U.S. Fish and Wildlife Service

Indiana Bat

(*Myotis sodalis*)

5-Year Review: Summary and Evaluation

Photo credit: USFWS/R. Andrew King

U.S. Fish and Wildlife Service
Interior Region 3 – Great Lakes

Indiana Ecological Services Field Office
Bloomington, Indiana

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1.0 GENERAL INFORMATION

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1.2 Methodology used to complete the review:

This 5-year review (review) was prepared by R. Andrew King, Endangered Species Biologist, U.S. Fish and Wildlife Service (Service), Indiana Ecological Services Field Office (INFO), in consultation with Service biologists from throughout the species' range.

To prepare this status review, the Service solicited pertinent information from the public through Federal Register notices in 2011 (76 FR 44564; July 26, 2011) and 2014 (79 FR 38560; July 8, 2014) and also reviewed past and recent scientific reports, published and unpublished records and a wealth of new literature that has become available since publication of the *Indiana Bat Draft Recovery Plan: First Revision* (2007 Plan) (USFWS 2007) and subsequent to the September 2009 5-year Review (USFWS 2009). We reviewed these documents for new information, but generally focused on new information received since the 2009 review that presented how the species' status and threats have changed since that time.

The Service reviewed comments received from the general public following the 26 July 2011 and 8 July 2014 Federal Register notices announcing initiation of this review. However, no new information that had a substantive bearing on the species' classification was received from the general public. Since publication of the 2009 review, we coordinated with state and federal natural resource agencies in 18 states and they provided us with substantive new population data conducted as part of the biennial Indiana bat winter population surveys (discussed below in 2.3.1.2) and current protection status of hibernacula in their respective jurisdictions. We used the most recent (2019) population and threats data (see 2.3.2.3) from across the species' range to assess whether the recovery criteria included within the 2007 Plan had been achieved (see Appendix A for detailed analyses). Ultimately, our recommendation of maintaining the Indiana bat in its current 'endangered' status has remained the same since the 2009 review.

1.3 Background

1.3.1 FR Notice Citations announcing initiation of this review:

76 FR 44564 (July 26, 2011) Endangered and Threatened Wildlife and Plants; 5-Year Status Reviews of Seven Listed Species.

79 FR 38560 (July 8, 2014) Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Status Reviews of Nine Listed Animal and Two Listed Plant Species.

1.3.2 Listing History

Original Listing
FR notice: 32(48) FR 4001
Date Listed: March 11, 1967
Entity Listed: Indiana Bat – *Myotis sodalis* (the species)
Classification: endangered

1.3.3 Associated rulemakings

Critical Habitat Designated
FR notice: 41(187) FR 41914
Date Listed: September 24, 1976
Entity Listed: 13 hibernacula (winter habitat) including 11 caves and two mines in six states were listed as Critical Habitat:
Illinois - Blackball Mine (LaSalle Co.); Indiana - Big Wyandotte Cave (Crawford Co.), Ray's Cave (Greene Co.); Kentucky - Bat Cave (Carter Co.), Coach Cave (Edmonson Co.); Missouri - Cave 021 (Crawford Co.), Caves 009 and 017 (Franklin Co.), Pilot Knob Mine (Iron Co.), Bat Cave (Shannon Co.), Cave 029 (Washington Co.); Tennessee - White Oak Blowhole Cave (Blount Co.); and West Virginia - Hellhole Cave (Pendleton Co.).

1.3.4 Review History

The Indiana bat was included in four previous 5-year reviews: (1) for wildlife classified as endangered or threatened prior to 1975 (44 FR 29566); (2) for species listed before 1976 and in 1979 and 1980 (50 FR 29901); (3) of all species listed before January 1, 1991 (56 FR 56882); and (4) the first species-specific review in 2009 (71 FR 55212; USFWS 2009). These 5-year reviews resulted in no change to the listing classification of 'endangered.'

1.3.5 Species' Recovery Priority Number at start of 5-year review: 5
A Recovery Priority Number (RPN) of "5" means that a species has a high degree of threat and a low recovery potential.

1.3.6 Recovery Plan or Outline
Name of Plan: Indiana Bat (*Myotis sodalis*) Draft Recovery Plan: First Revision
Date Issued: 13 April 2007
Date of Original Recovery Plan: 1976

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) Policy:

2.1.1 Is the species under review a vertebrate? *Yes.*

2.1.2 Is the species under review listed as a DPS? *No.*

2.1.3 Was the DPS listed prior to 1996? *Not Applicable*.

2.1.4 Is there relevant new information for this species regarding the application of the DPS policy? *No*. Band returns and some early population genetics research using mitochondrial DNA suggested Indiana bat populations had some discrete genetic structuring (USFWS 2007). However, more recent analyses using nuclear microsatellite markers showed an absence of differentiation among hibernacula across the species' range, suggesting the occurrence of extensive gene flow through wide-spread dispersal and mating (i.e., essentially a panmictic population; Vonhof et al. 2016). In addition, no other lines of evidence suggest that any population segments are markedly different or separated from other populations of the species as a consequence of physical, physiological, ecological, or behavioral factors. Therefore, based on the genetic and other biological evidence and the fact that the Indiana bats' range lies wholly within the United States, the discreteness standard within the Service's 1996 DPS policy has not been met and thus, no DPSs are recognized for this species.

2.2 Recovery Criteria:

2.2.1 Does the species have an approved recovery plan containing objective, measurable criteria? *No.* Although, the 2007 Plan was issued as a "draft" and was not finalized or formally "approved" by the Service, it does contain objective and measurable recovery criteria. We respond to the remaining questions regarding recovery criteria with respect to the 2007 Plan.

2.2.2 Adequacy of recovery criteria.

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat? *Yes.*

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)? *No*. There are no explicit threat-based criteria. Protection of hibernacula can help address some of the threats. However, protection is not fully defined. In addition, threats during migration, spring, fall, and summer are not addressed. Finally, white-nose syndrome (WNS) is not addressed.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met; citing information.

Appendix A contains a list of all the recovery criteria and a detailed assessment of their present status and Table 1 (below) contains a summary of current recovery criteria achievements.

2.3 Updated/New Information and Current Species Status

Since the last review was completed in 2009, a very large previously unknown Indiana bat hibernaculum was discovered near Hannibal, Missouri. This "new" Priority 1 site (an extensive abandoned limestone mine is now protected within Sodalis Nature Preserve) contained a minimum of 123,000 bats when partially surveyed in January 2013 and had over 197,000 when completely surveyed for the first time in January 2017. Based upon first-hand accounts of many very large clusters (a key trait of Indiana bats) of unidentified hibernating bats being present and observed by locals at this site for several decades prior to its discovery by bat biologists (Kirsten Alvey-Mudd, Missouri Bat Census, 2017, pers. comm.), the Service decided to add the same number of Indiana bats as was found in 2017 to each previous biennium for this site back through 1981. Incorporating the newly discovered bat numbers in this manner, improved the accuracy of the Missouri, Ozark-Central Recovery Unit (RU) and range-wide population estimates over those reported in previous years and also avoided what otherwise would have been artificial spikes in population trends in 2013, 2015 and 2017.

The 2019 (most current) range-wide Indiana bat population estimate was approximately 537,297 bats with 71% of these bats hibernating in sites located in Missouri and Indiana (36.3% and 34.4%, respectively). The 2019 range-wide population declined an additional 4% from the 2017 estimate and represented a 19% decline since the arrival of WNS in New York in 2007. A detailed summary of the 2019 and previous state-by-state, regional, recovery unit and range-wide population estimates and trends is available on the Service’s Indiana bat webpage and is hereby incorporated by reference (see USFWS 2019b).

TABLE 1. Summary of progress towards achieving recovery criteria.

Criterion	Relevant Measure	Current Status	Conclusion
Reclassification Criterion 1	Permanent protection of 80% of all Priority 1 hibernacula in each Recovery Unit.	Ozark-Central (n=9): 67% Midwest (n=13): 69% Appalachia (n=2): 50% Northeast (n=3): 67%	Not Achieved
Reclassification Criterion 2	A minimum overall population estimate equal to the (previously assumed) 2005 population estimate of 457,000 bats.	The 2019 overall population estimate is 537,297 bats, which exceeds the 457,000 minimum.	Achieved
Reclassification Criterion 3	Predicted continued positive population growth rate at each of the most populous hibernacula in each RU (using a linear regression with 90% confidence interval through 5 most recent population estimates as a means of predicting trend over the next 10-year period).	Noted below are the numbers of hibernacula that currently "pass" this criterion. Ozark-Central: 1 of 2 Midwest: 0 of 3 Appalachia: 0 of 4 Northeast: 0 of 2	Not Achieved
NOTE: The reclassification criteria (above) currently have not been met. Nonetheless, to see how much progress has been made to-date towards full recovery of the species, we also assessed the delisting criteria (below) using currently available data.			
Delisting Criterion 1	Protection of a minimum of 50% of Priority 2 hibernacula in each Recovery Unit.	Ozark-Central (n=23): 35% Midwest (n=26): 46% Appalachia (n=6): 33% Northeast (n=3): 0%	Not Achieved
Delisting Criterion 2	A minimum overall population estimate equal to the (previously assumed) 2005 population estimate of 457,000 bats.	The 2019 overall population estimate is 537,297 bats, which exceeds the 457,000 minimum.	Achieved
Delisting Criterion 3	Positive population growth rates at a minimum of 80% of all Priority 1A hibernacula/ complexes as evidenced by a positive slope of a linear regression through the 5 most recent population estimates post-reclassification.	40% (4 out of 10) of P1A hibernacula currently pass. Magazine Mine, IL: Pass Sodalis Nat. Pres., MO: Fail Wyandotte/Jughole, IN: Pass Ray's, IN: Fail Carter Caves, KY: Pass Coon & Grotto,IN: Fail White Oak Blowhole, TN: Fail Hellhole, WV: Fail Barton Hill Mine, NY: Pass Williams Mines, NY: Fail	Not Achieved

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology, life history, threats and conservation:

Three primary sources of information on the Indiana bat's biology and life history are 1) a proceedings edited by Kurta and Kennedy (2002) from a

2001 symposium entitled *The Indiana Bat: Biology and Management of an Endangered Species,* 2) the 2007 Draft Recovery Plan (USFWS 2007), and 3) the 2009 5-year review, which are hereby incorporated by reference. The 2007 Plan is available at http://www.fws.gov/midwest/Endangered/mammals/inba/index.html and the 2009 5-year review is available at http://ecos.fws.gov/docs/five_year_review/doc2627.pdf.

As one of the most researched bat species in North America (perhaps the world), keeping abreast of old and new literature pertaining to the Indiana bat is challenging. Therefore, since the last review, the Service's Indiana Field Office (INFO) launched an online bat literature database as a tool for improving management and accessibility of the rapidly growing number of scientific publications and other reference materials pertaining to Indiana bats and other bat species in eastern North America. The database currently contains over 2,700 references with over 700 items added over the past year. Approximately 700 publications specifically refer to various aspects of the Indiana bat's life history, ecology, habitat, population status and conservation. Other relevant bat-related topics in the database include WNS, bat and wind energy issues and other federally listed bat species. A publicly available version of the Service's bat literature reference database is available at http://www.refworks.com/refworks2/?site=040621159761600000%2fRWWEB103971662%2fUSFWS+Bat+Lit.+Database+-+Public+Version

Since the last review, over 200 new scientific papers, theses and dissertations have been published that directly or indirectly relate to the Indiana bat and its conservation. The following is a topical listing of some of the most relevant of these publications:

Artificial Roosts/Bat Boxes (Adams et al. 2015, Benedict et al. 2017, Bergeson et al. 2019, Hoeh et al. 2018, Mangan and Mangan 2016, Mering and Chambers 2014, and Rueegger 2016)

Bridges and Roadways (Bennett and Zurcher 2013, Bennett et al. 2013, Cervone et al. 2016, Fensome and Matthews 2016, Zurcher et al. 2010)

Climate Change (Adams 2010, Bergeson et al. 2013, Brandt et al. 2014, Burles et al. 2009, Dukes et al. 2009, Foden et al. 2019, Frick et al. 2010a, Jones and Rebelo 2013, Jones et al. 2009, Loeb and Winters 2012, Lundy et al. 2010, Matthews et al. 2011, O'Shea et al. 2016, Perry 2013, Prasad et al. 2007, Rebelo et al. 2010, Sherwin et al. 2013, Stepanian and Wainwright 2018, USGCRP 2018)

Contaminants (Bayat et al. 2014, Eidels et al. 2016, Mineau and Callaghan 2018, Secord et al. 2015, Stahlschmidt and Bruhl 2012, Yates et al. 2014)

Conservation (Dixon et al. 2013, Furey and Racey 2015, Hammerson et al. 2017, Loeb et al. 2009, Mering and Chambers 2014, Pfeiffer 2019, Pruitt 2013, Sparks et al. 2009, Voight and Kingston 2016)

Economic Importance (Boyles et al. 2011a, Boyles et al 2011b, Fisher and Naidoo 2011, Maine and Boyles 2015)

Forestry and Prescribed Fire (Austin et al. 2018, Bergeson et al. 2015, Brose et al. 2014, Caldwell et al. 2019, Cox et al. 2016, D'Acunto and Zollner 2019, Dickinson et al. 2009, Dickinson et al. 2010, Duchamp et al. 2010, Jachowski et al. 2016, Johnson et al. 2010, Johnson and King 2018, Loeb and O'Keefe 2011, Loeb and O'Keefe 2014, Luna et al. 2014, Nowacki and Abrams 2008, O'Keefe et al. 2013, O'Keefe and Loeb 2017, Pauli et al. 2015, Perry 2012, Schroeder et al 2017, Sheets et al. 2013a, Sheets et al. 2013b, Silvis et al. 2016a, Silvis et al. 2016b, Titchenell et al. 2011)

Genetics (Amelon et al. 2011, Oyler-McCance & Fike 2011, Oyler-McCance et al. 2018, Tujillo and Amelon 2009, Vonhof et al. 2016)

Habitat Modeling (De La Cruz and Ward 2016, Hammond et al. 2016, Pauli et al. 2015, Weber and Sparks 2013)

Hibernacula Management (Abigail and Chambers 2017, Boyles and Willis 2010, Crimmins et al. 2014, Muthersbaugh et al. 2019)

Hibernation Ecology (Boyles 2016, Boyles et al. 2008, Boyles and McKechnie 2010, Boyles and Brack 2013, Boyles et al. 2017, Britzke et al. 2012, Day and Tomasi 2014, Haase et al. 2019, Hayman et al. 2017, Langwig et al. 2012, Perry 2013, Thogmartin et al. 2014)

Invasive Species (Brack et al. 2013, Welch and Leppanen 2017)

Migration (Gumbert et al. 2011, Hicks et al. 2012, Judy et al. 2010, Pettit and O'Keefe 2017b, Roby et al. 2019, Rockey et al. 2013)

Paleontology (Colburn et al. 2015)

Population Ecology (Erickson et al. 2014a, Erickson et al. 2014b, Ingersoll et al. 2013, Powers et al. 2015, Thogmartin et al. 2012a, Thogmartin et al. 2012b, Thogmartin et al. 2013)

Range and Life History (Adams et al. 2015, Arndt et al. 2018, Bergeson et al. 2013, Brandebura et al. 2011, Caylor and Sheets 2014, Divoll and O'Keefe 2018, Gumbert and Roby 2011, Jachowski et al. 2014, Jachowski et al. 2016, Kniowski and Gehrt 2014, Lacki et al. 2009, Lacki et al. 2015, Mangan and Mangan 2016, Muthersbaugh et al. 2019, O'Keefe and Loeb 2017, Perry et al. 2016, Rockey et al. 2013, Silvis et al. 2014, Silvis et al. 2016c, Sparks and Brack 2010, St. Germain et al. 2017, Timpone et al. 2010, White et al. 2012, Womack et al. 2013a, Womack et al. 2013b)

Survey and Surveillance Techniques (Britzke et al. 2011, Britzke et al. 2014, Clement et al. 2014, Clement et al. 2015, Cliff et al. 2018, Coleman et al. 2014, Ford 2019, Francl et al. 2011, Hamilton et al.

2009, Hayman et al. 2017, Kaiser & O'Keefe 2015, Loeb et al. 2015, Meretsky et al. 2010, O'Keefe et al. 2014, Oyler-McCance et al. 2018, Robbins and Carter 2009, Romeling et al. 2012, Russo and Voight 2016, Samoray et al. 2019, Tonos et al. 2014, Turner et al. 2014, Whitby et al. 2014)

Theses (various topics) [Austin 2017, Bergeson 2012, Bergeson 2017, Bishop-Boros 2014, Boyles 2009, Byrne 2015, Cable 2019, Caylor 2011, Coleman 2013, Corcoran 2009, D'Acunto 2012, D'Acunto 2018, Damm 2011, Dey 2009, Fishman 2017, Flory 2010, Gikas 2011, Hale 2012, Hammond 2013, Hohoff 2016, Just 2011, Kniowski 2011, Langwig 2015, Lemen (J.L.) 2015, Lemen, (J.R.) 2015, Lemzouji 2010, Nocera 2018, Oehler 2011, Pauli 2014, Pennington 2014, Petitt 2015, Roby 2019, Romeling 2012, Schroder 2012, Sheets 2010, Sichmeller 2010, Titus 2018, Torrey 2018, Whitby 2012, Womack 2011, Womack 2017].

White-Nose Syndrome (not an exhaustive list) (Amelon et al. 2011, Blehert et al. 2009, Blehert 2012, Cheng et al. 2019, Cryan et al. 2010, Cryan et al. 2013, Drees et al. 2017, Erickson et al. 2016, Ford et al. 2011, Francl et al. 2012, Frick et al. 2010, Frick et al. 2015, Gargas et al. 2009, Grieneisen et al. 2015, Hayman et al. 2016, Hoyt et al. 2018, Hoyt et al. 2019, Ingersoll et al. 2013, Jachowski et al. 2014b, Janicki et al. 2015, Langwig et al. 2012, Langwig et al. 2015, Langwig et al. 2016, Lilley et al. 2016, Lorch et al. 2011, Lorch et al. 2013, Lorch et al. 2016, Maslo et al. 2017, Mayberry et al. 2018, Meierhofer et al. 2018, Meteyer et al. 2011, Nocera et al. 2019, O'Keefe et al. 2019, O'Shea et al 2016, Pettit and O'Keefe 2017a, Reichard et al. 2014, Reeder et al. 2012, Rocke et al. 2019, Russel et al. 2015, Swezey and Garrity 2011, Thogmartin et al. 2012a, Thogmartin et al. 2012b, Thogmartin et al. 2013, Turner et al. 2011, Turner et al. 2015, USFWS 2018, Verant et al. 2012, Verant et al. 2014, Verant et al. 2018, Warnecke et al. 2012, Warnecke et al. 2013, and Willis 2011), and

Wind Energy (Arnett et al. 2009, Arnett et al. 2011, Arnett and Baerwald 2013, Arnett et al. 2013, BWEC 2018, Cryan et al. 2014, Ellison 2012, Erickson et al. 2016, Frick et al. 2017, Hayes 2013, Khalil 2019, O'Shea et al. 2016, Pruitt and Reed 2018, Schirmacher et al. 2018).

2.3.1.2 Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Indiana bat winter population surveys are conducted every other winter (biennially) at most hibernacula across the species' range. In 2005, the INFO developed an Indiana bat hibernacula and winter population database. Every known Indiana bat hibernaculum (n=549) and its associated bat population data from 1930 through the present have been entered into this database. The INFO uses this database to generate the range-wide Indiana bat population estimate every other year. Likewise, the database is used to track population trends, identified threats, and conservation measures implemented at hibernacula.

As discussed in the last review, since the Indiana bat's original listing and since standardized winter surveys began in the early 1980's, the Indiana bat's overall population decreased precipitously until an increasing population trend began in 2003 and continued through 2007 (Figure 1). From the time of listing in 1967 through 2001, most of the overall population declines were attributed to declines at high-priority hibernacula in Kentucky and Missouri and to a lesser extent, Indiana. In contrast, a distinct population increase occurred from 2001 to 2007 due to population growth at hibernacula in Illinois, Indiana, Kentucky, New York, and West Virginia (USFWS, unpublished data, 2019), which presumably stemmed from conservation efforts at hibernacula and summer habitat areas. We presume the downward range-wide trend from 2009 to present was caused by significant WNS-associated declines in the Northeast, Appalachia and Midwest. Detailed state-by-state, recovery unit and range-wide population estimates for 2019 are available on the Service's Indiana bat website. (http://www.fws.gov/midwest/Endangered/mammals/inba/index.html).

Since publication of the last review, the Service received new population data from the 2011, 2013, 2015, 2017, and 2019 biennial winter surveys conducted throughout the species' range. The 2019 estimates were used in calculations to assess achievement of recovery criteria for this 5-Year review (see Appendix A).

Since the last review, WNS and the fungus that causes it, *Pseudogymnoascus destructans* (Pd), has spread across the entire range of the Indiana bat and caused mortality of tens of thousands of Indiana bats and affected eleven other bat species (WNS 2019). Thus, WNS has led to regional and range-wide declines in Indiana bat abundance and triggered a decreasing population trend at most, but not all, affected hibernacula (Thogmartin et al. 2012a, Thogmartin 2012b, Thogmartin et al. 2013). Essentially, all Indiana bat hibernacula across the range were considered to be WNS-affected by 2017 (USFWS, unpublished data, 2019). While Indiana bat numbers have fared better than some of its congeners (i.e., *M. lucifugus* and *M. septentrionalis*) (Turner et al. 2011), researchers remain concerned that its apparent tolerance of Pd may not be indicative of reduced long-term extinction risk (Maslo et al. 2017, Thogmartin et al. 2013).

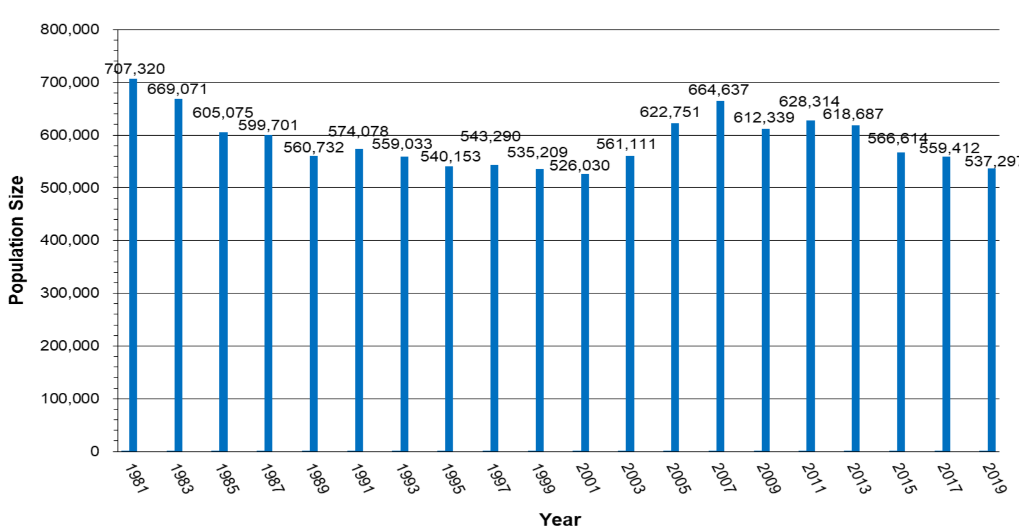


FIGURE 1. Range-wide Indiana bat population estimates from 1981 – 2019 (estimates derived from winter surveys at all known hibernacula) (USFWS 2019b).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

Pre-WNS population structure of the Indiana bat has been investigated using mitochondrial DNA from wing tissue of Indiana bats sampled at 13 hibernacula with the discovery of four separate population groups: Midwest, Appalachia, Northeast 1, and Northeast 2 (USFWS 2007). However, more recent analyses using nuclear microsatellite markers showed an absence of differentiation and widespread gene flow among hibernacula spread across the species' range, suggesting the occurrence of extensive gene flow through male dispersal and mating (i.e., essentially a panmictic population) (Vonhof et al. 2016). Whether WNS-associated population declines and potentially severe bottlenecks will adversely affect genetic diversity remains to be seen. It is also not known whether there are genetic differences between Indiana bats surviving WNS vs. those that are dying.

2.3.1.4 Taxonomic classification or changes in nomenclature:
No change.

2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):

The overall geographic range and distribution of winter habitat/hibernacula has changed relatively little since the Indiana bat was first listed with "extant" winter populations (i.e., one or more positive records over past 10 years/since 2009) presently occurring in 18 states (USFWS 2019a, USFWS 2019b). However, over the past ten years, as significant WNS-related population declines have occurred, there have also been considerable shifts in the spatial distribution and abundance of occupied hibernacula (Table 2). After the arrival of WNS, all four recovery units (RU) experienced declines in the number of their occupied hibernacula across almost all size classes. The most dramatic declines in the number of occupied hibernacula have occurred in the Northeast and Appalachia RUs. Remaining Indiana bats have also become significantly more concentrated in some areas. For example, Barton Hill Mine in New York now contains 93% of the Northeast RU's remaining Indiana bat population (Table 2).

In at least three known cases, the species has expanded its current winter range beyond its historical winter limits as a result of occupying man-made hibernacula (e.g., mines, tunnels, and a dam) in relatively recent times. Some occupied man-made structures are relatively far removed from natural cave areas (e.g., Black Ball Mine in northern Illinois, Lewisburg Limestone Mine in west central Ohio, Tippy Dam near the eastern border of Lake Michigan in Michigan). Of the 29 mines with extant winter populations, some have served as hibernacula for Indiana bats for nearly a century or more (e.g., Pilot Knob Mine in Missouri; Clawson 2002). Others, where mining activities have been abandoned more recently, have only supported significant winter populations within the past couple decades, such as the Magazine Mine in southern Illinois (Kath 2002). In 2012, biologists discovered the largest known winter population of Indiana bats within a large abandoned limestone mine in Hannibal, Missouri (i.e., Sodalis Nature Preserve; SNP). The discovery of this huge previously unknown population may help to explain why some other sites in Missouri had experienced otherwise puzzling declines (i.e., SNP may have drawn bats away from other sites over time).

TABLE 2. Pre- and post-WNS abundance and aggregation of Indiana bats at hibernacula by Recovery Unit.

Recovery Unit (pre-WNS year)	**# of Sites ≥100 bats**		**# of Sites ≥1,000 bats**		**# of Sites ≥10,000 bats**		**% of RU Population within Largest Hibernaculum in each RU**	
	Pre-WNS	**2019**	**Pre-WNS**	**2019**	**Pre-WNS**	**2019**	**Pre-WNS** (site/pop. size)	**2019** (site/pop. size)
Northeast (2007)	11	4	6	1	2	1	45% Williams Hotel Mine, NY; 24,317	93% Barton Hill, NY 12,570
Appalachia (2009)	13	3	3	0	1	0	51% Hellhole, WV 15,708	37% White Oak Blowhole, TN; 736
Midwest (2011)	46	38	18	14	8	6	21% Wyandotte, IN 64,372	32% Jug Hole, IN 79,358
Ozark-Central (2013)	28	22	11	9	2	2	70% Sodalis Nat. Pres., MO; 197,419	65% Sodalis Nat. Pres., MO; 180,801
Totals	98	67	38	24	13	9	USFWS, unpublished data, 2019	

These findings suggest that Indiana bats are capable of adapting to man-made sites and expanding their winter distribution by colonizing suitable hibernacula as they become available within and for some distance beyond their traditional winter range. In 2019, approximately 49.8% (267,286 bats) of the range-wide population of Indiana bats hibernated in man-made hibernacula (267,260 bats in 19 mines, 20 bats in 1 dam, and 6 bats in 1 tunnel) and 50.2% (269,991 bats) hibernated in natural caves (n=202; USFWS, unpublished data, 2019). In addition, it appears in some instances that Indiana bats may redistribute themselves over relatively short periods of time (e.g., several years) as evidenced by swift population declines in some hibernacula that coincided with rapid population increases at others nearby (e.g., Twin Domes and Wyandotte caves in Indiana, which are approx. 2.7 miles apart; USFWS, unpublished data, 2019). Such rapid increases cannot be attributed to reproduction alone, and are due at least in part to immigration.

Because maternity colonies are widely dispersed during the summer and difficult to locate, all the combined summer survey efforts have found only a fraction of the colonies presumed to exist (based on range-wide population estimates derived from winter hibernacula surveys). For example, based on the 2019 range-wide population estimate of 537,000 bats, and assuming a 50:50 sex ratio and an average maternity colony size of 50 to 80 adult females (Whitaker and Brack 2002), the 269 or so known maternity colonies may only represent 5 to 8% of the 3,356 to 5,370 maternity colonies that we assume exist (e.g., 537,000 total bats ÷ 2 = 268,500 females, ÷ 50 females/colony = 5,370 colonies). Regardless of reasonable disagreements regarding the average colony size, the geographic locations of the vast majority of Indiana bat maternity colonies remain unknown in much of the range.

Since the last review, the Service updated its range-wide presence/probable absence survey guidance for the Indiana bat to incorporate and standardize additional methods (Niver et al. 2014)[1]. The Service has also implemented standardized reporting of occurrence data which will serve to improve our ability to assess spatial and population trends over time and can be used for future reviews.

Additional summer survey efforts and spring/fall radio-tracking studies are needed to locate remaining maternity colonies in areas along the periphery of the range and interior areas heavily impacted by WNS (see Roby et al. 2019). Because of ongoing WNS-related declines, field surveys aimed at locating "new" maternity colonies and monitoring the status of known maternity colonies and hibernacula will remain vital to the species' long-term conservation and recovery. Likewise, a comprehensive analysis of existing positive and negative summer survey data is warranted.

[1] https://www.fws.gov/midwest/Endangered/mammals/inba/inbasummersurveyguidance.html

2.3.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Additional literature pertaining to the Indiana bat's habitat needs has been published since the last review (see "habitat modeling" references in section 2.3.1.1). However, our general understanding has not significantly changed.

2.3.1.7 Other: *None.*

2.3.2 Five-Factor Analysis

Pursuant to the ESA and our implementing regulations, we must determine whether species are threatened or endangered based on any one or a combination of the following five section 4(a)(1) factors (i.e., the "five-factor analysis"): 1) the present or threatened destruction, modification, or curtailment of habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; and 5) any other natural or manmade factors affecting the species' existence (16 U.S.C. 1533(a)(1), 50 CFR 424.11(c)). Below, we present our evaluation of the information regarding each of the ESA section 4(a)(1) factors and their impact on the extinction risk of the Indiana bat and whether any one or a combination of these factors are causing declines in the species or likely to substantially negatively affect it within the foreseeable future to such a point that it is at risk of extinction now or likely to become so in the foreseeable future. Please refer to the 2007 Plan (USFWS 2007, pp. 71-101) for an in-depth 5-factor threats analysis and a discussion of the species' status including biology and habitat, threats, and management efforts, as well as the last review.

The 1967 federal document that listed the Indiana bat as "threatened with extinction" (32 FR 4001, March 11, 1967) did not address the five factor threats analysis later required by section 4 of the 1973 ESA. The original recovery plan (USFWS 1983) identified threats or "causes of decline" as:

- natural hazards (i.e., flooding, freezing, mine ceiling collapse),
- human disturbance and vandalism at hibernacula (identified as "the most serious cause of Indiana bat decline"),
- deforestation and stream channelization,
- pesticide poisoning,
- indiscriminate scientific collecting,
- handling and banding of hibernating bats by biologists,
- commercialization of hibernacula,
- exclusion of bats from caves by poorly designed gates,
- man-made changes in hibernacula microclimate (blocking or adding entrances and/or by poorly designed gates), and
- flooding of caves by dams/reservoir developments.

Several of the original threats listed above have largely been addressed and are no longer adversely affecting the species to the degree or extent that they once had (e.g., human disturbance at hibernacula, indiscriminate scientific collecting, banding of hibernating bats, commercialization of hibernacula, and poorly designed cave gates). The 1999 agency draft recovery plan (USFWS 1999) identified all of the causes of decline listed above, but also pointed out that "although several human-related factors have caused declines in the past, they do not appear to account for the declines we are now witnessing."

The 2007 Plan (USFWS 2007) identified and expounded upon additional threats including:

- quarrying and mining operations (impacting summer and winter habitat),
- loss/degradation of summer/migration/swarming habitat,
- loss of forest habitat connectivity,
- some silvicultural practices and indiscriminate firewood collection,
- disease and parasites,
- predation,
- competition with other bat species,
- environmental contaminants (not just "pesticides"),
- climate change, and
- collisions with man-made objects (e.g., wind turbines, communication towers, airstrikes with airplanes, and roadkill).

With few exceptions, all of the previously identified threats are still affecting the species to varying degrees in 2019. The most significant range-wide threats to the Indiana bat have traditionally been habitat loss/degradation, forest fragmentation, winter disturbance, and environmental contaminants, but now WNS, non-native invasive species, climate change, and wind turbines have emerged as significant new threats to the recovery of the Indiana bat (see Frick et al. 2019).

While progress to alleviate some long-standing threats has been made over the years, we find that information presented in this review, together with other information available within our files, regarding WNS is substantial enough to make a determination that a reasonable person would conclude that the Indiana bat continues to warrant listing as endangered based on this factor alone. As such, we focus much of our discussion below on WNS and other threats that have emerged and have been better researched since the last review.

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

Destruction and degradation of the bat's winter hibernacula (i.e., caves and mines) and summer/fall/spring habitat (i.e., forests) has been identified as a long-standing and ongoing threat to the species. Many of the species' most important hibernacula have been protected via acquisition or conservation easements, but several key sites have not and remain vulnerable to vandalism, modifications of entrances/microclimate changes, and incompatible surrounding land use. At present, 59% of Priority 1 hibernacula (n = 27) are considered protected and 38% of Priority 2 sites (n = 58) (see Appendix A, Tables 1 and 5, respectively).

Among the currently protected high-priority hibernacula, there remains some degree of threat from potentially harmful developments and activities. For example, an underground pumped-water storage system designed to produce 240 mega-watts of electricity has recently been proposed in a decommissioned subterranean mine complex located near the Barton Hill Mine (BHM) in Essex County, New York. The BHM is the largest remaining Indiana bat hibernaculum in the Northeast (contained 93% of the Northeast RU's Indiana bats in 2019). It is not presently known if a hydrological connection exists between BHM and the proposed project's mine complex, but if there is, the hibernaculum could be altered (flooding and draining repeatedly) or its microclimate could be adversely affected.

In addition to urbanization and development, one of the greatest emerging causes of conversion of forest/habitat loss within the range of the Indiana bat is energy production and transmission (e.g., oil, gas, coal, wind) (Oswalt et al. 2019, USFWS 2007). A distinction should be drawn between forest habitat conversion for agriculture and conversion for development. Agricultural conversion has historically been responsible for high rates of forest conversion within the range of the Indiana bat; however, some marginal farmlands have been abandoned and allowed to revert back to forest. Since the time of listing as endangered, there has been a net increase in forestland within the range of the Indiana bat, particularly in the Northeast, but the overall amount of forestland has stagnated over the past decade (Oswalt et al. 2019). A recent analysis of U.S. forestlands also indicates an increase in forest fragmentation and a decrease in the amount of core forests in portions of the bat's range (Oswalt et al. 2019).

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

Human disturbance of hibernating bats was originally identified as one of the primary threats to the species and remains a threat at several important hibernacula in the bat's range (USFWS 2007). The primary forms of human disturbance to hibernating bats result from recreational caving, cave commercialization (i.e., cave tours and other commercial uses of caves), vandalism, and research-related activities. Disturbance of hibernating Indiana bats seldom results in immediate mortality of bats within the hibernacula, except in cases of vandalism when bats are purposely killed. Impacts of recreational caving on hibernating bats are more difficult to assess and to control compared with commercial uses because commercial caves are generally gated, or have some effective means of controlling access. Many noncommercial Indiana bat hibernacula also have controlled access, but others do not and may be used for recreational caving during the hibernation season. Disturbance of hibernating bats by cavers remains a threat in many hibernacula.

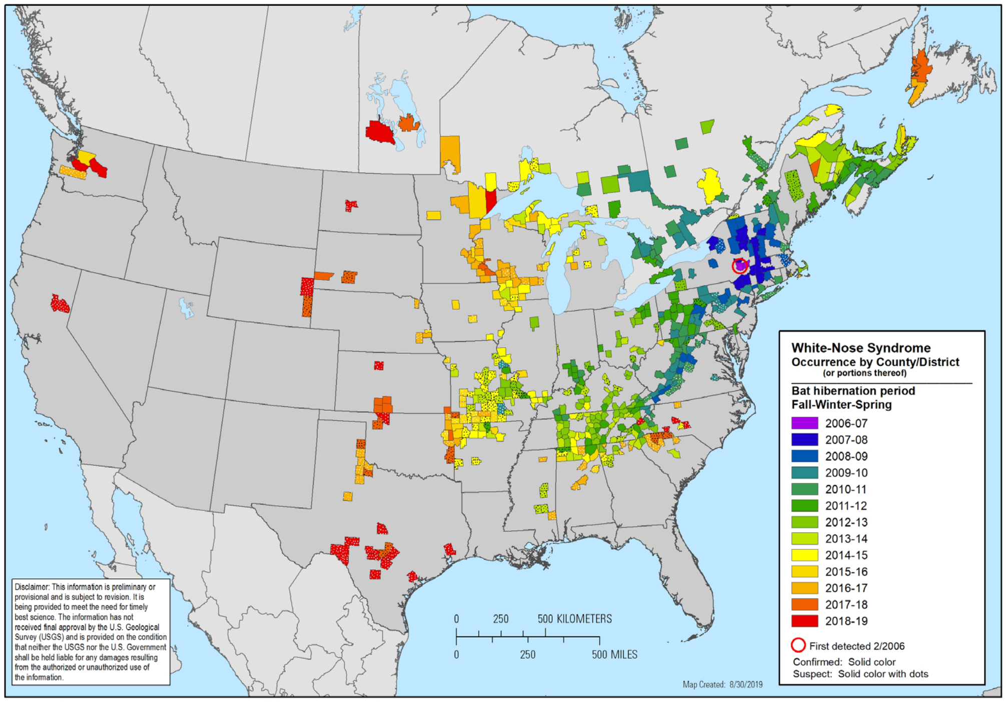
Steady progress has been made in reducing the number of caves and mines in which disturbance threatens hibernating Indiana bats, but the threat has not been eliminated. When biologists throughout the range of the Indiana bat were asked to identify the primary threat at specific hibernacula, "human disturbance" ranked the highest at 38% of Priority 1, 2 and 3 hibernacula combined (USFWS 2007, p. 82) (note that this ranking was prior to the wide-spread effects of WNS). Additional high-priority hibernacula have been protected via fee-simple acquisition and conservation easements and/or gated since the last review, but others remain vulnerable to unauthorized entry and vandalism (see App. A, Tables 1 and 5).

2.3.2.3 Disease or predation: *See the 2007 Plan for additional discussion of diseases and predation (USFWS 2007, page 87).*

White-Nose Syndrome

WNS is considered one of worst wildlife diseases in modern times (WNS 2019). Prior to the ongoing WNS epizootic, there had been little research into the occurrence and effects of diseases in bats in the United States, with the exception of rabies (Weller et al. 2009). Since the last review, WNS has spread across the entire range of the Indiana bat (Figure 2). Since the winter of 2007-2008, millions of bats have died from this devastating disease (USFWS 2012, WNS 2019). If current trends of mortality at affected sites and spread to additional sites continue, WNS threatens to drastically reduce the abundance of many species of hibernating bats in North America in a remarkably short period of time.

As of summer 2019, the causative fungal pathogen, *Pseudogymnoascus destructans* (Pd), has spread to 33 states and 7 Canadian provinces, and the syndrome currently affects 12 species of bat (WNS 2019, Figure 2). WNS infection leads to mortality by resulting in a massive homeostatic imbalance caused by the destruction of wing tissue (Cryan et al. 2010, Cryan et al. 2013), varying degrees of diminished and elevated immunological responses to the infection (Meteyer et al. 2012), and a loss of stored fat needed for overwinter survival (Blehert et al. 2009, Blehert 2012, Gargas et al. 2009). WNS has caused an overall estimated 90% decline in hibernating bat populations within the WNS-affected area and threatens regional or range-wide extinction in multiple species including the Indiana bat (Frick et al. 2010b, Thogmartin et al. 2013, Turner et al. 2011). However, some North American bat species are showing some resistance to WNS and some individuals of highly susceptible species (e.g., little brown bats, *Myotis lucifugus*) are persisting (Cheng et al. 2019, Dobony and Johnson 2018). Cheng et al. (2019) found that little brown bats in persisting populations had increased fat reserves in the autumn (i.e., they tended to be fatter than they had been in pre-WNS years), which may allow them to physically tolerate the high energetic costs of the disease. Low reproductive rates and long lifespan of bats will make any



Citation: White-nose syndrome occurrence map - by year (2019). Data Last Updated: 8/30/2019. Available at: https://www.whitenosesyndrome.org/static-page/wns-spread-maps.

FIGURE 2. WNS occurrence by county/district and year from 2006 to present. (updated 8/30/2019) (visit https://www.whitenosesyndrome.org/for current map)

possible recovery of Indiana bats and other impacted species extremely slow. In the interim, low bat abundance may have adverse affects on natural ecosystems (O'Keefe et al. 2019) and agriculture (Boyles et al. 2011a).

Management of WNS in bats is a complex challenge similar to other diseases in free-ranging wildlife populations. There is no effective method available to treat bats in the wild or to fully control the spread and persistence of the pathogen in the environment, but many efforts to develop treatments and controls are being researched. Members of local, state, federal, tribal, and nonprofit agencies, as well as an international group of researchers from academic and other institutions, are committed to understanding and managing this epizootic (WNS 2019). To date, management actions for reducing impacts of WNS on bat populations have primarily focused on reducing disturbance of bats through protection of hibernacula, and minimizing risks of human-assisted spread of Pd through managing access to caves, education and development of decontamination protocols.

Some WNS research has been focused on the Indiana bat, but an equal or greater focus has been on other WNS-affected species such as the little brown bat (*M. lucifugus*). While the little brown bat may serve as a surrogate subject for many of the patterns being investigated to understand WNS, some differences between it and the Indiana bat are known and have been taken into consideration.

Applicable WNS research was reviewed and the following list highlights some of the established facts and newly emerging information surrounding WNS, its impacts and potential treatments.

- WNS is caused by Pd, which invades and infects skin of the muzzle, ears, and wings of hibernating bats (Gargas et al. 2009). Growth of Pd is restricted to cold temperatures (0°C–19°C), with maximal growth rates at 13°C–15°C, which is within the range of temperatures typically selected by Indiana bats for hibernation (3°C–8°C). The strain of Pd in North America matches a strain commonly found in western Europe (Wibbelt et al. 2010).

- Field signs of WNS can include excessive or unexplained mortality at a hibernaculum; visible white fungal growth on the muzzle or wings of live or freshly dead bats; abnormal daytime flying during winter months or selecting roost sites closer to hibernacula openings/colder areas than normal; and severe wing damage in bats that have recently emerged from hibernation. Infected bats experience a cascade of physiologic changes that result in weight loss, dehydration, electrolyte imbalances, and death. Occasionally, carcasses of little brown bats by the hundreds to thousands have been found outside affected hibernacula with more found inside, but many affected bats appear to exit hibernacula and die elsewhere on the landscape.

- In New York, WNS initially killed up to 95% or more of bats in affected hibernacula (Turner et al. 2011), but more recently some evidence of WNS resiliency or resistance among little brown bats has been observed (e.g., Dobony and Johnson 2018).

- WNS is a multi-host pathogen that has infected 12 bat species including the Indiana bat, northern long-eared bat (*M. septentrionalis*; federally listed as "threatened" in 2015 predominately due to WNS impacts), little brown bat (under consideration for ESA listing due to WNS impacts), gray bat (*M. grisescens*) small-footed bat (*M. leibii*), southeastern bat (*M. austroriparius*), cave bat (*M. velifer*), long-legged bat (*M. volans*), western long-eared bat (*M. evotis*), Yuma bat (*M. yumanensis*), tri-colored bat (*Perimyotis subflavus*) (formerly known as the eastern pipistrelle; under consideration for ESA listing due to WNS impacts), and big brown bat (*Eptesicus fuscus*) and Pd has been detected on 8 additional bat species.

- Hibernating bats with WNS arouse much more frequently (torpor bouts of only 1-3 days) than normal (Reeder et al. 2012). Frequent arousal of bats leads to depletion of stored fat reserves before the end of winter. Therefore, starvation prior to the spring emergence of insects may be the ultimate cause of death of WNS-affected bats. This pattern is especially apparent during the first several years of a colony being infected with Pd, but after peak impact of the disease in a colony, surviving bats may exhibit arousal frequencies more typical of healthy bats before WNS had arrived (Lilley et al. 2016).

- Transmission of WNS is primarily bat-to-bat, but human-assisted transmission from WNS-affected hibernacula to unaffected hibernacula remains a possibility. Thus, in March 2009, the Service issued a cave advisory recommending that people refrain from entering caves and mines in WNS-affected and adjacent states. The National WNS Response Team revised this advisory to create "Recommendations for Managing Access to Subterranean Bat Roosts" in 2016. The purpose for this guidance is to reduce the potential for people to disturb hibernating bats or inadvertently transport Pd to uncontaminated habitats. (https://www.whitenosesyndrome.org/press-release/updated-cave-advisory-recommendations-for-managing-access-to-subterranean-bat-roosts-to-reduce-the-impacts-of-white-nose-syndrome-in-bats)

- Pd is now present in Washington State (since at least 2016) and WNS has since been confirmed there. While the exact means by which Pd reached the west coast is not known, the long distance to the nearest known occurrence of the fungus at the time and other genetic information suggests that natural movements of bats alone are unlikely to have transmitted it. Now that Pd is in the West, it appears to be expanding its range through more common bat-to-bat transmission. In July 2019, news that Pd may have reached northern California was announced (https://www.wildlife.ca.gov/Conservation/Laboratories/Wildlife-Investigations/Monitoring/WNS).

- If WNS-affected bats survive the potentially fatal wing damage and inflammation that may occur post-emergence, they typically can recover during the summer months (Fuller et al. 2011, Lorch et al. 2013). However, WNS-affected females that survive may have lower reproductive success (e.g., loss of fetus/pup or delayed parturition) (Francl et al. 2012). Bats in WNS endemic areas are generally re-infected with Pd each fall as they enter hibernation, but band recoveries have shown interannual survival of little brown bats for up to 6 years in spite of WNS (Reichard et al. 2014).

- Pd can persist in the soil of caves and mines for long periods of time, potentially causing bats to become repeatedly exposed each year (Lorch et al. 2013, Hoyt et al. 2014, Langwig et al. 2015).

- Langwig et al. (2012) found bats roosting at more humid and warmer temperatures manifested higher fungal loads and greater impacts of WNS and evidence of threshold fungal loads, above which the probability of mortality increased sharply. The local microclimate within hibernacula appeared to be a key determinant in forcing disease. In addition, they found that differences in bat sociality during hibernation can influence the impacts of WNS on their populations. The fraction of little brown bats roosting individually increased (i.e., they became less social) after populations had declined; having fewer neighbors during hibernation reduced their pathogen exposure. Apparently, the total number of individuals within a hibernaculum did not determine transmission intensity (i.e., no evidence of density-dependent transmission), interactions among species appeared to play a relatively minor role in transmission, and clustering behavior facilitated high transmission regardless of colony size. [Langwig et al. are currently leading an effort to better characterize microclimates at Indiana bat hibernacula with remaining populations in hopes of improving our understanding of Pd growth and WNS impacts, which could lead to new or improved treatments and/or management options]

- Current WNS treatment/control efforts are focused on integrated approaches that combat Pd directly or reduce infection and mortality in bats, as well as promoting overall health of bat populations to support resistance to and recovery from WNS. Disease management options that are currently being researched include vaccination to strengthen immune responses to infection, ultraviolet (UV) light to kill Pd, anti-fungal biological agents (e.g., probiotics, chitosan, and bacterially produced volatile compounds), anti-fungal chemical agents (e.g., Chlorine dioxide, decanal, B23 and Polyethylene glycol 8000), and gene manipulation/RNA silencing of Pd (via a partitivirus) (WNS 2019). Some of these treatments have demonstrated effectiveness against Pd in the laboratory; however, field trials to assess applicability, safety, and efficacy in wild bats, as well as potential ecologic side effects, are ongoing and are in various stages of development. The potential for causing adverse effects by introducing various natural and/or synthetic microbicidal agents into natural cave ecosystems remains a significant concern in need of further investigation as does the overall challenge of implementing widespread and/or targeted applications at meaningful scales. Physical manipulation of hibernacula is also being explored as a means to make the environment less conducive to Pd growth (e.g., making them colder) (Zalik et al. 2016). Some have recently suggested that management efforts that increase bats' ability to increase fat stores in autumn (e.g., improving foraging habitat quality and quantity near hibernacula) may help facilitate population persistence (Cheng et al. 2019). In contrast to these approaches, some have suggested that WNS treatments and interventions may be unnecessary, have unintended consequences, or may even exacerbate population declines (Dobony and Johnson 2018, Tuttle 2019).

- Because WNS is not the only cause of bat mortality and population decline, conservation of bat populations will require a holistic approach. In recent years, the Conservation and Recovery Working Group (organized under the National WNS Plan; USFWS 2011a) has sought to minimize potential non-WNS-related stressors to bats by developing and promoting the use of guidelines containing bat-friendly management practices on a variety of topics. For example, beneficial forest management guidelines for WNS-affected bats in the eastern U.S. were recently published (Johnson and King 2018).

- The Service and other state and federal managers/biologists and other researchers and conservation partners have taken many additional actions in response to WNS. A summary of these actions is available at https://www.whitenosesyndrome.org/ under the "What are We Doing?" heading.

Current and Projected WNS Impacts on Indiana Bats

- By 2015, 99% of the range-wide Indiana bat population was hibernating in WNS-affected sites (USFWS 2019a). At present, all known Indiana bat hibernacula fall within the "endemic area" or zone of WNS in North America and are assumed to be WNS-affected.

- The percent change in the range-wide Indiana bat population from 2007 (i.e., since arrival of WNS in NY) to 2019 = -19.2% (see USFWS 2019b).

- States with largest net loss of Indiana bats since 2007 (% decline since 2007): Indiana = -53,220 (-22%), New York = -39,367 (-75%), Missouri = -18,157 (-9%), Kentucky = -15,220 (-21%), West Virginia = -14,125 (-96%), Tennessee =-6,509 (-73%), Ohio = -4,739 (-62%), and Pennsylvania = -1,027 (-99%).

- Thogmartin et al. (2012) developed a stochastic, stage-based population model to forecast the population dynamics of the Indiana bat subject to two different WNS scenarios: "acquired immunity" (AI) and "persistent mortality" (PM). The AI model predicted that by 2022, only 12 of the initial 52 wintering populations would possess wintering populations of >250 females and 3.7% of wintering populations would be above 250 females after 50 years (year 2057) after a 69% decline in abundance to around 64,768 bats. Under the PM scenario, Indiana bats continued to decline after 2022 and reached their nadir by 2035, resulting in a remaining population of 43,000 bats; after that point in time, the underlying positive population dynamic in 3 of the 4 Recovery Units pre-WNS led to a 4% increase over the year 2035 population size. The PM scenario led to 297,000 fewer bats at the end of the projection interval compared to the AI scenario (10,000 fewer bats in the Ozark-Central, 203,000 fewer in the Midwest, 21,000 fewer in the Appalachians, and 63,000 fewer in the Northeast). At the nadir of projections, they predicted regional quasi-extirpation of wintering populations in 2 of 4 Recovery Units while in a third region, where the species is currently most abundant, >95% of the wintering populations were predicted to be below 250 females. Their modeling suggested WNS is capable of bringing about severe numerical reduction in population size and local and regional extirpation of the Indiana bat.

Note: This paper was published just before the discovery of the new P1 hibernaculum in Hannibal, Missouri, Sodalis Nature Preserve, and therefore, it was not included in this modeling.

- Maslo et al. (2017) found that a relatively high annual survival in infected Indiana bats may veil a persistent extinction risk from disease. They conducted a mark–recapture study of Indiana bats at a WNS-positive mine in New Jersey during 2011–2016, and observed a decrease in annual survival of both females and males. They modeled two explanatory mechanisms potentially driving the observed patterns: (1) phased exposure to disease through the spatial spread of the pathogen within the hibernaculum; and (2) cumulative mortality risk from iterative yearly WNS infection. Their results suggest that Indiana bats tolerate a pathogen load prior to onset of infection, leading to a less pronounced population decline than for other susceptible species. However, the cumulative long-term risk of WNS to Indiana bats may be more severe than current population trends suggest. Despite their relatively high survival rates, however, they found strong evidence for a declining trend in this vital rate over time since disease emergence, and both population models stabilized at negative growth. Therefore, the apparent tolerance of Pd by Indiana bats (compared to species such as little brown bats that show precipitous declines in early years of infection) may not be indicative of reduced long-term extinction risk. Subtle cumulative costs, aggregating over time, may insidiously compromise population persistence in ways that take a decade or more to reach their full impact (due to baseline host life expectancy). The selective forces acting on Indiana bats appear to be considerably weaker than those on little brown bats, as evidenced by their more gradual population decline and lower mortality levels in most sites. Therefore, evolutionary processes are unlikely to rescue populations from extirpation even if resistant genotypes are present. However, less pronounced population-level impacts likely render proposed conservation actions more feasible for Indiana bats. These researchers' vital rate sensitivity analysis suggested that modest increases in survival (4–5%) through targeted intervention may return declining populations to stability (k = 1.0).

- Unlike the social changes observed in hibernating little brown bats, Langwig et al. (2012) stated that "the smaller changes in sociality observed in Indiana myotis apparently were not large enough to reduce transmission and disease impact to allow for populations to stabilize, and this puts this species at a high risk of extinction."

- Because of WNS, Indiana bats also have additional energetic demands.
  - Because WNS causes rapid fat depletion, affected bats have less fat reserves than non-WNS-affected bats when they emerge from hibernation (Reeder et al. 2012; Warnecke et al. 2012) and have wing damage (Meteyer et al. 2009; Reichard and Kunz 2009) that makes flight (migration and foraging) more challenging.
  - Females that migrate successfully to their summer habitat must partition energy resources between foraging, keeping warm, reproducing, and recovering from the disease.
  - Bats may use torpor to conserve energy during cold, wet weather when insect activity is reduced and increased energy is needed to thermoregulate. However, use of torpor reduces healing opportunities, as immune responses are suppressed (Field et al. 2018).
  - Dobony et al. (2011) and Frick et al. (2010) found evidence of lower reproductive rates in little brown bat maternity colonies in the years immediately after onset of WNS.
  - Francl et al. (2012) observed a reduction in juveniles captured pre- and post-WNS in West Virginia, suggesting similarly reduced reproductive rates.
  - Meierhofer et al. (2018) found higher resting metabolic rates in the spring in WNS-infected (vs. uninfected) little brown bats suggesting additional energy costs during spring in WNS survivors.
- A full bibliography of WNS-related research is available at https://www.whitenosesyndrome.org/static-page/publishing-science

In short, WNS has significantly and rapidly raised the degree of threat against the Indiana bat by causing reductions in its fitness, reproductive success and survival, which has lowered the species' overall recovery potential (see discussion at 3.2).

2.3.2.4 Inadequacy of existing regulatory mechanisms:

No updates since the last review except for the following. Ownership of Indiana bat habitat is probably the primary factor that limits effectiveness of existing regulatory mechanisms. Of the 85 Priority 1 and 2 hibernacula, 16 (19%) are federally owned, 22 (26%) are state-owned, 45 (53%) are privately owned, 1 (1%) is city owned and 1 (1%) has an unknown ownership (USFWS 2019a). ESA protection extends to hibernacula that are privately owned, but recovery options are often limited on private lands. However, it should be noted that most private hibernacula owners are cooperative in efforts to protect Indiana bats.

2.3.2.5 Other natural or man-made factors affecting its continued existence:

Several natural factors are a threat to local bat populations, including flooding and freezing events at winter hibernacula (USFWS 2007). These natural events typically are not widespread, but rather associated with specific flood/freeze-prone sites.

Anthropogenic factors that may affect the continued existence of Indiana bats include numerous environmental contaminants (e.g., organophosphate and carbamate insecticides, oil spills, and PCBs), collisions with man-made objects (e.g., poorly constructed cave gates, vehicles, and wind turbines), non-native invasive species (NNIS), and climate change. For this review, we have focused on four emerging man-made threats: wind energy/turbines, climate change, NNIS, and light pollution.

Wind Energy/Turbines

With growing concerns about climate change, wind energy has become one of the fastest growing sources of renewable energy in the United States (AWEA 2019). The current juxtaposition of wind energy facilities within the range of the Indiana bat may lead to a meaningful impact on the population dynamics of the species, depending upon the magnitude of risk from collision faced by migrating and summer resident bats. Large-scale fatalities of bats (mostly other species) have occurred at multiple wind energy facilities across the range of the Indiana bat and beyond. While much of the emphasis of early wind energy-wildlife research was on bird impacts, more recent studies have found that far more bats than birds are typically killed in the Midwest and Eastern United States (Arnett and Baerwald 2013, O'Shea et al. 2016). Increasingly, monitoring efforts have focused on bat fatalities, and research to understand bat interactions with turbines is providing new insights into this problem. Studies of bat fatalities have shown that turbines have been consistently associated with fatalities of some species of bats particularly, migratory tree-roosting bats including hoary bats (*Lasiurus cinereus*), eastern red bats (*L. borealis*), and silver-haired bats (*Lasionycteris noctivagans*), which make up a large proportion of the bats killed (Arnett et al. 2009, Arnett et al. 2011, Arnett and Baerwald 2013, Arnett et al. 2013, BWEC 2018, Cryan et al. 2014, Ellison 2012, Erickson et al. 2016, Frick et al. 2017, O'Shea et al. 2016, Pruitt and Reed 2018, Schirmacher et al. 2018).

The only well-documented method to reduce fatalities at wind turbines is limiting operation during high-risk periods, such as nocturnal periods of low wind speeds during fall migration (Arnett et al. 2011, Baerwald et al. 2009). Such operational curtailment can reduce bat fatalities by 44–93% (Arnett et al. 2011). The American Wind Energy Association (AWEA) has adopted policies to limit blade movement in low-wind speeds as a voluntary operating protocol that could reduce fatalities up to 30% (AWEA 2017). Studies are underway regarding new methods for possible reductions in fatalities (e.g. acoustic deterrents and smart curtailment).

A total of 13 Indiana bat fatalities has been documented at wind energy facilities in six states (Illinois, Indiana, Iowa, Ohio, Pennsylvania, and West Virginia) since 2009 (Pruitt and Reed 2018). To put this number of fatalities in context, it is important to understand that monitoring of bat fatalities at wind facilities is expensive and difficult. Not all facilities conduct fatality monitoring, and even when monitoring is conducted only a small proportion of dead bats are found during ground searches. We assume that additional Indiana bat mortality has occurred at these facilities and at other wind facilities throughout the range of the species. Additional Indiana bat fatality information and Service guidance is available online (see Pruitt and Reed 2018, USFWS 2011b).

Erickson et al. (2016) used a spatially explicit full-annual-cycle model to investigate how wind turbine mortality and WNS may singly and then together affect population dynamics of Indiana bats. In their simulation, wind turbine mortality impacted the metapopulation dynamics of the species by causing extirpation of some of the smaller winter colonies. In general, effects of wind turbines were localized and focused on specific spatial subpopulations. Conversely, WNS had a depressive range-wide effect. Wind turbine mortality interacted with WNS and together these stressors had a larger impact than would be expected from either alone, principally because these stressors together act to reduce species abundance across the spectrum of population sizes. Their findings illustrated the importance of not only prioritizing the protection of large winter colonies as is currently done, but also of protecting metapopulation dynamics and migratory connectivity. Multiple wind companies are working with the Service to operate their facilities in ways to avoid impacts to Indiana bats. Others have developed habitat conservation plans (HCPs) and received incidental take permits to address unavoidable impacts.

Climate Change

Climate change has already had observable impacts on biodiversity, ecosystems, and the benefits they provide to society. These impacts include the migration of native species to new areas and the spread of invasive species. Such changes are projected to continue, and without substantial and sustained reductions in global greenhouse gas emissions, extinctions and transformative impacts on some ecosystems cannot be avoided in the long term. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities (USGCRP 2018).

Mounting data on the impact of climate change, including extreme events such as drought and flooding, on bats are a cause for concern as recent increases in global temperature represent one fifth, or less, of those expected over the next century (Frick et al. 2019, O'Shea et al. 2016, Rebelo et al. 2010, Sherwin et al. 2013, USGCRP 2018). In combination with WNS, habitat destruction, and other sources of environmental degradation, climate change poses a serious and increasing threat to Indiana bats. During the last 30 years of the 20th century, evidence accumulated suggests that the phenology of organisms, species biogeography and the composition and dynamics of communities are changing in response to a changing climate (Walther et al. 2002).

Climate influences food availability, timing of hibernation, frequency and duration of torpor, rate of energy expenditure, reproduction and development rates of juveniles (Sherwin et al. 2013). Warmer climates may benefit females by causing earlier parturition and weaning of young, allowing more time to mate and store fat reserves in preparation for hibernation. Similarly, earlier gestation and parturition may benefit juveniles by providing a longer growth period prior to the breeding season (Burles et al. 2009). Frick et al. (2010a) supported this finding by showing that little brown bat pups born early in the summer have higher survival and first-year breeding probabilities than those born later in the summer. In contrast, disruption of hibernation, extreme weather events, reduced water availability in arid environments, and the spread of disease may also cause significant mortalities (Adams and Hayes 2008, Adams 2010, Hayes and Adams 2017).

Among the most likely future impacts are changes in the range of migratory species, which recently has been reported in two European bat species (Lundy et al. 2010, Ancillotto et al. 2016) and the Mexican free-tailed bat (*Tadarida brasiliensis*) in the southeastern U.S. (McCracken et al. 2018). Similarly, the common vampire bat (*Desmodus rotundus*) is expected to expand its range northward from Mexico to the southern tip and coastal areas of Texas and potentially eastward to Florida where fossil evidence suggests it previously occurred during the Pleistocene (Gut 1959, Mistry and Moreno-Valdez 2008). Dixon (2011) provided genetic evidence that one lineage of little brown bats (*M. l. lucifugus*) expanded their range northwards after taking refuge in the southeastern U.S. during the last glacial maximum during the Pleistocene. Climate change is also likely to affect the timing of migration. Stepanian and Wainwright (2018) found that Mexican free-tailed bats are migrating to Bracken Cave in Texas roughly two weeks earlier than they were just two decades ago. They now arrive, on average, in mid-March rather than late March, likely in response to insect prey becoming available earlier in the year.

It is not clear how Indiana bat maternity colonies will respond behaviorally to the anticipated changes to their climatically suitable summer habitats. Females show high multi-annual fidelity to roost areas and may migrate up to 673 km (418 miles) (Butchkoski and Bearer 2016), often from different hibernacula, to reach these colonies (Kurta et al. 2002, Winhold and Kurta 2006). Thus, Loeb and Winters (2012) suggested initial shifts may occur at the microhabitat scale with females selecting roosts in more shaded areas than currently observed in many areas and that larger scale range shifts may take more time and locating more climatically suitable areas may result in the temporary or long-term disruption of the colony structure. Loeb and Winters (2012) modeled the current summer maternity distribution of Indiana bats and then modeled future distributions based on four different climate change scenarios. They found that due to projected changes in temperature, the most suitable summer range for Indiana bats would decline and become concentrated in the northeastern U.S. and Appalachian Mountains (Figure 3). The western part of the range (Missouri, Iowa, Illinois, Kentucky, Indiana, and Ohio)– currently considered the heart of Indiana bat maternity range – would become unsuitable under most climates that were modeled. Their model suggested that once average summer (May through August) maximum temperatures reach 27.4°C (81.3°F), the climatic suitability of the area for Indiana bat maternity colonies would decline. Once these temperatures reach 29.9°C (85.8°F), the area is forecast to become completely unsuitable. Interestingly, models by Thogmartin et al. (2012a) also predicted Indiana bats should fair relatively well in the Northeast RU due to increased precipitation coupled with warming winter conditions that may allow for higher reproduction and winter survival there. These studies may have implications for managers in the Northeast and the Appalachian RUs as these areas may serve as climatic refugia for Indiana bats when other parts of the range become too warm.

Changes in temperature may also affect hibernation periods and the availability of suitable hibernacula in the future (e.g., some currently occupied sites may become too warm). Increased variation in climatic extremes raises the possibility of bats emerging from hibernation early or at a greater frequency. That would not only put hibernating bats at risk from depleted energy stores, but could also affect the birth and survival of pups. Resources, especially insect prey, may be limited or variable during

FIGURE 3. Forecasted climatically suitable areas for Indiana bat maternity colonies under four climate scenario/global circulation model scenarios and three time periods. (from Loeb and Winters 2012)

periods of early arousal from hibernation. Thus, climate change will likely also affect the future distribution of suitable hibernacula (Humphries et al. 2002). Therefore, finding suitable maternity sites may be a function of finding new hibernacula, and summer and winter range shifts may occur concurrently. Furthermore, it remains uncertain as to how climate change may influence and interact with future WNS infection rates of Indiana bats (e.g., some "cold" sites may become more suitable to Pd growth if hibernacula microclimates warm).

At least some of the world's forested ecosystems already may be responding to climate change and raise concern that forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming and drought, even in environments that are not normally considered water-limited (Allen et al. 2010, Zhang et al. 2010). Climate change could have large impacts on tree species in the eastern United States that are commonly used by Indiana bats as roost trees. For example, of the 134 eastern U.S. tree species modeled by Iverson et al. (2008), approximately 66 species would gain habitat and 54 species would lose at least 10% of their suitable habitat by year 2100 from climate change. They predicted that most of the tree species' suitable habitat in the eastern U.S. is expected to generally move northeast, up to 800 km (assuming the hottest climate scenario and the highest emissions trajectory) and that the spruce-fir zone would retreat up the Appalachian mountain chain while southern oaks and pines advance northward. Somewhat surprisingly, in an abundance study of 86 eastern U.S. tree species over time, Fei et al. (2017) found that more tree species had experienced a westward shift (73%) than a poleward shift (62%), which they attributed to changes in moisture availability.

The composition of tree species in eastern hardwood forests are expected to change due to longer growing seasons, shorter/warmer winters, increased extreme precipitation events, changes in soil moisture and drought, enhanced fire risk, and intensified biological stressors. Model results project that species currently near their northern range limits in the region may become more abundant and more widespread under a range of climate futures. At the same time, observed trends have suggested that forest species may be more prone to range contraction at southern limits and less able to expand ranges northward to track climate change (Brandt et al. 2015).

Questions about the degree to which negative effects of climate change will be offset by positive effects on other life history features, whether population losses in one part of the species' range will be offset by gains in other regions, and the degree to which bats can adapt by adjusting their behavioral, ecological, and phenological characteristics remain largely unanswered. Further monitoring and research is needed to better understand the impacts of climate change on Indiana bats and their habitat.

Non-Native and Invasive Species

Biological invasions by non-native invasive species (NNIS) are one of the most significant environmental threats to the maintenance of natural forest ecosystems in North America and elsewhere (Liebhold et al. 1995). Invasive forest insect pests (and fungal diseases) have the ability to cause massive mortality events across vast areas. Apart from the staggering economic losses attributed to exotic insect pests such as the gypsy moth (*Lymantria dispar L*), emerald ash borer (EAB; *Agrilus planipennis*) and Asian long-horned beetle (*Anoplophora glabripennis*)(Wallner 1997, Aukema et al. 2011), these pests can have devastating adverse impacts on the health, productivity, species richness and overall biodiversity of eastern U.S. forests and the bat communities dependent on them. The impacts of NNIS to Indiana bats specifically are not well documented, but are presumed to be significant in some portions of the species' range.

The EAB is a non-native, invasive, phloem-feeding beetle that was inadvertently introduced into Michigan in the late 20th century and has since spread and killed hundreds of millions of native ash (*Fraxinus*) trees and cost municipalities, property owners, nursery operators and the forest products industry hundreds of millions of dollars (EABIN 2019). Canopy gaps and accumulation of coarse woody debris caused by dying ash trees have cascading impacts on forest communities, and have caused shifts in understory vegetation that enhance growth of NNIS, increase successional rate to shade-tolerant species (i.e., mesophication), alter soil chemistry and soil-dwelling and herbivorous arthropod communities, and alter bird foraging behavior, abundance, and community composition. (Dolan and Kilgore 2018, Klooster et al. 2018).

Impacts of EAB-induced ash mortality on Indiana bats have not yet been quantified. Dying ash trees along the EAB invasion front may temporarily benefit some Indiana bat colonies by providing an abundance of available roosting habitat. However, the long-term loss of ash species is more likely to be detrimental by eliminating the future availability of ash species as suitable roost trees and causing a decline in insect diversity and abundance. While Indiana bats can roost in many different tree species (USFWS 2007), they have exhibited a preference for some tree species (Kurta et al 2002). For example, Kurta et al. (1996), demonstrated a preference by Indiana bats for green ash (*F. pennsylvanica*) over silver maple (*Acer saccharinum*) in Michigan, and Carter (2003) showed that these bats chose green ash and pin oak (*Quercus palustris*) more often than expected based on availability in Illinois. Therefore, adverse impacts are likely to be greatest in portions of the Indiana bat range where ashes were/are a primary source of roost trees (e.g., southern Michigan). A significant loss of roost trees may fragment a maternity colony and reduce reproductive success (Kurta et al. 2002). Effects of EAB may be similar to those caused by chestnut blight and Dutch-elm disease.

Other NNIS that negatively impact the quality of Indiana bat habitat include plants such as Asian bush honeysuckles (*Lonicera* spp.), Japanese honeysuckle (*Lonicera japonica*), Russian olive (*Elaeagnus angustifolia*), Oriental bittersweet (*Celastrus orbiculatus*), and Kudzu (*Pueraria montana* var. *lobata*), which can outcompete and choke out native trees and thereby alter the long-term succession of the forest. Non-native plants may also reduce the amount of insect biomass available to bats and other insectivores and disrupt terrestrial and aquatic food webs (Tallamy 2004, Tallamy et al. 2010, McNeish et al. 2017). Numerous other NNIS ranging from fungi to exotic earthworms impact forest dynamics within the Indiana bat range, but few are well studied or easily controlled at present (Brack et al. 2013, Welch and Leppanen 2017). Further research and strategic eradication and control efforts of NNIS are encouraged as they indirectly support the maintenance of quality habitat for Indiana bats.

Artificial Lighting/Light Pollution

The rapid global spread of artificial light at night is causing unprecedented disruption to ecosystems, but its biological impacts have only recently been recognized (Rowse et al. 2016). Artificial lighting attracts and repels animals in taxon-specific ways and may affect their physiological processes. Being nocturnal, bats are among the taxa most likely to be affected by light pollution. Bats may react to artificial lighting in a number of ways, including deserting roosts which are lit, delaying roost emergence thus shortening time available for foraging, and avoiding drinking, foraging or commuting in lit areas (Haddock et al. 2019, Russo et al. 2017, Stone et al. 2009, Stone et al. 2015). Artificial lighting, therefore, has potentially serious conservation consequences. It has been associated with lower colony size in some species suggesting continued use of artificial lighting could negatively impact local populations (Kurvers and Hölker. 2015, Stone et al. 2015).

At present, very little information is available as to what impacts light pollution may be having on Indiana bat populations or to what degree. However, we can gain some insight from surrogate species of insectivorous bats and from anecdotal accounts of Indiana bat behavior. For example, from his study of radio-tagged Indiana bats near the Indianapolis Airport, Sparks (2003) concluded that the most heavily used foraging areas were in the middle of the darkest regions of his study area and that the effects of artificial light were in need of additional study. Others have noted that bat responses to lighting are species-specific and reflect differences in flight morphology and performance. For example, fast-flying aerial hawking species frequently feed around street lights, and relatively slow-flying bats (like the Indiana bat), that forage in more confined spaces tend to be more light-averse (Rydell and Baagøe 1996, Rowse et al 2016). Additional research on the potential impacts of artificial lighting on Indiana bats is needed particularly as lighting technologies are rapidly changing, with the increased use of light-emitting diode (LED) street lamps (Stone et al. 2012).

2.4 Synthesis

Since the last review, WNS has caused severe declines in many Indiana bat populations and has rapidly erased decades worth of population gains. At present, very few healthy populations remain in the Northeast and Appalachia RUs. WNS impacts are expected to continue across the range for years to come as are other ongoing threats (e.g., climate change, NNIS, and wind turbines) to the bats and their habitats. Given the species' limited reproductive potential, populations are not likely to rebound in the near term. In short, over the past decade, WNS has increased the Indiana bat's risk of extinction as the resiliency, redundancy, and representation of its remaining populations have declined (see Smith et al. 2018).

The majority of the Indiana bats' population-based, and protection-based recovery criteria have not yet been achieved. At this time, only one of the three reclassification criteria, Criterion 2, has been met (Table 1, see Appendix A for details). Reclassification Criteria 1 and 3 have not been met. Therefore, identified threats have not yet been sufficiently reduced and stable population growth at the most important hibernacula has not been sustained for long enough for the species to be reclassified (i.e., downlisted) as "threatened."

Although Delisting Criterion 2 is being numerically met, Delisting Criteria 1 and 3 have not been met. Therefore, additional recovery efforts, such as protection of additional Priority 2 hibernacula are needed (i.e., Delisting Criterion 1), and positive population trends at more P1A sites (i.e., Delisting Criterion 3) are needed (Table 1, see Appendix A for details).

Based on the Service's review, the Indiana bat should remain listed as 'endangered' because the species status has not improved since listing and new and old threats have not been sufficiently ameliorated. We reached this conclusion by using the most current population data from 2019 (USFWS 2019a, USFWS 2019b) (in conjunction with the recovery criteria set forth in the 2007 Plan (USFWS 2007, see Appendix A)) and a review of new information on threats.

3.0 RESULTS

3.1 Recommended Classification:

____ **Downlist to Threatened**
____ **Uplist to Endangered**
____ **Delist** (*Indicate reasons for delisting per 50 CFR 424.11):*
  ____ *Extinction*
  ____ *Recovery*
  ____ *Original data for classification in error*
__X_ **No change is needed**

3.2 New Recovery Priority Number: 5

The Recovery Priority Number (RPN) remains at "5" following the guidelines in Federal Register notice 48(184) FR 43098-43105 (September 21, 1983). An RPN of "5" means that a species has a high degree of threat and a low recovery potential.

Brief Rationale: In the previous review, the RPN was changed from "8" to "5" due to factors associated with WNS. The ongoing WNS epizootic persists and thus the "degree of threat" to the Indiana bat remains "high." The high category means "extinction is almost certain in the immediate future because of a rapid population decline or habitat destruction" whereas the moderate category means "the species will not face extinction if recovery is temporarily held off although there is continual population decline or threat to its habitat." Prior to emergence of the WNS threat, the Service considered the Indiana bat to have a "high" recovery potential (i.e., biological/ecological limiting factors and threats were well understood and intensive management was not needed and/or recovery techniques had a high probability of success). The Service now considers the Indiana bat to have a "low" recovery potential, because we currently have very limited ability to alleviate the threat posed by WNS. Preliminary/experimental management techniques/efforts will likely be intensive with an uncertain probability of success. At this time, the Service is not aware of any significant "conflict" that would warrant adding a “c” designation to the Indiana bat’s RPN. Therefore, according to Table 3 in 48(184) FR 43098-43105 (above), a species having a “high” degree of threat, a “low” recovery potential and no conflict should be assigned a recovery priority number of “5.” The RPN can be changed at any time and changes will be considered as our understanding of WNS and its management improves.

3.3 Listing and Reclassification Priority Number: Not applicable.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

Future revisions to the Indiana Bat Recovery Plan should addresses WNS and other longstanding and emerging threats. Although WNS was not identified/addressed as a threat in the 2007 Plan, the population-based recovery criteria in the 2007 Plan are likely to remain as one of the most effective means of assessing the WNS-related mortality and potential recovery from WNS in the future.

The Service has a long and successful record of collaborating with many state and federal partners to survey and monitor Indiana bat populations at their hibernacula and these should continue.

Additional efforts to monitor known maternity colonies and to discover additional ones on the summer landscape is needed particularly in regions hardest-hit by WNS. In some areas, aerial tracking of radio-tagged females during the spring migration is likely to be the most efficient means of locating and subsequently conserving new maternity colonies (see Roby et al. 2019).

We also recommend that the Service and our partners support and take actions to implement the North American Bat Monitoring Program (NABat; https://www.nabatmonitoring.org/).

Additional research to better understand the impacts of WNS on the species and the larger bat community is warranted as well as research, funding and strategic implementation of practicable management actions should they prove successful at improving Indiana bat survival and reproduction. In the interim, we should continue to pursue tried and true management approaches of fostering high reproductive success and survival, such as providing for the continual recruitment of large-diameter snags in landscapes with a variety of well-connected forested habitat types and protecting hibernating bats from indiscriminate alterations to hibernacula, unauthorized human disturbance, and excessive research-related activities (see Boyles 2017).

We concur with Ingersoll et al. (2016) who stated… “Although research on bat responses to WNS must proceed apace in hopes of mitigating the most severe effects of this disease, renewed management attention to other threats may hold more immediate promise for reducing further declines. Reducing such threats could alleviate synergistic or interacting effects that may be compounding threats to bats, ameliorate other stressors to make bats more resilient to WNS, and enable immediate intervention on threats more amenable to management than WNS." In other words, effective Indiana bat conservation will require further research to mitigate impacts of WNS, and renewed attention to other threats to the species.

To be most effective at alleviating threats, we will also need to continue public education/outreach efforts about WNS, wind turbine conflicts, climate change, NNIS, light pollution and other threats to bats and pursue opportunities to share how others can help bats (e.g., Johnson and King 2018).

The Service also needs to make a more concerted effort to reach out to public and private stakeholders to improve understanding of our legal responsibilities (e.g., ESA) and mutual natural resource goals (see D'Acunto and Zollner 2019).

It is also apparent from this review that additional attention should be placed on securing permanent/long-term protection of additional Priority 1 and Priority 2 hibernacula. Several Priority 1 hibernacula would satisfy Reclassification Criterion 1 if their cave/mine entrances were gated or if appropriate buffer zones were delineated and protected.

We also recommend that the Service continue to pursue some of the highest priority recovery actions identified within the 2007 Plan that have yet to be completed in an effort to improve or refine our current understanding of the Indiana bat's population status and progress towards recovery (e.g., develop site-specific hibernacula management plans at high priority hibernacula, develop standardized methods for characterizing and monitoring hibernacula microclimates, and determine beneficial land management practices for maternity colonies).

In order to successfully implement the recovery actions outlined in the 2007 Plan across the species' range, the Service will need to continue to improve and maintain a significant, ongoing level of coordination with state, federal and private agencies, bat surveyors, the caving and academic communities, and other conservation and research partners to further develop and maintain the Service's existing hibernacula and maternity colony databases.

Finally, to ensure we are obtaining reliable information about Indiana bat summer occurrences, the Service will need to continue to 1) update and improve our range-wide presence/probable absence survey protocols, 2) work with others to test and approve the accuracy of new automated acoustic ID software versions and 3) provide training on proper survey techniques and interpretation and reporting of survey results.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of the INDIANA BAT (*Myotis sodalis*)

Current Classification: **Endangered**

Recommendation resulting from the 5-Year Review:

___ Downlist to Threatened
___ Uplist to Endangered
___ Delist
_X_ No change is needed

Appropriate Recovery Priority Number: __5___

Review Conducted By: R. Andrew King, Indiana ES Field Office, Bloomington, IN

FIELD OFFICE APPROVAL:
Lead Field Supervisor, Fish and Wildlife Service

Approve______________________________ Date 9/30/19
Scott E. Pruitt,
Indiana ES Field Office,
Bloomington, IN

<u>APPENDIX A:</u>

Status of Recovery Criteria from the Indiana Bat Draft Recovery Plan: First Revision (USFWS 2007)

(as of September 2019)

The recovery criteria are presented in quotations (and blue text) and their supporting text from the Plan (USFWS 2007) is shown in italics. Current status of each criterion is summarized within yellow text boxes with supporting tables and figures.

Reclassification Criteria (RC):

"Reclassification Criterion 1: Permanent protection at 80 percent of all Priority 1 hibernacula in each Recovery Unit, with a minimum of one Priority 1 hibernaculum protected in each unit." (In the Appalachia and Northeast Recovery Units, 80-percent protection would translate to 100-percent protection because these units have two and three Priority 1 hibernacula, respectively.)

Greater than 80 percent of the Indiana bat population hibernates in the Priority 1 hibernacula. Thus, by achieving this criterion, a significant proportion (but not necessarily 80%) of the Indiana bat range-wide population will be protected from disturbance in its winter habitat and from anthropogenic changes to the thermal regime of the hibernacula. Protection of hibernacula includes conserving a buffer zone around each hibernaculum and restoration of hibernacula if necessary.

Protection of hibernacula was and remains a primary focus of the recovery plan for this species (U.S. Fish and Wildlife Service 1983). To be considered protected, the hibernacula can be publicly or privately owned, but there must be a long-term voluntary landowner agreement, such as a stewardship plan, conservation easement, habitat management plan, or memorandum of agreement that protects the hibernacula in perpetuity. Protection of hibernacula includes assuring minimal disturbance to the bats during the season of hibernation (e.g., only authorized surveys or other conservation-related activities). While it is advisable to avoid disturbance between mid-August and mid-May, entry to hibernacula should be prohibited between September 1 to April 30 in most of the species' range, and September 1 to May 31 in the northern portion of the range (Connecticut, Massachusetts, Michigan, New York, and Vermont).

The protection of hibernacula also involves conserving a buffer zone around each hibernaculum to prevent adverse impacts to the physical structure or microclimate. In general, conservation of buffer zones ensures the elimination of the negative effects of disturbances such as land clearing or development. Specific management plans for each P1 hibernaculum will be developed (see Recovery Action 1.1.1.2.2 and 1.1.1.2.3) that include recommendations on size and management actions for a buffer zone.

Status of Reclassification Criterion 1 (as of Aug. 2019)**: NOT ACHIEVED.**
Currently, none of the four Recovery Units has successfully achieved adequate protection of 80% or more of their respective Priority 1 hibernacula (see Table 1). This criterion directly addresses threats at the most important hibernacula and ensures that they be addressed throughout the range by the per Recovery Unit requirement (i.e., redundancy).

[Previous Status: In 2009, none of the four RUs had achieved this criterion.]

TABLE 1. Status of Priority 1 hibernacula in regards to Reclassification Criterion 1. Responses highlighted in bright green represent positive changes/increased protection since the last 5-year review in 2009.

Recovery Unit & Priority 1 Hibernacula Names	Priority 1 Subcategory	Ownership	Has Long-term/ Permanent Protection Been Secured?	Is Wintertime Human Disturbance Physically Controlled?	Is Human Disturbance of Hibernating Bats still a Threat in this Hibernaculum?	Are Surface Buffer Zones Being Conserved/ Protected?	Pass/Fail (80% of hibernacula must pass for an RU to "pass")
Ozark-Central (n= 9)							FAIL **(67% pass)**
Magazine Mine, IL	A	Private	Yes	Yes (gate)	No	Yes	Pass
Bat, MO	B	State	Yes	Yes (gate)	No	Yes	Pass
Brooks, MO	B	Federal	Yes	No	Yes	No	Fail
Copper Hollow Sink, MO	B	State	Yes	No	Yes	No	Fail
Great Scott, MO	B	State	Yes	Yes (gate)	No	Yes	Pass
Onyx, MO	B	State	Yes	Yes (gate)	No	Yes	Pass
Pilot Knob Mine, MO	B	Federal	Yes	No	Yes	Yes	Fail
Ryden, MO	B	State	Yes	Yes (gate)	No	Yes	Pass
Sodalis Nature Preserve, MO	A	City	Yes	Yes (gates)	No	Yes	Pass
Midwest (n=13)			\				FAIL **(69% pass)**
Batwing, IN	B	State	Yes	Yes (gate)	No	Yes	Pass
Coon, IN	A	Private	Yes	No	Yes	Yes	Fail
Grotto, IN	A	Private	Yes	Yes (fence)	No	Yes	Pass
Jug Hole, IN	A	Private	Yes	No	Yes	Yes	Fail
Ray's, IN	A	Private	No	No	Yes	No	Fail
Twin Domes, IN	A	State	Yes	Yes (fence)	No	Yes	Pass
Wyandotte, IN	A	State	Yes	Yes (new gate)	No	Yes	Pass
Bat, KY	A	State	Yes	No	Yes	Yes	Fail
Coach, KY	B	Private	Yes	Yes (gates)	No	Yes	Pass
Dixon, KY	B	Federal	Yes	Yes	No	Yes	Pass
Line Fork, KY	B	State	Yes	Yes	No	Yes	Pass
Long, KY	B	Federal	Yes	Yes (gate)	No	Yes	Pass
Saltpeter, KY	A	State	Yes	Yes (gates)	No	Yes	Pass
Appalachia (n=2)							FAIL **(50% pass)**
White Oak Blowhole, TN	A	Federal	Yes	Yes (gate)	No	Yes	Pass
Hellhole, WV	A	Private	No	Yes (fence)	Yes	No	Fail
Northeast (n=3)							FAIL **(67% pass)**
Barton Hill, NY (see sec. 2.3.2.1)	A	Private	Yes	Yes	Yes	Yes	Fail
Williams Hotel Mine, NY	B	Private	Yes	Yes	No	Yes	Pass
Walter Wms. Pres. Mine, NY	A	State	Yes	Yes	No	Yes	Pass

"Reclassification Criterion 2: A minimum overall population estimate equal to the 2005 population estimate of 457,000."

Because of lack of information on the species' demographic parameters, it is not possible to calculate a minimum viable population number for this species or to justify biologically an overall numerical population goal. Furthermore, a low population number was not one of the reasons that the bat was originally listed as endangered; the species was listed because of vulnerability to human and environmental disturbance and subsequent large-scale declines (Barbour and Davis 1969; Mohr 1972; Greenhall 1973; L. Pruitt, pers. comm., 2006). Species experts consider the 2005 population estimate of 457,000 to be an adequate number for recovery as long as the threats to the species have been alleviated (e.g., RC 1), the population growth rate has been positive (e.g., RC 3), and there is a range-wide distribution that incorporates the need for redundancy, resiliency, and representation (i.e., achieved via recovery unit-based criteria).

At the present time, hibernaculum counts comprise the only data that can be used as a basis for reclassification and delisting of the Indiana bat. Given the progress that has been made to date in securing hibernacula and in analyzing information needs for the species, and given the recent apparent upward trends in species numbers, reclassification on the basis of hibernaculum data represents an acknowledgement of progress made towards recovery.

NOTE: As mentioned above, at the time RC2 was written in 2007, the Service and species experts believed the 2005 population estimate of 457,000 to be an adequate number for recovery as long as the threats to the species have been alleviated (e.g., RC1), the population growth rate has been positive (e.g., RC3), and there is a range-wide distribution that incorporates the need for redundancy, resiliency, and representation (i.e., achieved via recovery unit-based criteria). Since then, we have had to recalculate our previous range-wide population estimates to account for additional bats discovered at previously unknown hibernacula (e.g., added 197,000 bats to previous survey periods following discovery of bats at Lime Kiln Mine/Sodalis Nature Preserve in MO) and to add/subtract bats at sites where more accurate estimates became available (e.g., Pilot Knob Mine in MO). At present, the overall population estimate for 2005 stands at approximately 623,000 bats (not 457,000) and the 2019 estimate is 537,000 bats. So, while the current population stands at approximately 80,000 bats above the previously set 457,000 benchmark, it also represents an 18% decline from where the population actually stood in 2005.

Status of Reclassification Criterion 2 (as of of Aug. 2019)**: ACHIEVED.**
In January and February 2019, significant new Indiana bat population data was obtained during biennial winter surveys of hibernacula across the species' range. The Service's Indiana Field Office coordinated with all bat surveyors, collated the new data, and calculated a 2019 population estimate (Tables 2 and 3; USFWS 2019b). The 2019 population estimate is approximately 537,000 Indiana bats. Because the 2019 estimate is > 457,000 bats, the numerical requirement of Reclassification Criterion 2 has been achieved.

RC2 sets a min. population estimate that must be met before we would consider the species eligible to reclassify to "threatened" status. The range-wide population estimate for the Indiana bat is generated every 2 years, and represents the Service's single most important and straightforward means of indirectly assessing how well all threats to the species are being reduced or mitigated on an overall basis.

[Previous Status: In 2009, the range-wide population was approx. 612,000 bats; the criterion was met.]

TABLE 2. 2019 range-wide population estimate for the Indiana bat by USFWS Region (USFWS 2019b).

USFWS Region	State	2011	2013	2015	2017	2019	% Change from 2017	% of 2019 Total
Region 2	**Oklahoma**	**13**	**5**	**5**	**8**	**8**	**0.0%**	**0.0%**
Region 3	Missouri	212,942	214,453	216,289	217,884	195,157	-10.4%	36.3%
	Indiana	225,477	226,572	185,720	180,611	184,848	2.3%	34.4%
	Illinois	57,212	66,817	69,924	81,143	78,403	-3.4%	14.6%
	Ohio	9,870	9,259	4,809	2,890	2,890	0.0%	0.5%
	Michigan	20	20	20	20	20	0.0%	0.0%
	Total	**505,521**	**517,121**	**476,762**	**482,548**	**461,318**	**-4.4%**	**85.9%**
Region 4	Kentucky	70,626	62,018	64,599	58,057	55,946	-3.6%	10.4%
	Tennessee	12,887	15,569	4,952	2,567	2,397	-6.6%	0.4%
	Arkansas	1,206	856	1,398	1,722	2,749	59.6%	0.5%
	Alabama	261	247	90	85	90	5.9%	0.0%
	North Carolina	1	1	0	0	0	0.0%	0.0%
	Georgia	0	0	0	1	0	-	-
	Total	**84,981**	**78,691**	**71,039**	**62,432**	**61,182**	**-2.0%**	**11.4%**
Region 5	New York	15,654	17,772	15,564	12,693	13,412	5.7%	2.5%
	West Virginia	20,296	3,845	2,373	1,076	620	-42.4%	0.1%
	Virginia	863	632	601	495	648	30.9%	0.1%
	New Jersey	409	448	193	118	79	-33.1%	0.0%
	Pennsylvania	516	120	24	23	11	-52.2%	0.0%
	Vermont	61	53	53	19	19	0.0%	0.0%
	Total	**37,799**	**22,870**	**18,808**	**14,424**	**14,789**	**2.5%**	**2.8%**
Range-wide Total:		**628,314**	**618,687**	**566,614**	**559,412**	**537,297**	**-4.0%**	**100.0%**
		2-yr. Net Change:	**-9,627**	**-52,073**	**-7,202**	**-22,115**		
		2-yr. % Change:	-1.5%	-8.4%	-1.3%	-4.0%		

TABLE 3. 2019 range-wide population estimate for the Indiana bat by Recovery Unit (USFWS 2019b).

IBat Recovery Unit	State	2011	2013	2015	2017	2019	% Change from 2017	% of 2019 Total
Ozark-Central	Missouri	212,942	214,453	216,289	217,884	195,157	-10.4%	36.3%
	Illinois	57,212	66,817	69,924	81,143	78,403	-3.4%	14.6%
	Arkansas	1,206	856	1,398	1,722	2,749	59.6%	0.5%
	Oklahoma	13	5	5	8	8	0.0%	0.0%
	Total	**271,373**	**282,131**	**287,616**	**300,757**	**276,317**	**-8.1%**	**51.4%**
Midwest	Indiana	225,477	226,572	185,720	180,611	184,848	2.3%	34.4%
	Kentucky	70,626	62,018	64,599	58,057	55,946	-3.6%	10.4%
	Ohio	9,870	9,259	4,809	2,890	2,890	0.0%	0.5%
	Tennessee	1,791	2,369	2,401	1,587	1,561	-1.6%	0.3%
	Alabama	261	247	90	85	90	5.9%	0.0%
	SW Virginia	307	214	137	70	119	70.0%	0.0%
	Michigan	20	20	20	20	20	0.0%	0.0%
	Georgia	0	0	0	1	0	-	-
	Total	**308,352**	**300,699**	**257,776**	**243,321**	**245,474**	**0.9%**	**45.7%**
Appalachia	West Virginia	20,296	3,845	2,373	1,076	620	-42.4%	0.1%
	E. Tennessee	11,096	13,200	2,551	980	836	-14.7%	0.2%
	Pennsylvania	516	120	24	23	11	-52.2%	0.0%
	Virginia	556	418	464	425	529	24.5%	0.1%
	North Carolina	1	1	0	0	0	-	-
	Total	**32,465**	**17,584**	**5,412**	**2,504**	**1,996**	**-20.3%**	**0.4%**
Northeast	New York	15,654	17,772	15,564	12,693	13,412	5.7%	2.5%
	New Jersey	409	448	193	118	79	-33.1%	0.0%
	Vermont	61	53	53	19	19	0.0%	0.0%
	Total	**16,124**	**18,273**	**15,810**	**12,830**	**13,510**	**5.3%**	**2.5%**
Range-wide Total:		**628,314**	**618,687**	**566,614**	**559,412**	**537,297**	**-4.0%**	**100.0%**
	2-yr. Net Change:		**-9,627**	**-52,073**	**-7,202**	**-22,115**		
	2-yr. % Change:		-1.5%	-8.4%	-1.3%	-4.0%		

"Reclassification Criterion 3: Documentation using statistically reliable information that indicates important hibernacula within each Recovery Unit, on average, have positive annual population growth rates and minimal risk of population declines over the next 10-year period. Using population estimates from the most recent 10 years (i.e., five sequential biennial surveys), linear regression lines will be calculated for each of the most populous hibernacula and/or hibernaculum complexes (P1s and largest P2s) that collectively account for 80% or more of their respective Recovery Units' estimated total number of bats. Each hibernaculum's regression line and 90% confidence interval will be projected through the most recent five data points and extended into the next 10-year period as a means of estimating future potential population levels. For reclassification, the slope of each hibernaculum's regression line must be positive or neutral and the lower bound of the 90% confidence interval must not fall below the minimum threshold set at 90% of the hibernaculum's 2005 population estimate by the end of the predicted 10-year period (see Figure 15)."

In other words, a 90% confidence interval for the regression extended forward 10 years will need to sit above 90% of a given hibernaculum's 2005 population estimate.

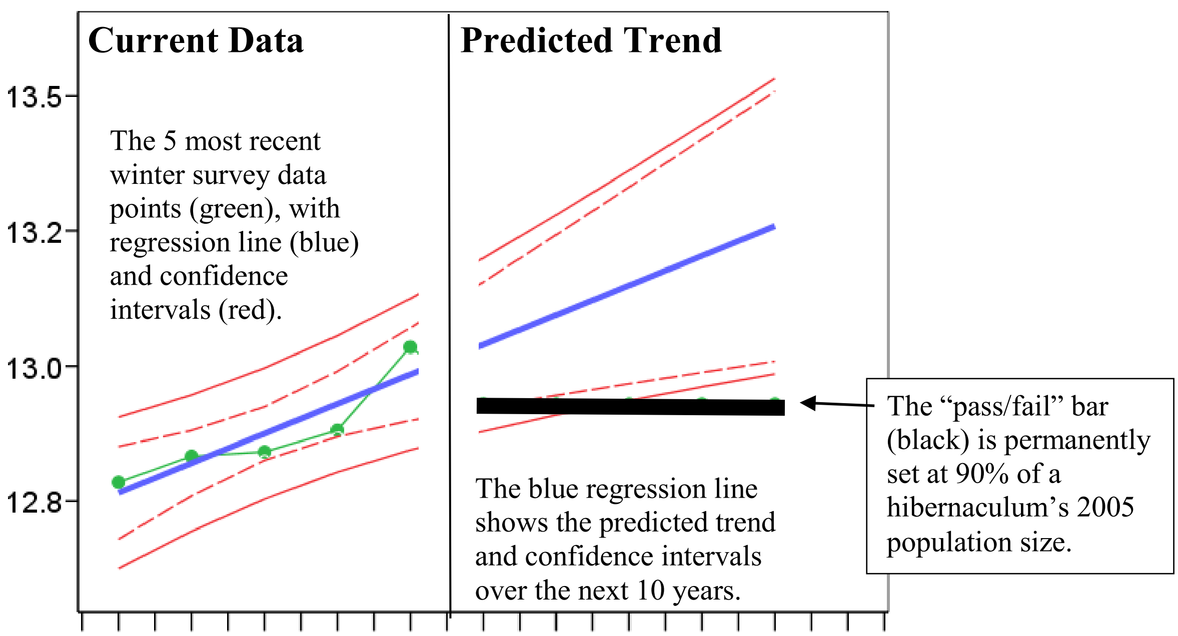


Figure 15. *Example regression (blue line) and confidence intervals (red; 90% - broken lines, 95% solid lines) using a 10-year data set that would "pass" Reclassification Criterion 3. Note: The Y axis is population size in natural logarithms so that constant growth becomes a straight line, instead of an exponential curve. The X axis is the year. The left side shows the 10-year data set that generates the regression line and confidence intervals. The right side is the continuation of the regression line and confidence intervals 10 years into the future, and compares the predicted trend (blue line) to the "pass/fail" bar, which is permanently set at 90% of a hibernaculum's 2005 population size.*

The data in Figure 15 would pass Reclassification Criterion 3 because the 90% confidence interval around the projected regression line rises above the bar by the end of the 10-year period. Therefore, we have a relatively high level of confidence that this example hibernaculum would continue to maintain a positive population growth rate and would not drop below the pass/fail bar over the next 10 years.

Meeting Reclassification Criterion 3 requires a positive population growth rate within each RU and allows only a small statistical possibility of a future population decline to a size that is at or below the 2005 population level. Criterion 3 complements Criterion 2, which requires the population to be larger (i.e., to be estimated to be larger) than the 2005 population estimate. Criterion 3 is a conservative extension of this requirement because it also requires that each hibernaculum's predicted estimate of population size 10 years after downlisting be so far above its 2005 population estimate that a 90% confidence limit on the predicted estimate must also be greater than 90% of each hibernaculum's 2005 population estimate.

The 80% requirement within Reclassification Criterion 3 allows some P1 hibernacula or hibernaculum complexes in the Midwest RU to have less strong trends. In the Northeast and Appalachian Mountain RUs, which have few P1 hibernacula, the 80% requirement will require that all of their Priority 1 hibernacula meet the trend requirement, because even one hibernaculum with a lower trend will drop the proportion in the region below the 80% mark. For the Ozark-Central RU to meet this criterion with a reasonable confidence level, the estimated number of bats hibernating in Pilot Knob Mine will need to be confirmed as previously discussed. Because Pilot Knob Mine is assumed to account for the majority of hibernating bats in the Ozark-Central RU, an inability to accurately estimate numbers there could be an obstacle to future downlisting. Again, we propose that Pilot Knob Mine's estimated population remain in future regional and range-wide population estimates and count towards meeting the recovery criteria unless improved survey techniques and/or field tests for improved accuracy indicate otherwise. [**UPDATE**: An internal survey for bats was conducted in Pilot Knob Mine in 2008 and population estimates where adjusted accordingly (downward)]

In 2005, approximately 80% of each RUs bats overwintered in a combined total of 12 hibernacula and hibernaculum complexes that would each need to pass Reclassification Criterion 3. The current list of hibernacula needing to pass this criterion includes:

- *Ozark-Central RU – Pilot Knob Mine (MO), Magazine Mine (IL), and Great Scott Cave (MO)*
- *Midwest – Wyandotte Complex (IN; includes Bat Wing, Jug Hole, Twin Domes, and Wyandotte caves), Ray's Cave (IN), Coon-Grotto Complex (IN) and Bat Cave (Carter Co., KY)*
- *Appalachian Mountain – Hellhole Cave (WV) and White Oak Blowhole Cave (TN)*
- *Northeast – Ulster County Complex (NY; includes Walter Williams Preserve Mine and Williams Hotel Mine), Barton Hill Mine (NY), and Jamesville Quarry Cave (NY).* [NOTE: this list of hibernacula will be updated in the final recovery plan].

Based on the five most recent winter survey data points (1997, 1999, 2001, 2003, and 2005), five out of these 12 hibernacula/complexes currently would pass this criterion and several others are likely to pass it over the next one or two survey periods, provided that their population numbers continue to increase.

As mentioned above, Reclassification Criterion 3 allows a small possibility of modest population decline over the predicted 10-year period. As Schwartz et al. (2006) point out in their discussion of grizzly bear recovery, once populations reach carrying capacity they are relatively stable (i.e., slope of regression lines ≈ 0), and out of necessity have confidence intervals about their trend lines that are fully 50% in negative numbers. The only way for a population to continue to fulfill Criterion 3 is either for it to continue to grow indefinitely, or for confidence intervals around its trend line to be quite small. It is possible or likely that neither of these requirements will be achievable continuously for all necessary hibernacula. Therefore, if range-wide recovery of the bat is prolonged and some hibernacula had fully met Criterion 3 at some point during their "recovery phase" and then subsequently stabilized near their 2005 population level, then the Service may still consider those populations as having passed this criterion.

Status of Reclassification Criterion 3 (as of Aug. 2019): **NOT ACHIEVED.**
In January and February 2019, new Indiana bat population data was obtained during the biennial winter surveys of hibernacula across the species' range. The Service's Indiana Field Office used this new population data to determine whether Reclassification Criterion 3 had been achieved. We statistically analyzed population data and trends from 2011-2019 (i.e., the 5 most recent population estimates) from the most populous hibernacula/hibernacula complexes within each of the four Recovery Units (USFWS 2019a: Table 4, Figs. 1-11). Based on the resulting linear regressions and 90% confidence intervals, one (Magazine Mine in S. Illinois) out of 11 (9%) "passed" Reclassification Criterion 3 while high variability and/or overall negative population trends (presumably due to WNS-associated mortality) at the ten other important hibernacula/complexes caused them to "fail" (Table 4, Figs. 1-11).

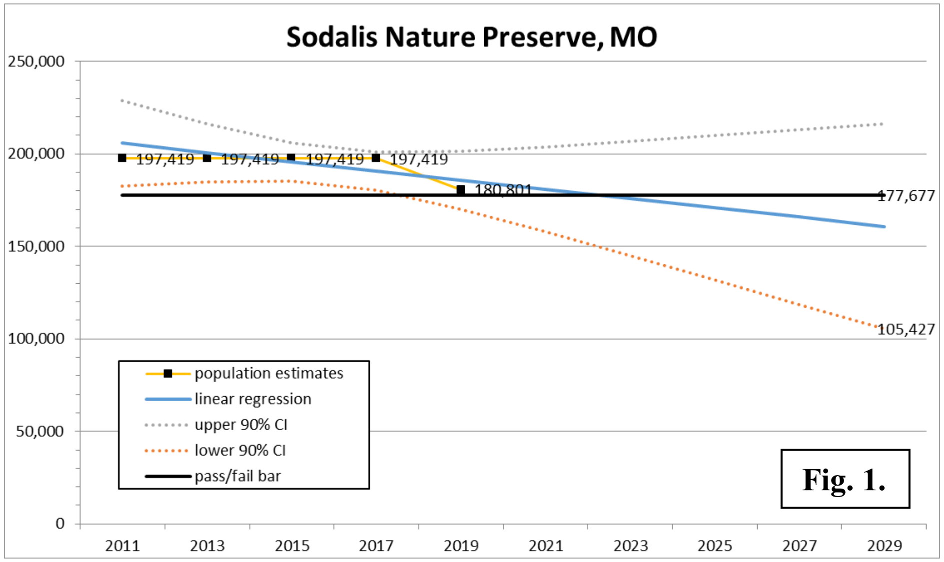
[Previous Status: In 2009, RC3 was not achieved as 71% or 10 out of 14 P1A hibernacula passed.]

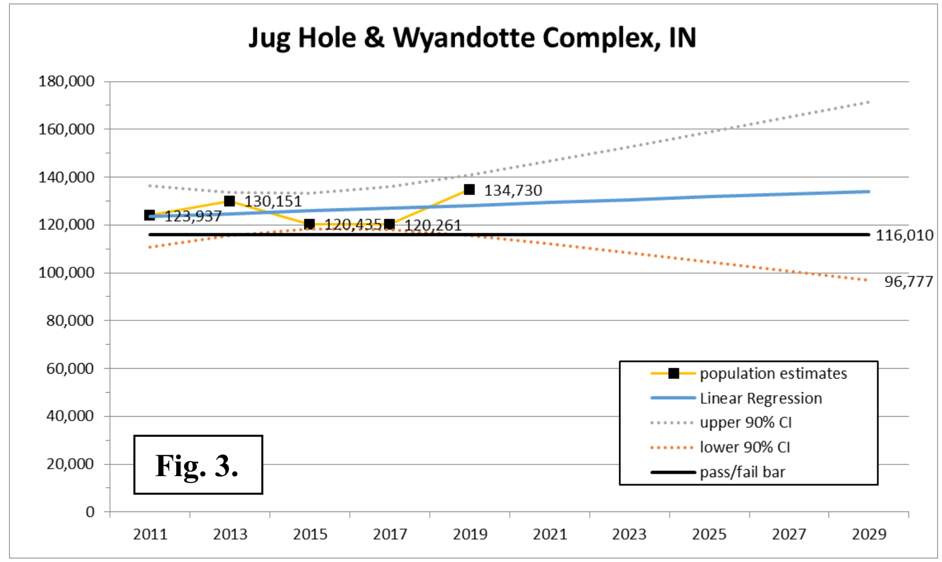
TABLE 4. The five most recent Indiana bat population estimates for the most populous hibernacula within each Recovery Unit that were used to assess whether Reclassification Criterion 3 had been met. To pass this criterion the projected Y-intercept of the lower bound of the 90% confidence interval surrounding the linear regression line must be greater than the "pass-fail" bar.

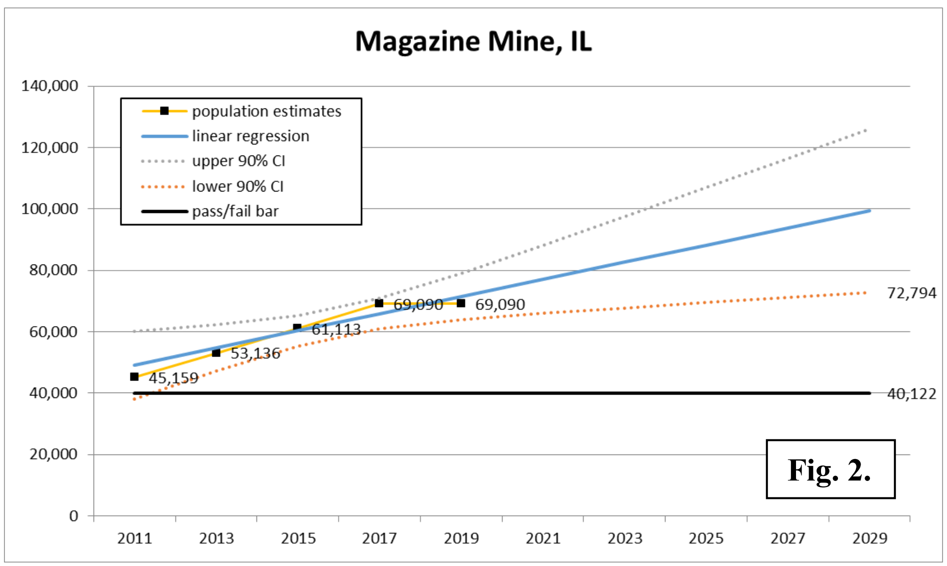
Recovery Unit*	State	Most Populous Hibernacula in Each RU in 2019	2011	2013	2015	2017	2019	2019 Total Pop. Est. for Each RU	% of the 2019 RU Total Pop. that the Most Populous Hib. Represent	The "Pass/ Fail Bar" (90% of 2005 pop. est.)	Projected Y-Intercept of Lower bound of 90% CI** (year 2029)	Pass or Fail?
1	MO	Sodalis Nature Preserve	197,419	197,419	197,419	197,419	180,801	276,317	90%	177,677	105,427	FAIL
	IL	Magazine Mine	45,159	53,136	61,113	69,090	69,090			40,122	72,794	PASS
2	IN	Jug Hole/Wyandotte Complex	123,937	130,151	120,435	120,261	134,730	245,474	81%	116,010	96,777	FAIL
	KY	Carter Caves Complex	45,849	36,528	41,446	40,191	38,043			32,029	18,505	FAIL
	IN	Ray's	48,403	49,617	30,518	31,503	25,693			48,893	-66,243	FAIL
3	TN	White Oak Blowhole Complex	11,063	13,042	2,551	975	835	1,996	81%	7,876	-34,646	FAIL
	WV	Hellhole	18,557	2,540	1,875	794	372			10,701	-5,175	FAIL
	VA	Rocky Hollow	266	192	240	205	327			140	85	FAIL
	VA	Arbogast/Cave Hollow	320	334	125	79	83			211	-665	FAIL
4	NY	Barton Hill Mine	7,398	13,553	14,023	11,083	12,570	13,510	97%	24,149	2757	FAIL
	NY	Ulster Co. Complex	6,511	3,374	1,109	1,240	579			6,136	-13,709	FAIL

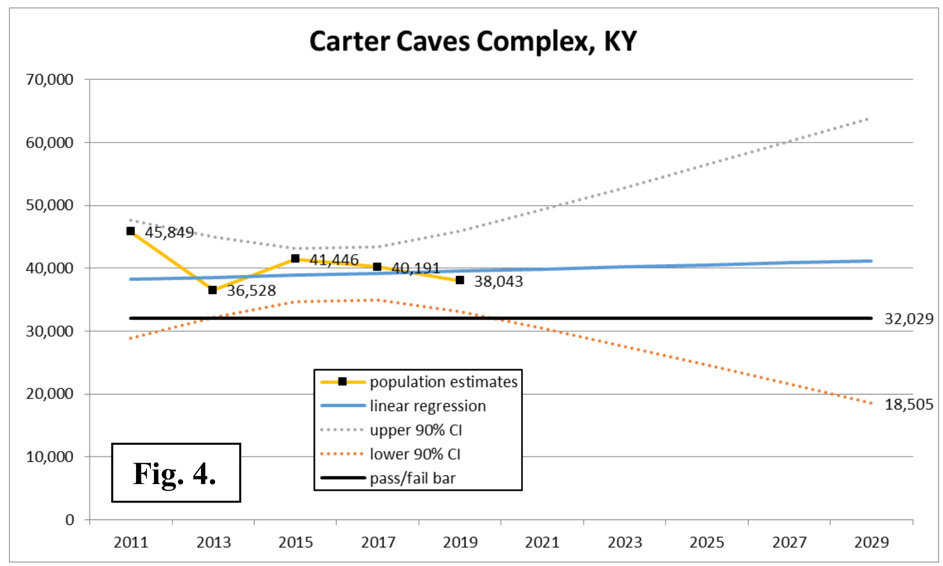
* Recovery Units: 1 = Ozark-Central, 2 = Midwest, 3 = Appalachia, and 4 = Northeast.
** linear regressions and confidence intervals were calculated using the Real Statistics add-in for Microsoft Excel (http://www.real-statistics.com).

FIGURES 1 – 11. Linear regressions used to assess pass/fail status for Reclassification Criterion 3.









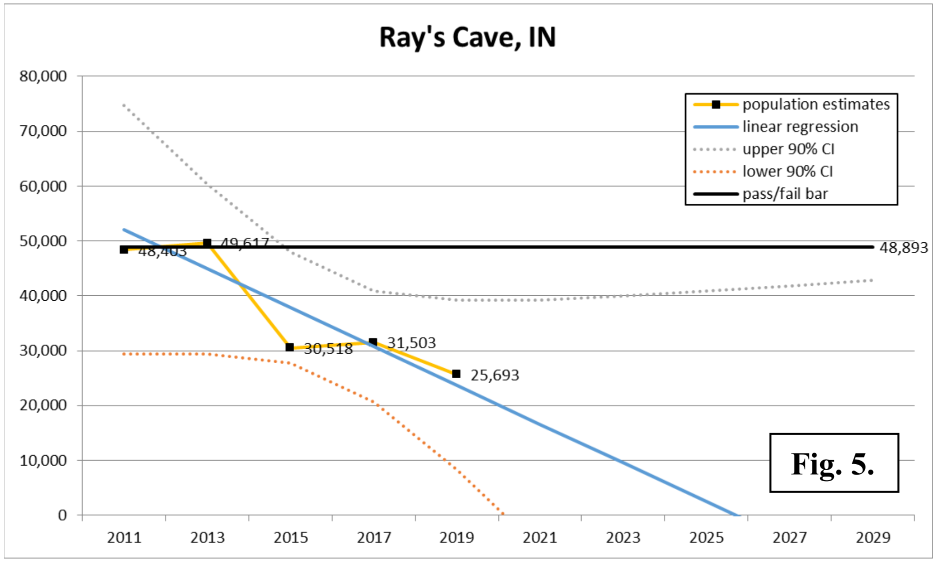


Fig. 5.

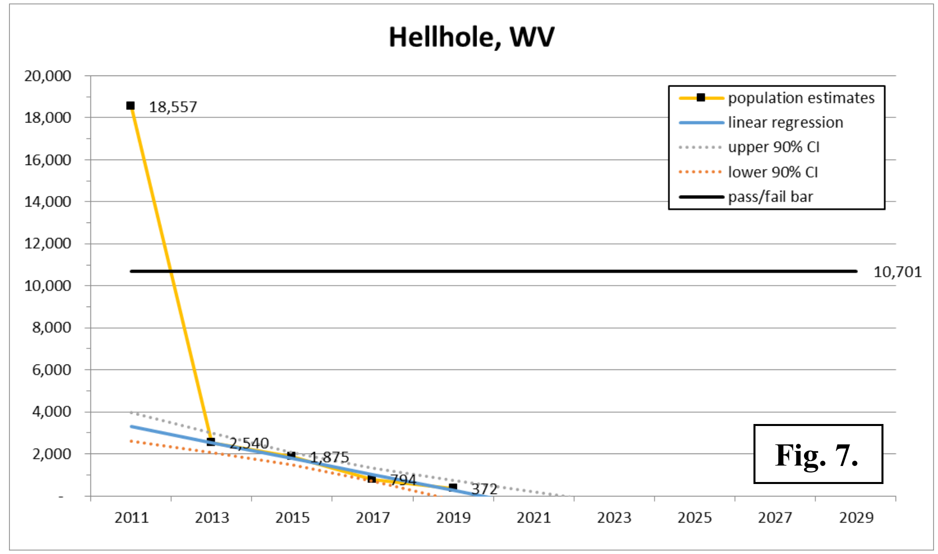


Fig. 7.

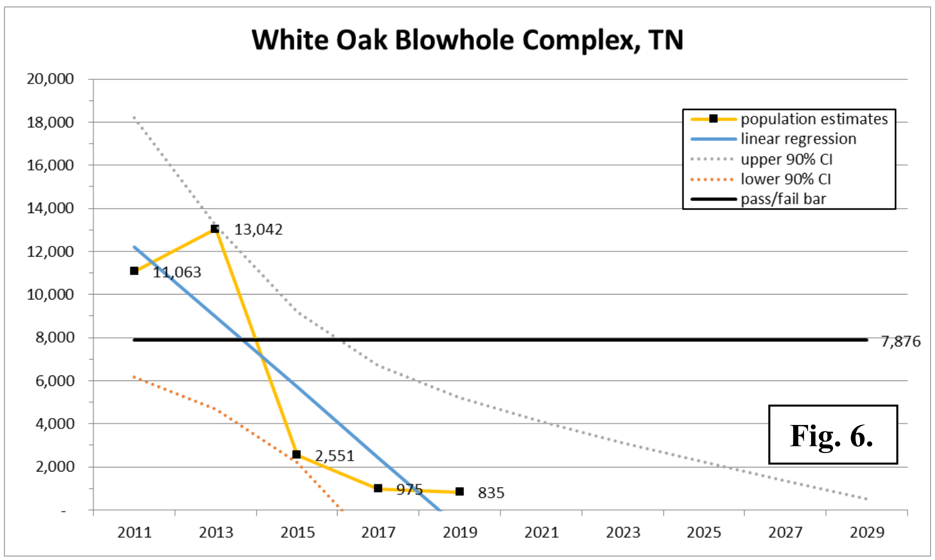


Fig. 6.

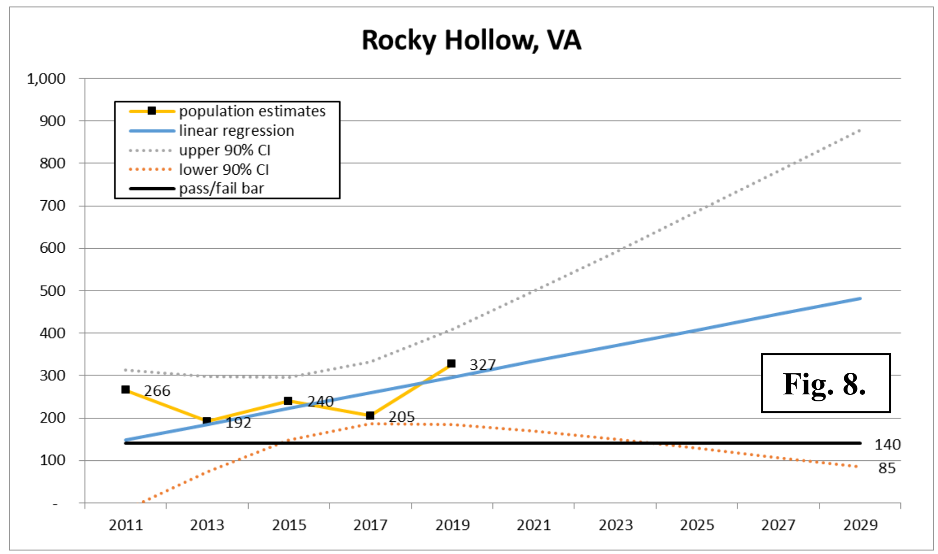


Fig. 8.

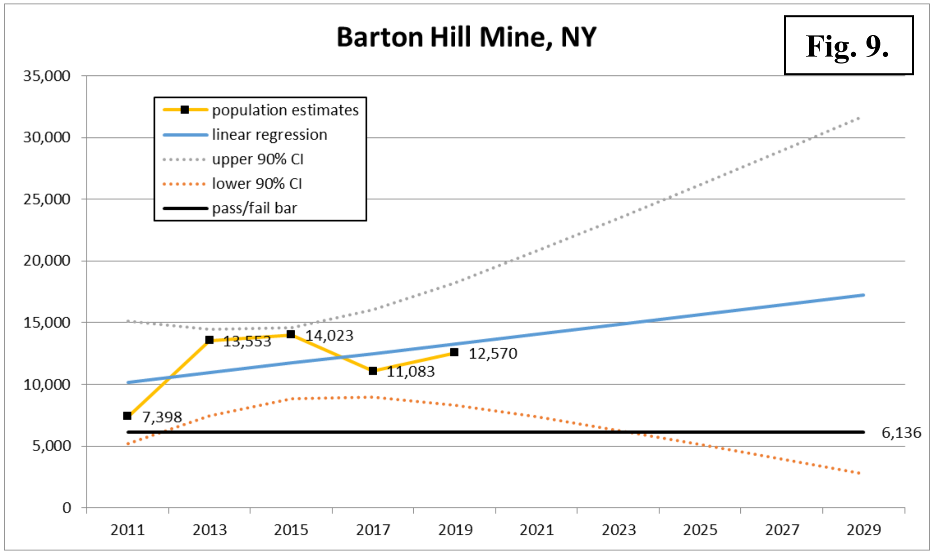


Fig. 9.

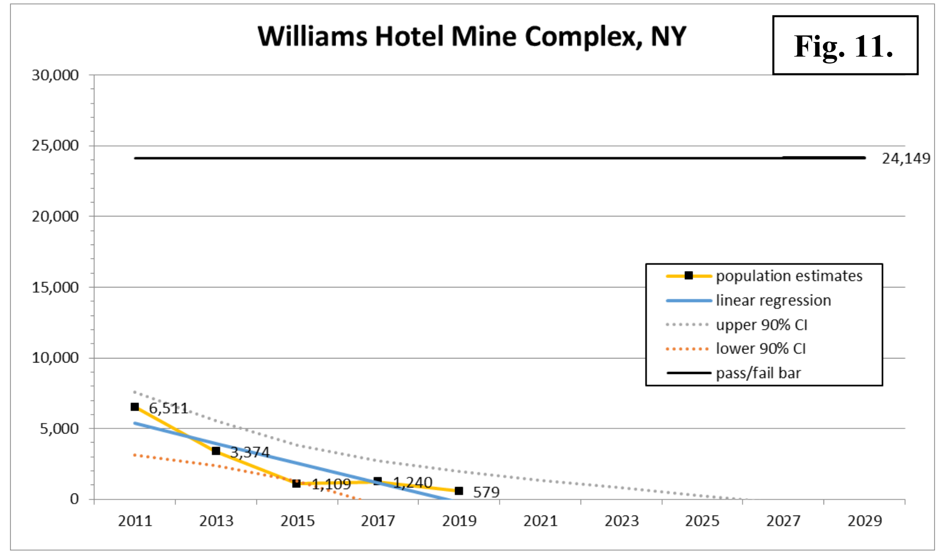


Fig. 11.

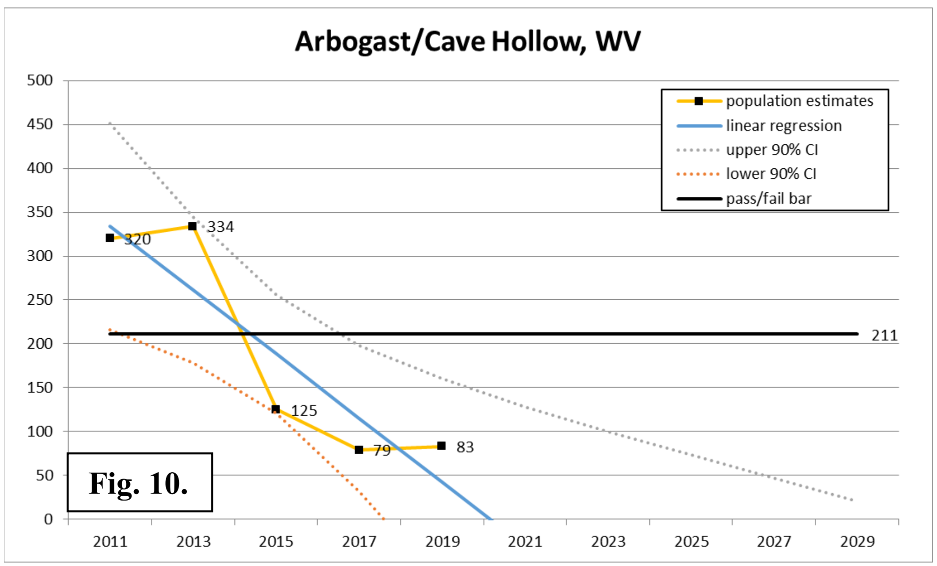


Fig. 10.

NOTE: The reclassification criteria (above) currently have not been met. Nonetheless, to see how much progress has been made to-date towards full recovery of the species, we also assessed the delisting criteria (below) using currently available data.

Delisting Criteria

We do not currently know what "normal" fluctuations in population size might be for the various RUs, and such fluctuations may well vary among RUs. Thus, writing strict requirements for delisting is inappropriate at this time. In addition, as discussed earlier, delisting requirements based exclusively on hibernaculum survey data are also inappropriate. Given that trend information, even high-quality trend information, becomes less, rather than more positive as a species reaches carrying capacity, multiple lines of evidence are the best insurance against overly optimistic delisting decisions. We provide here an initial delisting requirement, and add adaptive requirements for continuously improving the delisting requirement as data become available.

The Indiana bat will be considered for delisting when the Reclassification Criteria have been met, and the following additional criteria have been achieved.

"Delisting Criterion 1: Protection of a minimum of 50 percent of Priority 2 hibernacula in each Recovery Unit."

Greater than 14 percent of the Indiana bat population hibernates in the Priority 2 hibernacula. By achieving this criterion, a significant proportion (but not necessarily 14%) of Indiana bats range-wide will be protected from disturbance in winter habitat and from anthropogenic changes to the thermal regime of hibernacula. Protection of hibernacula includes conserving a buffer zone around each hibernacula and restoration of hibernacula if necessary.

See Reclassification Criterion 1 for further detail and justification.

Status of Delisting Criterion 1 (as of Aug. 2019): **NOT ACHIEVED.**
Currently, adequate protection of 50% or more of Priority 2 (P2) hibernacula in each of the four Recovery Units (RU) has not been achieved (see Table 5). Protection has been secured at 30% (7 of 23) of P2 hibernacula in the Ozark Central RU, 46% RU (12 of 26) in the Midwest, 33% (2 of 6) in the Appalachia RU, and 0% (0 of 3) in the Northeast RU.

[Previous Status: In 2009, DC1 was not met as protection was secured at 25% of P2 hibernacula in the Ozark Central, 42% in the Midwest, 25% in the Appalachia, and 0% in the Northeast RUs.]

TABLE 5. Current status of Priority 2 hibernacula regarding Delisting Criterion 1.

RU / State	County	Hibernaculum Name	P2 Subcategory	Current Ownership	Has Long-term /Permanent Protection Been Secured?	Is Wintertime Human Disturbance Physically Controlled?	Is Human Disturbance of Hibernating Bats still a Threat in this Hibernaculum?	Are Surface Buffer Zones Being Conserved/ Protected?	Pass/Fail
Ozark-Central (n=23): 35% currently "pass"									
AR	Madison	Horsethief	B	Private Individual(s)	Unknown	No	Yes	No	FAIL
AR	Newton	Cave Mountain	A	Federally owned	Yes	No	Yes	Unknown	FAIL
AR	Newton	Edgeman	A	Private Individual(s)	Yes	Yes (gate)	No	Yes	PASS
AR	Newton	Horseshoe	B	Federally owned	Yes	No	Yes	Unknown	FAIL
IL	Alexander	Mine 30	A	Private Organization	Yes	Yes (gate)	No	Yes	PASS
IL	Hardin	Griffith	A	Federally owned	Yes	Yes (gate)	No	Unknown	FAIL
IL	Hardin	Gutherie	B	Private Individual(s)	No	No	Yes	Unknown	FAIL
IL	Jackson	Toothless	B	State-owned	Yes	Yes (gate)	No	Yes	Uncertain
IL	Jersey	Brainerd	A	State-owned	Yes	Yes (gate)	No	Yes	PASS
IL	LaSalle	Blackball/Zimmerman Mine	A	State-owned	Yes	No	Yes	Unknown	FAIL
IL	Pope	Ellis	A	Federally owned	Yes	Yes	No	Yes	PASS
MO	Barry	Chimney Rock	B	Federally owned	Yes	No	Yes	No	FAIL
MO	Franklin	Bear	B	State-owned	Yes	Yes (gate)	No	No	FAIL
MO	Pulaski	Great Spirit	B	State-owned	Yes	Yes (gate)	No	Yes	PASS
MO	Pulaski	Tunnel	B	Private Individual(s)	Unknown	No	Yes	No	FAIL
MO	Shannon	Big Bear	A	Private Organization	Yes	Unknown	Unknown	Unknown	Uncertain
MO	Shannon	Cookstove	A	Private Organization	Yes	Yes (gate)	No	No	FAIL
MO	Shannon	Martin # 1	A	Private Individual(s)	Unknown	Yes (gate)	No	No	FAIL
MO	Shannon	Mose Prater	A	Federally owned	Yes	Yes (gate)	No	Yes	PASS
MO	Shannon	Powder Mill Creek	A	State-owned	Yes	Yes (gate)	No	Yes	PASS
MO	Ste. Genevieve	Coldwater Spring	A	Private Individual(s)	Unknown	Yes	Unknown	Unknown	Uncertain
MO	Washington	Hamilton	A	State-owned	Yes	Yes (gate)	No	No	FAIL
MO	Washington	Scotia Hollow	B	Private Organization	Unknown	Yes (gate)	No	Yes	PASS

TABLE 5. Continued.

RU / State	County	Hibernaculum Name	P2 Subcategory	Current Ownership	Has Long-term /Permanent Protection Been Secured?	Is Wintertime Human Disturbance Physically Controlled?	Is Human Disturbance of Hibernating Bats still a Threat in this Hibernaculum?	Are Surface Buffer Zones Being Conserved/ Protected?	Pass/Fail
Midwest (n=26): 46% currently "pass"									
IN	Greene	Clyfty	A	Private Individual(s)	Yes	No	Yes	Unknown	FAIL
IN	Harrison	Parker's Pit	A	Private Individual(s)	No	No	Yes	No	FAIL
IN	Harrison	Wallier	A	Private Organization	Yes	No	Yes	Yes	FAIL
IN	Washington	Endless	A	State-owned	Yes	Yes	No	Yes	PASS
KY	Breckinridge	B&O	A	Private Individual(s)	No	Yes	No	No	FAIL
KY	Breckinridge	Norton Valley	B	Private Individual(s)	No	No	No	No	FAIL
KY	Breckinridge	Thornhill	B	Private Individual(s)	No	Yes (gate)	No	No	FAIL
KY	Carter	Laurel	A	State-owned	Yes	No	Yes	Yes	FAIL
KY	Edmonson	Colossal	A	Federally owned	Yes	Yes (gate)	No	Yes	PASS
KY	Edmonson	Jesse James	B	Private Individual(s)	Yes	Yes (gates)	No	Yes	PASS
KY	Estill	Morton	A	Private Individual(s)	No	No	No	No	FAIL
KY	Jackson	Wind	A	Private Individual(s)	No	No	Yes	No	FAIL
KY	Lee	Cave Hollow	A	Federally owned	Yes	Yes (gate)	No	Yes	PASS
KY	Lee	Stillhouse	B	Federally owned	Yes	Yes (gate)	No	Yes	PASS
KY	Letcher	Green	A	Private Individual(s)	No	No	No	Yes	FAIL
KY	Menifee	Little Amos	B	Federally owned	Yes	Yes	No	Yes	PASS
KY	Rockcastle	Smokehole	A	Private Individual(s)	No	No	Yes	No	FAIL
KY	Rockcastle	Waterfall	A	Federally owned	Yes	Yes (gate)	No	Yes	PASS
KY	Wayne	Wind	A	Private Individual(s)	No	No	Yes	No	FAIL
OH	Preble	Lewisburg Limestone Mine	A	Private Individual(s)	No	Yes	Yes	No	FAIL

TABLE 5. Continued.

RU / State	County	Hibernaculum Name	P2 Subcategory	Current Ownership	Has Long-term /Permanent Protection Been Secured?	Is Wintertime Human Disturbance Physically Controlled?	Is Human Disturbance of Hibernating Bats still a Threat in this Hibernaculum?	Are Surface Buffer Zones Being Conserved/ Protected?	Pass/Fail
TN	Campbell	New Mammoth	B	Private Individual(s)	No	No	Yes	Yes	FAIL
TN	Fentress	Wolf River	A	Private Organization	Yes	Yes (gate)	No	Yes	PASS
TN	Marion	Nickajack	B	Federally owned	Yes	Yes (gate)	No	Yes	PASS
TN	Montgomery	Bellamy	B	State-owned	Yes	Yes	No	Yes	PASS
TN	Warren	Hubbards	B	Private Organization	Yes	Yes (gates)	No	Yes	PASS
VA	Lee	Cumberland Gap Saltpeter	B	Federally owned	Yes	Yes (gates)	No	Yes	PASS
Appalachia (n=6): 33% currently "pass"									
PA	Blair	Hartman Mine	B	State-owned	Yes	Yes (gates)	No	Yes	PASS
TN	Blount	Bull	A	Federally owned	Yes	Unknown	Unknown	Yes	Uncertain
TN	Blount	Kelley Ridge	A	Private Individual(s)	Unknown	Unknown	Unknown	Unknown	Uncertain
TN	Hawkins	Pearson	B	State-owned	Yes	Yes (gate)	No	Yes	PASS
VA	Wise	Rocky Hollow	B	Unknown	Unknown	Yes (gate)	No	Yes	Uncertain
WV	Pendleton	Trout	B	Private Organization	No	Yes	Yes	No	FAIL
Northeast (n=3): 0% currently "pass"									
NY	Jefferson	Glen Park	A	Private Organization	No	No	Yes	No	FAIL
NY	Onondaga	Jamesville Quarry Cave	B	Private Individual(s)	No	Yes	No	No	FAIL
NY	Ulster	Williams Lake Mine	B	Private Individual(s)	Yes	Yes	Yes	Yes	FAIL

"Delisting Criterion 2: A minimum overall population estimate equal to the 2005 population estimate of 457,000."

See Reclassification Criterion 2 for justification.

Status of Delisting Criterion 2 (as of Aug. 2019): **Provisionally ACHIEVED.**
In January and February 2019, new Indiana bat population data was obtained during biennial winter surveys of hibernacula across the species' range. The Service's Indiana Field Office used these data to calculate the 2019 overall population estimate (USFWS 2019b) (Tables 2 and 3). The current range-wide population estimate is approximately 537,000 Indiana bats, which is approximately 80,000 bats above the 457,000 benchmark and thus Delisting Criterion 2 is currently being met.

[Previous Status: In 2009, the range-wide pop. stood at approximately 612,000 bats and thus achieved this criterion.]

NOTE: For Reclassification Criterion 3 (RC3) and Delisting Criterion 3 (DC3) to be successfully met, the overall population minimum established in RC2 and DC2 will have to, by default, increase or stabilize well above 457,000 bats. In the future, the Service plans to modify this criterion to require that the overall population estimate must be equal to or greater than the population estimate at the time of reclassification, which will be by statistical necessity much greater than 457,000 bats.

"Delisting Criterion 3: Documentation using statistically reliable information that shows a positive population growth rate over an additional five sequential survey periods (i.e., 10 years). The protocol will attempt to include methods for estimating variances in counts, ideally allowing partitioning of variance into components based on population growth processes and on sampling variance. Each Priority 1A hibernaculum will be analyzed independently for trends in growth, with the exception of hibernacula that act as a composite unit (e.g., Wyandotte, Twin Domes, Batwing) or "complex", in which case all hibernacula within the composite unit will be analyzed collectively. Documented increases at 80% of P1A hibernacula are needed for reclassification. An increase will be measured using linear regression through the data points; a slope greater than 0 will be considered an increase.

If improvement in the precision of hibernacula sampling techniques falls short of that desired, we will attempt to determine the population growth rate based on concordance of estimates from two data sets developed independently. The second data set, proposed to be developed from implementation of the recovery actions related to population demographic research, will result in a demographically based life-history model for population growth rate. The model will be derived from reproduction data and survival rate estimates based on individual animal capture-recapture histories in the field."

See Reclassification Criterion 3 for further detail and justification.

Status of Delisting Criterion 3 (as of Aug. 2019): **NOT ACHIEVED.**
We analyzed population data from 2011-2019 (i.e., the 5 most recent population estimates) for each of the Priority 1A hibernacula and P1A hibernacula complexes (n=10) (USFWS 2019a) (Table 6). Based on the resulting linear regressions, four out of the ten hibernacula or 40% have positive slopes/pass this criterion. Therefore, the requirement for Delisting Criterion 3 has not been met.

[Previous Status: In 2009, 80% or 8 out of 10 P1A hibernacula had positive slopes to their regression lines and thus DC3 had been achieved.]

Winter bat populations within 60% of P1A hibernacula have suffered declines and currently have a negative trend/linear regression line over the past ten-year period. The declining P1A hibernacula include Sodalis Nature Preserve (Lime Kiln Mine), Ray's Cave, Coon & Grotto Complex, White Oak Blowhole Complex, Hellhole Complex, and the Williams Hotel Mine Complex. Furthermore, we have yet to consistently achieve the desired level of accuracy in our hibernacula sampling techniques that would allow us to reliably estimate confidence intervals around each of our population data points. Likewise, the Service has not yet developed a second, independent data set that could be used with a demographically based life-history model for population growth rate as stated in the original criterion. However, significant progress in developing a demographic model for the Indiana bat has been made (Thogmartin et al. 2013), which was identified as a recovery action within the recovery plan.

TABLE 6. Indiana bat population estimates for Priority 1A hibernacula/complexes (n=10) that were used to assess whether or not Delisting Criterion 3 had been met. For this criterion to be achieved, 80% of the linear regressions through each P1A hibernaculum's data must have a positive slope (i.e., slope > 0).

Recovery Unit*	State	County	Hibernaculum Name	2011	2013	2015	2017	2019	Is Slope >0?	Pass or Fail?
1	IL	Alexander	Magazine Mine	45,159	53,136	61,113	69,090	69,090	YES	PASS
	MO	Marion	Sodalis Nature Preserve	197,419	197,419	197,419	197,419	180,801	NO	FAIL
2	IN	Harrison	Wyandotte/Jughole Complex	123,937	130,151	120,435	120,261	134,730	YES	PASS
	IN	Greene	Ray's	48,403	49,617	30,518	31,503	25,693	NO	FAIL
	KY	Carter	Carter Caves Complex	45,849	36,528	41,446	40,191	38,043	YES	PASS
	IN	Monroe	Coon and Grotto Complex	47,185	38,345	24,381	19,124	14,757	NO	FAIL
3	TN	Blount	White Oak Blowhole Complex	11,063	13,042	2,551	975	835	NO	FAIL
	WV	Pendleton	Hellhole	18,557	2,540	1,875	794	372	NO	FAIL
4	NY	Essex	Barton Hill Mine	7,398	13,553	14,023	11,083	12,570	YES	PASS
	NY	Ulster	Williams Hotel Mine Complex	6511	3374	1109	1240	579	NO	FAIL

* Recovery Units: 1 = Ozark-Central, 2 = Midwest, 3 = Appalachia, and 4 = Northeast.