Distribution, Abundance, and Ecology of the Desert Massasauga Rattlesnake, *Sistrurus catenatus edwardsi.*

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Final Report

Submitted by:

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INTRODUCTION

The massasauga rattlesnake, *Sistrurus catenatus,* occurs across a broad geographic range (Stebbins, 1985; Conant and Collins, 1991) but is characterized by disjunct populations isolated due to habitat destruction (Seigal, 1986; Lowe *et al.*, 1986; Dodd, 1987; Greene & Campbell, 1992). The species is represented by three putative subspecies, the eastern massasauga (*S. c. catenatus*), the western massasauga (*S. c. tergeminus*), and the desert massasauga (*S. c. edwardsi*). It is legally protected in Arizona, Indiana, Iowa, Minnesota, New York, Pennsylvania and Wisconsin (Allen, 1988; Greene & Campbell, 1992) and has recently been listed as a category 1 candidate for listing under the Endangered Species Act. It also occurs in both Canada (where it is listed as endangered) and Mexico, although it's range in both of these countries is extremely limited and fragmented (Stebbins, 1985; Conant and Collins, 1991; Greene & Campbell, 1992; Lisle Gibbs, pers. comm.). Massasauga rattlesnakes appear to have narrow ecological tolerances, as evidenced by the decline and disappearance of populations across their geographic range. Preferred habitat consists of lowland wet meadows, swamps, bogs, cienegas, streams, and seasonally moist grasslands, although populations in the desert southwest persist in dry grasslands (Ernst, 1992). What little is known of massasauga reproduction, habitat utilization, and feeding habits is known from few studies of the eastern massasauga, *S. c. catenatus* (*e.g.*. Wright, 1941; Greene and Oliver, 1965; Keenlyne and Beer, 1973; Keenlyne, 1978; Reinert, 1981; Reinert and Kodrich, 1982; Seigal, 1986). Across most of it's range the primary threat to massasauga populations appears to be degradation, fragmentation, or destruction of habitat (Seigal, 1986; Dodd, 1987; Greene and Campbell, 1992), although road kills and willful extermination appear to be regulating factors for some populations.

The desert massasauga (*Sistrurus catenatus edwardsi*), Arizona's rarest rattlesnake, appears to be limited to a single substantial population which occurs in the San Bernardino Valley of Cochise County. This extremely localized population was known almost exclusively from road-collected specimens and was presumed to be small and perhaps in decline (Greene & Campbell, 1992; Schwalbe, 1989; Lowe *et al.*, 1986) prior to this study. A lack of data has prevented assessment of status of Arizona's populations of desert massasauga. Herein, we discuss historic distribution, present our assessment of status for the San Bernardino population, and present baseline natural and life history data.

METHODS AND MATERIALS

Study Site. A grassland habitat occurring on the divide between the San Simon and San Bernardino Valleys (*ca.* 1,370 m elevation) of Cochise County was chosen as the field site based on the relatively high proportion of museum specimens collected from that vicinity. [redacted] The grassland is dominated by tobosa (*Hilaria mutica*) although other grasses occur in low density. Mesquite, yucca, and tree cholla occur in very low density throughout the grassland, although they represent the only natural vegetation which emerges above the 30 - 40 cm high tobosa grass. The ground is covered by red igneous rock ("malpais") which is scattered and loose at the surface throughout much of the grassland. Several large hills or cinder cones (*e.g.* Red Hill) and a crater (Paramore Crater), all volcanic in origin, dominate an otherwise flat landscape. The area is characterized by moderately wet and mild winters, an exceptionally dry and mildly hot season (April, May, and June), and a wet late summer (July and August) season. This last season (known locally as the "monsoons") is characterized by sporadic late afternoon thunderstorms and plays a critical role in the natural and life history of many organisms in the area. Temperatures infrequently rise above 100 °F during a typical summer.

Historically, these valleys were much more mesic. Increasing summer monsoon rains from *ca.* 9 kyr BP to 4 kyr BP (Martin, 1963; Spaulding and Graumlich, 1986) supported the spread of mesic (in comparison to the contemporary desert grasslands) grasslands in valleys and on bajadas (Van Devender, 1995). Indeed, fossil vertebrates from Howell's Ridge cave (Little Hatchet Mountains, New Mexico) indicate that during the middle Holocene the Playas Valley supported a thriving grassland community as well as a perennial pluvial lake with fish (Colorado chub, *Gila robusta*) and microtine rodents (Van Devender and Worthington, 1977). Since 4 kyr BP, waning monsoons and periodic droughts have caused lake desiccation and promoted the invasion of grasslands by desert scrub species (Van Devender, 1995). Nevertheless, healthy grasslands dominated the San Simon, San Bernardino, and Sulpher Springs Valleys prior to 1880 (Bahre, 1995). Late nineteenth century drought combined with intensive grazing at the turn of the century (and continued grazing during the twentieth century) exacerbated grassland decay, resulting in the doubling of scrub-dominated lands in southern Arizona by 1952 (Parker and Martin, 1952). Many historically lush grasslands in the area (*e. g.*, San Bernardino Ranch, the flats north of Douglas, the San Simon Valley between San Simon Cienega and Portal) are now desert scrub rent by channelization and headward cutting of washes and streambeds (Bahre, 1995). It appears that the once contiguous desert grasslands of the San Bernardino and Sulpher Springs Valleys are now relict isolates.

Sampling. Rattlesnakes were sampled by three standard techniques; 1) manual searches of suitable habitat, 2) drift-fence trapping efforts (1994 and 1995 only), and 3) driving roads from *ca*. one half hour prior to sunset to *ca*. 3 hours after sunset. During 1993 field personnel were on site from April through August while during 1994 and 1995 the field site was manned from late June through early September. All sampling techniques were employed within 500 m of State Hwy. 80, along the *ca*. 16 km sampling transect . Captured snakes were weighed to the nearest 0.1 g, measured to the nearest mm (snout to vent length and total length), sexed, palped to determine reproductive status, meristic characters were quantified (scale rows, rattles, *etc*.), and live snakes were individually marked (using PIT tags) prior to release at each capture site. Some large adult snakes had small (< 5% body weight) transmitters surgically implanted in the peritoneal cavity following procedures outlined in Reinert and Cundall (1982). Radio-tagged snakes were held for no more than 72 hours before being released. Radio-tagged animals were located on a daily basis from May through September. Drift fences were monitored on a daily basis during June, July, August, and September. The techniques described above are standard techniques in field herpetology (Fitch, 1987; Reinert, 1992).

RESULTS and DISCUSSION

Note: Project objectives are addressed below. This report constitutes a discussion of preliminary analysis of data gathered during the first 3 years of this study. Additional data (to be gathered in 1996) and more rigorous analysis may effect changes in results, interpretation, and conclusions.

Historic and Extant Populations in Arizona.

Verifiable records (museum vouchers) document the occurrence of at least 2 and perhaps 4 historic populations of desert massasauga in Arizona. The best known of these populations is the "San Bernardino Valley" population which prior to this project was known from <15 voucher specimens taken from localities scattered along State Hwy. 80 between Douglas, AZ and Apache, AZ. A second population at the southern end of the Sulphur Springs Valley is known from a handful of museum specimens. Two other populations are known from single specimens. Charles Lowe (pers. comm.) reports a single specimen from U. S. Hwy. 70 east of Safford, AZ. A single specimen (USNM 17789) collected in the "late 1890's" (AZGF Heritage Data Management System) is listed as having been collected at the "Fort Huachuca parade grounds". I have not had the opportunity to inspect this specimen. In consideration of the collection date, it is possible that the locality information attached to the specimen actually represents a shipping locality rather than a collection locality. An absence of reported sightings or specimens from anywhere west of the Sulphur Springs Valley (including the highly populated region surrounding the alleged collection locality) lends credence to this inference. At this time the Huachuca specimen should be questioned with regard to its validity as an historical locality voucher because the specimen is: 1) *ca.* 90 years old and poorly documented, 2) comes from "atypical" habitat when compared to other Arizona specimens, and 3) represents a significant range extension within Arizona and is the most western purported collection locality for the species as a whole. While the locality information for the specimen may be valid, several lines of evidence suggest it is erroneous.

Recent specimens are known only from the San Bernardino Valley - San Simon Valley Divide and the southern portion of the Sulphur Springs Valley population in Arizona. [redacted] A voucher specimen from this locality would authenticate a *ca.* 20 mile northeastern range extension in the Sulphur Springs Valley and provide only the 2nd recent specimen from this valley. Specimens from the Sulphur Springs Valley are of considerable importance for two reasons; first, the valley holds the most western population of desert massasauga in North America, and second, the valley has been heavily impacted by agricultural practices and consequently the geographic range and size of desert massasauga populations in this valley are unknown. All "sightings" must be viewed with extreme skepticism, however, especially if they are made by amateur naturalists. Juvenile Mojave rattlesnakes (*Crotalus scutulatus*), which are abundant in desert grasslands, bear a superficial resemblance to desert massasauga.

All recent substantiated locality records of massasauga in Arizona have come from the San Bernardino/San Simon Valley and Sulphur Springs Valley of Cochise County. A single recent voucher specimen from the southern Sulphur Springs Valley suggests an extant population persists there. [redacted] The status of this extant population is discussed below.

Population Size and Relative Abundance.

Note: Herein we report both population size estimates and relative (to syntopic snake species) abundance. We calculated local population size estimates from small databases with low recapture rates and then extrapolated from these estimates to obtain a total population size estimate for massasauga throughout this desert grassland. While the data set does not lend itself to accurate population size estimation (due to low sample size, low recapture rates, and sampling design limitations), it provides a better picture of population size than a graphical representation of capture histories. Furthermore, given the secretive nature of these rare animals and the logistic difficulties involved in capturing them, this data set is impressive. It represents a *ca.* 8 fold increase in the total number of documented massasauga specimens in Arizona. Since it is unlikely that a better data set will be obtained for this state endangered population, we have chosen to use the data to provide a population size estimate. The population sizes provided are **estimates**, and they should be interpreted and utilized with a knowledge of the limitations of the sampling design and data set upon which they are based.

Total sampling effort over the course of the study included a minimum of 502 hours of road-sampling. Road-sampling time consisted of driving and collecting animals (handling time) alone and did not include processing time (*e.g.* weighing, measuring, sexing, *etc.*). Handling time for each specimen on the roadway was typically less than 3-5 minutes. Since we recorded nightly the time we spent road-sampling, but not distances traveled, we can only estimate the number of times the study site was crossed. Assuming an average speed of 40 km/h (*ca.* 25 mph), we traversed *ca.* 20,080 km (12,478 miles) of roadway or, alternatively, we crossed the study site *ca.* 1,255 times. This estimate represents a minimum bound on the number of passes through the study site, since 30 mph was the speed at which road-sampling was standardized for the study and handling time was often much more rapid than 3 to 5 minutes.

We also captured massasauga by setting drift fences and conducting field searches, although these methods proved inefficient by comparison with road riding. Drift fences consisted of 50 foot (*ca.* 15 m) lengths of 18 inch (*ca.* 46 cm) high aluminum sheeting set 10 -15 cm in the ground. During

1993 two fences with pitfall traps (5 gallon buckets) at each end of the fence were set. These traps captured no snakes. In subsequent years we set funnel traps along the fence as illustrated in Figure 1. We monitored 3 fences (24 traps) during 1994 and 5 fences (40 traps) during 1995. Fences were operational every day we were in the field and were checked each morning around 0900 hours. Funnel traps were topped with plywood/Styrofoam covers to reduce heat stress on any animals captured after mid-morning. We experienced no snake mortality in the funnel traps.

Figure 1. Diagrammatic overhead view of a drift fence/funnel trap set. Funnel traps are not drawn to scale.

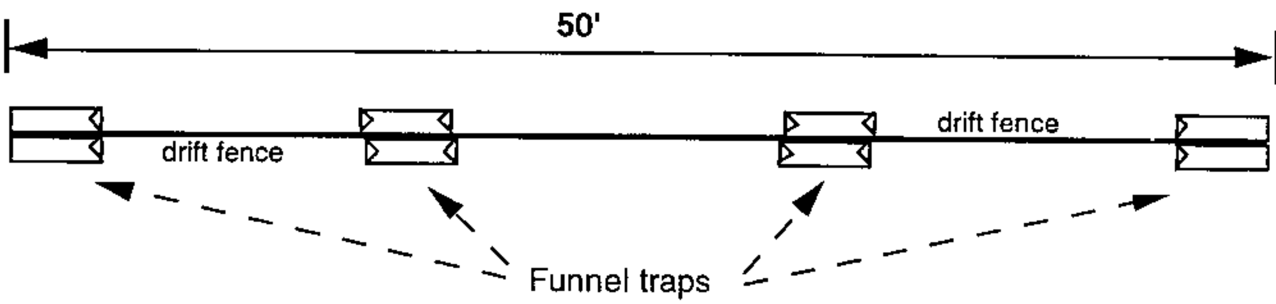


Table I presents a breakdown of the source (field vs. road collected) and status (alive or dead) of the massasauga we captured and recaptured. We monitored the population in this fashion over three summers (April - August 1993, June - September 1994, July - September, 1995) and captured 55 live (AOR + FLD) desert massasauga and later recaptured 10 (AOR RECAP + DOR RECAP + FLD RECAP), for a total of 65 live captures. No snake was recaptured more than once. All recaptures occurred within 2 months of the original capture. Additionally, we found 47 massasauga

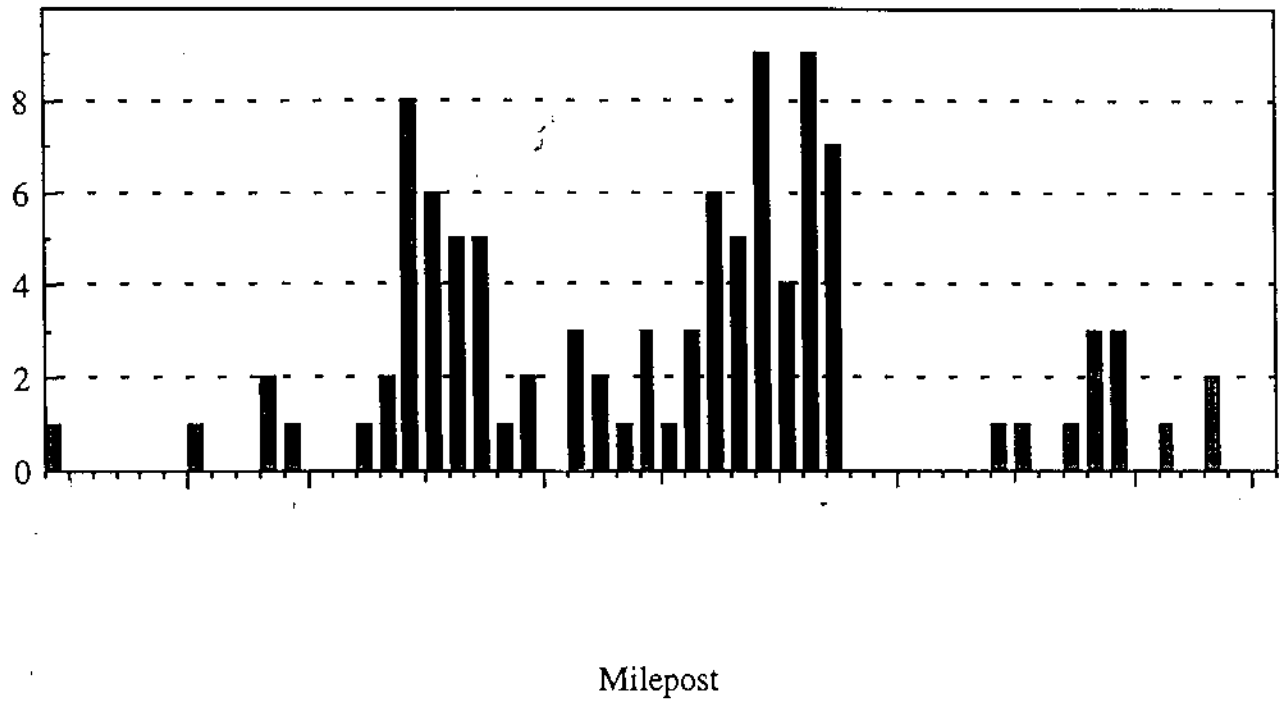
Table I. Sources of the 109 desert massasauga captured in this study. AOR = alive on road, DOR = dead on road, FLD = field, and RECAP = recaptures.

Source	Count	Percent
AOR	48	44.0%
AOR RECAP	4	3.7%
DOR	44	40.4%
DOR RECAP	3	2.8%
FLD	7	6.4%
FLD RECAP	3	2.8%

dead on the road (DOR + DOR RECAP), 3 of which were recaptures (DOR RECAP). One of these DOR RECAP animals had a smashed PIT tag and was not included in population estimates. DOR desert massasauga accounted for 47.5% of the snakes captured on the road (n=99; AOR + AOR RECAPS + DOR + DOR RECAPS) and 43.1% of total captures (n=109). DOR snakes were not utilized in population size estimates, with the exception of the two identifiable DOR recaptures. Nine of the field captures were effected within 500 m of Hwy. 80 either in drift fence/funnel traps or during field searches.

Population Size. We attempted to estimate population size using both open (POPAN) and closed (CAPTURE) population models. Closed models assume that over the period of observation the population does not incur mortality, natality, immigration, or emigration. While these assumptions are seldom valid for real-world populations and are certainly violated in this study, closed population models can derive estimates from relatively small data sets. Open population estimates on the other hand are more

Figure 2. Capture frequencies along 16 km of Highway 80 in Cochise County, AZ by 0.2 mile increments. Locations of intersections and prominent landmarks are noted on the x-axis.



robust, but require much larger data sets with relatively high recapture rates. Our data set proved too small to allow accurate estimation of population size via open models. We therefore used closed models to estimate population size over the entire sampling period (1993-1995), in addition to estimating population size for 1994 and 1995 separately. The single year estimates come closer to meeting the assumptions inherent in the closed model, but suffer from smaller sample size and sampling design.

Animals were sampled along a single linear transect (*ca.* 16 km) through *ca.* 485 km^2 of desert grassland habitat. The estimate of 485 km^2 was calculated by projecting maps of habitat provided by Mendelson and Jennings (1992) (and habitat surveys by A. T. Holycross in 1995) onto USGS 7.5 minute topographic maps. A planimeter was used to calculate area. We excluded areas of mixed scrub/grassland or mixed *Yucca*/grassland as well as a patch of desert grassland in the vicinity of Rodeo, NM [which is mapped by Mendelson and Jennings (1992)] in our estimate. This patch of desert grassland is not contiguous with the grassland we worked in and is being heavily invaded by desert scrub and non-native grasses. Additionally, only one desert massasauga (AMNH 107537) has been collected from this grassland. Animals captured along the 16 k transect and subsequently radio-tagged were most frequently observed within 250 m of the highway, but were occasionally found as far as 500 m from the highway. For this reason, we assume this transect effectively sampled only that portion of the population occupying the area within *ca.* 250 m of the highway (*ca.* 8 km^2) or *ca.* 1.7% of the desert grassland by area.

This sampling design violates assumptions about emigration and immigration inherent to closed population estimates. Emigration of marked animals and immigration of unmarked animals will lead to overestimation of population size, since the proportion of marked animals is decreasing, even if overall population size (or density) within the sampled area is constant. However, observation of radio-tagged snakes suggests that desert massasauga occupy distinct home ranges which are limited in size. Furthermore, we find no indication of seasonal migration, as has been observed in eastern massasauga, timber rattlesnakes, and prairie rattlesnakes. Since adult snakes (which comprise the majority of the sample) appear to be philopatric, emigration and immigration from the sampling area probably do not grossly affect our estimate.

Due to the roadway, the area sampled acts as a population sink where attrition exceeds levels found elsewhere in the population. Presumably, attrition due to road mortality and collection by hobbyists (conducted almost exclusively along the roadway) are taking marked and unmarked animals in the same proportion they occur in the sampling area, and thus should not affect sampling fractions. However, road attrition contributes to decreased densities in the sampled area *a priori*. This would lead to underestimation of total population size upon extrapolation. Because they cannot be recaptured, DOR specimens were not included in the population size analyses.

We used the computer program CAPTURE to estimate abundance from complete capture histories for each animal across all (n=12) sampling periods (sampling period = one calendar month). Thus, input consists of a matrix in which each row is a series of "1's" or "0's" representing a capture or lack of capture (respectively) for a given individual in each sampling period (column). The program CAPTURE allows the user to fit a specific closed population model to the data by testing the data for conformity with the assumptions of various closed models (*e.g.* no time, behavior, or heterogeneity effects). Based on these tests we selected two models for use in estimating population size for each of the three data sets (1993-1995, 1994 alone, and 1995 alone). The null model (M_o) assumes that all individuals are equally 'cacheable' in all sampling intervals. The jackknife (M_h) estimator assumes capture probabilities vary by individual. The Darroch (M_t) estimator assumes capture probabilities vary temporally. The Chao (M_{th}) estimator assumes capture probabilities vary both temporally and individually. Population estimates based on these models are presented in Table II.

Table II. Population estimates, standard errors, and confidence intervals derived from three data sets using closed population models. These estimates apply solely to the area sampled. See text for details and caveats.

Data Set	Model	Population Estimate	Standard Error	95% Confidence Interval
1993-1995	M_h	167	28	125 - 237
	M_o	189	54	118 - 344
1994	M_t (Darroch)	113	54	56 - 297
	M_{th}	152	95	62 - 502
1995	M_o	31	9	22 - 62
	M_h	29	5	23 - 43

Extrapolating total population size from the population estimates for the area sampled assumes that densities are equivalent throughout the area occupied by the population as whole. As discussed above, the sampled area in this study is probably not representative of densities throughout the remainder of the habitat due to increased attrition along the sampling transect itself.

Herein, we do not attempt to weight malpais bajadas more heavily in our estimate of population size. Instead, we assume that the area sampled represents a mosaic of habitats in proportion to their occurrence throughout this desert grassland. Our surveys (subjective assessments) of habitat in the grassland support this assumption. Thus, a size estimate for the portion of the population occupying the sampled habitat should be indicative of densities throughout the habitat overall.

Each of the three data sets suffers from differing violations of the model. The entire data set (1993-1995) is over a sufficiently long period of time that mortality and natality are probably inflating the estimate, but benefit from a larger data set overall. The single year data sets (1994 and 1995) come much closer to meeting the assumptions of a closed population model, but are plagued by small data sets and low recaptures (especially 1995). We have no reason to believe that any one of these estimates should be weighted more heavily in calculating an integrated estimate. Therefore, we simply use the mean (113 individuals) of the estimates in Table I as the population size in the sampled area and presume this to represent *ca.* 1.7% of the total population size (since we presume to have sampled 1.7% of the total habitat).

This results in an estimated total population size of 6,647 individuals. Assuming the road effectively sampled an area of 16 km^2 (500 m either side of the transect), we then sampled *ca.* 3.3% of the total habitat, resulting in a population size of 3,424. Again, these estimates represent a minimum bound on the total population size if the following reasonable assumptions are true: 1) the area sampled is a population sink and massasauga are at lower densities here than in unsampled areas, 2) the two estimates of proportion of the area sampled to total available habitat are overestimates. The 8 km^2 estimate probably approaches the true area sampled. The 16 km^2 estimate represents a maximum bound on the proportion of sample area to total habitat area and thus a minimum bound on extrapolated total population size.

Relative Abundance. When estimates of population size are imprecise due to unrealistic relaxation of model assumptions or small sample sizes (and/or recapture rates) additional measures of abundance or status are useful. One such measure is abundance relative to syntopic taxa in the same guild. For this reason, we compare capture rates of desert massasauga with syntopic snakes (Table III). Inherent to such comparisons is the assumption that all snake species are equally 'cacheable' under all environmental conditions, in all seasons, by the methods employed. This clearly is not true, as species differ dramatically in activity and movement patterns, natural history, and thus susceptibility to capture under various conditions and by different methods. Nevertheless, some species are similar enough that comparisons of capture rates probably reflect real-world differences in densities/population sizes. For this reason, comparison of desert massasauga capture rates with other rattlesnakes, particularly with Mojave rattlesnakes, is useful. Mojave rattlesnakes are often one of the most abundant snakes encountered in desert grasslands, and at least during the first 2 years of their lives, fill a niche which largely overlaps that of desert massasauga.

Table III. Relative capture rates by taxon.

"%TS" represents the percent of total snakes captured. "%RS" represents the percent of rattlesnakes captured.

Year	Total Snakes	Crotalinae		*C. scutulatus*			*S. catenatus*			*C. atrox*		
		n	%TS	n	%TS	%RS	n	%TS	%RS	n	%TS	%RS
1993	70	50	71.4	22	31.4	44.0	19	27.1	38.0	9	12.9	18.0
1994	261	160	61.3	84	32.2	52.5	47	18.0	29.4	29	11.1	18.1
1995	336	187	55.7	96	28.6	51.3	43	12.8	23.0	48	14.3	25.7
Total	667	397	59.4	202	30.3	50.9	109	16.3	27.5	86	12.9	21.7

As presented in Table III, desert massasauga represent 16.3% of the total snakes captured and 27.4% of the rattlesnakes captured over the course monitoring efforts to date. Sixteen percent represents a significant proportion of total snake captures, especially in light of snake diversity (over 19 species documented) in this grassland and suggests that desert massasauga are either relatively abundant or exceptionally prone to capture by the methods employed. Indeed, only Mojave rattlesnakes were captured more frequently than desert massasauga within the study area. Desert massasauga were captured more frequently than gopher snakes (*Pituophis catenifer*, 13.3% total captures), western diamondback rattlesnakes (12.9% total captures), common kingsnakes (*Lampropeltis getula*, 6.6% total captures), and checkered garter snakes (*Thamnophis marcianus*, 6.5% total captures) within the study area. Many of these species which are exceptionally common outside the study site were only collected with any frequency at the periphery of the site. Thus, within the core grassland of the study site where edge effects of desert-scrub habitat are negligible, desert massasauga make up an even greater proportion of the total snakes captured than suggested by Table II.

Diet

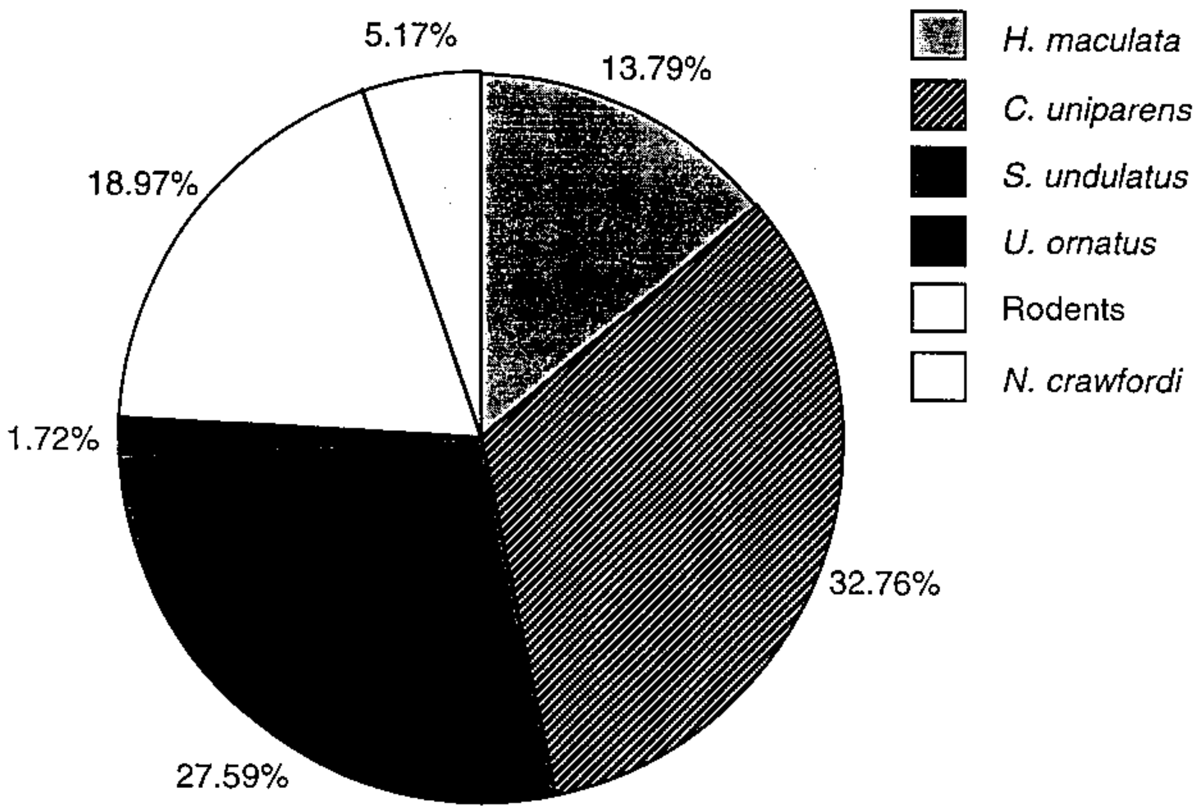
Diet was assessed using gut contents from DOR specimens and fecal samples expressed from live snakes. Each extracted sample was examined for prey remains. Individual mammalian guard hairs were identified to the ordinal level using gross morphological, surface "scale", and medulla characters. Lizards were identified to species primarily via scale characters, although "blind" identification using scale characters was substantiated through examination of whole bodies, limbs, or tails in several cases. Thus, since most prey were identified from scales or hairs alone, successive feedings on the same prey species by an individual massasauga had a high probability of being undetected.

Fifty-eight prey items were identified from the gastro-intestinal tracts of 51 desert massasauga. The majority of samples (78.9%) were collected as either feces from live snakes (n=26) or from the large intestine of DOR snakes (n=19). The remaining samples (n=12) were collected from the stomachs of DOR snakes. We collected identifiable prey remains from the feces of 26 (40%) of the 65 snakes captured alive (56 captures + 9 recaptures). None of the snakes captured alive appeared to contain prey in their stomachs. Identifiable prey remains were taken from 31 (70.4%) of the 44 DOR snakes collected. Of these 61.3% (n=19) were taken from the intestines while 38.7% (n=12) were taken from the stomachs of desert massasauga.

Of the total sample, five snakes contained remains from two different prey types, while the stomach of a sixth contained three partially digested lizards (*Cnemidophorus uniparens, Holbrookia maculata,* and *Sceloporus undulatus*) in its stomach. Three females (one AOR, two DOR) had consumed both a lizard and a rodent. The two remaining males (both DOR) contained remains of two different lizard species. Both males had consumed a *Cnemidophorus uniparens*, with *Holbrookia maculata* and *Sceloporus undulatus* comprising the remaining item, respectively. For the purpose of describing diet and statistical analysis (intraspecific comparisons of diet) the 58 prey items were treated as independent samples (*i.e.*. multiple samples from the same individual were treated as if they had come from multiple individuals).

Of the prey items 75.9% (n=44) were commonly observed diurnal grassland lizards (*C. uniparens, S. undulatus, H. maculata, Urosaurus ornatus*), while 24.1% (n=14) were mammalian remains. Figure 3 illustrates the relative abundance of each prey type (largely identified to species) in the diet of this sample of desert massasauga. Composition of diet (lizards vs. mammals) did not significantly differ between samples collected from AOR (n=26) vs. DOR (n=32) snakes (X^2=2.0, DF=1, p=0.1603), stomach (n=12) vs. intestine or fecal (n=45) samples (X^2=2.2, DF=1, p=0.1416), or between male (n=30) and female (n=28) snakes (X^2=0.2, DF=1, p=0.6413). The origin (stomach vs. intestine) of one sample was not noted, hence total sample size in that analysis was 57.

Figure 3. Relative abundance (n=58) of prey types found in the gastrointestinal tracts of 51 desert massasauga collected in Cochise County, Arizona.



C. uniparens, S. undulatus, and *H. maculata* are fast-moving diurnal denizens of small patches of open ground and are thus frequently found around *Dipodomys spectabilis* mounds. *C. uniparens* and *H. maculata* in particular appear to be associated with these mounds, and are often found asleep in the loose dirt at burrow entrances after dark. Most of the partially digested *S. undulatus* found in the stomachs of DOR desert massasauga were gravid females about to oviposit as evidenced by the presence of shelled eggs. *U. ornatus*, a seldom consumed lizard species, is also abundant in the grassland but largely occupies fence posts, large rocks, and other vertical structures inaccessible to these snakes. Desert massasauga may prey on ground-dwelling lizards either by using a sit-and-wait strategy near the entrances to *D. spectabilis* mounds or by actively foraging for them during the night. The latter strategy seems more likely since radio tracked desert massasauga (males and non-gravid females) rarely occupied *D. spectabilis* burrows during the day when sit-and-wait strategies would need to be employed in order to catch diurnal lizards.

The designation "rodents" potentially includes *Baiomys taylori* and species of the genera *Perognathus, Reithrodontomys, Peromyscus,* and *Onychomys* which are the only rodents at the site small enough to be consumed by adult desert massasauga. Indeed, adult *Onychomys* are probably to large for ingestion by the majority of adult desert massasauga. Shrew hair is easily distinguished from rodent hair and the only shrew present in the study area is *Notiosorex crawfordi*, the desert shrew. Several of these shrews were captured in pitfall traps in the study area during 1993.

No evidence of direct predation on invertebrates was found in any of the specimens I examined. In several cases lizard scales and insect exoskeletons (usually Coleoptera) were found together, in which case I assumed the insects had been consumed by the lizards prior to ingestion by the snake.

Dr. Harry Greene of the University of California at Berkeley examined 12 museum specimens (American Museum of Natural History, Museum of Southwestern Biology, University of Arizona, and Smithsonian National Museum) from the San Bernardino Valley/San Simon Valley and discovered identifiable prey remains in 4 animals. Identification of prey from the gastrointestinal tracts of these museum specimens appear to parallel patterns observed in the sample reported on above, but were not included in the analysis. Interestingly, Dr. Greene reports forcipules from a centipede (*Scolopendra*) in the stomach of a specimen (AMNH 107537) collected near the New Mexico state line on Hwy. 80. Since other small rattlesnakes (*e. g. Crotalus lepidus* and juvenile *C. willardi*) are known to prey on *Scolopendra*, the remains are probably indicative of direct predation as opposed to incidental ingestion. Dr. Greene's notes indicate that the three remaining specimens were collected within the confines of the of the present study site. One of these specimens (UAZ 45477) contained a hatchling *Cnemidophorus sp.*. in its stomach, while another (UAZ 45668) contained a rodent tentatively identified by Dr. Greene as "*cf. Perognathus*". The third specimen (MSB 42754) contained a *Cnemidophorus sp.*. in its stomach and mammal hair in its intestine.

While at the museums listed above, Dr. Greene also examined four specimens from other Arizona localities, as well as one Colorado specimen, four specimens from Texas, and fourteen from New Mexico. No prey remains were found in the Colorado specimen nor were any found in the four Arizona specimens. Two of the Texas specimens contained rodent remains. Three of the New Mexico specimens Dr. Greene examined contained remains in their stomachs including a "*Sceloporus sp.*" (MSB 32059), *Cnemidophorus sp.*" (MSB 34658), and "1 colubrid, *cf. Sonora* or *Tantilla*" (MSB 30927).

Preliminary evaluations of the diet of Mojave rattlesnakes from this site suggest an ontogenetic shift from lizards to rodents with increasing snout-vent length, a trend which is not observed in sympatric western diamondback rattlesnakes. Thus, desert massasauga may be competing with juvenile Mojave rattlesnakes for lizards.

Habitat Affiliations

As illustrated in Figure 2, desert massasauga were not collected randomly along the sampled transect.

In this area gentle sloping "bajadas" from the high malpais hillsides cross the highway. Bajada habitat is noticeably different from the adjacent flatlands in that it supports relatively dense stands of tobosa and has more surface rock. Peaks in massasauga abundance along the highway correlate strongly with areas where hillsides intercept the highway. A second, less intense area of massasauga abundance occurs . again corresponding to the proximity of a hillside bajada on the eastern side of the highway.

Both sides of the highway in this

area are flat, and on the west side of this portion of the transect, the earth was plowed and planted with Lehmann's love grass which has become established as the dominant grass. In addition to an absence of massasauga, very few specimens of any snake species were collected along this portion of the roadway. Future analysis of habitat use by radio-tracked desert massasauga will provide a more reliable picture of desert massasauga habitat requirements.

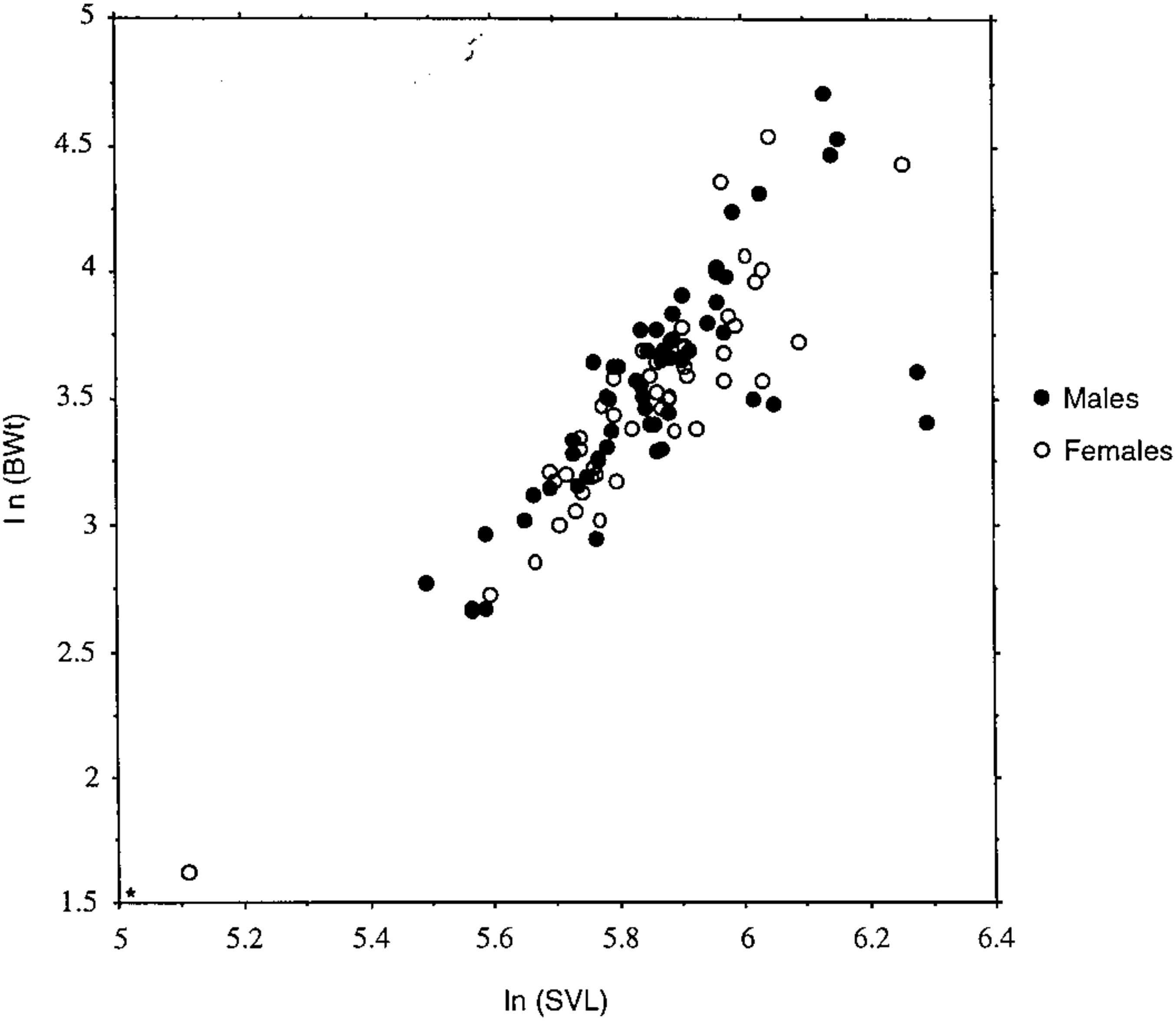
Morphological Notes

Body weight ranged from 3.9 - 112 g (mean = 36.7, SD = 18) and snout-vent length ranged from 162 - 541 mm (mean = 350.9, SD = 59.7). Number of rattles varied between 1 and 7 with a mean of 3.5 for the sample. Number of ventral scutes ranged between 137 and 153 (mean = 146.1, SD = 3.5). Number of subcaudal scutes ranged between 25 and 34 (mean = 30.2, SD = 1.9) for males and 20 and 28 for females (mean = 24.7, SD = 1.5). Tail length averaged 12.7% of SVL in males and 9.9% of SVL in females. Figure 4 illustrates a regression of BWt on SVL and shows that age classes are not discernible by morphological grouping subsequent to the initial young-of-the-year (YOY) ranking for the two neonatal snakes captured in September. Interestingly, variation in female body weight does not appear to be any greater than variation in male body weight.

Natural and Life History Notes

Mating behaviors were never observed in the field, despite intensive radiotelemetric observation. However, desert massasauga kept in environmental chambers (which mimic natural seasonal and daily light

Figure 4. Relationship of ln(BWt) and ln(SVL) for desert massasauga captured along Hwy. 80, Cochise County, AZ during 1993, 1994, and 1995. The asterisk (*) indicates a neonate of unknown sex. Of the two longest male specimens with low body weights, one was a nearly eviscerated road kill, while the other was an old thin snake captured alive.



and temperature cycles) at Arizona State University mated in both the fall and spring when animals were paired. A higher proportion of the pairs mated in the spring than in the fall.

Parturition occurs in early September as supported by the following observations. A neonatal (5.1 g, 166 mm SVL) specimen with a fresh umbilicus was found outside a bannertail kangaroo rat (*Dipodomys spectabilis*) mound on 10 September 1995. At a separate location on 11 September 1995, a radio-tagged pregnant female gave birth in a bannertail kangaroo rat burrow. Unfortunately, only one of the offspring was captured; it weighed 3.9 g and measured 162 mm SVL.

A total of 6 live females (of were captured in the course of the study which were either in late stages of yolk deposition or were pregnant, each carrying between 4 and 8 (mean = 5.8, SD = 1.8) yolked follicles or embryos. In collaboration with Dr. Stephen Goldberg, phenology of reproduction is being described from histological examination of the gonads of DOR specimens collected over the course of this investigation. Not all DOR specimens were suitable for histological investigation, due to Dr. Goldberg's investigation revealed that of 16 DOR females suitable for histological examination, (1 in June, 8 in July, 6 in August, and 1 in September) none showed any evidence of yolk deposition or other reproductive activity. Nine of these females were over 326 mm SVL (the smallest reproductive female observed in the population) and presumably capable of reproduction. The remaining 5 female snakes measured 262, 299, 312, 317, and 321 mm SVL and may also have been capable of reproduction.

Fourteen of the DOR male snakes examined by Dr. Goldberg provided some insight into male reproductive cycles. Ten of 12 males collected in July and August were undergoing spermiogenesis. Sperm was identified in the vas deferens of four of these 10 specimens. Two males collected in May also had sperm in the vas deferens; testis tissues in one of these specimens was decayed and prevented assessment of reproductive cycle status, while the other was undergoing recrudescence. These data suggest that spermiogenesis occurs in the summer and early fall and that males may be capable of storing sperm over winter and using this sperm for copulation(s) in the spring.

CONCLUSIONS

Desert massasauga are relatively abundant within the narrow confines of tobosa grassland habitat in the San Bernardino Valley as evidenced by **both** population estimates and abundance relative to other snakes. Nevertheless, the population probably represents a subset of a much larger historic population, as evidenced by rare records from further south in the San Bernardino Valley (5.5 miles north of Douglas on Hwy. 80; UAZ 47272) and further north in the San Simon Valley (1 mile south of Rodeo on Hwy. 80; AMNH 107537). These locations have not produced new records in the 46 and 30 years (respectively) elapsed since these specimens were taken. As the grasslands of these portions of the valleys receded, massasauga populations undoubtedly receded with them.

While the San Bernardino/San Simon Valley population of desert massasauga appears to be relatively abundant within the confines of the tobosa grassland community it occupies, this community is extremely small and may be shrinking due to invasion of desert scrub. Climatic fluctuations (*e.g.* droughts) or continued conversion of the grasslands to desert scrub (*e.g.* via overgrazing) could severely bottleneck or extirpate this population. Monitoring the health of this desert grassland, in addition to efforts to abate the conversion of this unique desert grassland into desert scrub, will benefit the massasauga population as well as a host of other rare grassland vertebrates found here.

This study was not designed to determine if grazing by cattle has affected or is affecting desert massasauga in this area. Radiotelemetric observations and capture data (Figure 2) suggest that desert massasauga require dense stands of tobosa grass, especially during the monsoon season when they appear to be most active. Heavy grazing would clearly destroy this important component of habitat. Massasauga use tobosa clumps for cover, as do several of their prey. Clearly, complete destruction of cover would have a negative impact on the snakes. On the other hand, the persistence of this grassland and population of desert massasauga in the presence of grazing for over 150 years suggests the area is resistant to grazing-mediated desert scrub invasion. Exclosure studies will be necessary to definitively evaluate current effect(s) of grazing on desert massasauga.

Prior to desertification, the San Bernardino/San Simon Valley population may have been contiguous with the Sulphur Springs Valley population. These populations are isolated now, if they were not isolated previously. Future genetic analyses would offer insight into the historic context of desert massasauga population structure in southeastern Arizona, as well as provide a better picture of the recent biogeographic history of the desert grasslands in this unique area.

The exceptionally high proportion of desert massasauga found DOR (47%) illustrates that highway mortality is a significant source of non-natural attrition for the population, particularly within the sampled area. Based on the two population sizes reported herein and assuming that 16 massasauga die on the road each year (mean # DOR snakes/year), the road takes 14.2% of the population in the sample area each year. This level of take represents between 0.2% and 0.5% of the total population each year. Since we only sampled the road for approximately half the season in any given year, the estimate of 16 DOR desert massasauga/year is low. Also, our estimate does not include animals poached from the roadway. While the road attrition is not likely to extirpate the population based on these figures, it does appear to be a significant source of mortality for the population, especially within the confines of sampled area. Since total population size is tenuously based on extrapolation, population size within the sample area should be of prime management concern. If, for some reason, this desert massasauga population is centered within the sample area, road mortality could be a direct threat to population persistence.

It would seem prudent to curb road mortality through the construction of drift fences which divert massasauga under the road through culverts. Similar structures have been used to reduce roadway mortality for toads in England and snakes in Florida. These structures could be erected only within core areas of massasauga activity Metal flashing (12" high) sunk 4" in the ground and fastened to existing fence lines could be used to direct snakes to existing and newly constructed culverts under the highway. The area of core massasauga activity is also a core activity area for other rare desert grassland species such as *Baiomys taylori*, some *Sigmodon sp.*, *Lampropeltis triangulum*, *Gyalopion canum*, and others. Indeed, milk snakes were only documented in this portion of the state as a result of this study, If desert massasauga are the rarest rattlesnake in the state, milk snakes are the rarest snake. Protection of a variety of rare terrestrial species could be effected by erecting diversionary drift fences in this area.

Management Recommendations: The following recommendations are made in the spirit of ensuring the persistence of the desert massasauga as a part of Arizona's natural heritage. Recommendations are ranked according to their importance.

1. Implement a program to monitor habitat quality and quantity in this desert grassland. Again, this will benefit all desert grassland endemics. Erect diversionary drift fences along existing fence lines on both sides of Highway 80 Fences should divert small terrestrial animals under culverts. Permanent drift fences also would allow agency personnel to easily monitor the population by setting funnel traps along its length during key periods of snake activity.

2. Engage in and support activities which will abate the conversion of valley grasslands to desert scrub (*e.g.* mesquite removal by local ranchers, control of exotic plants, *etc.*).

3. Erect diversionary drift fences along existing fence lines on both sides of Highway 80 Fences should divert small terrestrial animals under culverts. Permanent drift fences also would allow agency personnel to easily monitor the population by setting funnel traps along its length during key periods of snake activity.

4. Continue to list the desert massasauga as a state sensitive species (state-endangered). Continue to protect the species from unnecessary collection.

5. Support genetic analyses which would offer insight into the historic context of desert massasauga population structure in southeastern Arizona.

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