a single record may represent more than one Kirtland's snake individual or records over more than one year (Ohio Department of Natural Resources, unpublished data). In Ohio, there are 18 townships classified as "extant," but of these, 11 are single individuals in single years. Six natural habitat areas have extant records that include multiple Kirtland's snake individuals from multiple years. There are 33 townships with unknown status, and 25 of these are prior to 1966. No township met the criteria for "extirpated."

Pennsylvania: Pennsylvania Fish and Boat Commission (unpublished data) provided records as large polygons. Each polygon may represent more than one Kirtland's snake individual or records over more than one year. There are no extant records in Pennsylvania, and all of their records are prior to 1966. The state has conducted surveys at several of the historical Kirtland's snake sites recently and did not detect any individuals. Survey effort at seven sites was not sufficient to achieve "extirpated" status, so these records are categorized as "unknown." Three sites were determined to be extirpated," based on survey effort.

Tennessee: Tennessee provided one record for one site (Frymire & Scott, 2012). This record represents more than one Kirtland's snake individual in more than one year. Tennessee's only record is "extant" and was first detected in 2006. This record is in a natural habitat area.

Wisconsin: Wisconsin did not have GIS records for their data owing to the age of the records. Only county-level data are available, indicating historic presence of Kirtland's snake in three counties, most recently in 1926, but there are no vouchered specimens from Wisconsin. Surveys have occurred in the area more recently but have not detected Kirtland's snake. The Wisconsin Department of Natural Resources considers this species non-native or accidental in the state (R. Paloski, Wisconsin Department of Natural Resources, pers. comm. 2017).