ARTICLES

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The Louisiana Pinesnake (*Pituophis ruthveni*): At Risk of Extinction?

Pituophis ruthveni (Louisiana Pinesnake) is one of the rarest snakes in the United States (Conant 1956; Young and Vandeventer 1988; Rudolph et al. 2006). The historical range included portions of eastern Texas and western Louisiana (Sweet and Parker 1990; Reichling 1995). This species is generally associated with sandy, well-drained soils; open pine forests, especially longleaf pine (*Pinus palustris*) savannahs; moderate to sparse midstory; and a well-developed herbaceous understory dominated by grasses. Baird's Pocket Gophers (*Geomys breviceps*) are also associated with loose, sandy soils, a low density of trees, open canopy, and an herbaceous understory (Himes et al. 2006; Wagner et al. 2017) and are the primary prey of *P. ruthveni* (Rudolph et al. 2002, 2006, 2012). *Pituophis ruthveni* also use gopher burrow systems for shelter, thermoregulation (Ealy et al. 2004), hibernation (Rudolph et al. 2007), and escape from fire (Rudolph et al. 1998a).

Land use changes have reduced the extent of large contiguous blocks of open pine forests within the historical range of *P. ruthveni* (Bridges and Orzell 1989). In most of the remaining forested habitat, intensive short-rotation pine (*Pinus* spp.) silviculture and widespread fire suppression have reduced the diverse herbaceous vegetation that characterized the original pine forests of Louisiana and eastern Texas by increasing shade (especially early in the rotation), the use of herbicides, and litter buildup in the absence of fire (Frost 1993). Reduction of the herbaceous vegetation may lead to declines of *Geomys breviceps* populations, which in turn, may lead to declines of *P. ruthveni* populations (Rudolph and Burgdorf 1997).

The conservation status of *P. ruthveni* is in question; the International Union for Conservation of Nature (IUCN) Red List of Threatened Species assessed *P. ruthveni* as endangered at the global level, based on a limited area of occupancy, severely fragmented habitat, and declining area, extent, and quality of habitat (criteria B1ab(iii); Hammerson 2007). *Pituophis ruthveni* was designated a Candidate Species under the U.S. Endangered Species Act in 1999 (USFWS 2013), and ultimately listed as a Threatened Species in 2018 (USFWS 2018).

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Trapping efforts to survey *P. ruthveni* within its historical range in eastern Texas and western Louisiana began in 1992 and have continued to the present. Despite increasing trapping effort over time, capture rates in recent years have been low. Additionally, incidental records, including road-kills and hand captures as well as those obtained from published literature, museum specimens, and current research activities by collaborators have declined. From 1992 to present, an increasingly large group of formal and informal cooperators has been active in the field and alert to the importance of reporting incidental (non-trap) *P. ruthveni* observations. Since 1992, a total of 49 unique incidental records of *P. ruthveni* have been recorded. During the first 12 years (1992–2003), 35 incidental records were obtained. During the second 12 years (2004–2015), 14 incidental records were obtained, a decline of 60% compared to the first 12 years. Although effort expended in locating snakes is unknown, we believe the amount of effort increased substantially in the last half of this period due to many more observers involved in conservation activities with *P. ruthveni*.

The effects of declining habitat quality and fragmentation are amplified for rare species, especially those with small ranges (Sodhi et al. 2009). The paucity of new captures under increasing trapping effort and the increasing scarcity of incidental records, in conjunction with the previously acknowledged (Hammerson 2007) warning signs, raised questions about the current status of *P. ruthveni*. Are the snakes simply difficult to detect and exist in small, stable populations or are they on the brink of extinction?

The data available when population levels are low is generally inappropriate to estimate population size. Frequently, only presence/absence, sightings, or capture data (with few to no recaptures) are available and include many zeros and/or gaps in data collection. Geographic range can be determined by plotting all presence records and determining occupied habitat minimum convex polygons. Extinction risk can be estimated with quantitative analyses, including population viability analyses (PVA). These methods range from a simple time series approach to complex demographic models; the choice of which to use depends on the available data (Gerber and González-Suárez 2010).

For trapping data containing many periods with zero captures, regression models of index of abundance (capture rate) over time, using zero-inflated distribution models (Welsh et al. 1996) can be used, but these methods do not take into account detectability. By their nature, it is hard to determine the abundance of snakes; ignoring detection probability may lead to incorrect conclusions (Kéry 2002; Steen 2010). Separating variation in year-to-year population density (trend) from sources of variation due to observation (detectability, trap design, placement, etc.) may strengthen a simple PVA (Holmes 2001, Staples et al. 2004).

Recently, state-space models have been used to estimate separately the contributions to variability from population fluctuations and from observation error in a time series of abundances (Dennis et al. 2006). Early models using maximum likelihood methods required no zeros in data and no gaps in time (Dennis et al. 2006). More recently developed state-space models (Humbert et al. 2009; Dennis and Ponciano 2014) accommodate gaps in time, but not zero abundances. Autoregressive state-space models are simple time series models that allow zero abundances and gaps in time. These are 2-part models that separately estimate variation due to annual population changes (process error) and fluctuations in counts due to measurement, or observation error (de Valpine and Hastings 2002).

Because the detailed life history information required for most PVA models frequently is not available for populations at the brink of extinction, Holmes et al. (2007) developed a corrupted stochastic exponential with Gaussian errors (CSEG) model. The model uses a time series of population counts to estimate mean annual growth rate and the variation due to error. Although the model accommodates time periods with no data, zero abundances are not allowed. Considering the zero abundances as missing values will bias the predicted population size in those years, but will still provide acceptable estimates of population trend and process variance. These values can be used to forecast risk of quasi-extinction over a range of time. Quasi-extinction risk is the probability that a population will experience a decline past a pre-defined threshold. Thresholds can be chosen to reflect critical population sizes below which persistence is questionable. Ellner and Holmes (2008) developed robust theoretical minimum uncertainty confidence intervals for quasi-extinction risks calculated from the CSEG model. When graphed, these confidence intervals can be used to visually display the probability of quasi-extinction across a range of thresholds and projection times. This allows managers to see the relationship between time and extinction risk and determine the immediacy of actions required to avert extinction.

We first used known records to identify occupied habitat for *P. ruthveni* during four time periods (1992–1997, 1998–2003, 2004–2009, 2010–2015) to evaluate the temporal changes in occupied habitat and to delineate current isolated blocks of occupied habitat in Louisiana and eastern Texas. We used Bayesian autoregressive state-space models to model trends in capture rate, as a surrogate for population trends, and to estimate the contribution to annual variability from process and observation errors in each modeled population. We used CSEG models to estimate extinction risk over a range of thresholds (quasi-extinction) for each modeled population and determined conservation status for modeled populations using IUCN Red List criteria.

Materials and Methods

Trapping protocol.—Between 1992 and 2015, traps were placed at researcher-selected sites within accessible properties, dispersed as widely as possible throughout the historical range of *P. ruthveni* (Rudolph et al. 2006). Funding issues resulted in gaps of 1–9 years (depending on location) when no trapping occurred. Numerous cooperators have been involved in the trapping efforts (see Acknowledgements). The purposes of these trapping efforts have varied over the years to include capture of animals for radio-telemetry studies (Rudolph and Burgdorf 1997; Rudolph et al. 1998b; Ealy et al. 2004; Himes et al. 2006), examination of the effects of road mortality on snake populations (Rudolph et al. 1999), and presence/absence surveys (Rudolph et al. 2006).

Traps were operated for variable numbers of years (Table 1) in 10 counties in Texas and 7 parishes in Louisiana (Appendix 1). Traps consisted of 1.2 × 1.2-m plywood and hardware cloth boxes with a funnel entrance on each side and 15.2-m drift fences extending from each entrance (Burgdorf et al. 2005). All traps contained a water source and most traps contained hide boxes for additional cover. The basic trap design underwent minor modification by the various individuals involved in the trapping program, and occasionally major modifications. Minor modifications consisted of changes in mesh size, alteration of funnel entrance diameter to reduce by-catch, and minor structural modifications of the traps themselves. These modifications are unlikely to have had a major impact on trap success. Cooperators made major modifications to trap design in a few instances. One modification consisted of a straight line arrangement instead of one drift fence radiating from each of the four sides of the box trap. Two different configurations were involved with this major modification. One configuration (N = 4) consisted of two box traps connected to each other by 30.5 m of drift fence with one 15.2-m drift fence continuing from each trap. Only those funnel entrances associated with a drift fence were open. These arrays consisted of the same amount of total drift fence (70 m), and the same number of funnel openings (4) as the single trap configuration. A second configuration (N = 2) consisted of three box traps with 53.3 m of drift fence between trap 1 and 2, and 53.3 m of fencing between trap 2 and 3. These arrays consisted of 106.7 m of total drift fence, but used the same number of funnel openings (4) as the single trap configuration. A second major modification consisted of smaller (1.2 × 0.6 m) traps (N = 3) that were partially buried. These traps used funnels that were slightly tilted downward to potentially facilitate snake movement into the box. These major modifications had an unknown effect on trap success and defining a "trap" was not always straightforward. For purposes of this report, we considered all boxes connected by drift fences to be a single trap.

Traps were checked 1–2 times per week and all snake captures were recorded. Species other than *P. ruthveni* were generally released near the point of capture; however, occasionally snakes were taken to a lab as required for other purposes. All *P. ruthveni* were returned to the labs for measuring, sex determination, and collection of DNA and fecal samples. After processing in the labs, *P. ruthveni* were released at their capture site, with the exception of a limited number of animals that were used for radio-telemetry studies or retained for captive breeding. The animals used in radio-telemetry studies were released and subject to recapture, animals removed for captive breeding were no longer in the population and were identical to mortalities. Since 1996, all released *P. ruthveni*, with the exception of six animals (5 in Louisiana and 1 in Texas), were implanted with radio-transmitters and/or passive integrated transponder (PIT) tags.

Occupied habitat.—A database has been maintained since 1992 containing all known records of *P. ruthveni* obtained from the published literature, museum specimens, and current

Table 1. Number of trap days, number of unique captures, size of minimum convex polygons (MCP) for the trapping effort, and size of occupied habitat minimum convex polygons (OHMCP) for five populations of *Pituophis ruthveni* from 1992 through 2015 during four sequential time periods. The minimum OHMCP that results from a 1-km buffer around an occurrence point is 314 ha. ANF = Angelina National Forest; BP = Bienville Parish; FP = Fort Polk; PR = Peason Ridge; N/S = Newton/Sabine counties.

Population	Time period	Trap days	Unique captures	Trapping MCP (ha)	OHMCP (ha)
ANF	1992–1997	7,588	2	5,489	6,556
	1998–2003	23,320	2	6,253	1,192
	2004–2009	10,847	3	1,607	2,259
	2010–2015	23,291	1	1,614	314
BP	1992–1997	3,112	11	592	13,303
	1998–2003[1]	0			7,421
	2004–2009	21,802	25	5,806	17,533
	2010–2015	15,698	19	4,800	7,444
FP	1992–1997[2]	226	0		3,006
	1998–2003	34,309	11	27,685	10,465
	2004–2009	59,996	8	28,647	6,404
	2010–2015	25,720	7	24,871	6,021
N/S	1992–1997	7,192	9	444	2,803
	1998–2003	8,985	0	1,338	314
	2004–2009	20,115	2	10,736	577
	2010–2015[3]	20,336	0	2,666	0
PR	1992–1997[2]	444	0		314
	1998–2003[2]	2,748	0		314
	2004–2009	11,863	1	6,364	421
	2010–2015	10,998	4	610	910

[1]No trapping at BP in this time period. OHMCP is based on incidental records only.
[2]Too few traps to calculate MCP.
[3]No trap or incidental records from N/S in 2010–2015.

research activities by the authors and collaborators. This database currently (through 2015) contains 240 unique (not including recaptures) records and 32 recaptures. We plotted all database records obtained from 1992 to 2015, including recaptures and incidental records, to update the delineation of occupied habitat and determine temporal trends in known geographic range. We grouped records into clusters (hereafter populations), defined as a group of ≥ 3 records obtained from 1992 to 2015 within 10 km of another record. In order to have sufficient data for analysis, we discounted all records that did not include location information (N = 3), single records (N = 3), and groups of two records (N = 2) separated from the nearest adjacent records by >10 km. We constructed minimum convex polygons around these points, including a 1-km buffer, the approximate diameter of a home range (Rudolph, unpublished data) to estimate occupied habitat. To estimate temporal change in occupied habitat for each population, occupied habitat minimum convex polygons (OHMCPs) were then constructed and plotted for the following time intervals: 1992–1997, 1998–2003, 2004–2009, and 2010–2015. To estimate areal coverage of trapping efforts, we constructed minimum convex polygons around traps for the same time intervals as above. Only traps that were within 10 km of the 1992–2015 OHMCP for each population were included.

Trapping trend and quasi-extinction risk.—We used a first-order autoregressive (AR(1)) state-space model to describe the time series of snake capture rates (unique captures per 1,000 trap days per year) for each population. An AR(1) model is a simple regression model in which the independent variable is capture rate lagged by one time period (year). The state-space model allows the estimation of variation due to process (environmental and demographic stochasticity) separately from variation due to observation, or measurement error (Kéry and Schaub 2012). The model was analyzed using the Monte Carlo Markov Chain algorithm in JAGS 3.4.0 using the r2jags package of the R computing environment (R Core Team 2015; Su and Yajima 2015). We ran the model for each of the populations defined in this study.

Bayesian analyses require providing the model with prior probabilities of the parameters: Uniform distributions were used for standard deviations of process and observation error (Kéry and Schaub 2012). Each model was fitted with two chains, each having 25,000 Markov chain Monte Carlo (MCMC) iterations, no thinning, and the first 1,000 iterations discarded. Model convergence was assumed when the R-hat statistic was <1.1 for all parameters (Brooks and Gelman 1998).

We used a CSEG model (Ellner and Holmes 2008) to determine the probability of each population crossing a range of quasi-extinction thresholds (0-99% decline). We used the MARSS package for R (Holmes et al. 2015) to determine μ (estimated population growth rate), the probability of quasi-extinction, and process variance from the time series of trap capture rates for each population. Years with zero capture rates were replaced with missing values. TMU (Theoretical Minimum Uncertainty) confidence intervals associated with the predicted relationship between time and risk of quasi-extinction at a range of thresholds were determined for a 100-year forecast. Actual extinction (100% decline) cannot be estimated mathematically (log of 0 is undefined). Therefore, our thresholds ranged from 0 to 99% decline in trapping rate as a surrogate for population size.

Conservation status.—The IUCN criteria for endangered or critically endangered status can be based on population size, geographic range, or quantitative analyses to indicate the probability of extinction (IUCN 2016). Although the IUCN Red List criteria are intended for global assessments, criteria can be applied to regional assessments for isolated populations (Gärdenfors et al. 2001). The Red List classifies extinction risk, which in combination with other factors such as costs and probability of positive outcomes, may help guide management (Collen et al. 2016).

The Red List criteria based on geographic range in the form of extent of occurrence is < 500,000 ha for endangered status and < 10,000 ha for critically endangered (Criterion B1, IUCN 2012). Two of three possible additional conditions are required for inclusion in a threatened category: severely fragmented habitat (Criterion A) and continuing decline (Criterion B) or extreme fluctuations (Criterion C) in distribution, habitat, subpopulations, or numbers. We considered our calculated OHMCPs in four time periods to reflect extent of occurrence (Akçakaya et al. 2006) and changes in distribution.

The Red List criteria for quantitative analysis (Criterion E) considers a population to be endangered if the probability of extinction is ≥ 20% in the longer of 20 years or 5 generations and critically endangered if the probability of extinction is ≥ 50% in the longer of 10 years or 3 generations (IUCN 2016). If we consider a generation to be 11 years for *P. ruthveni* (USFWS 2014), the criteria become ≥ 20% probability of extinction in 55 years for endangered status and ≥ 50% probability of extinction in 33 years for critically endangered status.

Results

Since its description in 1929 (Stull 1929) through 1991, prior to the initiation of our studies, *P. ruthveni* was recorded in 11 counties in Texas and seven parishes in Louisiana (N = 84, Fig. 1A). From 1992 through 2015, records exist from only six counties in Texas and five parishes in Louisiana (N = 151, Fig. 1B). The absence of post-1991 records from five counties in Texas and two parishes in Louisiana, which had produced historical records, occurred despite increased field work and extensive trapping effort throughout the 1992–2015 time period.

Trapping results.—Traps (N = 543) were placed at sites throughout much of the historical range of *P. ruthveni*. A total of 440,002 trap days were logged between 1992 and 2015. Most traps were in areas that did not produce captures. In retrospect, this was due to inappropriate habitat, local extirpation, or perhaps were not within historically occupied areas. The trapping effort produced 105 unique *P. ruthveni* captures in 308,590 trap days from five populations of variable size (1,997–27,704 ha; Table 1). Dividing the trapping effort, within the defined populations, into four sequential time periods of six years provided quantification of the trapping effort across the 24-year period.

Occupied habitat.—We delineated five populations based on spatial proximity and a minimum of three records (Fig. 2). Maps for each population included four generally overlapping polygons representing occupied habitat during each of the successive 6-year intervals (Fig. 3). Polygons tended to decrease in size in the more recent time intervals, sometimes dramatically, yet the area trapped tended to increase in size over time (Table 1). For most populations, there has been considerable effort to trap beyond the OHMCPs in an attempt to locate additional occupied habitat.

Trapping trend and quasi-extinction risk.—The FP population was trapped from 2000 to 2015; however, previously untrapped occupied habitat was discovered in 2009. When this approximately 25-ha area in Compartment 34 was included, the actual capture rate was dramatically higher in subsequent years (Fig. 4). Therefore, we modeled FP data with and without (FP34) this recently identified occupied habitat.

Year-to-year trap success was extremely variable for most populations (Fig. 4), resulting in wide 95% credible intervals (95% probability that the true mean is within this interval) associated with estimates of long-term average trapping rates (Table 2). Process error was less than observation error for all populations except N/S. BP capture rates were most variable (SD = 1.5) and observation error was 14 times greater than process error. Although trapping methodology was similar among populations, only BP had more than one gap with years of no trapping (ANF and N/S, 1 gap; BP, 3 gaps). Credible intervals for long-term average trapping rates for the ANF population included zero, indicating possible extirpation of this population.

The capture rate estimated from the CSEG model for FP as a whole had an estimated average decline of about 3% per year; removing Compartment 34 resulted in a somewhat steeper decline of about 4% per year, although the variability in trend for this population both with (SD = 0.23) and without Compartment 34 (SD = 0.25) was great enough that 95% confidence intervals included zero. Theoretical minimum uncertainty confidence intervals (TMU CI) associated with risk of quasi-extinction plotted against time (TMU plot) indicated that although some decline should be expected every year, it is uncertain (TMU CI = 0.0315–1.000) that the decline for FP will be as much as 90% within the next 100 years (Fig. 5, Appendix 2).

In contrast, the estimated average decline in trapping rate for the ANF population was 17% per year with very low variability (SD < 0.001). The TMU CIs indicated a high degree of certainty for a 90% decline beginning in 15 years and a near certainty of extinction (99% decline) by 30 years (Fig. 5, Appendices 2 and 3). The N/S population also had an estimated average decline in trapping rate of about 9% per year with very small variability (SD < 0.001) and the TMU CIs similarly indicated a high degree of certainty for a > 90% decline within 30 years and a 99% decline within 58 years. The BP trapping rate was predicted to decline less steeply (4% per year) with a high degree of certainty for a 90% decline in 74 years (Fig. 5); a 99% decline is uncertain throughout the forecast period (100 years) (Appendices 2 and 3). The PR population had a short trapping history (10 years) and too few non-zero capture rates to estimate quasi-extinction risk.

Conservation status.—None of the five *P. ruthveni* populations had an OHMCP > 18,000 ha in any time period (Table 1). In the most recent time period (2010–2015), all populations had an OHMCP < 10,000 ha and each potentially could be considered critically endangered according to Red List Criterion B (IUCN 2012). The extent of occurrence for all populations combined was < 15,000 ha in 2010–2015. The degree of habitat fragmentation

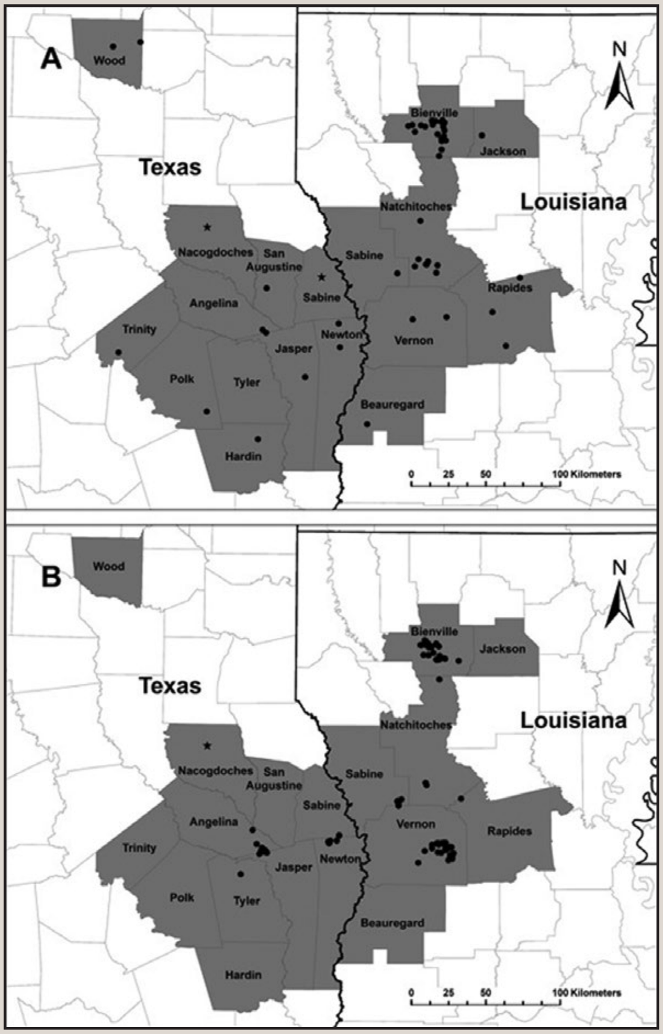

Fig. 1. Records of all known *Pituophis ruthveni*, excluding radio-telemetry redetections: (A) prior to 1992 (N = 84), (B) from 1992 through 2015 (N = 151). Counties and parishes with known records are shaded gray. Questionable records (N = 10) are not shown. Stars indicate a record is known for the county, but the exact location is unknown.

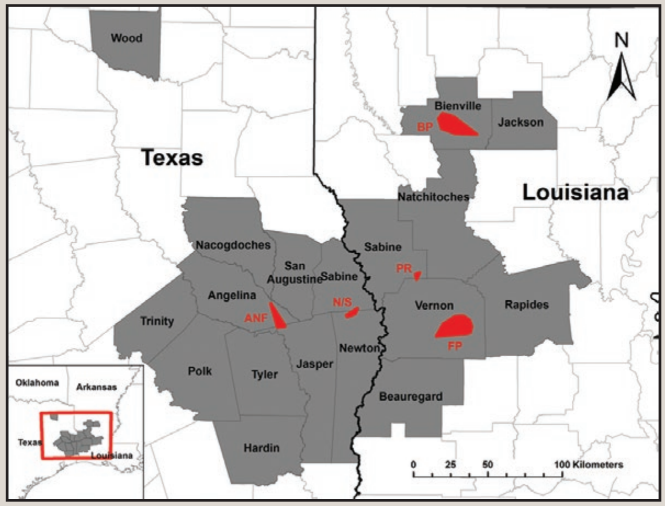

Fig. 2. Five populations (red polygons) of *Pituophis ruthveni* delineated based on spatial proximity and a minimum of three records. ANF: Angelina National Forest; BP: private land in Bienville Parish, Louisiana; FP: Fort Polk, Department of Defense; PR: Peason Ridge, Department of Defense; N/S: private land in Newton County, Texas and Sabine National Forest. Counties and parishes with known records are shaded gray.

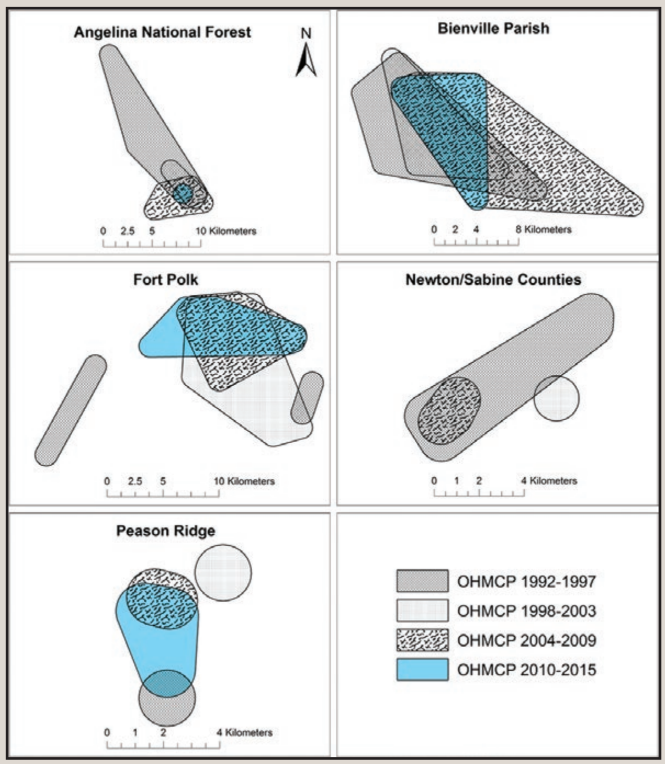

Fig. 3. Changes in occupied habitat minimum convex polygons (OHMCP) for five populations of *Pituophis ruthveni* in eastern Texas and west-central Louisiana from 1992 through 2015 over four sequential time periods.

has not been quantified for the five populations; however, suitable soils and thus potential habitat is highly fragmented across the historical range (Wagner et al. 2014).

The ANF population met IUCN Criterion E for critically endangered status (Fig. 5, Appendix 3), using a 99% decline to reflect actual extinction within 33 years. However, given the rarity of the species, the adverse effects of genetic issues and environmental stochasticity may indicate a greater level of decline from which the species will not be able to recover. Using a 90% decline quasi-extinction threshold, the N/S populations would meet the IUCN criteria for critically endangered status (Fig. 5, Appendix 2). The projected 90% decline quasi-extinction risk for the BP population in 33 years did not indicate critically endangered status, but the projected risk by 55 years (TMU CI = 0.0002–0.9685) indicated uncertainty as to its endangered status. The model for the FP trapping rate, both with and without FP34, indicated a declining population, but the TMU CIs indicated considerable uncertainty in a 90% decline quasi-extinction risk projected over time (Appendix 2).

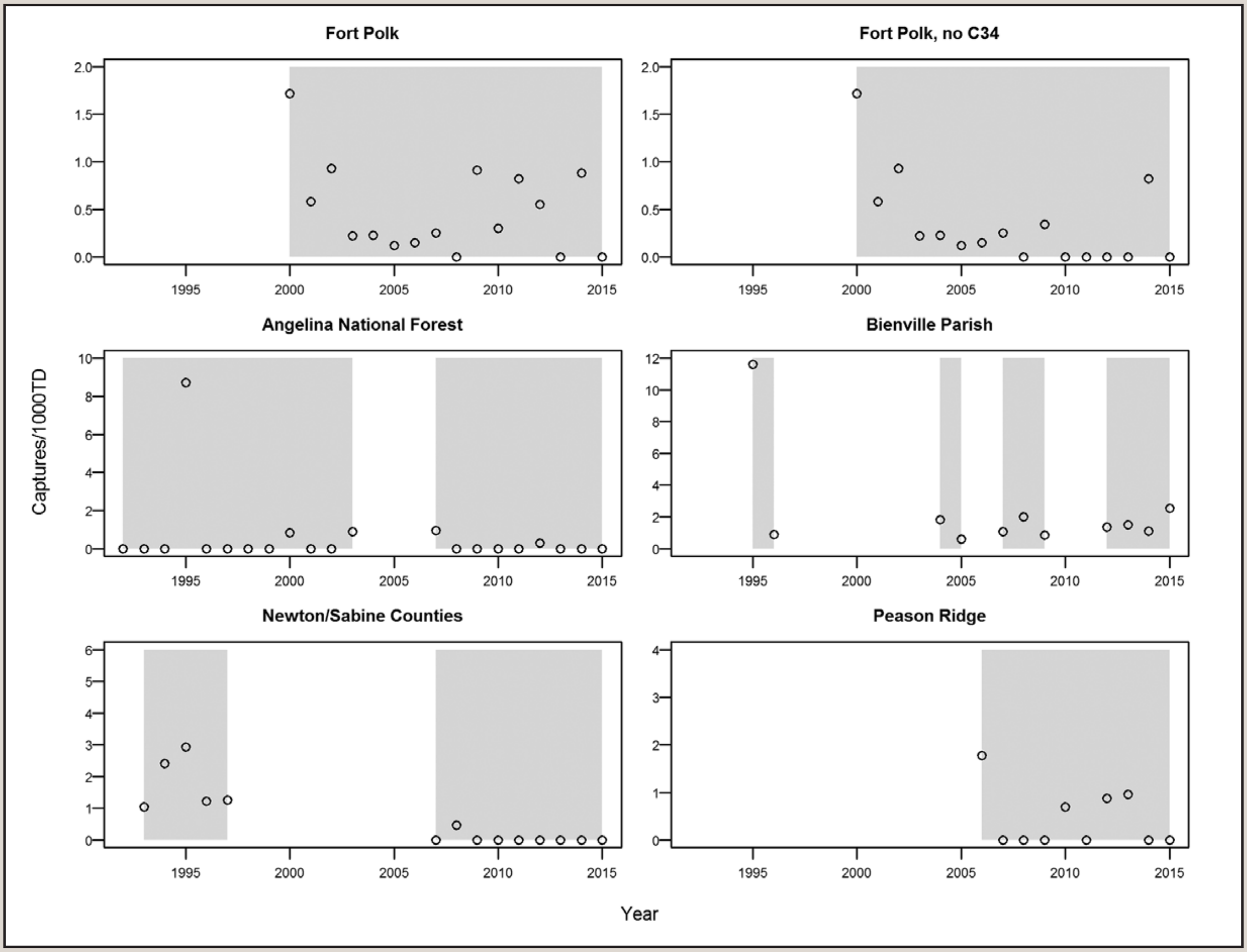

Fig. 4. Within-year unique captures per 1,000 trap days of *Pituophis ruthveni* in eastern Texas and west-central Louisiana from 1992 through 2015. Light gray shading indicates years that trapping occurred on each area. In 2009, an additional part of Fort Polk (Compartment 34) was added to the trapping layout.

Discussion

Occupied habitat.—Our delineation of five populations resulted in one less than the previous U.S. Fish and Wildlife Service designation (USFWS 2014). We considered the Sabine National Forest and Newton County populations as one population (N/S), since records are within 10 km of each other, and dropped the Kisatchie National Forest population since there are only two records in this area. Angelina National Forest (ANF), Bienville Parish (BP), Peason Ridge (PR), and Fort Polk (FP) had sufficient data to continue to be considered extant populations. However, records from the Winn District of the Kisatchie National Forest were dropped from the Bienville Parish population since there are only two records, and they are >10 km from the nearest records. USFWS also dropped this segment of the Bienville Parish population since it no longer met their temporal criteria (USFWS 2014) for currently occupied habitat.

Trapping trend and quasi-extinction risk.—The distribution of records pre- and post-1992 suggests a significant range contraction. Despite more than 377,000 trap days and 137 records since 1992, all records were from only six counties in Texas and five parishes in Louisiana. This represents a substantial decline from the 11 counties and 7 parishes represented by the relatively few records (N = 84) prior to 1992.

Our modeling of the trap data from 1992–2015 was particularly instructive. Four of the populations (FP and FP34, N/S, ANF, BP) had a negative relationship between capture rate and year. Observation error was much higher than process error in all populations except N/S. High observation error is not unexpected for snake species due to their rarity and secretive nature (Durso et al. 2011), but observation error does not contribute to quasi-extinction risk (See and Holmes 2015). The ratio of process error to observation error was moderate for N/S (1.60) and low (< 1) for all other populations. There have been no captures in the N/S population since 2008.

Additionally, models estimating quasi-extinction risk assume future environmental conditions will be similar to the present. Caution is advised in relying on estimates too far into the future, but management decisions can take into account a range of possible future conditions (Crone et al. 2013). The TMU CI indicated with a high degree of certainty (> 95%) that, without improvement in population trends, the ANF, N/S, and BP populations are at risk.

Table 2. Predicted mean trapping rate (captures per 1,000 trap days) and variability due to process and observation error estimated from state-space models using *Pituophis ruthveni* captures from five populations. LCI = lower 95% credible limit; UCI = upper 95% credible limit; Ratio = Process error/observation error; ANF = Angelina National Forest; BP = Bienville Parish; FP = Fort Polk; FP34 = Fort Polk without compartment 34; PR = Peason Ridge; N/S = Newton/Sabine counties.

	Predicted mean trapping rate			Process error			Observation error			
Population	Estimate	LCI	UCI	Estimate	LCI	UCI	Estimate	LCI	UCI	Ratio
FP	0.81	0.39	1.20	0.15	0.10	0.29	0.40	0.26	0.59	0.38
FP34	0.57	0.15	0.97	0.14	0.10	0.26	0.43	0.30	0.63	0.32
ANF	0.50	-0.35	1.57	1.07	0.32	2.39	1.28	0.33	2.38	0.84
BP	4.09	1.69	6.63	0.18	0.10	0.50	2.60	1.71	4.04	0.07
N/S	0.80	0.22	1.41	0.69	0.10	1.32	0.43	0.10	1.21	1.60
PR	0.73	0.12	1.35	0.16	0.10	0.35	0.54	0.34	0.89	0.30

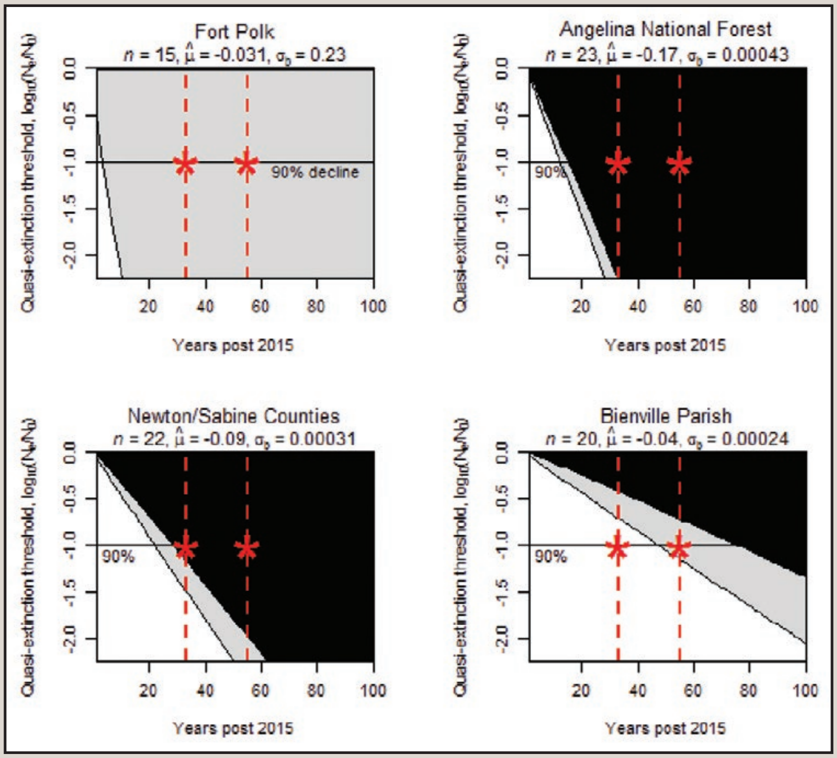

Fig. 5. Theoretical minimum uncertainty plots for *Pituophis ruthveni* populations. The Peason Ridge population had too few trapping years and non-zero capture rates to estimate quasi-extinction risk. The vertical dashed lines indicate 33 and 55 years post-2015. The horizontal line indicates a quasi-extinction threshold of 90% trapping rate decline. The black shaded area indicates a TMU lower CI > 95% at the threshold on the y-axis and the forecasted year on the x-axis. The white area indicates TMU upper CI < 5%, given the quasi-extinction threshold and forecasted year. Gray indicates areas of uncertainty. The red stars indicate quasi-extinction thresholds of 90% decline in trapping rate at 33 and 55 years from 2015. (n = number of time steps in series, $\hat{\mu}$ = estimate rate of decline, σ_b = standard deviation, TMU CI = theoretical minimum uncertainty confidence limits).

According to two Red List criteria (B and E) and our field work, the situation in Texas is of particular concern. There have been no detections of *P. ruthveni* in either of the state's populations since 2008, with the exception of two animals that were captured in 2007 and released in 2008. One of those snakes was found dead on a road in 2009 and the other was recaptured and brought into the captive population in 2012. The failure to detect additional *P. ruthveni* during this period occurred despite intensive trapping effort at the sites known to support a population since the 1990s. Each of these sites produced multiple captures of *P. ruthveni* per year as late as the mid-1990s (Sabine National Forest) or the mid-2000s (Newton County and Angelina National Forest). These data suggest a substantial population decline in recent years. We are not optimistic that viable populations still occur in Texas and fear that extirpation in the state is imminent, if it has not already occurred.

Beyond the boundaries of the populations considered above, there have been a number of isolated records since 1992, mostly in the earlier years. We have installed traps at or in the vicinity of most of these sites without success. It is unlikely that these records are indicative of viable populations. They are exclusively situated in landscapes that are more fragmented, less influenced by fire, and generally less suitable for *P. ruthveni* than occupied sites. It is unlikely that relict populations on these sites are faring any better than those on sites represented by multiple records, and are almost certainly subject to even more rapid declines. An additional site in Louisiana, on the Winn District of the Kisatchie National Forest, produced two captures in 2,763 trap days in 2000, the first year of surveys. An additional 13,742 trap days during 2001–2002, 2004–2006, and 2008–2014 resulted in zero unique captures. This site, a very fragmented block of habitat, may no longer be occupied.

Concerns about the conservation status of *P. ruthveni* have been expressed for many years (Conant 1956; Rudolph et al. 2006). In the 1980s, a captive population was established at the Memphis Zoo and has expanded over time (Reichling et al. 2016). Beginning in 2010, this captive population was used to provide individuals for reintroduction. To date, 94 individuals have been released to restored habitat on the Kisatchie National Forest in Louisiana. Initial indications (growth and survival) are encouraging, although reproduction has yet to be documented.

In our opinion, prevention of the extinction of *P. ruthveni* may be possible. However, it will require a substantial increase in resources and an accelerated commitment to address the issues related to management. Three management issues are crucial to the ultimate success in the recovery of *P. ruthveni*: 1) identification and management of additional reintroduction sites, 2) obtaining additional genetic material to bolster that presently available in the captive population, and 3) commitment of adequate resources to increase the size of the captive population and increase the production of genetically appropriate snakes for reintroduction. Failure to resolve these issues in the near future will progressively and rapidly erode the probability of survival of this iconic species of the fire-maintained pine forests of the West Gulf Coastal Plain.

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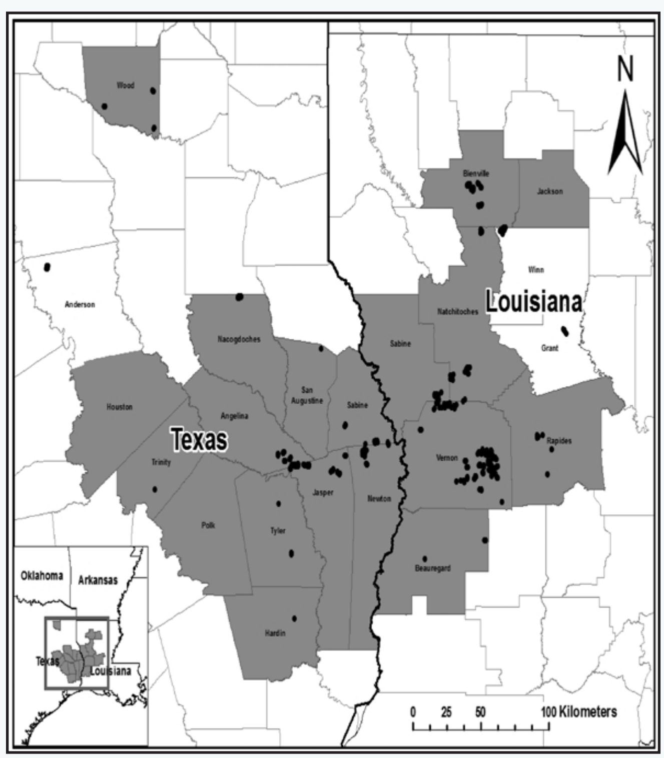
Appendices

Appendix 1. Locations of Louisiana Pinesnake traps since 1992 (N = 543; 25 traps not shown due to inaccurate location information). Historical range (gray) consists of all counties and parishes with known records.



Appendix 2. Estimation of probability of trapping rate (population) decline of 90% (quasi-extinction) and theoretical minimum uncertainty confidence limits (TMC) for the Louisiana Pinesnake populations. The Peason Ridge population had too few trapping years and none-zero capture rates to estimate quasi-extinction risk.

UCL below 0.05, probability of 90% decline <5%
Uncertain
LCL > 0.95, probability of 90% decline >95%

	ANF				N/S				BP				FP			
	Time steps post 2015	probability of 90% decline	TMU LCL	TMU UCL	Time steps post 2015	probability of 90% decline	TMU LCL	TMU UCL	Time steps post 2015	probability of 90% decline	TMU LCL	TMU UCL	Time steps post 2015	probability of 90% decline	TMU LCL	TMU UCL
	1	0.0000	0.0000	0.0000	1	0.0000	0.0000	0.0000	1	0.0000	0.0000	0.0000	1	0.0000	0.0000	0.0000
	2	0.0000	0.0000	0.0000	2	0.0000	0.0000	0.0000	2	0.0000	0.0000	0.0000	2	0.0009	0.0001	0.0058
	3	0.0000	0.0000	0.0000	3	0.0000	0.0000	0.0000	3	0.0000	0.0000	0.0000	3	0.0076	0.0008	0.0434
	4	0.0000	0.0000	0.0000	4	0.0000	0.0000	0.0000	4	0.0000	0.0000	0.0000	4	0.0222	0.0024	0.1174
	5	0.0000	0.0000	0.0000	5	0.0000	0.0000	0.0000	5	0.0000	0.0000	0.0000	5	0.0430	0.0044	0.2115
	6	0.0000	0.0000	0.0000	6	0.0000	0.0000	0.0000	6	0.0000	0.0000	0.0000	6	0.0675	0.0067	0.3102
	7	0.0000	0.0000	0.0000	7	0.0000	0.0000	0.0000	7	0.0000	0.0000	0.0000	7	0.0939	0.0089	0.4045
	8	0.0000	0.0000	0.0000	8	0.0000	0.0000	0.0000	8	0.0000	0.0000	0.0000	8	0.1208	0.0111	0.4901
	9	0.0000	0.0000	0.0000	9	0.0000	0.0000	0.0000	9	0.0000	0.0000	0.0000	9	0.1475	0.0132	0.5655
	10	0.0000	0.0000	0.0000	10	0.0000	0.0000	0.0000	10	0.0000	0.0000	0.0000	10	0.1735	0.0150	0.6309
	11	0.0000	0.0000	0.0000	11	0.0000	0.0000	0.0000	11	0.0000	0.0000	0.0000	11	0.1985	0.0167	0.6869
	12	0.0001	0.0000	0.0071	12	0.0000	0.0000	0.0000	12	0.0000	0.0000	0.0000	12	0.2225	0.0182	0.7346
	13	0.1109	0.0070	0.5058	13	0.0000	0.0000	0.0000	13	0.0000	0.0000	0.0000	13	0.2454	0.0196	0.7751
	14	0.8448	0.3941	0.9892	14	0.0000	0.0000	0.0000	14	0.0000	0.0000	0.0000	14	0.2672	0.0208	0.8094
	15	0.9990	0.9616	1.0000	15	0.0000	0.0000	0.0000	15	0.0000	0.0000	0.0000	15	0.2880	0.0219	0.8383
	16	1.0000	0.9999	1.0000	16	0.0000	0.0000	0.0000	16	0.0000	0.0000	0.0000	16	0.3077	0.0229	0.8628
	17	1.0000	1.0000	1.0000	17	0.0000	0.0000	0.0000	17	0.0000	0.0000	0.0000	17	0.3264	0.0237	0.8835
	18	1.0000	1.0000	1.0000	18	0.0000	0.0000	0.0000	18	0.0000	0.0000	0.0000	18	0.3442	0.0245	0.9010
	19	1.0000	1.0000	1.0000	19	0.0000	0.0000	0.0000	19	0.0000	0.0000	0.0000	19	0.3611	0.0252	0.9158
	20	1.0000	1.0000	1.0000	20	0.0000	0.0000	0.0000	20	0.0000	0.0000	0.0000	20	0.3773	0.0258	0.9283
	21	1.0000	1.0000	1.0000	21	0.0000	0.0000	0.0002	21	0.0000	0.0000	0.0000	21	0.3926	0.0264	0.9389
	22	1.0000	1.0000	1.0000	22	0.0001	0.0000	0.0124	22	0.0000	0.0000	0.0000	22	0.4073	0.0269	0.9479
	23	1.0000	1.0000	1.0000	23	0.0031	0.0000	0.1459	23	0.0000	0.0000	0.0000	23	0.4213	0.0273	0.9555
	24	1.0000	1.0000	1.0000	24	0.0511	0.0004	0.5333	24	0.0000	0.0000	0.0000	24	0.4347	0.0277	0.9620
	25	1.0000	1.0000	1.0000	25	0.2816	0.0099	0.8800	25	0.0000	0.0000	0.0000	25	0.4475	0.0281	0.9675
	26	1.0000	1.0000	1.0000	26	0.6686	0.0882	0.9869	26	0.0000	0.0000	0.0000	26	0.4597	0.0284	0.9722
	27	1.0000	1.0000	1.0000	27	0.9211	0.3411	0.9994	27	0.0000	0.0000	0.0000	27	0.4714	0.0287	0.9762
	28	1.0000	1.0000	1.0000	28	0.9907	0.6908	1.0000	28	0.0000	0.0000	0.0000	28	0.4827	0.0290	0.9796
	29	1.0000	1.0000	1.0000	29	0.9994	0.9153	1.0000	29	0.0000	0.0000	0.0000	29	0.4935	0.0292	0.9825
	30	1.0000	1.0000	1.0000	30	1.0000	0.9868	1.0000	30	0.0000	0.0000	0.0000	30	0.5038	0.0294	0.9850
	31	1.0000	1.0000	1.0000	31	1.0000	0.9988	1.0000	31	0.0000	0.0000	0.0000	31	0.5138	0.0296	0.9871
IUCN CR	32	1.0000	1.0000	1.0000	32	1.0000	0.9999	1.0000	32	0.0000	0.0000	0.0000	32	0.5234	0.0298	0.9889
≥50%	33	1.0000	1.0000	1.0000	33	1.0000	1.0000	1.0000	33	0.0000	0.0000	0.0000	33	0.5327	0.0299	0.9905
	34	1.0000	1.0000	1.0000	34	1.0000	1.0000	1.0000	34	0.0000	0.0000	0.0000	34	0.5416	0.0301	0.9918
	35	1.0000	1.0000	1.0000	35	1.0000	1.0000	1.0000	35	0.0000	0.0000	0.0000	35	0.5502	0.0302	0.9929
	36	1.0000	1.0000	1.0000	36	1.0000	1.0000	1.0000	36	0.0000	0.0000	0.0000	36	0.5584	0.0303	0.9939
	37	1.0000	1.0000	1.0000	37	1.0000	1.0000	1.0000	37	0.0000	0.0000	0.0000	37	0.5664	0.0304	0.9948
	38	1.0000	1.0000	1.0000	38	1.0000	1.0000	1.0000	38	0.0000	0.0000	0.0000	38	0.5742	0.0305	0.9955
	39	1.0000	1.0000	1.0000	39	1.0000	1.0000	1.0000	39	0.0000	0.0000	0.0000	39	0.5817	0.0306	0.9961
	40	1.0000	1.0000	1.0000	40	1.0000	1.0000	1.0000	40	0.0000	0.0000	0.0000	40	0.5889	0.0307	0.9966
	41	1.0000	1.0000	1.0000	41	1.0000	1.0000	1.0000	41	0.0000	0.0000	0.0000	41	0.5959	0.0307	0.9971
	42	1.0000	1.0000	1.0000	42	1.0000	1.0000	1.0000	42	0.0000	0.0000	0.0001	42	0.6027	0.0308	0.9975
	43	1.0000	1.0000	1.0000	43	1.0000	1.0000	1.0000	43	0.0000	0.0000	0.0005	43	0.6093	0.0309	0.9978
	44	1.0000	1.0000	1.0000	44	1.0000	1.0000	1.0000	44	0.0000	0.0000	0.0024	44	0.6157	0.0309	0.9981
	45	1.0000	1.0000	1.0000	45	1.0000	1.0000	1.0000	45	0.0000	0.0000	0.0095	45	0.6218	0.0310	0.9984
	46	1.0000	1.0000	1.0000	46	1.0000	1.0000	1.0000	46	0.0000	0.0000	0.0297	46	0.6279	0.0310	0.9986
	47	1.0000	1.0000	1.0000	47	1.0000	1.0000	1.0000	47	0.0000	0.0000	0.0758	47	0.6337	0.0311	0.9988
	48	1.0000	1.0000	1.0000	48	1.0000	1.0000	1.0000	48	0.0002	0.0000	0.1604	48	0.6394	0.0311	0.9989
	49	1.0000	1.0000	1.0000	49	1.0000	1.0000	1.0000	49	0.0009	0.0000	0.2875	49	0.6449	0.0311	0.9991
	50	1.0000	1.0000	1.0000	50	1.0000	1.0000	1.0000	50	0.0031	0.0000	0.4453	50	0.6502	0.0312	0.9992
	51	1.0000	1.0000	1.0000	51	1.0000	1.0000	1.0000	51	0.0094	0.0000	0.6092	51	0.6554	0.0312	0.9993
	52	1.0000	1.0000	1.0000	52	1.0000	1.0000	1.0000	52	0.0246	0.0000	0.7530	52	0.6605	0.0312	0.9994
	53	1.0000	1.0000	1.0000	53	1.0000	1.0000	1.0000	53	0.0555	0.0000	0.8606	53	0.6655	0.0312	0.9995
IUCN EN	54	1.0000	1.0000	1.0000	54	1.0000	1.0000	1.0000	54	0.1098	0.0000	0.9298	54	0.6703	0.0313	0.9996
≥20%	55	1.0000	1.0000	1.0000	55	1.0000	1.0000	1.0000	55	0.1928	0.0002	0.9685	55	0.6750	0.0313	0.9996
	56	1.0000	1.0000	1.0000	56	1.0000	1.0000	1.0000	56	0.3034	0.0005	0.9874	56	0.6795	0.0313	0.9997
	57	1.0000	1.0000	1.0000	57	1.0000	1.0000	1.0000	57	0.4334	0.0016	0.9955	57	0.6840	0.0313	0.9997
	58	1.0000	1.0000	1.0000	58	1.0000	1.0000	1.0000	58	0.5687	0.0043	0.9985	58	0.6883	0.0313	0.9997
	59	1.0000	1.0000	1.0000	59	1.0000	1.0000	1.0000	59	0.6943	0.0103	0.9996	59	0.6926	0.0313	0.9998
	60	1.0000	1.0000	1.0000	60	1.0000	1.0000	1.0000	60	0.7989	0.0222	0.9999	60	0.6967	0.0314	0.9998
	61	1.0000	1.0000	1.0000	61	1.0000	1.0000	1.0000	61	0.8773	0.0436	1.0000	61	0.7008	0.0314	0.9998
	62	1.0000	1.0000	1.0000	62	1.0000	1.0000	1.0000	62	0.9306	0.0786	1.0000	62	0.7047	0.0314	0.9999
	63	1.0000	1.0000	1.0000	63	1.0000	1.0000	1.0000	63	0.9636	0.1305	1.0000	63	0.7086	0.0314	0.9999
	64	1.0000	1.0000	1.0000	64	1.0000	1.0000	1.0000	64	0.9823	0.2010	1.0000	64	0.7123	0.0314	0.9999
	65	1.0000	1.0000	1.0000	65	1.0000	1.0000	1.0000	65	0.9920	0.2888	1.0000	65	0.7160	0.0314	0.9999
	66	1.0000	1.0000	1.0000	66	1.0000	1.0000	1.0000	66	0.9966	0.3899	1.0000	66	0.7196	0.0314	0.9999
	67	1.0000	1.0000	1.0000	67	1.0000	1.0000	1.0000	67	0.9987	0.4973	1.0000	67	0.7232	0.0314	0.9999
	68	1.0000	1.0000	1.0000	68	1.0000	1.0000	1.0000	68	0.9995	0.6034	1.0000	68	0.7266	0.0314	0.9999
	69	1.0000	1.0000	1.0000	69	1.0000	1.0000	1.0000	69	0.9998	0.7009	1.0000	69	0.7300	0.0314	0.9999
	70	1.0000	1.0000	1.0000	70	1.0000	1.0000	1.0000	70	0.9999	0.7847	1.0000	70	0.7333	0.0314	1.0000
	71	1.0000	1.0000	1.0000	71	1.0000	1.0000	1.0000	71	1.0000	0.8522	1.0000	71	0.7365	0.0315	1.0000
	72	1.0000	1.0000	1.0000	72	1.0000	1.0000	1.0000	72	1.0000	0.9031	1.0000	72	0.7397	0.0315	1.0000
	73	1.0000	1.0000	1.0000	73	1.0000	1.0000	1.0000	73	1.0000	0.9395	1.0000	73	0.7428	0.0315	1.0000
	74	1.0000	1.0000	1.0000	74	1.0000	1.0000	1.0000	74	1.0000	0.9639	1.0000	74	0.7458	0.0315	1.0000
	75	1.0000	1.0000	1.0000	75	1.0000	1.0000	1.0000	75	1.0000	0.9794	1.0000	75	0.7488	0.0315	1.0000
	76	1.0000	1.0000	1.0000	76	1.0000	1.0000	1.0000	76	1.0000	0.9888	1.0000	76	0.7517	0.0315	1.0000
	77	1.0000	1.0000	1.0000	77	1.0000	1.0000	1.0000	77	1.0000	0.9941	1.0000	77	0.7546	0.0315	1.0000
	78	1.0000	1.0000	1.0000	78	1.0000	1.0000	1.0000	78	1.0000	0.9971	1.0000	78	0.7574	0.0315	1.0000
	79	1.0000	1.0000	1.0000	79	1.0000	1.0000	1.0000	79	1.0000	0.9986	1.0000	79	0.7602	0.0315	1.0000
	80	1.0000	1.0000	1.0000	80	1.0000	1.0000	1.0000	80	1.0000	0.9993	1.0000	80	0.7629	0.0315	1.0000
	81	1.0000	1.0000	1.0000	81	1.0000	1.0000	1.0000	81	1.0000	0.9997	1.0000	81	0.7655	0.0315	1.0000
	82	1.0000	1.0000	1.0000	82	1.0000	1.0000	1.0000	82	1.0000	0.9999	1.0000	82	0.7681	0.0315	1.0000
	83	1.0000	1.0000	1.0000	83	1.0000	1.0000	1.0000	83	1.0000	0.9999	1.0000	83	0.7707	0.0315	1.0000
	84	1.0000	1.0000	1.0000	84	1.0000	1.0000	1.0000	84	1.0000	1.0000	1.0000	84	0.7732	0.0315	1.0000
	85	1.0000	1.0000	1.0000	85	1.0000	1.0000	1.0000	85	1.0000	1.0000	1.0000	85	0.7756	0.0315	1.0000
	86	1.0000	1.0000	1.0000	86	1.0000	1.0000	1.0000	86	1.0000	1.0000	1.0000	86	0.7780	0.0315	1.0000
	87	1.0000	1.0000	1.0000	87	1.0000	1.0000	1.0000	87	1.0000	1.0000	1.0000	87	0.7804	0.0315	1.0000
	88	1.0000	1.0000	1.0000	88	1.0000	1.0000	1.0000	88	1.0000	1.0000	1.0000	88	0.7827	0.0315	1.0000
	89	1.0000	1.0000	1.0000	89	1.0000	1.0000	1.0000	89	1.0000	1.0000	1.0000	89	0.7850	0.0315	1.0000
	90	1.0000	1.0000	1.0000	90	1.0000	1.0000	1.0000	90	1.0000	1.0000	1.0000	90	0.7873	0.0315	1.0000
	91	1.0000	1.0000	1.0000	91	1.0000	1.0000	1.0000	91	1.0000	1.0000	1.0000	91	0.7895	0.0315	1.0000
	92	1.0000	1.0000	1.0000	92	1.0000	1.0000	1.0000	92	1.0000	1.0000	1.0000	92	0.7917	0.0315	1.0000
	93	1.0000	1.0000	1.0000	93	1.0000	1.0000	1.0000	93	1.0000	1.0000	1.0000	93	0.7938	0.0315	1.0000
	94	1.0000	1.0000	1.0000	94	1.0000	1.0000	1.0000	94	1.0000	1.0000	1.0000	94	0.7959	0.0315	1.0000
	95	1.0000	1.0000	1.0000	95	1.0000	1.0000	1.0000	95	1.0000	1.0000	1.0000	95	0.7980	0.0315	1.0000
	96	1.0000	1.0000	1.0000	96	1.0000	1.0000	1.0000	96	1.0000	1.0000	1.0000	96	0.8000	0.0315	1.0000
	97	1.0000	1.0000	1.0000	97	1.0000	1.0000	1.0000	97	1.0000	1.0000	1.0000	97	0.8020	0.0315	1.0000
	98	1.0000	1.0000	1.0000	98	1.0000	1.0000	1.0000	98	1.0000	1.0000	1.0000	98	0.8040	0.0315	1.0000
	99	1.0000	1.0000	1.0000	99	1.0000	1.0000	1.0000	99	1.0000	1.0000	1.0000	99	0.8059	0.0315	1.0000
	100	1.0000	1.0000	1.0000	100	1.0000	1.0000	1.0000	100	1.0000	1.0000	1.0000	100	0.8078	0.0315	1.0000

APPENDIX 3. Estimation of probability of trapping rate (population) decline of 99% (quasi-extinction) and theoretical minimum uncertainty confidence limits (TMC) for the Louisiana Pinesnake populations. The Peason Ridge population had too few trapping years and none-zero capture rates to estimate quasi-extinction risk.

UCL below 0.05, probability of 99% decline <5%
Uncertain
LCL > 0.95, probability of 99% decline >95%

	ANF			
	Time steps post 2015	probability of 99% decline	TMU LCL	TMU UCL
	1	0.0000	0.0000	0.0000
	2	0.0000	0.0000	0.0000
	3	0.0000	0.0000	0.0000
	4	0.0000	0.0000	0.0000
	5	0.0000	0.0000	0.0000
	6	0.0000	0.0000	0.0000
	7	0.0000	0.0000	0.0000
	8	0.0000	0.0000	0.0000
	9	0.0000	0.0000	0.0000
	10	0.0000	0.0000	0.0000
	11	0.0000	0.0000	0.0000
	12	0.0000	0.0000	0.0000
	13	0.0000	0.0000	0.0000
	14	0.0000	0.0000	0.0000
	15	0.0000	0.0000	0.0000
	16	0.0000	0.0000	0.0000
	17	0.0000	0.0000	0.0000
	18	0.0000	0.0000	0.0000
	19	0.0000	0.0000	0.0000
	20	0.0000	0.0000	0.0000
	21	0.0000	0.0000	0.0000
	22	0.0000	0.0000	0.0000
	23	0.0000	0.0000	0.0000
	24	0.0000	0.0000	0.0003
	25	0.0003	0.0000	0.0446
	26	0.0410	0.0002	0.5036
	27	0.4486	0.0280	0.9508
	28	0.9226	0.3476	0.9994
	29	0.9983	0.8586	1.0000
	30	1.0000	0.9936	1.0000
	31	1.0000	0.9999	1.0000
IUCN CR	32	1.0000	1.0000	1.0000
≥50%	33	1.0000	1.0000	1.0000
	34	1.0000	1.0000	1.0000
	35	1.0000	1.0000	1.0000
	36	1.0000	1.0000	1.0000
	37	1.0000	1.0000	1.0000
	38	1.0000	1.0000	1.0000
	39	1.0000	1.0000	1.0000
	40	1.0000	1.0000	1.0000
	41	1.0000	1.0000	1.0000
	42	1.0000	1.0000	1.0000
	43	1.0000	1.0000	1.0000
	44	1.0000	1.0000	1.0000
	45	1.0000	1.0000	1.0000
	46	1.0000	1.0000	1.0000
	47	1.0000	1.0000	1.0000
	48	1.0000	1.0000	1.0000
	49	1.0000	1.0000	1.0000
	50	1.0000	1.0000	1.0000
	51	1.0000	1.0000	1.0000
	52	1.0000	1.0000	1.0000
	53	1.0000	1.0000	1.0000
IUCN EN	54	1.0000	1.0000	1.0000
≥20%	55	1.0000	1.0000	1.0000
	56	1.0000	1.0000	1.0000
	57	1.0000	1.0000	1.0000
	58	1.0000	1.0000	1.0000
	59	1.0000	1.0000	1.0000
	60	1.0000	1.0000	1.0000
	61	1.0000	1.0000	1.0000
	62	1.0000	1.0000	1.0000
	63	1.0000	1.0000	1.0000
	64	1.0000	1.0000	1.0000
	65	1.0000	1.0000	1.0000
	66	1.0000	1.0000	1.0000
	67	1.0000	1.0000	1.0000
	68	1.0000	1.0000	1.0000
	69	1.0000	1.0000	1.0000
	70	1.0000	1.0000	1.0000
	71	1.0000	1.0000	1.0000
	72	1.0000	1.0000	1.0000
	73	1.0000	1.0000	1.0000
	74	1.0000	1.0000	1.0000
	75	1.0000	1.0000	1.0000
	76	1.0000	1.0000	1.0000
	77	1.0000	1.0000	1.0000
	78	1.0000	1.0000	1.0000
	79	1.0000	1.0000	1.0000
	80	1.0000	1.0000	1.0000
	81	1.0000	1.0000	1.0000
	82	1.0000	1.0000	1.0000
	83	1.0000	1.0000	1.0000
	84	1.0000	1.0000	1.0000
	85	1.0000	1.0000	1.0000
	86	1.0000	1.0000	1.0000
	87	1.0000	1.0000	1.0000
	88	1.0000	1.0000	1.0000
	89	1.0000	1.0000	1.0000
	90	1.0000	1.0000	1.0000
	91	1.0000	1.0000	1.0000
	92	1.0000	1.0000	1.0000
	93	1.0000	1.0000	1.0000
	94	1.0000	1.0000	1.0000
	95	1.0000	1.0000	1.0000
	96	1.0000	1.0000	1.0000
	97	1.0000	1.0000	1.0000
	98	1.0000	1.0000	1.0000
	99	1.0000	1.0000	1.0000
	100	1.0000	1.0000	1.0000

N/S			
Time steps post 2015	probability of 99% decline	TMU LCL	TMU UCL
1	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0000
25	0.0000	0.0000	0.0000
26	0.0000	0.0000	0.0000
27	0.0000	0.0000	0.0000
28	0.0000	0.0000	0.0000
29	0.0000	0.0000	0.0000
30	0.0000	0.0000	0.0000
31	0.0000	0.0000	0.0000
32	0.0000	0.0000	0.0000
33	0.0000	0.0000	0.0000
34	0.0000	0.0000	0.0000
35	0.0000	0.0000	0.0000
36	0.0000	0.0000	0.0000
37	0.0000	0.0000	0.0000
38	0.0000	0.0000	0.0000
39	0.0000	0.0000	0.0000
40	0.0000	0.0000	0.0000
41	0.0000	0.0000	0.0000
42	0.0000	0.0000	0.0000
43	0.0000	0.0000	0.0000
44	0.0000	0.0000	0.0007
45	0.0000	0.0000	0.0098
46	0.0001	0.0000	0.0663
47	0.0010	0.0000	0.2448
48	0.0101	0.0000	0.5418
49	0.0582	0.0000	0.8118
50	0.2029	0.0005	0.9504
51	0.4574	0.0045	0.9917
52	0.7268	0.0271	0.9991
53	0.9032	0.1051	0.9999
54	0.9763	0.2765	1.0000
55	0.9960	0.5216	1.0000
56	0.9995	0.7550	1.0000
57	1.0000	0.9057	1.0000
58	1.0000	0.9731	1.0000
59	1.0000	0.9943	1.0000
60	1.0000	0.9991	1.0000
61	1.0000	0.9999	1.0000
62	1.0000	1.0000	1.0000
63	1.0000	1.0000	1.0000
64	1.0000	1.0000	1.0000
65	1.0000	1.0000	1.0000
66	1.0000	1.0000	1.0000
67	1.0000	1.0000	1.0000
68	1.0000	1.0000	1.0000
69	1.0000	1.0000	1.0000
70	1.0000	1.0000	1.0000
71	1.0000	1.0000	1.0000
72	1.0000	1.0000	1.0000
73	1.0000	1.0000	1.0000
74	1.0000	1.0000	1.0000
75	1.0000	1.0000	1.0000
76	1.0000	1.0000	1.0000
77	1.0000	1.0000	1.0000
78	1.0000	1.0000	1.0000
79	1.0000	1.0000	1.0000
80	1.0000	1.0000	1.0000
81	1.0000	1.0000	1.0000
82	1.0000	1.0000	1.0000
83	1.0000	1.0000	1.0000
84	1.0000	1.0000	1.0000
85	1.0000	1.0000	1.0000
86	1.0000	1.0000	1.0000
87	1.0000	1.0000	1.0000
88	1.0000	1.0000	1.0000
89	1.0000	1.0000	1.0000
90	1.0000	1.0000	1.0000
91	1.0000	1.0000	1.0000
92	1.0000	1.0000	1.0000
93	1.0000	1.0000	1.0000
94	1.0000	1.0000	1.0000
95	1.0000	1.0000	1.0000
96	1.0000	1.0000	1.0000
97	1.0000	1.0000	1.0000
98	1.0000	1.0000	1.0000
99	1.0000	1.0000	1.0000
100	1.0000	1.0000	1.0000

BP			
Time steps post 2015	probability of 99% decline	TMU LCL	TMU UCL
1	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0000
25	0.0000	0.0000	0.0000
26	0.0000	0.0000	0.0000
27	0.0000	0.0000	0.0000
28	0.0000	0.0000	0.0000
29	0.0000	0.0000	0.0000
30	0.0000	0.0000	0.0000
31	0.0000	0.0000	0.0000
32	0.0000	0.0000	0.0000
33	0.0000	0.0000	0.0000
34	0.0000	0.0000	0.0000
35	0.0000	0.0000	0.0000
36	0.0000	0.0000	0.0000
37	0.0000	0.0000	0.0000
38	0.0000	0.0000	0.0000
39	0.0000	0.0000	0.0000
40	0.0000	0.0000	0.0000
41	0.0000	0.0000	0.0000
42	0.0000	0.0000	0.0000
43	0.0000	0.0000	0.0000
44	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000
46	0.0000	0.0000	0.0000
47	0.0000	0.0000	0.0000
48	0.0000	0.0000	0.0000
49	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000
51	0.0000	0.0000	0.0000
52	0.0000	0.0000	0.0000
53	0.0000	0.0000	0.0000
54	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000
56	0.0000	0.0000	0.0000
57	0.0000	0.0000	0.0000
58	0.0000	0.0000	0.0000
59	0.0000	0.0000	0.0000
60	0.0000	0.0000	0.0000
61	0.0000	0.0000	0.0000
62	0.0000	0.0000	0.0000
63	0.0000	0.0000	0.0000
64	0.0000	0.0000	0.0000
65	0.0000	0.0000	0.0000
66	0.0000	0.0000	0.0000
67	0.0000	0.0000	0.0000
68	0.0000	0.0000	0.0000
69	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000
71	0.0000	0.0000	0.0000
72	0.0000	0.0000	0.0000
73	0.0000	0.0000	0.0000
74	0.0000	0.0000	0.0000
75	0.0000	0.0000	0.0000
76	0.0000	0.0000	0.0000
77	0.0000	0.0000	0.0000
78	0.0000	0.0000	0.0000
79	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000
81	0.0000	0.0000	0.0000
82	0.0000	0.0000	0.0000
83	0.0000	0.0000	0.0000
84	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000
86	0.0000	0.0000	0.0000
87	0.0000	0.0000	0.0000
88	0.0000	0.0000	0.0000
89	0.0000	0.0000	0.0001
90	0.0000	0.0000	0.0004
91	0.0000	0.0000	0.0013
92	0.0000	0.0000	0.0037
93	0.0000	0.0000	0.0091
94	0.0000	0.0000	0.0205
95	0.0000	0.0000	0.0417
96	0.0000	0.0000	0.0777
97	0.0000	0.0000	0.1327
98	0.0000	0.0000	0.2090
99	0.0000	0.0000	0.3053
100	0.0001	0.0000	0.4162

FP			
Time steps post 2015	probability of 99% decline	TMU LCL	TMU UCL
1	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0001
5	0.0000	0.0000	0.0011
6	0.0002	0.0000	0.0051
7	0.0005	0.0000	0.0149
8	0.0013	0.0000	0.0328
9	0.0025	0.0000	0.0598
10	0.0044	0.0000	0.0957
11	0.0069	0.0001	0.1392
12	0.0102	0.0001	0.1886
13	0.0141	0.0001	0.2418
14	0.0187	0.0002	0.2971
15	0.0239	0.0002	0.3529
16	0.0296	0.0002	0.4080
17	0.0359	0.0003	0.4612
18	0.0427	0.0003	0.5119
19	0.0498	0.0003	0.5596
20	0.0573	0.0004	0.6041
21	0.0650	0.0004	0.6452
22	0.0730	0.0005	0.6829
23	0.0812	0.0005	0.7172
24	0.0896	0.0005	0.7484
25	0.0981	0.0005	0.7765
26	0.1067	0.0006	0.8018
27	0.1154	0.0006	0.8245
28	0.1241	0.0006	0.8448
29	0.1329	0.0007	0.8629
30	0.1416	0.0007	0.8790
31	0.1504	0.0007	0.8933
32	0.1591	0.0007	0.9060
33	0.1678	0.0007	0.9172
34	0.1765	0.0008	0.9271
35	0.1851	0.0008	0.9359
36	0.1936	0.0008	0.9437
37	0.2021	0.0008	0.9505
38	0.2105	0.0008	0.9565
39	0.2188	0.0008	0.9618
40	0.2270	0.0008	0.9665
41	0.2351	0.0009	0.9706
42	0.2432	0.0009	0.9742
43	0.2511	0.0009	0.9773
44	0.2590	0.0009	0.9801
45	0.2668	0.0009	0.9826
46	0.2744	0.0009	0.9847
47	0.2820	0.0009	0.9866
48	0.2895	0.0009	0.9882
49	0.2968	0.0009	0.9897
50	0.3041	0.0009	0.9910
51	0.3113	0.0009	0.9921
52	0.3183	0.0009	0.9931
53	0.3253	0.0009	0.9939
54	0.3322	0.0009	0.9947
55	0.3390	0.0009	0.9953
56	0.3457	0.0009	0.9959
57	0.3523	0.0010	0.9964
58	0.3588	0.0010	0.9969
59	0.3652	0.0010	0.9972
60	0.3715	0.0010	0.9976
61	0.3777	0.0010	0.9979
62	0.3839	0.0010	0.9981
63	0.3899	0.0010	0.9984
64	0.3959	0.0010	0.9986
65	0.4018	0.0010	0.9987
66	0.4076	0.0010	0.9989
67	0.4133	0.0010	0.9990
68	0.4189	0.0010	0.9992
69	0.4245	0.0010	0.9993
70	0.4299	0.0010	0.9994
71	0.4353	0.0010	0.9994
72	0.4407	0.0010	0.9995
73	0.4459	0.0010	0.9996
74	0.4511	0.0010	0.9996
75	0.4562	0.0010	0.9997
76	0.4613	0.0010	0.9997
77	0.4662	0.0010	0.9997
78	0.4711	0.0010	0.9998
79	0.4760	0.0010	0.9998
80	0.4807	0.0010	0.9998
81	0.4854	0.0010	0.9998
82	0.4901	0.0010	0.9999
83	0.4946	0.0010	0.9999
84	0.4992	0.0010	0.9999
85	0.5036	0.0010	0.9999
86	0.5080	0.0010	0.9999
87	0.5124	0.0010	0.9999
88	0.5166	0.0010	0.9999
89	0.5209	0.0010	0.9999
90	0.5250	0.0010	1.0000
91	0.5291	0.0010	1.0000
92	0.5332	0.0010	1.0000
93	0.5372	0.0010	1.0000
94	0.5412	0.0010	1.0000
95	0.5451	0.0010	1.0000
96	0.5490	0.0010	1.0000
97	0.5528	0.0010	1.0000
98	0.5565	0.0010	1.0000
99	0.5602	0.0010	1.0000
100	0.5639	0.0010	1.0000