Tiger Rattlesnake Ecology and Management

(Heritage Grant Number U97015 - Urban Rattlesnakes: A Management Plan)

FINAL REPORT

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INTRODUCTION

Prior to this study, the tiger rattlesnake (*Crotalus tigris*) was one of the least studied rattlesnake species in the United States (Ernst 1992). Much of what was known about tiger rattlesnakes came from a small number of field observations and museum specimens, consisting mainly of physical descriptions, scale counts and information on their distribution (Baird 1859, Amaral 1929, Klauber 1931, Gloyd 1940, Campbell & LaMar 1989). Knowledge of the natural history of this secretive species was largely anecdotal (Gloyd 1937, Fowlie 1965, Klauber 1972; Armstrong & Murphy 1979; Lowe, et al. 1986). Basic ecological and physiological data were virtually nonexistent until Beck (1995) published data on a small sample (n = 3) of male tiger rattlesnakes that he studied using radiotelemetry.

Duvall et al. (1995) tracked 6 tiger rattlesnakes using radiotelemetry, but their objective was to document the presence of rattlesnakes in isolated preserves throughout the Phoenix, Arizona metropolitan area, and to assess the degree to which these snakes were using surrounding urbanized areas. Because they only located radio-equipped snakes a total of 32 times, they learned a limited amount about tiger rattlesnake biology. However, they recognized the need for a more detailed study of rattlesnakes living near urbanized areas. In this vein, McNally & Hare (1996) radiotracked several rattlesnakes, one of which was a male tiger rattlesnake, to determine movement patterns of rattlesnakes that were translocated by the Rural Metro Fire Department (RMFD) in Tucson. These snakes appeared to exhibit aberrant movement patterns, and little was learned about the natural behavior of tiger rattlesnakes.

Herpetologists have recognized the need for a detailed study of *C. tigris* for decades (Gloyd 1940, Klauber 1956, Ernst 1992, Rubio 1998). Therefore, our goal was to expand our knowledge of tiger rattlesnakes by intensively studying a large sample of radiotagged snakes. In this report we present the results of the first five years (1997 – 2001) of an ongoing, long-term study of tiger rattlesnakes at an urban/wildland interface near Tucson, Arizona. Specifically, we studied tiger rattlesnakes at Saguaro National Park (SNP), and at two sites on private land immediately adjacent to the park: a low-density residential area, and the future site of a large urban development. We also obtained information from tiger rattlesnakes captured by RMFD personnel.

In addition to studying tiger rattlesnake natural history and ecology, our objective was to use this knowledge to develop more effective management strategies for rattlesnakes in general. In particular, there is a need to manage rattlesnakes that live along the boundaries of parks and preserves and that move into adjacent urbanized areas. Tiger rattlesnakes are a good choice for investigating the effects of urbanization on rattlesnakes for several reasons. The range of the tiger rattlesnake in Arizona is centered around Phoenix and Tucson, two rapidly expanding urban areas surrounded by wildlands. Tiger rattlesnakes prefer rocky desert uplands; these upland areas are also considered prime real estate, and they are being developed at an alarming rate. An estimated 3,000-5,000 rattlesnakes, including tiger rattlesnakes, are removed by RMFD every year from the yards of residents living in Tucson (McNally 1995, G. Good, RMFD, pers. comm.). In Phoenix, rattlesnake removal services are also provided by the fire department and by members of the Arizona Herpetological Association, an amphibian and reptile enthusiasts' club (J. Feldner, pers. comm.). Rattlesnake management is also an issue at SNP. One of the biggest concerns facing the park is what to do about wildlife that move in and out of the park, especially as the city of Tucson continues to expand, further surrounding the park (Goode 2001, SNP Resource Management Plan). This is also true for other urban/wildland interfaces in the Tucson and Phoenix areas, including US Forest Service lands in the Santa Catalina and Rincon Mountains, Pima County Park lands in the Tucson and Tortolita Mountains, municipal lands comprising the Phoenix mountain parks, and a variety of other land ownership entities throughout Pima and Maricopa counties. Our goal was to use the results of this research to address these growth-related concerns.

METHODS

Study Area

We studied tiger rattlesnakes (Figure 1) at three sites in the Rincon Mountain District of SNP (Figure 2). The Tanque Verde Ridge (TVR) site is located in the extreme southwest

Figure 1. Adult male tiger rattlesnake (*Crotalus tigris*). Photograph by Chris Scott.

corner of the park. This site is bordered by Old Spanish Trail, a busy commuter road that runs along the west boundary of the park, and a low-density housing area immediately adjacent to the south boundary. The Rocking K (RK) site is situated along the park's south boundary approximately 4 km east of TVR. This area is the future site of the Rocking K development, a large scale project consisting of a resort and golf courses, approximately 5,000 dwelling units, and small commercial zones. The Loop Road (LR), the only road in the park used by visitors, begins and ends at the Visitor Center and it alos provides access to the Javelina Picnic Grounds.

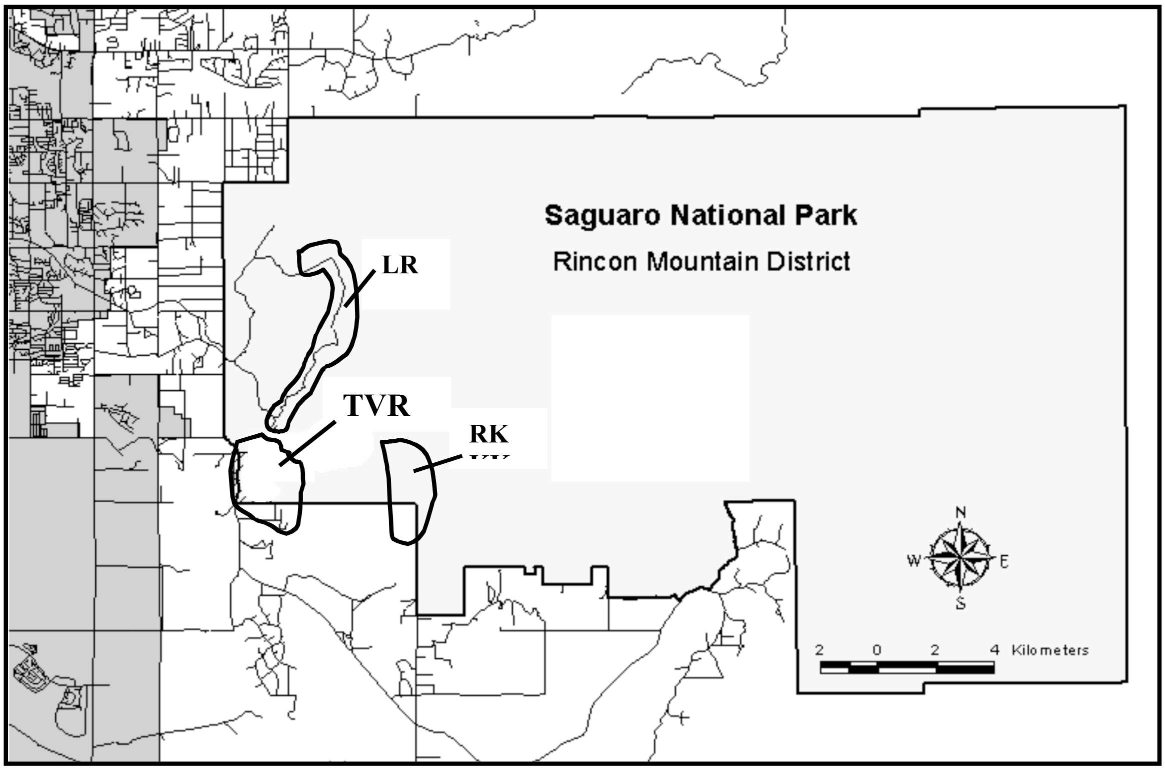

Figure 2. Map of Saguaro National Park and surrounding urban areas, showing all three study areas. LR = Loop Road; TVR = Tanque Verde Ridge; RK = Rocking K Ranch.

All three sites are characterized by steep rocky slopes, ridges with exposed bedrock, and bajadas dissected by numerous washes, some of which are characterized by relatively well developed soil terraces and xeroriparian vegetation. Vegetation is typical of Sonoran Desertscrub, Arizona Upland Subdivision (Turner & Brown 1982). Common plants include saguaro (*Carnegia gigantea*), foothill paloverde (*Cercidium microphyllum*), brittlebush (*Encelia farinosa*), prickly pear and cholla (*Opuntia* spp.), and velvet mesquite (*Prosopis velutina*). Elevation at all three sites ranges from approximately 900 – 1100 m (2,940 – 3,700 ft). We also obtained information from tiger rattlesnakes, which were removed from residences by RMFD personnel. These snakes originated from throughout the foothills of the Santa Catalina Mountains, approximately 10-25 km northwest of our main study areas at SNP.

Search Effort

When we began the study in August 1997, with the aid of numerous volunteers, we conducted walking searches in an attempt to obtain tiger rattlesnakes for radiotelemeter implants. In 1998, we turned our attention to radiotracking the snakes we captured and implanted in 1997. We continued to conduct a limited number of searches in 1998, acquiring several more snakes for implantation. In 1999, we began studying tiger rattlesnakes at RK, where we conducted several searches in an attempt to acquire snakes for implantation. In 2000, we did not conduct any walking searches specifically for tiger rattlesnakes; however, we obtained numerous snakes from tortoise researchers who captured them while conducting distance sampling at RK. In 2001, we conducted one walking search at TVR, and we received several more snakes from tortoise researchers who were continuing to conduct distance sampling at RK.

We also acquired snakes while radiotracking, including those found in association with our radiotagged snakes, which occurred on several occasions during the mating season. Because the amount of time searching for snakes while radiotracking is less than when conducting snake hunts, we compared the number of snakes captured during each activity to arrive at an estimate of total search effort. We estimated search effort of tortoise researchers to be equal to search effort while conducting snake hunts, because it is likely that tortoise researchers missed few tiger rattlesnakes while searching (D. Swann, R. Averill-Murray, pers. comm.).

Road Cruising

We spent a significant amount of time road cruising the LR, where we acquired numerous snakes. The LR is nine miles in length, winding through relatively pristine desert. The LR begins at approximately 1000 m, and reaches a maximum elevation of approximately 1200 m. We found tiger rattlesnakes along a 3.7 mile stretch of the LR, where the road winds through rocky foothill areas on the west side of Tanque Verde Ridge. We did not encounter any tiger rattlesnakes in lower elevation creosote flats.

Capture, Marking and Handling

We captured snakes using 24” tongs (Whitney, Inc). We transported snakes in cloth bags to the senior author’s residence for processing (e.g., measured, sexed, palpated). We permanently marked each snake by injecting a passive integrated transponder (PIT tag) under the skin. These tiny electronic devices are about the size of a grain of rice. PIT tags enabled us to identify individuals by passing a PIT tag reader (Destron-Fearing Co.), which displays a 10-digit alphanumeric code, over the snake’s body. We coded digits 0-9 with different paint colors, which were then used to paint the first three proximal rattle segments of the rattle based on the last three numeric digits of the alphanumeric code. This gave each snake a unique rattle paint code, making it unnecessary to recapture snakes observed in the field if the paint colors were visible. In some cases, when snakes were recaptured for growth measurements or to replace their radiotelemeter, we repainted the rattle if necessary. In general, paint marks were quite resilient; however, over time they will either wear off or the rattle segments containing the paint mark will break off. Therefore, they are not considered permanent. The paint mark also allowed us to quantify the number of times a rattlesnake shed its skin.

We used plastic tubes (JB Specialties, Inc.), a hook (Rattlesnake Museum, Albequerque, NM) and a "squeezebox" (a wooden box lined with foam padding) to safely handle rattlesnakes during capture and processing. Our experience handling venomous snakes minimized risk to both the snakes and ourselves. Snakes were released within 3-48 hours, depending on whether or not they were chosen for a radiotelemeter implant.

Morphology

We recorded snout-vent length (SVL), tail length, mass, head width and head length for all snakes captured. We measured SVL using a squeezebox. We traced the total length of the snake (minus the rattle) twice on the plexiglass cover of the squeezebox. We measured the trace twice to help insure accuracy. If measurements differed by greater than 1% of the total length, then we measured again until we obtained two measurements that were within 1% of each other. We also traced the outline of the head to get length and width measurements.

We tubed snakes in order to measure tail length, which we subtracted from the total length to arrive at SVL. We weighed snakes in a cloth bag and then subtracted the mass of the empty bag to determine the mass of the snake. We calculated the mass of the snake per unit body length by dividing the mass by SVL. This produces a body condition index (BCI), which can be compared among individuals. We also calculated the ratio of tail length to body length to facilitate sexing, as female tails are shorter than males' relative to their body length.

Demography

We sexed all snakes captured and classified each one into one of three age classes: adult, subadult, and neonate. For a female snake to be classified as an adult, it had to exceed the minimum size at which we found gravid individuals. For a male snake to classified as an adult, it had to exceed the minimum size at which males have been found to be reproductively mature (Goldberg 1999). We distinguished neonates from subadults based on their small size and by the presence of a rattle consisting of only one segment called the button, indicating that the snake had only shed once, approximately one week after birth.

Reproduction

Each time we tracked a snake, we recorded whether or not it was with a conspecific of the opposite sex. We classified each conspecific pairing into one of three categories: accompaniment, courtship, or copulation. We defined accompaniment as a male and female located within 1 m of each other. Courtship consisted of obvious behaviors such as chin-pressing and tail-searching (Klauber 1972). Copulation, which can be difficult to discern from courtship (Schuett & Gillingham 1988), was only scored if we were certain that intromission had occurred, as evidenced by a distended cloaca of the female, or the female dragging the male around while in a copulatory lock.

We palpated female snakes to assess reproductive condition. Small, hard ovarian follicles were easily palpated on females in the late summer and fall. Larger, softer yolking follicles were evident in spring, and embryos could be detected in summer. Although experience has enabled us to be fairly accurate in our assessment of female reproductive condition, there is some margin for error, especially in determining the exact number of ova or embryos.

Although we tracked several radiotagged females, which undoubtedly gave birth, we were unable to obtain any data on their litters because we were unsuccessful in finding the neonates. On several occasions, we had females, which were obviously gravid, make movements after a long period of quiessence. Upon locating the female, it was obvious she had given birth, however, we were unable to find her offspring when we returned to her previous location.

In an attempt to assess male reproductive condition, we recorded the presence of semen expressed from the hemipenal shafts. We have not yet determined if semen contains live sperm; however, a reptile and amphibian veterinarian (J. Jarchow, pers. comm.) indicated that live sperm are almost certainly present in the semen of mature males during the mating season.

Radiotelemetry

We surgically implanted temperature-sensing radiotelemeters (Holohil, Ltd., Model SR2) into 35 tiger rattlesnakes. Radiotelemeters were designed to last two years; unfortunately, more than half failed prematurely due to faulty batteries. Therefore, we were unable to track the snakes we captured in 1997-1998 as long as originally intended. In a few cases, individuals were only tracked a few times before their radiotelemeter failed. Despite these problems, we were still able to follow several individuals for multiple years, and we were able to obtain a large dataset on numerous individuals.

We only implanted snakes if the mass of the radiotelemeter (11.6 g) was 5% or less of the snake's mass. This resulted in a minimum mass of 232 g to be eligible for an implant, although a snake also had to be large enough in diameter (determined by visual inspection and based on experience) to receive an implant. Occasionally, a snake met the minimum mass criteria but was rejected because it appeared to be too thin or unhealthy. We anesthetized snakes using Isoflurane (Abbott Laboratories), an inhalant, which is highly soluble in tissue and allows for precise dosing. Using a sterile procedure (modified from Reinert & Cundall 1982), we implanted transmitters into the peritoneum (i.e., gut cavity), with the antennae placed under the skin and stretched toward the head to increase the range of signal detection. Several snakes received multiple implants. No snakes died or showed any obvious ill effects of implantation.

Spatial Ecology

We used either a Trimble (Trimble, Inc.) or Garmin E-Map (Garmin, Inc.) global positioning system (GPS) receiver to record snake locations. We post-processed locations recorded with the Trimble receiver using Pathfinder software (Trimble, Inc.) to obtain 1-3 m accuracy. We used base station files obtained from the US Forest Service office at Tucson, which was approximately 15 miles from our study area, for differential correction. Locations recorded with the Garmin receiver were not post-processed. However, these locations were accurate to within 4-7 m because they were obtained after GPS signals were no longer being scrambled by the government. All GPS data were imported into ArcView (ESRI, Inc.) for
display and spatial analyses using the Animal Movement Analysis extension (obtained online from Alaska Biological Science Center, USGS-Biological Resources Division).

We used a variety of parameters to characterize tiger rattlesnake movement patterns, including total distance moved, mean distance moved per day, mean distance moved per movement bout, maximum distance moved, and whether or not the snake was moving when located. To characterize home ranges, we estimated their size using the minimum convex polygon (MCP) technique and the 95% active kernal technique. We estimated core activity areas using the 50% isopleth generated by the active kernal technique. This area contains half of all the locations for a given snake. We examined annual and seasonal differences in movement patterns and home range size and use when sample sizes permitted.

Growth

We used morphological data and information on shedding frequency to examine growth. We attempted to recapture radiotagged snakes upon emergence from winter dens in the spring and again before they reentered their dens in the fall in order to remeasure them. By catching snakes just before and just after they overwintered, we were able to examine growth rates during the active season and determine the effects of hibernation on growth and mass. We also compared the growth of radiotelemetered snakes with data from non-radiotelemetered snakes, which were recaptured opportunistically. By comparing radiotelemetered snakes with non-radiotelemetered snakes, we were able to indirectly examine the effects, if any, that implants may be having on snakes.

Feeding and Diet

We obained information on tiger rattlesnake diet through analyses of fecal matter, which we obtained by forcing feces out of the hind gut. Fecal samples were frozen and later placed in water to thaw and to dissolve feces into identifiable prey remains. Prey remains consisted of hair, claws, bones, teeth, feathers and scales. We were able to identify prey remains to class level in all cases, genus level in some cases, and species level in a few cases. We have recently begun more extensive analyses of prey remains in an attempt to refine our ability to identify remains to the species level. This requires microscopic analyses of mammal hair, and time-consuming comparisons of minute bone fragments and teeth with museum reference collections, which in some cases, have yet to be prepared.

We also palpated all captured and recaptured snakes to determine if we could detect a food bolus, indicating recent feeding. Because snakes swallow their food whole, it is often possible to determine if they have fed recently by the presence of a large bulge or bolus in the stomach or fore gut. However, due to the strength of their axial muscles, and the action of their digestive enzymes, a snake could have eaten recently, but an obvious bolus may not be detectable. Via palpation, it is often possible to feel the prey item in the gastrointestinal tract. However, in most cases, it is difficult to unambiguously define prey items. Therefore, we only included prey items if we were absolutely certain they were present.

We kept detailed records of several feeding episodes, which we observed under natural conditions throughout the course of the study. Although we did not observe feeding often enough to have any statistical significance, the episodes we observed provide us with valuable information on the natural history of tiger rattlesnakes.

Habitat Analyses

We examined microhabitat and macrohabitat use. For microhabitat analyses, in 1997 we recorded data on several variables within a 1-m^2 area centered around each snake location. We waited until radiotelemetered rattlesnakes moved to another location before collecting microhabitat data to avoid disturbing the snakes. We gathered data at random sites throughout each snake home range, which allowed us to compare microhabitat use versus availability using logistic regression analysis, which allowed us to make inferences about the preferred habitat of tiger rattlesnakes. Within each 1-m^2 quadrat, we recorded the percentage of exposed ground, litter, grass, forb, shrub, tree, cactus, and total canopy cover. We recorded whether or not a woodrat midden was present, and the distance to the nearest midden if one was not present. We recorded data on geomorphic substrate type, which was based on particle size and fell into seven categories: bedrock, boulder, rock, gravel, pebble, sand, and soil. We recorded the dominant species of grass, forb, shrub, tree, and cactus. And, we recorded the slope and aspect of each snake location.

To compare macrohabitat use versus availability, we created a georeferenced map of the TVR study site based on tiger rattlesnake habitat types. Habitat types were based on our observations of tiger rattlesnake movement patterns. We identified four habitat types: exposed rock outcrops on ridges, rocky slopes, disected bajada, and xeroriparian wash consisting of the terrace with soil development, and the sandy active channel. We created the habitat map by walking the perimeter of each habitat type using a Trimble GPS unit. We generated line data, which were differentially corrected using carrier phase post-processing, to obtain 1-3 m accuracy. We analyzed habitat data by overlaying the habitat map with home range polygons and calculating the proportion of habitat types used compared to the proportion of habitat types available within each home range. At the landscape scale, we compared the proportion of tiger rattlesnake habitat types available within the entire study area with the proportion of habitat types within each home range. To conduct this analysis, we defined the study area as a polygon containing all known tiger rattlesnake locations.

Small-Mammal Trapping

We trapped nocturnal rodents in different habitat types and at randomly selected snake locations at different times throughout the course of the study. Our objective was to combine the results of small-mammal trapping with diet and fecal analyses to in an attempt to gain greater insight into foraging ecology and diet of tiger rattlesnakes. In 1997, we set five 16-trap grids centered around snake locations in different habitat types, which we ran for five nights (400 trap-nights). This pilot effort helped us determine relative abundance and species diversity at the Tanque Verde Ridge site, and it confirmed previous observations that small mammals occur in relatively low numbers in rocky foothill areas of the Sonoran Desert (D. Swann, pers. obs.). In 1998, after studying tiger rattlesnakes for one year and becoming more familiar with their habitat use, we set four 50-trap grids (with traps spaced at 5-meter intervals) in different habitat types: wash, bajada, slope and ridge. We ran these grids for 8 nights for a total of 1600 trap-nights. Where possible, when the number of individuals per species was six or greater, we used Program CAPTURE to obtain abundance estimates. Unfortunately, capture-recapture rates were very low in all habitat types, which led to wide confidence intervals, making it difficult to draw meaningful conclusions.

To determine if small mammals might play a role in tiger rattlesnake movement patterns at the microhabitat scale, we placed 9-trap grids centered around randomly chosen snake locations. Each grid was paired with another grid, which was placed at a random distance and direction from the grid at the snake location. The 9-trap array consisted of three rows of three traps each with the center trap placed at the snake location (the snake was no longer present at the location). Traps were spaced at 2-meter intervals. We compared capture data from the grids at snake locations to the randomly placed grids. We ran 20 grids (10 at snake locations and 10 at random locations) for four nights each for a total of 720 trap nights. To examine small mammal species diversity by habitat type, we pooled all trapping data.

Lizard Abundance Index

We used data from our incidental lizard observations (see below) to develop an encounter rate index of relative abundance and species diversity within different tiger rattlesnake habitats. As with small-mammal trapping, our goal was to increase our understanding of tiger rattlesnake foraging ecology and diet by characterizing the available prey base. We recorded the habitat type (based on tiger rattlesnake habitat use) in which each lizard was observed, providing us with both the diversity of lizard species and the relative abundance within each species by habitat type and by season. We then compared this to tiger rattlesnake habitat use to look for potential patterns.

Incidental Amphibian and Reptile Observations

We recorded all amphibians and reptiles observed while conducting tiger rattlesnake research, whether radiotracking snakes, walking to and from our vehicles, or conducting other activities such as small-mammal trapping and habitat measurements. Each time an animal was observed we recorded the date, time, species, and habitat type. We also recorded sex and age class if discernable. These data were used to examine relative abundance of lizards, which was then compared to tiger rattlesnake movement patterns. These data were also gathered to aid the park in current efforts to conduct a comprehensive inventory of its herpetofauna.

Data Analyses

We used both graphical and statistical techniques to analyze data. We used ANOVA to analyze morphological data. We used regression to analyze the relationship of tail length to gender. We used t-tests to analyze differences in movement patterns and home range size by sex and by season. We used logistic regression to analyze microhabitat data. All data met assumptions for each statistical test. We considered tests to be statistically significant at □□ 0.05.

RESULTS AND DISCUSSION

Search Effort

We recorded time spent conducting field activities (e.g., snake hunts, radiotracking) in order to calculate the number of snakes captured per unit effort (Table 1). Road cruising was by far the most efficient method, with an average of 4 person-hours required to encounter a tiger rattlesnake. During dedicated snake hunts, we captured an average of one tiger rattlesnake per 18 person-hours, which is more than four times the number of hours needed to capture a snake while road cruising. Tortoise researchers only captured an average of one tiger rattlesnake per 50 person-hours.

Table 1. Number of tiger rattlesnakes captured per unit effort while conducting different activities at three study areas (TVR = Tanque Verde Ridge, RK = Rocking K Ranch, LR = Loop Road, µ = mean.)

Site	Method	Person-Hours	Snakes Captured*	Person-Hours/Snake
TVR	Snake Hunt	212	12	18
	Radiotracking	761	31	25
RK	Snake Hunts	71	4	18
	Radiotracking	338	39	9
	Tortoise Sampling	1168	22	53
LR	Road Cruising	140	40	4
Totals		**2690**	**148**	**µ = 18**

***Includes recaptures**

Snakes observed per unit effort may be used as an index of relative abundance, and as such, may be useful for comparing across taxa. This type of encounter rate index may have utility in a monitoring context, especially when reasonable estimates of absolute abundance are difficult to obtain, which is usually the case for snakes. However, using encounter rates as an index of relative abundance is likely to be confounded by a variety of factors, including species differences in crypticity, habitat use, and activity patterns to name a few. In any case, standardizing the number of snakes encountered by unit effort seems necessary if any conclusions about relative abundance are to be drawn.

In comparison to other rattlesnake species, which we observed incidentally during this study, tiger rattlesnakes appear to be more abundant. We observed 62 western diamond-backed rattlesnakes during the study, which is an average of 42 person-hours per snake. We observed only 5 black-tailed rattlesnakes, which is an average of one every 510 hours. Although these numbers would undoubtedly be greater if we were specifically searching for these species, we feel that they are reflective of the relative abundance of these rattlesnake species at our study areas.

Road Cruising

We captured a total of 40 tiger rattlesnakes (37 captures and 3 recaptures) on the LR, (Figure 3; Table 1). We included 5 additional tiger rattlesnakes in our LR sample; 4 were captured within 800 m of the road by biologists conducting research on tortoises in the vicinity, and 1 was captured by us in Freeman Wash approximately 200 m from the road. Tiger rattlesnakes encountered per unit effort varied from year to year (Table 2).

Table 2. Summary of the number of tiger rattlesnakes encountered (including 3 recaptures) on the Loop Road at Saguaro National Park from 1997-2001. The average number of hours and miles driven required to encounter a tiger rattlesnake are given.

Year	Snakes Encountered	Hours/Snake	Miles/Snake
1997	10	2.0	18.5
1998	16	1.4	16.9
1999	0	0	0
2000	4	11.6	124.3
2001	10	4.8	55.8

We documented 1478 individuals and 27 species of herpetofauna on the LR (Table 3). The red-spotted toad (*Bufo punctatus*) was by far the most commonly observed species.

Table 3. Number of individuals of each amphibian and reptile species observed on the Loop Road from 1997 – 2001. Total number of hours spent road cruising = 141; Total number of miles driven = 1582.

Species	No. Individuals	Individuals/Hour	Individuals/Mile
Bufo alvarius	340	2.41	0.215
Bufo cognatus	6	0.04	0.004
Bufo spp.	44	0.31	0.028
Bufo punctatus	601	4.26	0.380
Cnemidophorus tigris	2	0.01	0.001
Cophosaurs texanus	8	0.06	0.005
Coleonyx variegatus	130	0.92	0.082
Crotalus atrox	51	0.36	0.032
Crotalus molossus	5	0.04	0.003
Crotalus tigris	40	0.28	0.020
Heloderma suspectum	13	0.09	0.008
Hypsoglena torquata	17	0.12	0.011
Leptotyphlops humilis	1	0.01	0.001
Masticophis flagellum	3	0.02	0.002
Micruroides euryxanthus	1	0.01	0.001
Phrynosoma solare	16	0.11	0.010
Phylorhincus decurtatus	1	0.01	0.001
Pituophis catenifer	3	0.02	0.002
Rhinocheilus lecontei	11	0.08	0.007
Salvadora hexalepis	2	0.01	0.001
Sceloporus clarki	2	0.01	0.001
Scaphiophus couchi	48	0.34	0.030
Sceloporus magister	122	0.87	0.077
Tantilla hobartsmithi	1	0.01	0.001

Table 3 (con't.)

Species	No. Individuals	Individuals/Hour	Individuals/Mile
Thamnophis cyrtopsis	1	0.01	0.001
Urosaurus ornatus	3	0.02	0.002
Uta stansburiana	1	0.01	0.001
Unidentified	14	0.10	0.004
Total	**1487**	**10.54**	**0.931**

The most commonly observed nocuturnal lizard was the banded gecko (*Coleonyx variagatus*) and the most commonly observed diurnal lizard was the desert spiny lizard (*Sceloporus magister*). The most commonly observed snake was the western diamond-backed rattlesnake, followed closely by the tiger rattlesnake.

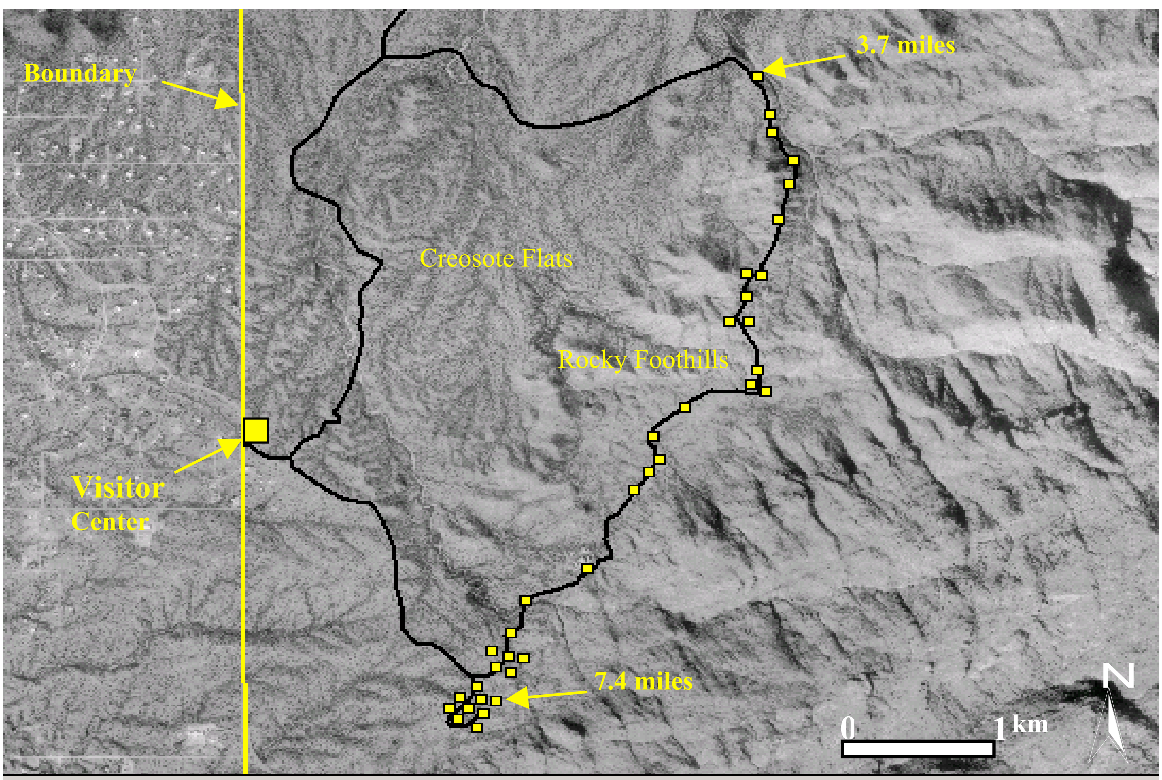

Figure 3. Aerial photograph showing the number of tiger rattlesnakes (n = 36) encountered while conducting road cruising surveys on the Loop Road as Saguaro National Park. Tiger rattlesnakes were captured only along a 3.7-mile segment where the road passes through rocky foothills of the Rincon Mountains. No tiger rattlesnakes were encountered in lower elevation creosote flats. Total number of hours spend road cruising = 141; total number of miles driven = 1582.

Road cruising has been a popular method for sampling herpetofauna for decades (Klauber 1935). Due to the secretive nature of many species, it can be difficult to find animals in numbers great enough to conduct meaningful analyses. This is one of the primary reasons why herpetofauna have been poorly studied compared to more visible taxa such as birds and mammals. Road cruising enables the researcher to cover a far greater area in far less time, and it is generally repeatable over time. Problems associated with road cruising include the nonrandom placement of roads, bias associated with the potential to attract animals to warm pavement at night, and the effects of automobiles on the abundance and behavior of some species.

Capture-Recapture

Not including recaptures, we captured and marked 169 tiger rattlesnakes from four sites (Figure 4). We recaptured 21 snakes, excluding radio-equipped snakes, which we periodically recaptured throughout the study to obtain data on growth. Due to low recapture rates, we did not attempt to estimate population size or survival at any of our sites.

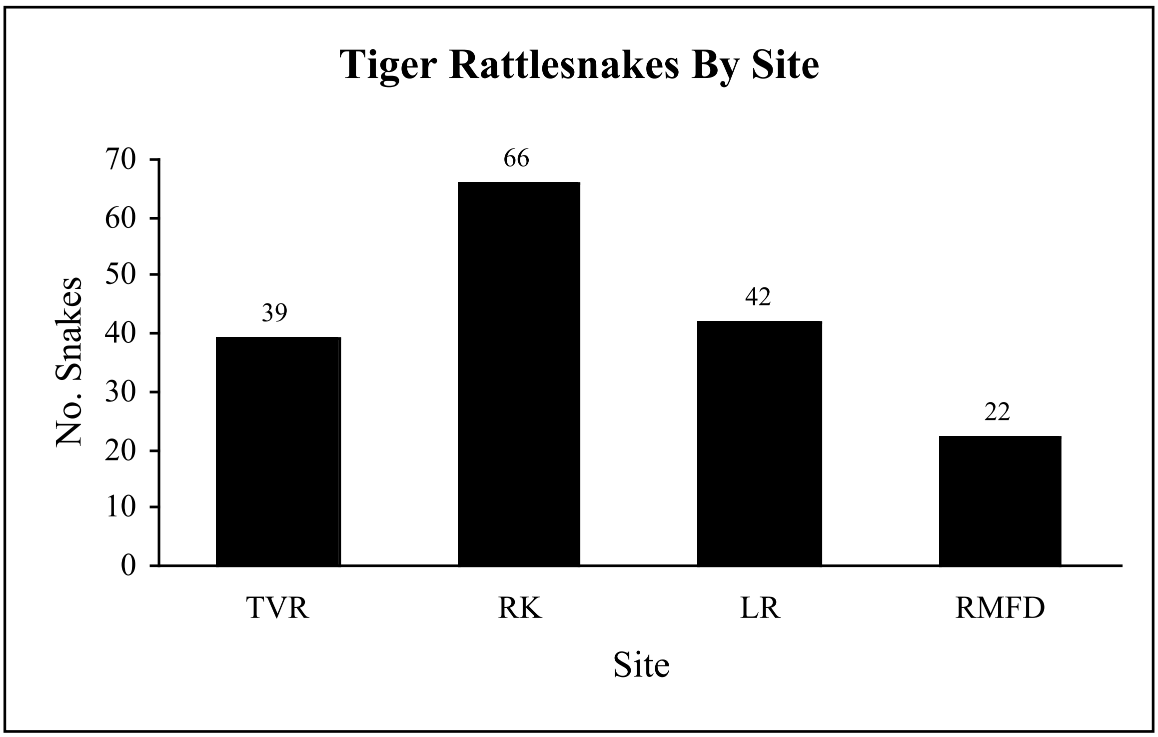

Figure 4. Tiger rattlesnakes captured by site. TVR = Tanque Verde Ridge; RK = Rocking K Ranch; LR = Loop Road; RMFD = Rural Metro Fire Department.

The number of tiger rattlesnakes obtained in this study was much higher than we expected. Anecdotal information on tiger rattlesnakes led us to believe that they were both rare (Wright & Wright 1957) and difficult to find (Lowe et al. 1986). Based on this study, it appears that tiger rattlesnakes can be locally abundant, especially in rocky foothill areas. In fact, at our study area, tiger rattlesnakes are one of the most commonly observed snakes.

The low of number of recaptures is probably not surprising based on prior research with rattlesnakes. Many snake researchers have commented on the difficulty in estimating population size and survival in snakes due to their secretive lifestyles. The actual abundance of snakes is likely much greater than their apparent rarity would suggest. However, given the large number of hours we spent in a relatively small area, it remains an enigma as to why we have such a low number of recaptures. In any case, when recapture rates are low, population and survival estimates based on capture-recapture probabilities tend to have extremely large confidence intervals, thereby limiting their value. In cooperation with SNP and Arizona Game and Fish Department personnel, we are exploring the use of distance sampling for estimating tiger rattlesnake abundance.

Demography

Gender (Figure 5) and age-class structure (Figure 6) at all four sites (including RMFD

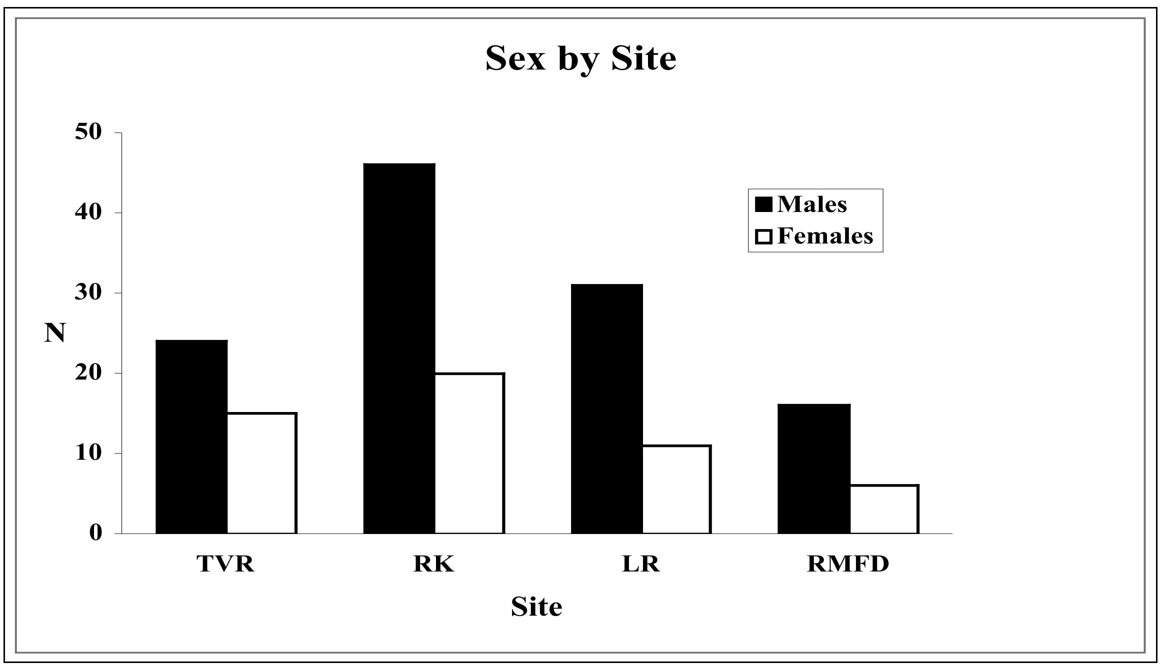

Figure 5. Sex ratios of all tiger rattlesnakes captured at all four sites from 1997-2001

snakes) were heavily biased towards adult males. Size class structure for all sites combined reflects a bias towards larger snakes (Figure 7); however, males and females did not differ in SVL at TV ($t = 1.59$, $df = 36$, $p < 0.119$).

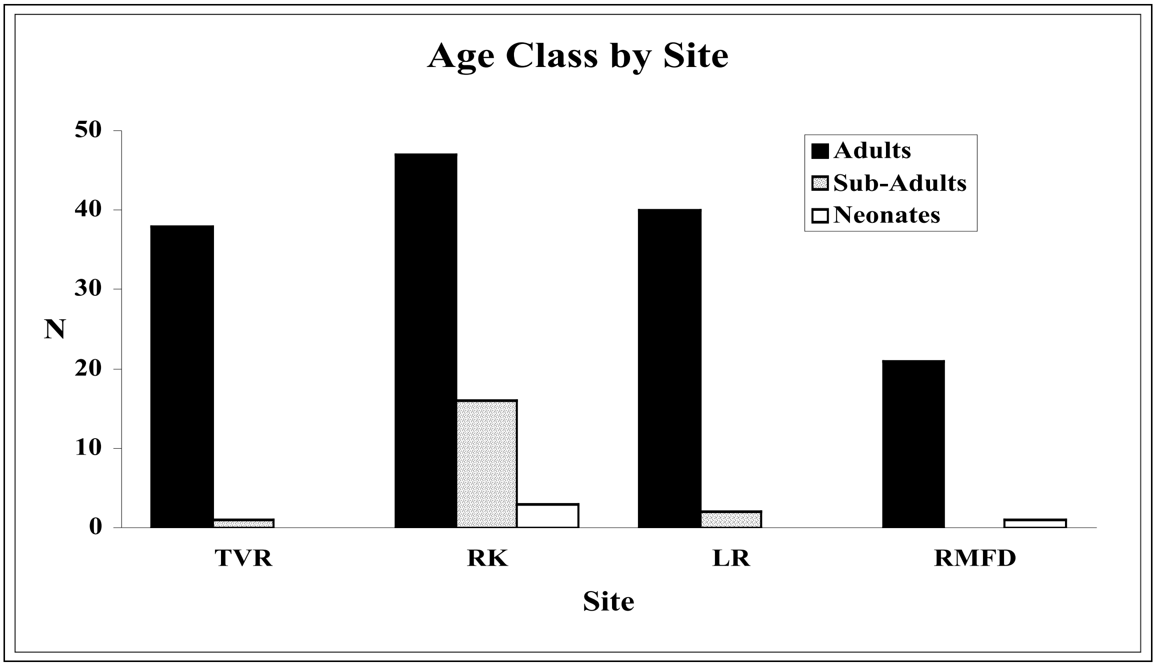

Figure 6. Age-classes of all tiger rattlesnakes captured at all four sites from 1997-2001.

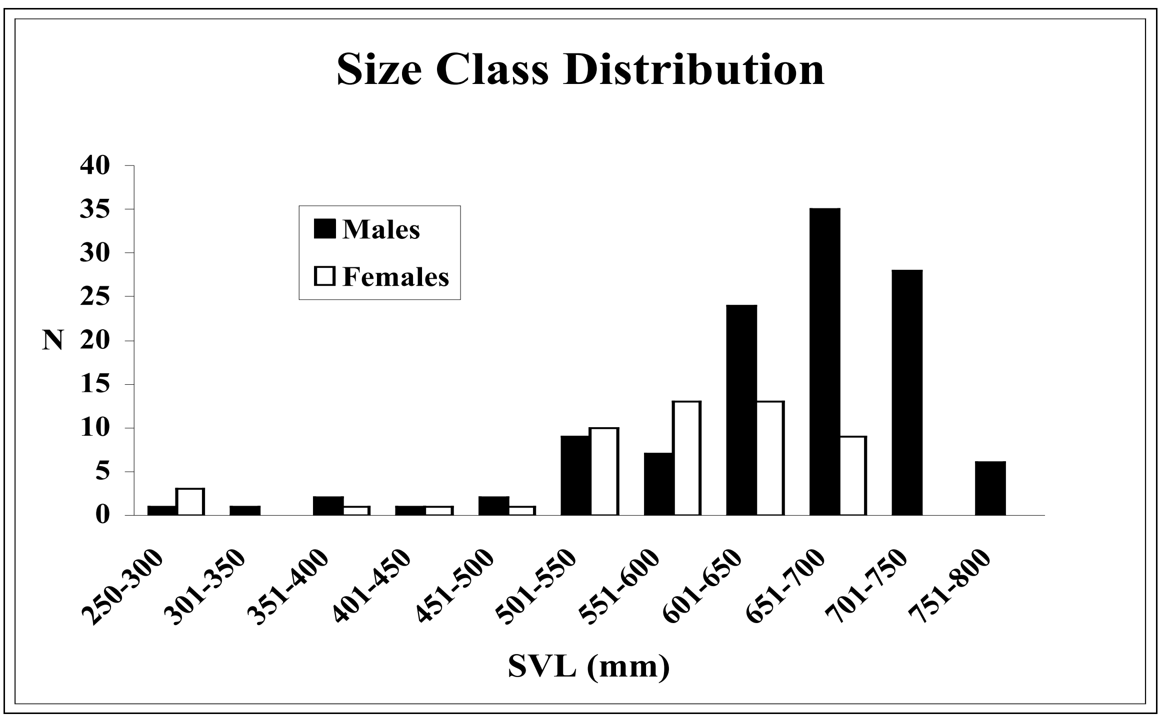

Figure 7. Size class distribution of all tiger rattlesnakes captured at all sites combined from 1997-2001.

Many studies have documented a strong bias towards large adult male rattlesnakes (Duvall et al. 1992). Speculation as to why males are easier to find than females abounds. Males are larger and therefore more conspicuous, which probably makes them easier to observe. A predominance of data on sex ratios in snakes points toward equality,making it unlikely that there are more males present in the population. Males are bigger risk takers, especially in a polygynous mating system where females are a scarce resource. This is the case with most temperate pit vipers, as females tend to give birth every 2-3 years meaning that a segment of the female population will be unreceptive in any given year. This causes males to move even further in pursuit of females, thus rendering them more likely to be observed.

We observed interesting interpopulational differences in age-class structure among our study areas. During the first two years of the study, we did not observe a single subadult tiger rattlesnake. After processing 70 adult snakes, we finally encountered a subadult at TVR in late August of 1999. This subadult remains the only one we observed at TVR. Similarly, we have only observed two subadults from the LR and we are yet to obtain a subadult from RMFD snakes, although we did acquire one neonate from RMFD personnel.

In contrast, we have encountered 16 subadults and three neonates from the RK population. Considering how close it is to the LR and TVR populations (2-8 km), this was a surprising difference. Marked differences in everything from body size to physiology have been documented in rattlesnakes (Beaupre 1995). However, the rock rattlesnake populations that Beaupre (1995) studied were at significantly different elevations, which may have accounted for the observed differences. Our study sites are very similar in elevation, varying by no more than 750 m, with significant overlap in elevations among sites. We are beginning to investigate other potential differences in these geographically close populations. For example, preliminary data suggest that tiger rattlesnakes at the TVR site eat predominantly small mammals, but snakes at the Rocking K site eat a greater proportion of lizards. We have recently begun microsatellite DNA analyses to explore these differences in more detail.

Morphology

Raw data for all snakes are shown in Appendix A. We summarized processing data for all snakes and all sites combined (Table 4), and by gender and age class for each site (Table 5).

Table 4. Morphometric data (mean ± standard error) for all tiger rattlesnakes from all sites combined from 1997-2001. All lengths and widths are in millimeters (mm).

	All Sites Combined	
Parameter	**Females**	**Males**
N	52	117
Percent adult	81%	89%
Snout-vent length*	573 ± 10	650 ± 10
Tail length*	40 ± 3	61 ± 3
Mass*	192 ± 9	287 ± 11
Head length	25 ± 2	27 ± 2
Head width	19 ± 1	20 ± 2
Number of segments	7 ± 2	7 ± 1
Rattle length	31 ± 3	35 ± 3
Percent with broken rattle	61%	81%

*** = significant at a = 0.05**

Snout-vent length varied by sex and by site (Figure 8). Males were longer ($F = 16.50$, $df = 1$, $p < 0.0002$), heavier ($F = 11.69$, $df = 1$, $p < 0.0013$), and more massive per unit body length than females. Males had 50% longer tails than females, and the ratio of tail length to SVL was greater in males ($t = 19.71$, $df = 167$, $p < 0.0001$). Simple regression revealed that there was no overlap in the range of tail to SVL ratio between males (1.387 + 0.0925 (SVL) = tail, $r^2 = 0.74$, n = 116, mean = 61.5 mm) and females (3.797 + 0.064 (SVL) = tail, $r^2 = 0.80$, n = 53, mean = 40.7 mm) indicating that this is a reliable character for sexing tiger rattlesnakes (Figure 9). Males tend to have both longer and wider heads than females, but not relative to their body size.

Most snake species show marked sexual size dimorphism, with males being the larger of the sexes (Shine 1978). Tiger rattlesnakes appear to conform to this general pattern. Various hypotheses have been proposed for why males tend to be larger than females. Among these hypotheses is the assertion that males are larger so they can be more effective in male-male agonistic encounters (Beaupre & Duvall 1998). However, this runs counter to the notion that large female body size should be selected for because larger females can give birth to more offspring, which is the case in many snake taxa (Shine 1978).

Table 5. Body and head size data (mean ± standard error) for all tiger rattlesnake age classes at all sites combined from 1997-2001. TVR = Tanque Verde Ridge, RK = Rocking K Ranch, LR = Loop Road, RMFD = Rural Metro Fire Department, F = female, M = male, SA = subadult, SVL = snout-vent length, TL = tail length, HL = head length, HW = head width.

	TVR			RK			LR			RMFD	
Parameter	**F**	**M**	**SA**	**F**	**M**	**SA**	**F**	**M**	**SA**	**F**	**M**
N	14	24	1	13	34	16	10	30	2	5	16
SVL	627 ± 6	659 ± 8	511	605 ± 7	667 ± 8	479 ± 10	604 ± 7	687 ± 8	511 ± 7	575 ± 8	678 ± 8
TL	44 ± 2	61 ± 3	38	42 ± 2	64 ± 2	41 ± 3	42 ± 2	66 ± 3	42 ± 3	42 ± 2	63 ± 3
Mass	244 ± 7	287 ± 9	113	179 ± 5	295 ± 9	91 ± 7	233 ± 8	341 ± 9	139 ± 7	240 ± 9	327 ± 11
Mass/SVL	0.389	0.436	0.221	0.296	0.442	0.190	0.386	0.496	0.272	0.417	0.482
HL	27 ± 1	27 ± 2	25	26 ± 1	28 ± 1	22 ± 2	26 ± 2	28 ± 1	26 ± 1	24 ± 1	28 ± 1
HW	20 ± 1	21 ± 2	17	19 ± 1	21 ± 1	17 ± 1	20 ± 1	21 ± 1	21 ± 1	19 ± 1	21 ± 1
HL/SVL	0.043	0.041	0.048	0.043	0.042	0.045	0.043	0.040	0.050	0.041	0.041

Tail length is often used to distinguish between sexes in snakes. Presumably, males have longer tails to accomodate their reproductive organs which are located in the tail. Another character used to sex snakes is number of subcaudal scales, with females having fewer subcaudals due to their shorter tail length. However, we observed some overlap in the number of subcaudals, suggesting that tail length relative to SVL may be a more reliable way to sex some snake species.

Reproduction

We observed reproductive activity (accompaniment, courtship, and copulation) only during the summer monsoon season (Table 6). We defined the monsoon season as beginning when the study area received its first substantial rainfall and ending when it received its last rainfall. In all years, the onset of the monsoon season was obvious due to a marked change from extremely dry to extremely humid weather conditions. Not surprisingly, we also determined that adult males produce semen more during this period (July-September) than during the spring or fall (Figure 10). Both males and females

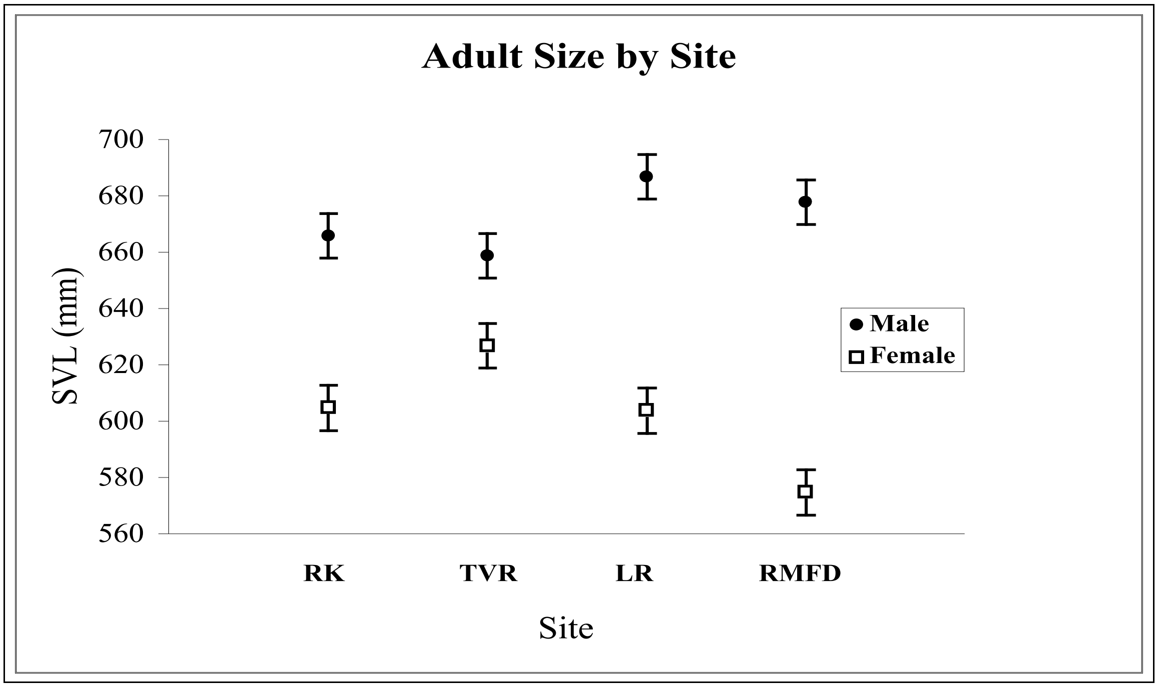

Figure 8. Adult size by sex at all four sites from 1997-2001. RK = Rocking K Ranch; TVR = Tanque Verde Ridge; LR = Loop Road; RMFD = Rural Metro Fire Department.

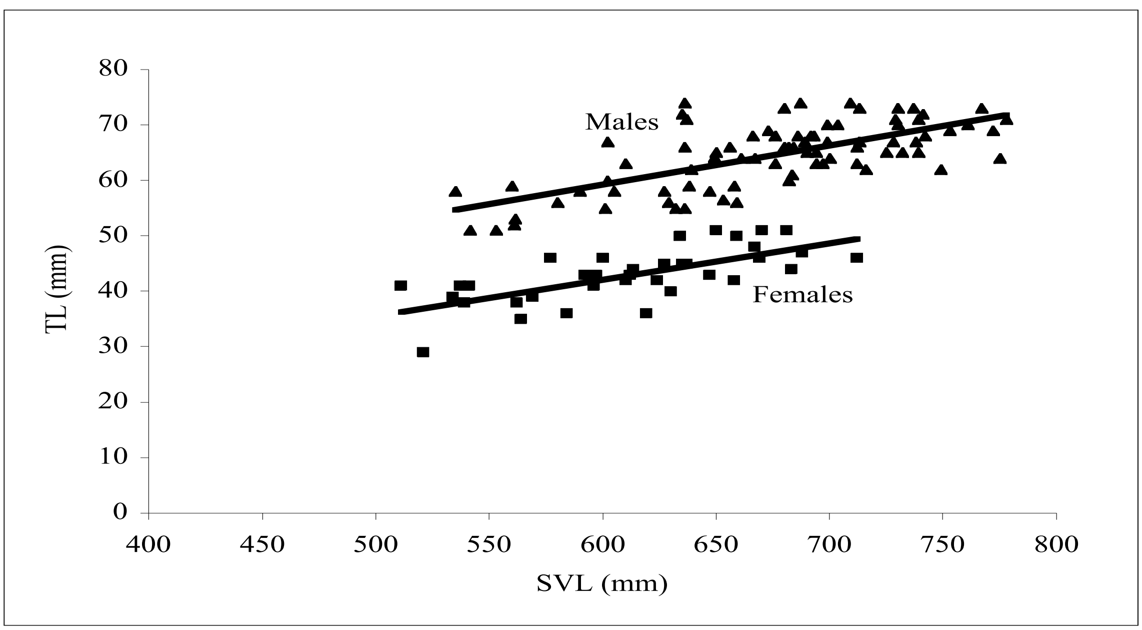

Figure 9. Graph showing the ratio of tail length (TL) to snout-vent length (SVL) in male tiger rattlesnakes (n = 169). Females (squares) exhibited no overlap with males (triangles) indicating that TL to SVL ratio is a reliable character for determining sex in tiger rattlesnakes. See text for equations and t-statistics.

Table 6. Date ranges by year of tiger rattlesnake reproductive activity (accompaniment, courtship, and copulation) compared to annual date ranges for the wet summer season.

Year	Reproductive Activity	Monsoon Season
1997	08/27 – 09/06	07/17 – 09/11
1998	07/08 – 09/22	07/03 – 09/11
1999	07/26 – 09/05	06/26 – 09/04
2000	--	06/17 – 09/11
2001	07/30 – 08/17	07/03 – 09/14
Total	**07/08 – 09/22**	**06/17 – 09/14**

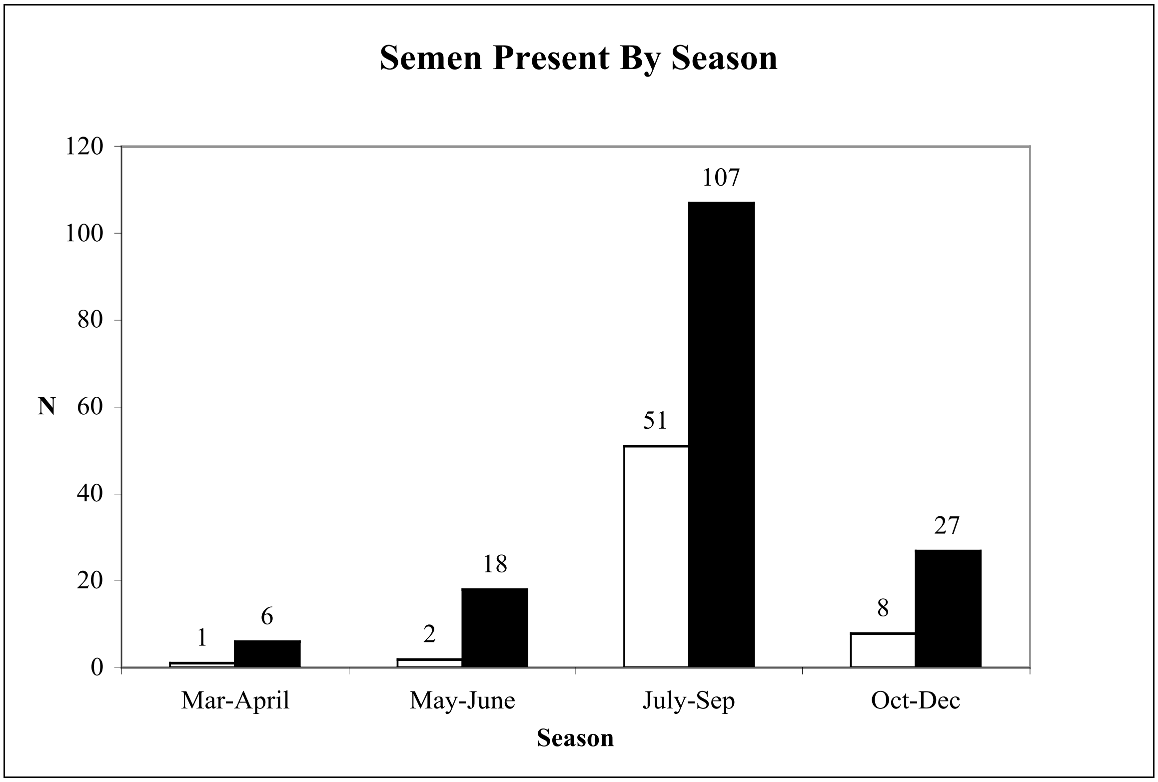

Figure 10. Seasonal incidence of semen expressed from the hemipenal shafts of male tiger rattlesnakes at all four sites from 1997-2001. White bars = semen present, black bars = all captures and recaptures combined.

paired with multiple partners (range = 2-5 partners) over the course of a single breeding season. Reproductive associations of male and female snakes lasted an average of 3.8 days (range = 1-9 days). In some cases, a male snake appeared to follow the same female over the course of a few to several days. In 1997, we were alerted by a resident living at the park boundary that a pair of tiger rattlesnakes was mating in his yard. We captured and implanted radiotelemeters into both animals. The male proceeded to follow the female over the course of several days, and we found him courting her on multiple occasions. Mating interactions between radiotagged individuals occurred on several occasions during 1998, a year of high reproductive activity, which coincided with a year in which we were radiotracking several male and female tiger rattlesnakes.

Overall, we observed tiger rattlesnakes engaged in some manner of reproductive activity 3.6% of the time (range = 0%-7.8%) when located. Far more reproductive activity occurred in 1998 than in any other year (Figure 11). A greater proportion of females gave birth in 1999 than in other years as well (Figure 12), providing further evidence that 1998 was an important breeding year (litters are born the year after mating takes place).

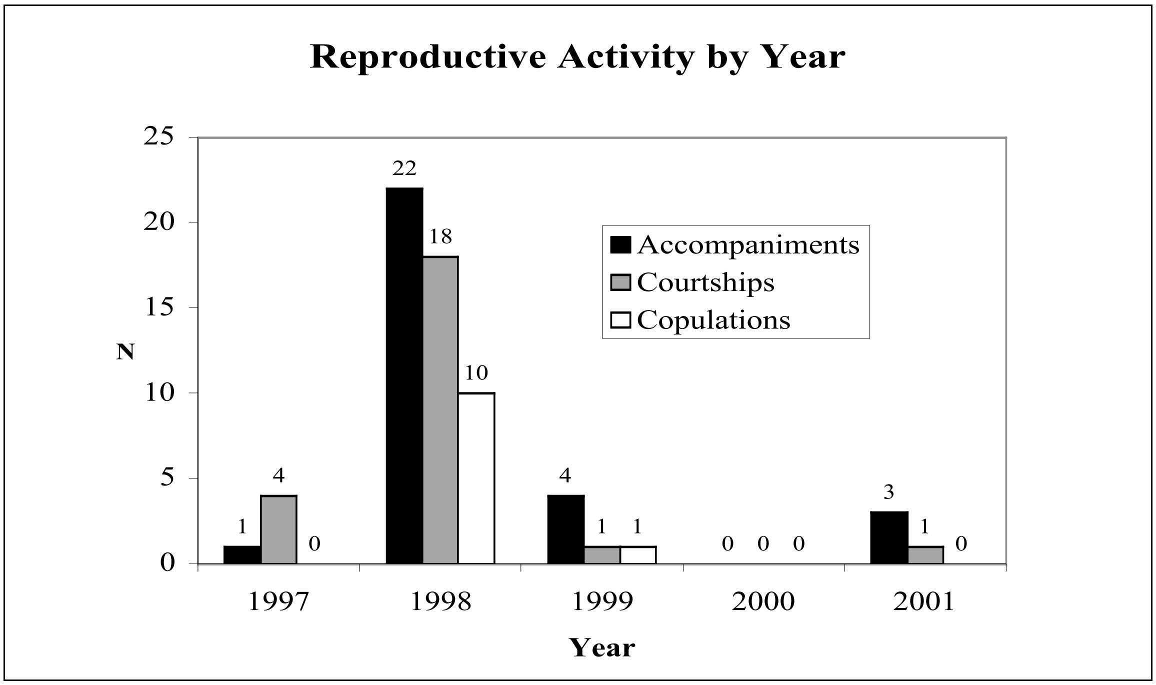

Figure 11. Tiger rattlesnake reproductive activity by year at the Tanque Verde Ridge study site from 1997-1999 and at the Tanque Verde Ridge and Rocking K study sites combined from 2000-2001.

Based on palpation of 15 gravid females, we determined average tiger rattlesnake litter size to be 3.4 ± 1.0 (SD) (range = 2-6). The actual number of young born is probably lower than our estimates, however, since we mostly performed follicle counts and not all follicles are ovulated. In any case, the exact number is small compared to litter sizes of other rattlesnake species found in Arizona (Table 7). Based on five females, which we captured to assess their reproductive condition, parturition occurred from August 1 to August 20. We were only able to obtain morphological data on one litter consisting of 5 neonates, which were born to a snake captured by RMFD personnel (Table 8). Neonates from this litter first shed their skin 8-9 days post-parturition.

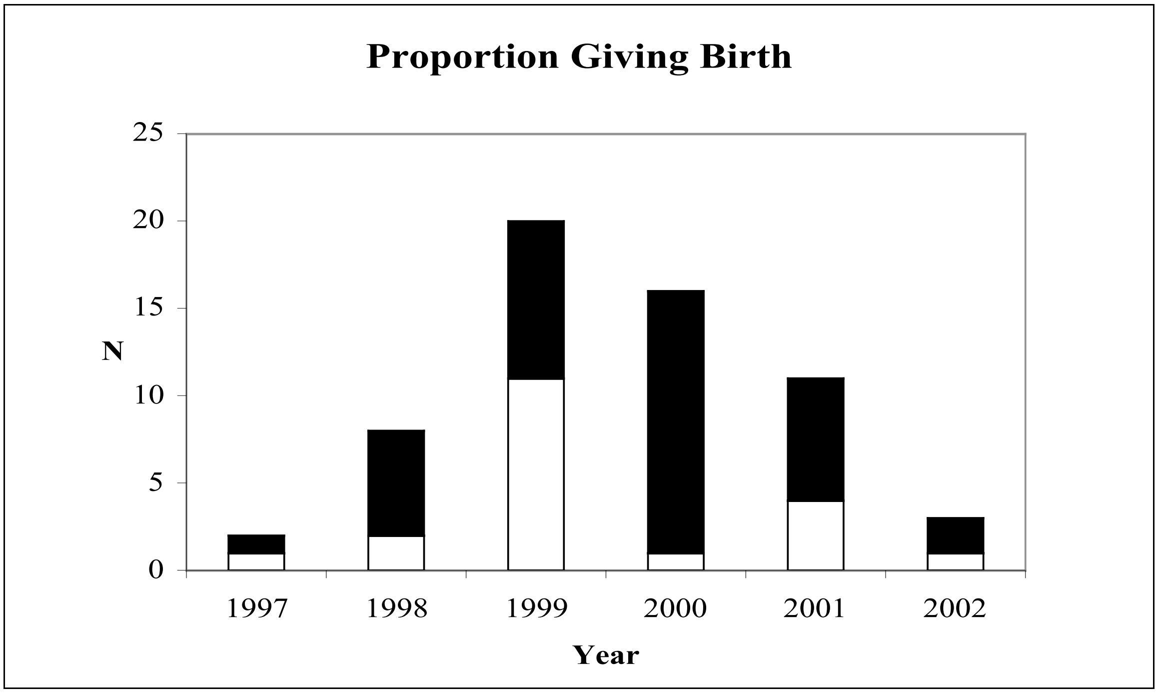

Figure 12. Number and proportion of tiger rattlesnakes giving birth by year at the Tanque Verde Ridge and Rocking K study sites from 1997-2001. White bars = gave birth; black bars = did not give birth.

Table 7. Average litter size of several rattlesnake species in Arizona (from Lowe et al. 1986).

Species	Average Litter Size
Crotalus. atrox	9
C. viridis	9
Sistrurus catenatus	9
C. scutulatus	8
C. cerastes	7
C. molossus	7
C. mitchellii	5
C. willardi	5
C. pricei	5
C. lepidus	4
C. tigris	3.4 ± 1.0 (range 2-6)

Table 8. Morphological data (mean ± standard error) for the litter born to CRTI #55, a female collected by the Tucson Rural-Metro Fire Department in 1999.

Littermate	Born	First Shed	Sex	SVL	TL	Mass	HL	HW
1	8/1/99	8/10/99	M	259	25.0	19.5	17.5	13.5
2	8/1/99	8/9/99	M	262	26.0	21.2	19.0	13.5
3	8/1/99	8/9/99	M	265	24.1	21.0	19.0	13.0
4	8/1/99	8/9/99	M	263	24.0	21.5	18.0	13.0
5	8/1/99	8/9/99	F	261	20.8	22.0	20.0	13.0
Mean			**4M:1F**	**262 ± 1.5**	**24.0 ± 1.4**	**21.0 ± 0.97**	**18.7 ± 0.99**	**13.2 ± 0.52**

On average, adult females give birth once every three years as indicated by the fact that only 33% of females captured during the course of this study were gravid. However, there was significant individual and annual variation. For example, more than half of the adult females we processed in 1999 produced a litter in that year, and two snakes gave birth in both 1998 and 1999. Gravid snakes are not significantly longer than non-gravid adult females ($t = 0.96$, $df = 42$, $p < 0.34$), but as expected, they are significantly heavier ($t = 2.30$, $df = 38$, $p < 0.03$) (Table 9). One gravid female we found measured 521 mm SVL, the smallest reproductively mature tiger rattlesnake yet recorded (cf. Goldberg 1999).

Table 9. Size (mean SVL ± standard error) of adult female tiger rattlesnakes that became gravid at any time during the study compared to size of females who were never found to be gravid, and to all adult females. Data are from all sites combined from 1997-2001

Category	SVL	Mass	N
Gravid Females	602 ± 7	245 ± 8	16
Non-Gravid Females	612 ± 7	211 ± 7	26
All Adult Females	608 ± 7	221 ± 8	42

Tiger rattlesnakes mate during the monsoon season. Females store sperm over the winter, ovulate upon emergence from their dens in the spring, and gestate until late July or early August, when they give birth. Spermatogenesis commences in late spring or early summer, and females initiate vitellogenesis during the summer monsoon of a reproductive year.

The type of mating system in effect is difficult to determine because of the variation in both male and female reproductive behavior. Tiger rattlesnakes may exhibit prolonged mate-searching polygyny (PMSP), characterized by females that are irregularly spaced, difficult to locate, and/or infrequently receptive (Duvall et al. 1992). Under this system, males find few if any females during the mating season and rarely encounter other males, resulting in very little male-male agonistic behavior (i.e., combat). We did not observe combat during the five-year study, and males in most years found only a single female, or no females at all.

In contrast, female defense polygyny (FDP), in which females are easier to locate, more abundant, and/or sexually receptive for longer periods of time (Duvall et al. 1992), may best describe the mating system in tiger rattlesnakes. Under FDP, males are expected to engage in serial mate guarding, attempting to monopolize the reproduction of multiple females in succession (Duvall et al. 1992). Males are also more likely to come into contact with other males, with combat a likely result. Indeed, we observed what appeared to be mate guarding on multiple occasions, and male-male combat in tiger rattlesnakes has been observed (P. Holm, pers. comm.). Further, while we witnessed no combat at our study sites, we did observe a male snake initiate combat behavior as we attempted to photograph him while copulating with a radiotagged female. The male rose up to combat our snake tongs while we used them to brush aside vegetation, which was obscuring our view of the copulating pair.

None of this information is convincing evidence of FDP, however, because long-term accompaniment does not necessarily represent mate guarding. Courtship and copulation behavior in male rattlesnakes is cued largely by pheromones that females produce upon shedding (Schuett 1992). Therefore, it is possible that males that remain with females for extended periods of time are simply waiting for them to shed. We observed a male vigorously courting a road-killed female, indicating the importance of chemosensory information in reproduction. In short, we need more data to determine the precise nature of the mating system of tiger rattlesnakes.

Tiger rattlesnake reproduction is extremely variable from year to year and appears to be significantly correlated with rainfall. In 1998, when we observed a dramatic increase in mating activity, we also received record amounts of rainfall due to a pronounced El Niño event (Figure 13). Rodents in the desert Southwest are known to breed prolifically following intense rainy seasons, in particular after abnormally wet winters (Y. Petryszyn, pers. comm.).

It is possible that female tiger rattlesnakes benefited from an elevated prey base in the spring and summer of 1998, accumulating sufficient fat reserves to initiate the energetically costly process of vitellogenesis. Snakes at our study sites averaged one litter every three years, but reproduction varied greatly from individual to individual. Two females gave birth in successive years (1998 and 1999), indicating that tiger rattlesnakes can reproduce annually if females have sufficient energy reserves.

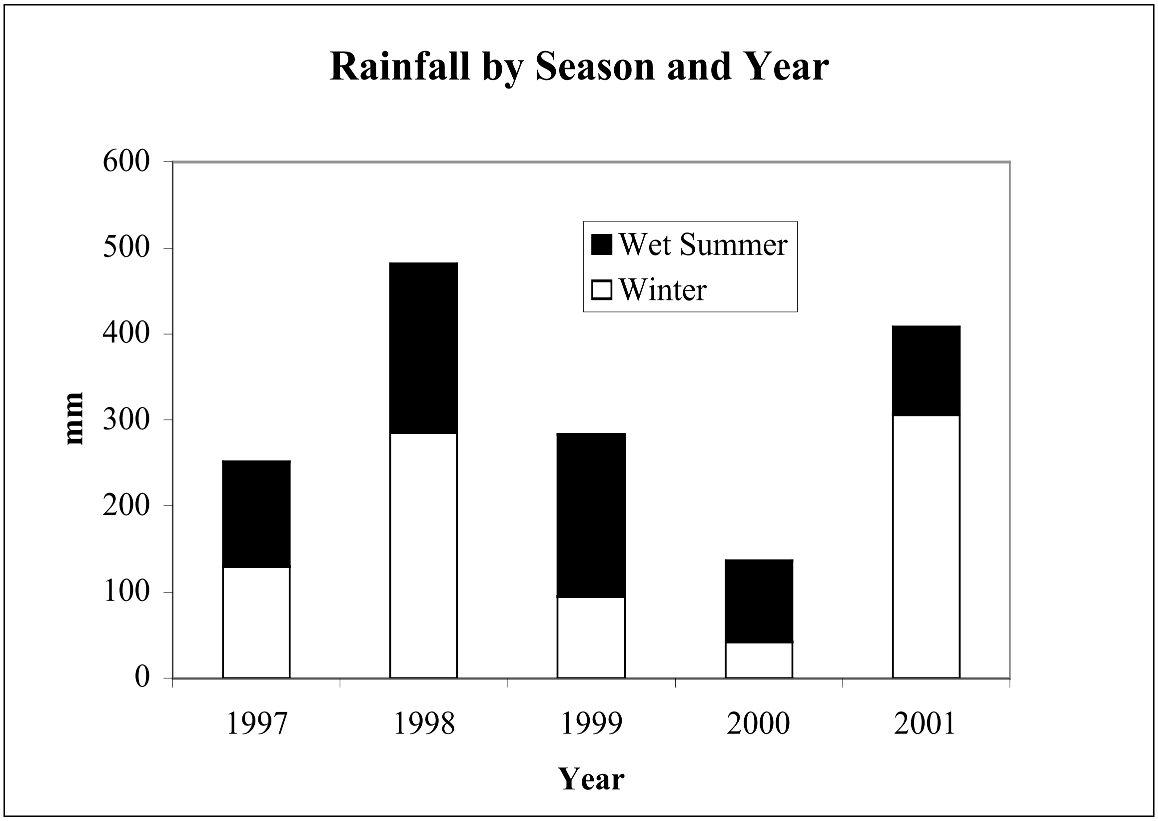

Figure 13. Seasonal rainfall by year at Saguaro National Park. Data are presented in "water years" meaning that the year begins at the onset of winter rains and ends when the summer rains end.

Growth

Females and males did not differ in annual growth rate (t = 0.58, df = 38, p = 0.57). Both sexes averaged a yearly SVL increase of 2.5%. Not surpisingly, virtually all growth occurred during the snakes' active season (April-early November) rather than over the winter, when no feeding took place (Figure 14).

We observed growth-rate differences between sites. Snakes at TVR grew more than twice as fast as snakes at the RK (Figure 15); however, these differences were not statistically significant (F = 2.57, df = 33, p = 0.14). Site differences in growth rates may be a consequence of divergent diets at the two sites. Snakes at TVR consumed primarily small mammals, relatively large prey with a high energy yield, while tigers at RK ate mostly lizards (see below). Thus, snakes at TVR may be accruing more energy, and as a result may be able to devote more resources to growth.

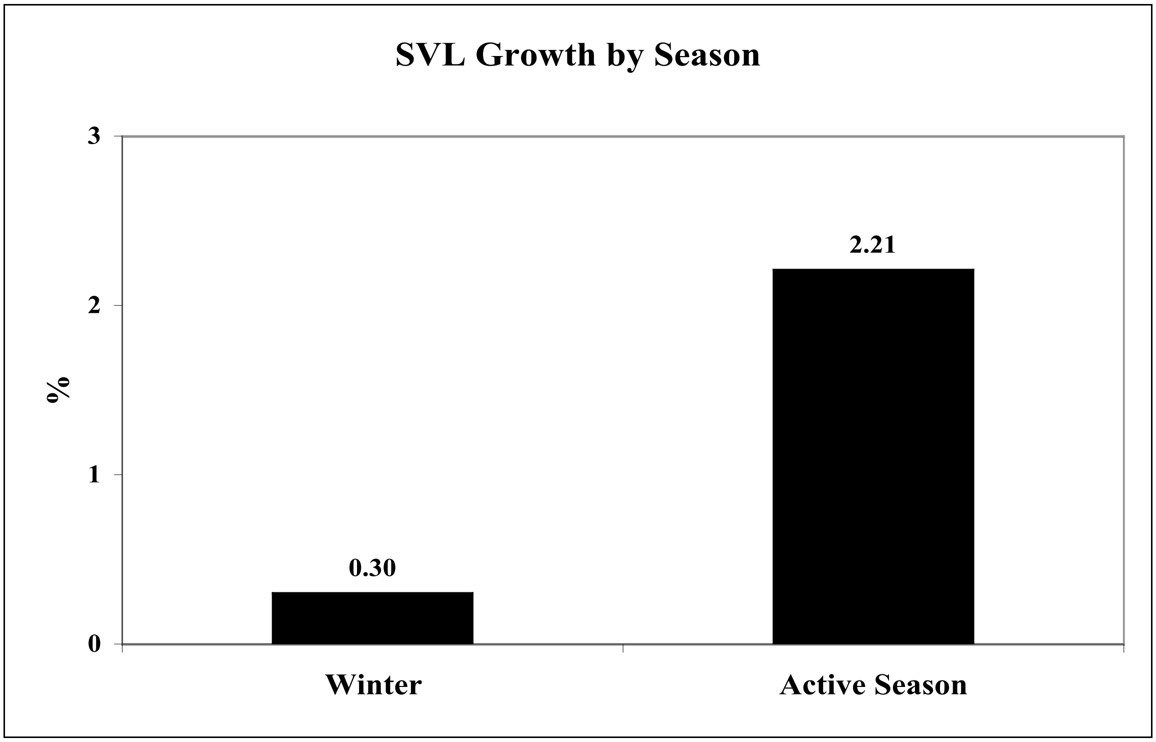

Figure 14. Mean annual growth in SVL for all tiger rattlesnakes combined, 1997-2001.

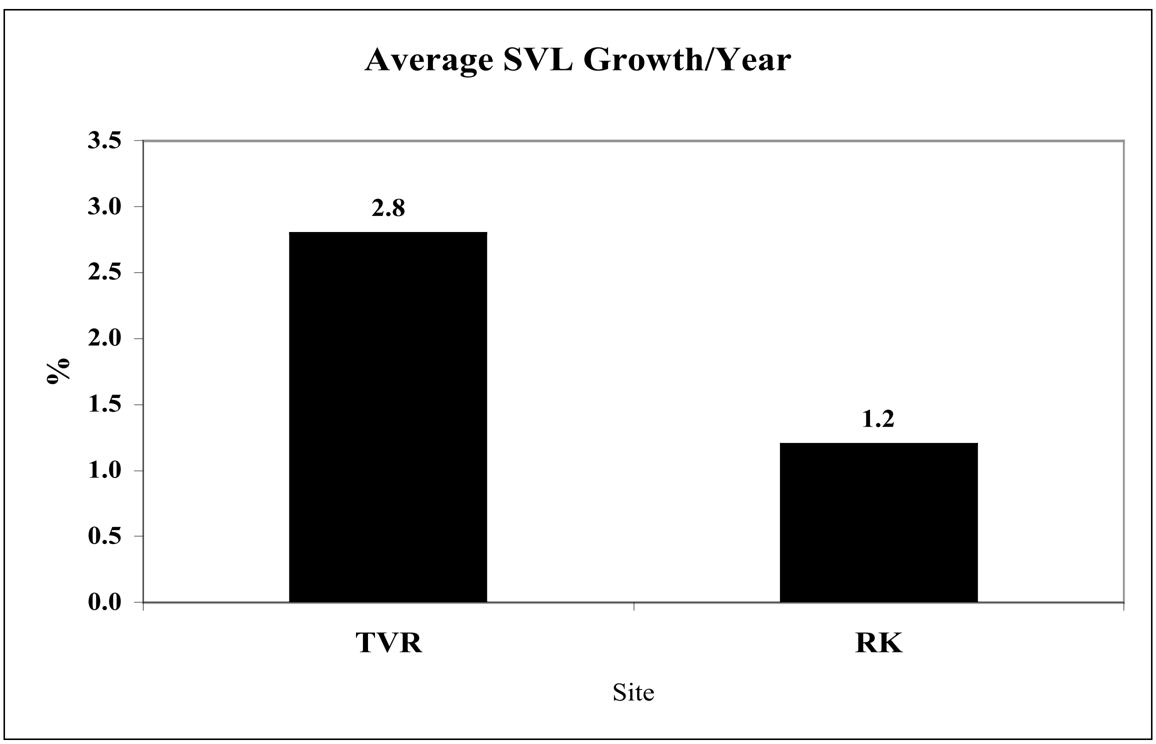

Figure 15. Average growth rate per year of all tiger rattlesnakes combined by site.

Our data suggest that implantation of radiotelemeters may retard growth in tiger rattlesnakes. Snakes without radios grew more than twice as rapidly as snakes with radios ($F = 8.96$, $df = 37$, $p = 0.01$; Figure 16). Perhaps implanted snakes spend more time basking to recover from surgery, compromising other activities such as foraging. It seems reasonable to assume that some energy must be allocated to healing at the expense of growth. Indeed, snakes with radios shed more often than those without (1.3 sheds/year and 1.1 sheds/year respectively), although this difference was not statistically significant ($t = 1.39$, $df = 24$, $p = 0.18$). Shedding in response to injury is a known response in snakes (Rubio, 1998).

However, short-term effects of surgery are not likely to be a major factor in growth-rate disparity, because snakes that had been implanted for two years still exhibited diminished growth. Perhaps the radiotag implant is constantly being "fought off" by the snakes immune system. Such a prolonged heightened immune response would of course require energy. It is also possible that the bulk of the transmitter may render the snake less mobile and as a result, less able to obtain prey. At this point, we cannot definitively say

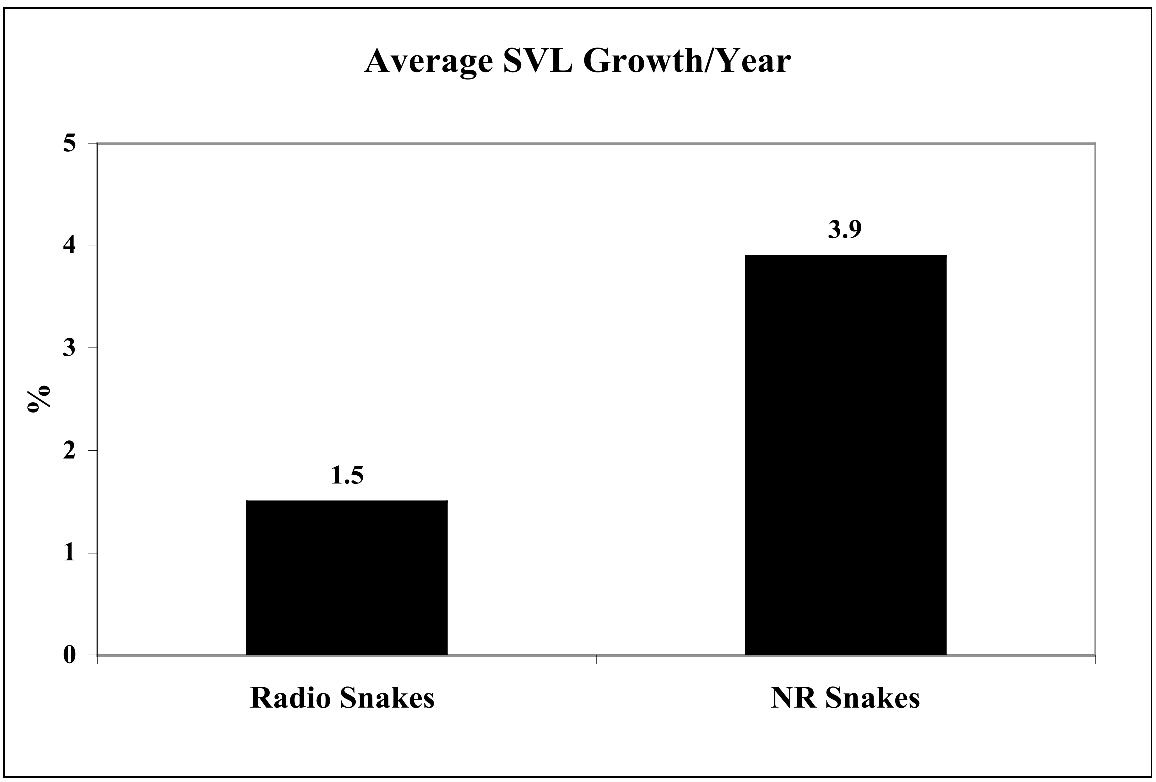

Figure 16. Average growth rate of tiger rattlesnakes implanted with a radiotag (Radio Snakes) and snakes without a radiotag implant (NR Snakes). Although snakes without implants grew more than twice as much as snakes with implants, the results were not statistically significant ($t = 0.61$, $df = 51$, $p < 0.512$) due to high individual variation in growth rates.

how transmitter implantation impacts tiger rattlesnake growth (or any other aspect of their biology). More research is needed to determine how the powerful and increasingly pervasive technique of radiotelemetry is affecting the biology and behavior of study organisms. Recognizing that effects of radiotelemetry implants may be negative is important, because it enables us to better determine potential sources of error in our data.

Spatial Ecology

We implanted radiotelemeters into 35 tiger rattlesnakes, which we located 2627 times (Figure 17). We utilized several movement and space-use parameters to compare the spatial ecology of males and females (Table 10). Females had smaller home ranges than males (Table 10; Figure 18), which is not surprising given that in most rattlesnake species males actively search for relatively sedentary female mates (Duvall et al. 1992). Both sexes exhibited seasonal differences in home range size and movement patterns, with conspicuous spikes occurring in wet summer, when most feeding and all mating takes place (Table 10; e.g., Figure 19). However, some seasonal activity differences between

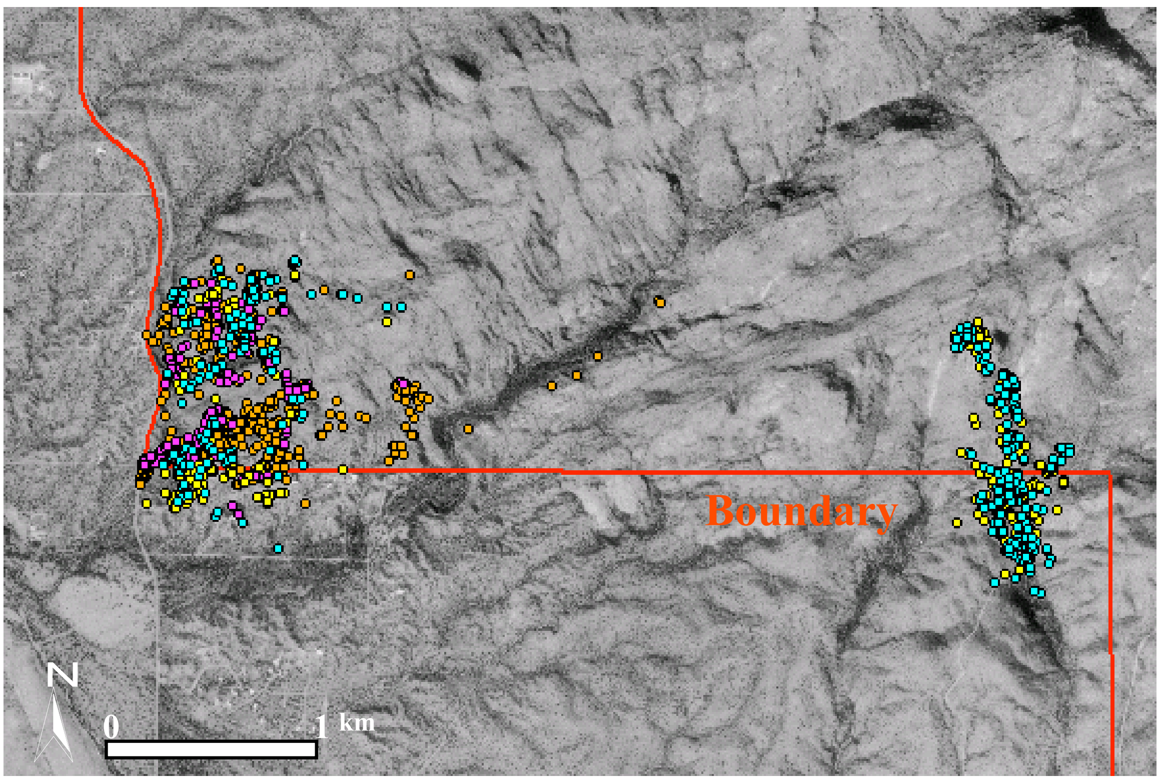

Figure 17. Digitized aerial photograph showing 2627 locations of 35 tiger rattlesnakes at the Tanque Verde Ridge study area (left) and the Rocking K Ranch study area from 1997-1998 and 2000-2001. Data for 1999 are not included because of technical difficulties with GPS post-processing. 1997 = purple, 1998 = orange, 2000 = blue, and 2001 = yellow.

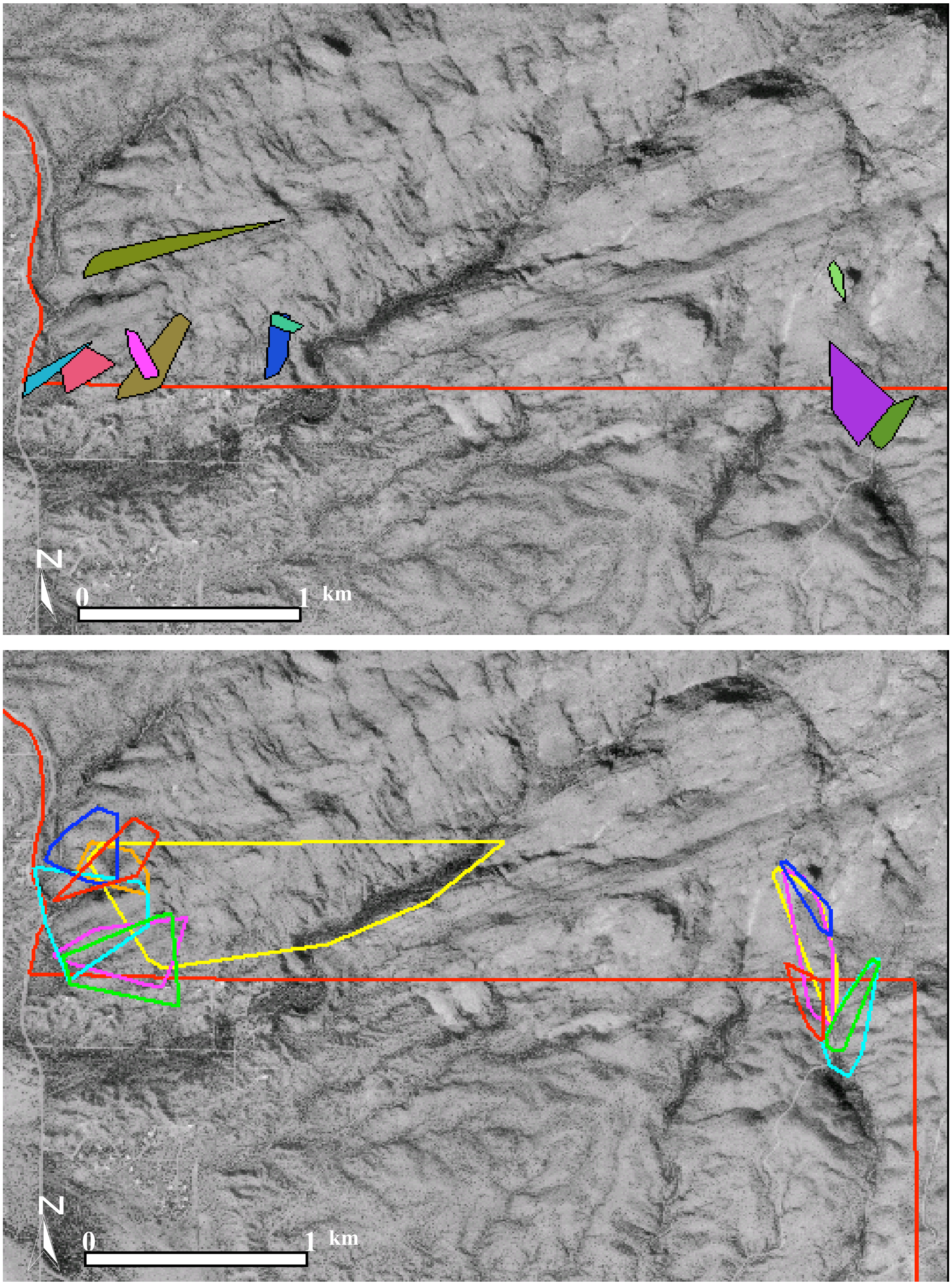

Figure 18. Minimum convex polygon home ranges for selected females (top) and males (bottom) at the Tanque Verde Ridge and Rocking K study areas. There is substantial overlap in male home ranges, therefore only the home range outline is displayed.

the sexes were apparent. Females moved more during the spring than males did (Table 10), which may be explained by the fact that females emerged from hibernation an average of 18 days (April 5 for females as opposed to April 23 for males) sooner than males did. By May and June (dry summer), males were more active and mobile than females and remained so until entering their winter dens in late October or November.

Males, but not females, exhibited annual differences in home range size and movement patterns in 1998 compared to 1997 (Figure 20). As noted above, 1998 was a very wet year during which a tremendous amount of tiger rattlesnake reproductive activity occurred. Thus increased male movement in 1998 probably reflected greater mate-searching activity stimulated by abnormally high rainfall. As female movement patterns remained relatively constant, differences in foraging behavior from year to year were not implicated.

We have not yet intensively investigated space use by site, but some differences do seem to exist. For instance, tiger rattlesnake movements at the RK were of a much more linear (north-south) nature than at TVR (Figure 17). We believe this is due to topographical differences between sites. At RK, one major north-south wash drains most of the study area, while TVR is characterized by a network of arroyos. As tiger rattlesnakes tend to use washes during the active season (see below), wash orientation probably has an effect on snake movement patterns.

Feeding and Diet

Prior to this study, the feeding habits of tiger rattlesnakes were not well known. The species' small head size has led to the suggestion that it consumes primarily lizards (Lowe et al. 1986, Ernst 1992). However, data from fecal samples revealed that tiger rattlesnakes take a variety of prey types and that they appear to feed predominantly on small mammals (Figure 21).

Both male and female tiger rattlesnakes foraged most actively and most successfully during the summer monsoon season (Figure 22). However, some gender differences in diet did exist, although these differences were not statistically different ($\chi^2 = 0.89$, df = 1, 87, $p = 0.35$). Males consumed an approximately equal proportion of lizards and rodents, while females ate more small mammals (Figure 23). This difference is probably not a consequence of divergence in head or body size, because males are larger than females. Rather, the difference may result from greater energy requirements of adult females. Vitellogenesis and embryo development are extremely costly activities; perhaps females need larger, higher-energy prey than males do. Another possibility is that diet differences are a residue of activity and movement differences between the sexes. Males move more frequently and travel greater distances than females, especially during the wet-summer active season. Therefore, males are likely to encounter more lizards (either active or resting; see below) than females. Females may be more restricted to rodents by their more sedentary habits.

Table 10. Summary of movement and home range data (mean ± standard error) for tiger rattlesnakes at Tanque Verde Ridge and Rocking K from 1997-2001 (N = 2627). Data from individual snakes were not used in the analyses unless the number of radiotelemeter fixed was at least n = 30.

Season	Parameter	Males	Females
Total	Total Distance Moved*	4009 ± 326.4	1578 ± 176.5
	Distance/Movement*	92.7 ± 7.3	42.4 ± 6.4
	Distance/Day*	22.4 ± 2.4	9.8 ± 1.2
	MCP*	15.0 ± 4.2	3.3 ± 0.5
	95% Active Kernel*	19.1 ± 4.8	4.6 ± 0.8
	50% Core Area*	3.4 ± 0.8	0.9 ± 0.2
Spring	Total Distance Moved	130 ± 53.2	219 ± 67.5
	Distance/Movement	24.0 ± 8.3	34.8 ± 13.1
	Distance/Day	3.7 ± 1.5	6.3 ± 2.0
	MCP	0.2 ± 0.2	0.3 ± 0.2
	95% Active Kernel	2.6 ± 1.5	3.1 ± 2.6
	50% Core Area	0.6 ± 0.4	0.5 ± 0.4
Dry Summer	Total Distance Moved*	481 ± 206.2	103 ± 45.2
	Distance/Movement	61.9 ± 24.9	11.9 ± 4.2
	Distance/Day*	14.6 ± 7.4	2.2 ± 1.0
	MCP*	1.5 ± 1.1	0.05 ± 0.02
	95% Active Kernel*	2.9 ± 1.0	0.3 ± 0.1
	50% Core Area*	0.6 ± 0.2	0.05 ± 0.02
Wet Summer	Total Distance Moved*	2142 ±281.4	707 ± 106.9
	Distance/Movement*	91.0 ± 11.2	32.6 ± 4.2
	Distance/Day*	34.9 ± 4.4	11.4 ± 1.6
	MCP*	10.1 ± 1.8	1.7 ± 0.6
	95% Active Kernel*	16.9 3.8	3.8 ± 1.3
	50% Core Area*	3.0 ± 0.9	0.8 ± 0.2
Fall	Total Distance Moved*	1002 ± 263.9	438 ± 61.5
	Distance/Movement*	65.3 ± 13.9	30.9 ± 5.1
	Distance/Day*	28.4 ± 7.3	11.7 ± 2.0
	MCP*	5.0 ± 1.8	0.7 ± 0.1
	95% Active Kernel*	15.2 ± 5.9	2.7 ± 0.6
	50% Core Area*	3.1 ± 1.1	0.6 ± 0.2

***Significant at a = 0.05**

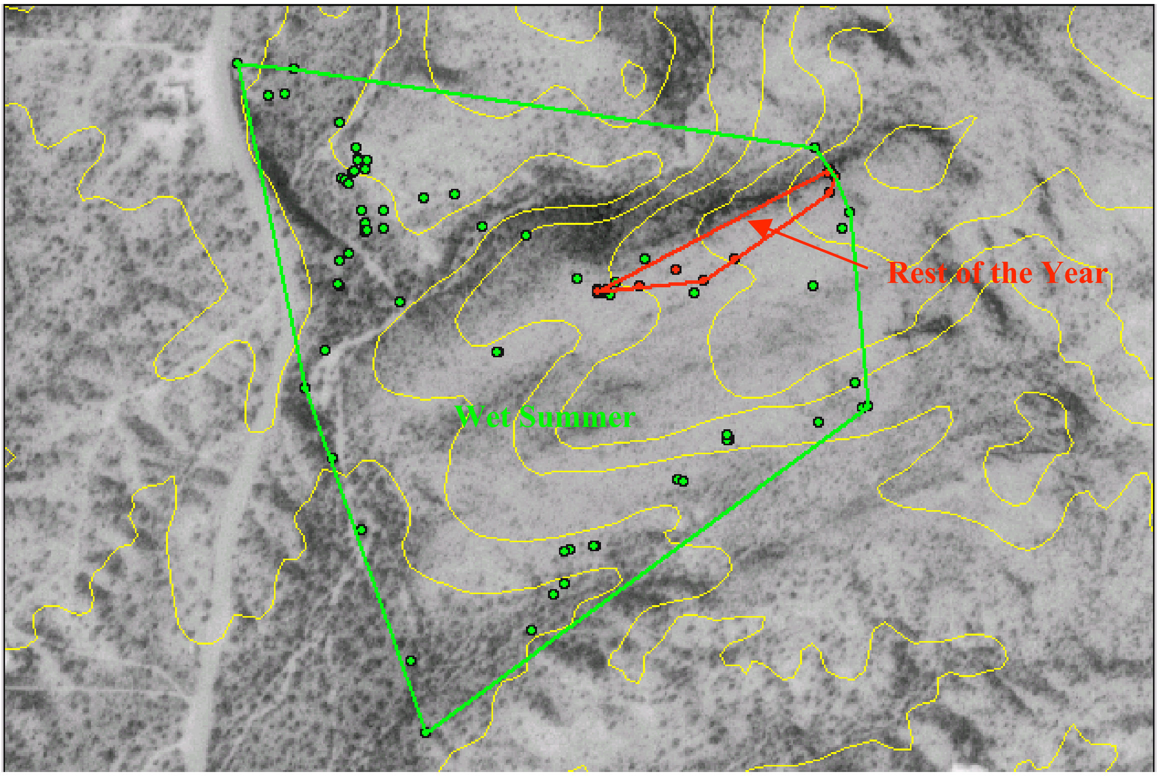

Figure 19. Minimum convex polygon home ranges for wet summer compared to the rest of the year for a male tiger rattlesnake at Tanque Verde Ridge in 1998. This pattern of seasonal home range use was typical for all tiger rattlesnakes, although more so for males than for females.

We also observed feeding differences between sites ($\chi^2 = 4.73$, df = 1, 74, p = 0.03). Tiger rattlesnakes took more lizards than rodents at RK, but nearly three times more rodents than lizards at TVR (Figure 24). We did not observe snakes to employ divergent foraging strategies from site to site. Rather, our data reveal that lizards are simply more abundant at RK (Table 11).

Of 29 identified lizard remains in tiger rattlesnake feces, 27 were whiptails (*Cnemidophorus* species). Whiptails are active, fast-moving diurnal lizards that are extremely common at RK and less so at TVR (Table 11). The few feeding episodes we observed, suggest that tiger rattlesnakes ambush whiptails that wander into striking range (as they do with rodents); however, active searching for sleeping or resting lizards may also be important. We witnessed what appeared to be active foraging on multiple occasions, as snakes were observed to move throughout woodrat middens and other rodent burrow systems, exhibiting increased tongue-flicking.

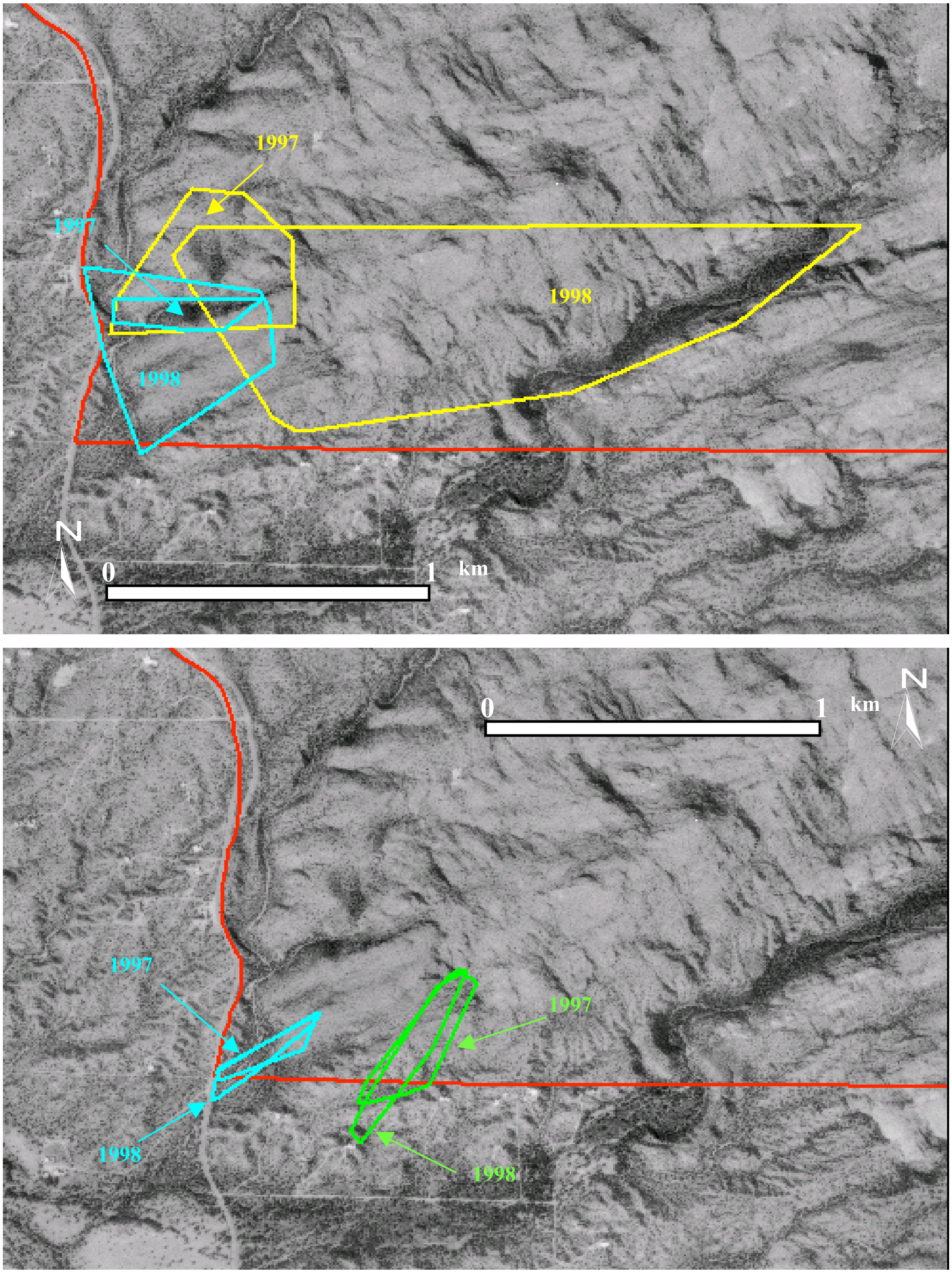

Figure 20. Minimum convex polygon home ranges for selected males (top) and females (bottom) at the Tanque Verde Ridge study area in 1997-1998. Male home range size varied in size from year to year, but female home range size did not.

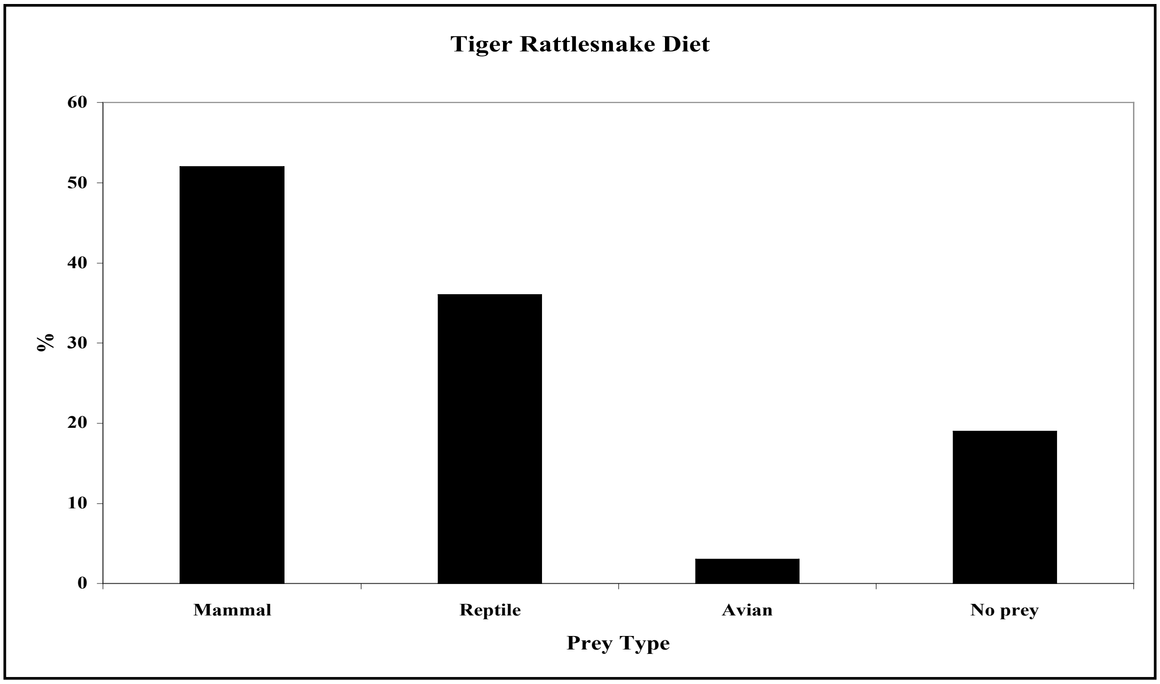

Figure 21. Percent of prey types in tiger rattlesnake diet for 105 tiger rattlesnakes from all sites combined from 1997-1999.

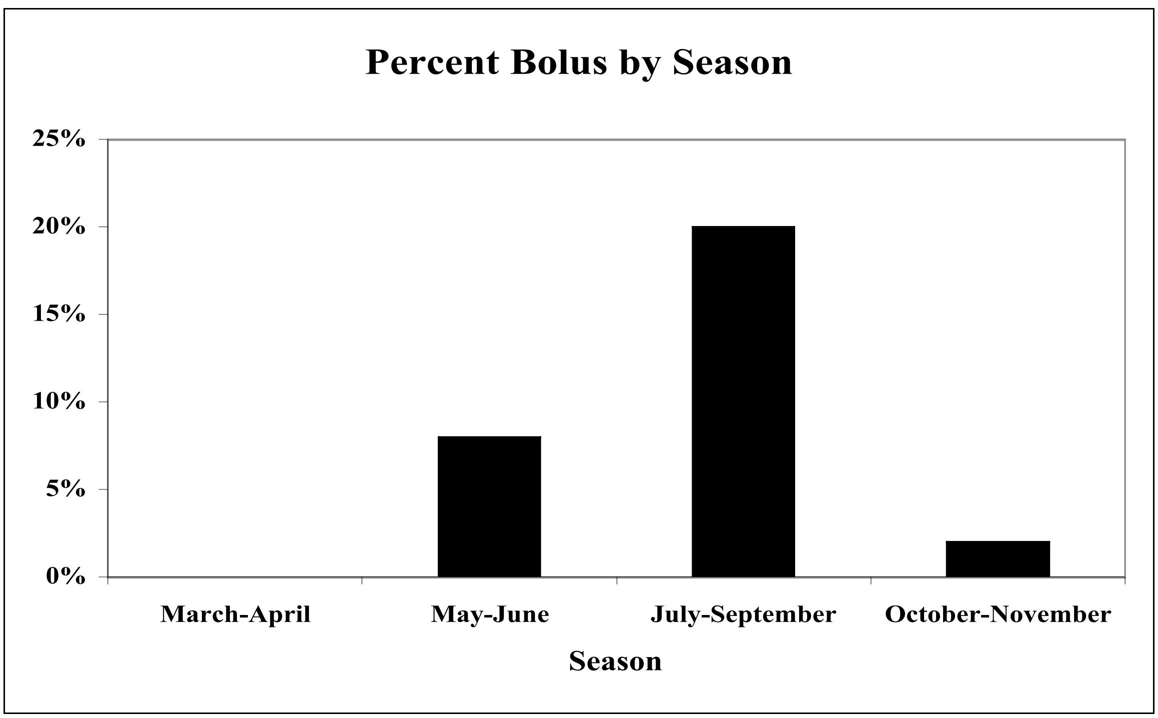

Figure 22. Percentage of tiger rattlesnakes (all sites and all years combined) found to contain a food bolus in their gastrointestinal tract at different times of the year. Food boli were detected via external palpation.

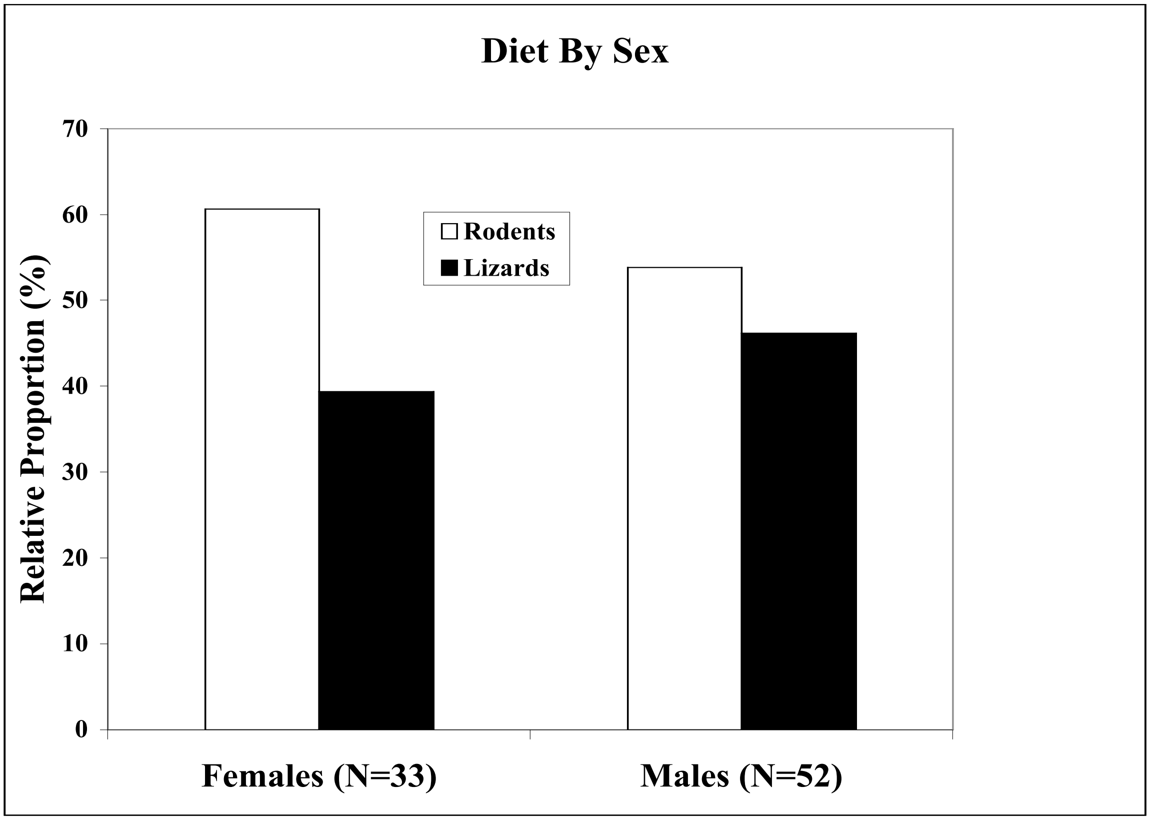

Figure 23. Proportion of male and females tiger rattlesnakes eating rodent and lizard prey at all site and in all years combined.

Table 11. Relative abundance, by site, of lizard species (all except *Heloderma suspectum*) considered potential prey of tiger rattlesnakes.

Lizard Category	TVR	RK	Total
Prey lizards	364	527	891
Cnemidophorus individuals	149	227	376
Prey lizards/hour search effort	0.48	1.56	0.81
Cnemidophorus individuals/hour search effort	0.19	0.68	0.34

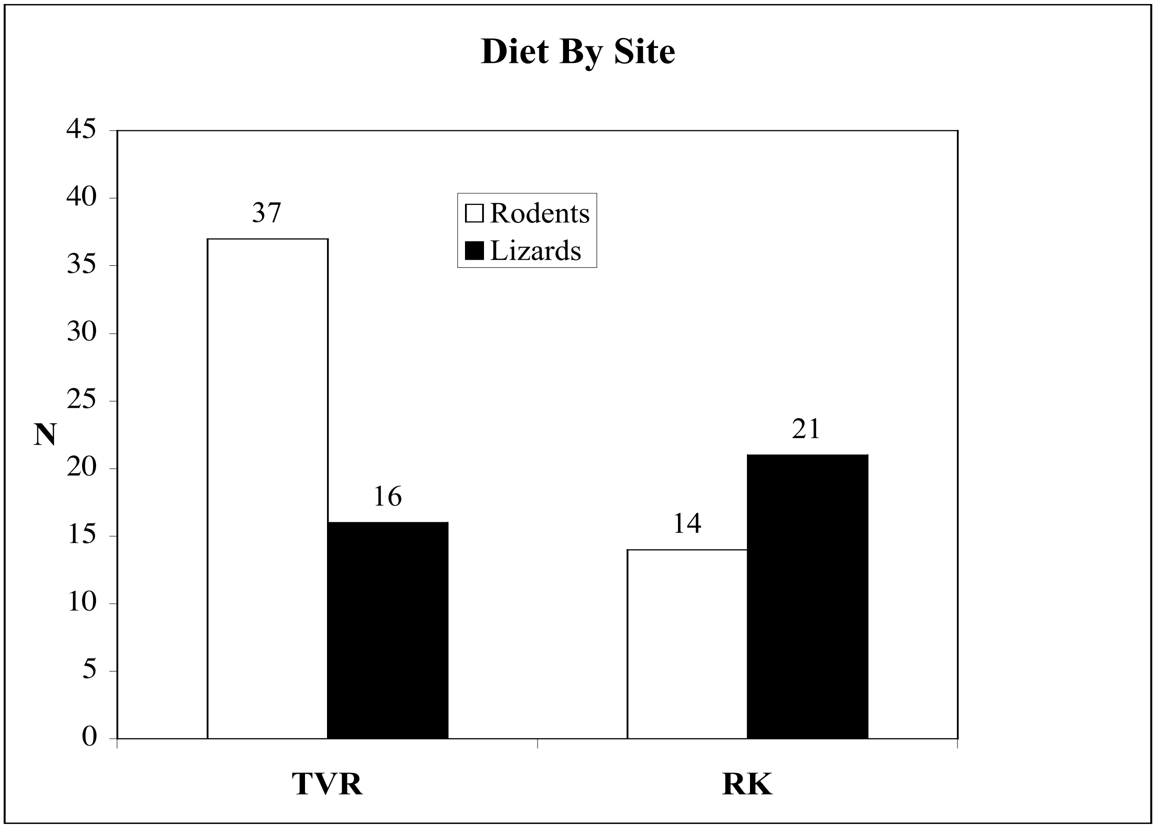

Figure 24. Number of tiger rattlesnake fecal samples containing rodent and lizard remains by site.

Habitat

Logistic regression analysis performed on microhabitat data from 1997 revealed differences in habitat use between sexes that varied by habitat type (uplands [= slope and ridge] versus lowlands [= wash and bajada]) (Table 12). The differences were based on comparison with random locations within tiger rattlesnake home ranges. In lowlands, female tiger rattlesnakes were associated with significantly greater shrub, tree and canopy cover than males. Males were found more often in prickly pear cactus than females and males were also found closer to woodrat middens. In uplands, females were associated with greater grass and tree cover than males.

These results seem to reflect the tendancy for females to remain in cover more often than males, which is likely a byproduct of males' tendancy to move more often than females. Increased movement on the part of males is in turn related to the fact they must actively search for more sedentary females in order to obtain mating opportunities. Likewise, the tendancy for males to be found in association with woodrat middens reflects their predilection to actively forage, whereas females ambush more often (see Diet and Feeding).

Table 12. Logistic regression analysis of microhabitat data for locations (N = 203) of 10 tiger rattlesnakes, Tanque Verde Ridge site, 1997. Lowlands = wash and bajada, uplands = slope and ridge. P>F = ANOVA, P>C^2 =Kruskal-Wallis ANOVA on ranks, which was used to determine final probabilities because the variables were not normally distributed.

Lowlands Category	**Male**	**Female**	**P>F**	**P>C^2**	**Sex**
Midden Distance	3.68	6.13	0.057	0.058*	F
% Exposed	31.18	30.78	0.964	0.962	
% Litter	18.82	5.81	0.039	0.754	
% Grass	14.41	18.75	0.581	0.501	
% Forb	1.47	4.09	0.514	0.416	
% Shrub	3.23	24.77	0.021	0.063*	F
% Tree	0.59	7.73	0.040	0.009**	F
% Cactus	30.29	12.16	0.009	0.004**	M
% Canopy	10.00	23.00	0.081	0.086*	F
		Uplands			
Midden Distance	6.26	5.33	0.589	0.693	
% Exposed	62.12	52.14	0.229	0.294	
% Litter	4.24	9.05	0.377	0.360	
% Grass	0.76	7.38	0.051	0.088*	F
% Forb	6.36	2.62	0.292	0.189	
% Shrub	10.30	12.86	0.682	0.984	
% Tree	0.76	4.52	0.024	0.051*	F
% Cactus	15.45	11.43	0.497	0.231	
% Canopy	10.15	9.76	0.954	0.800	

***P < 0.10**
****P < 0.05**

Tiger rattlesnakes exhibited pronounced seasonal differences in habitat use (Figure 25). The typical pattern consisted of very low activity in spring and dry summer as snakes remained mostly on rocky slopes with some individuals moving into washes. We observed a dramatic increase in movment during wet summer as snakes primarily used wash and bajada areas to forage and mate. In fall, tigers continued to move, although less so than in wet summer, as snakes made their way back to their winter dens located on rocky slopes above washes and bajada areas.

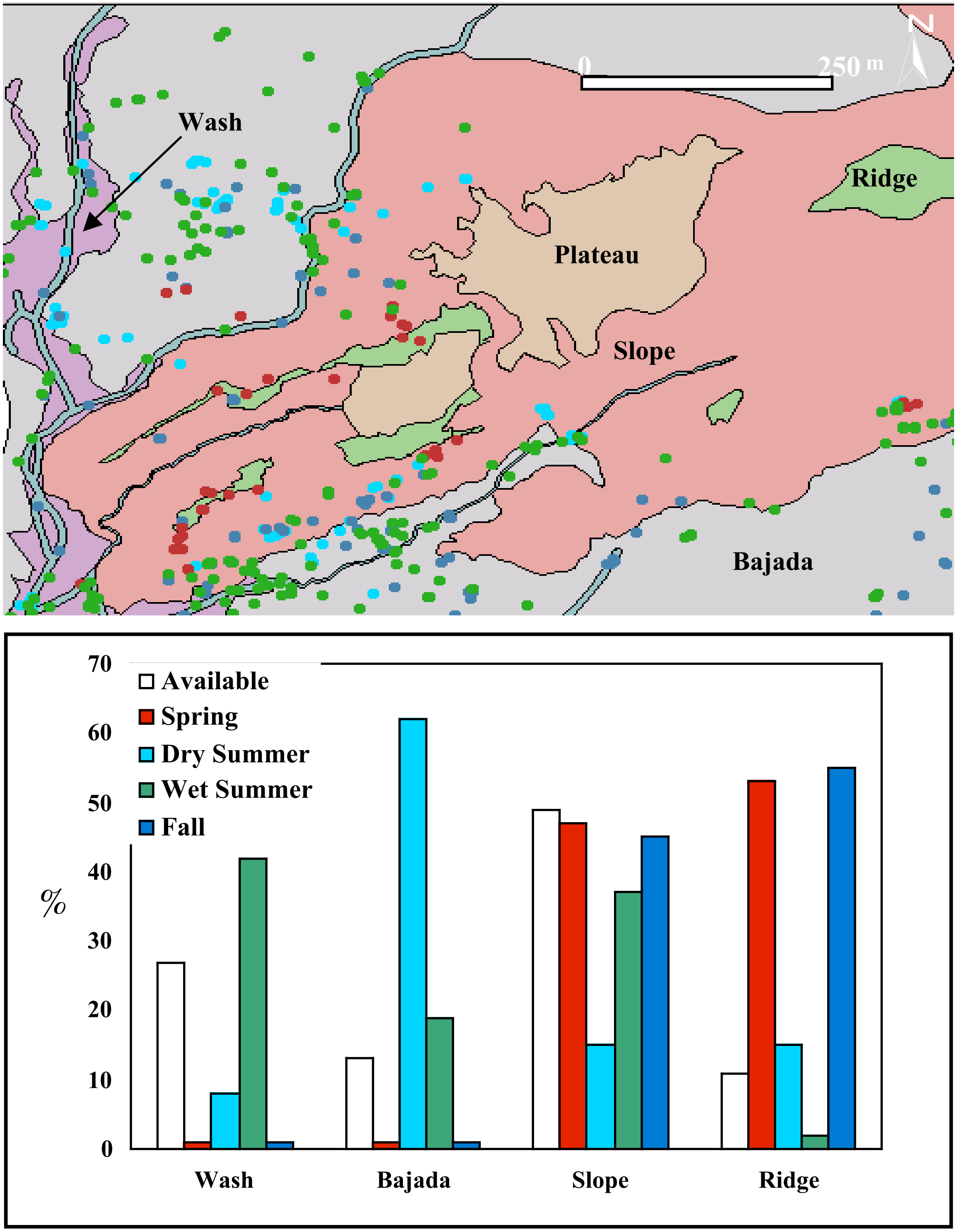

Figure 25. Tiger rattlesnakes exhibit pronounced seasonal variation in movement patterns and habitat selection. The habitat map (top) shows a subset of tiger rattlesnake locations from 1997-1998. The histogram (bottom) shows the proportion of tiger rattlesnake locations relative to availability of each habitat type.

Small-Mammal Trapping

Small mammal diversity varied by habitat type at our study sites (Table 13). Although relative abundance of small mammals varied by habitat type, we were unable to precisely quantify the differences using mark-recapture data because sample sizes were low. We had hoped to draw conclusions regarding potential interactions of tiger rattlesnakes and their small-mammal prey, but dismal trapping success made it difficult. However, we did document distinct changes in species composition among habitat types. For example, *Chaetodipus intermedius* is only found on rocky slopes and ridges, while *C. penicilatus* is only found in wash and bajada areas.

These habitat differences may play a role in tiger rattlesnake foraging ecology. We may be able to address this more thoroughly as we progress with our fecal analyses. Presumably, we will be able to pinpoint more accurately the rodent species consumed by tiger rattlesnakes. This will allow us to say more about the effect of habitat type on tiger rattlesnake diet, which we can then couple with information on season, sex, reproductive status and body size.

Table 13. Small mammals trapped at the Tanque Verde Ridge site from 1998-1999. CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus peniculatus*, CHIN = *Chaetodipus intermedius*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*, NEAL = *Neotoma albigula.*

Habitat Type	Species	Number Caught	Number Recaptured	Population Estimate	95% CI
Wash	CHBA	50	11		
	CHPE	22	15	15	14-25
	CHIN	1	0		
	PEAM	7	4	7	7-17
	PEER	2	0		
Slope	CHBA	5	19		
	CHPE	3	1		
	CHIN	9	1	23	10-105
	NEAL	12	1		
	PEER	6	2		
Ridge	CHBA	2	2		
	CHIN	18	5	31	23-55
	PEER	4	4		
	NEAL	2	1		
Bajada	CHBA	7	2		
	CHPE	17	13	21	19-33
	NEAL	3	0		

Lizard Abundance Index

We incidentally encountered a total of 46 reptile and amphibian species at TVR and RK (Table 14), 16 of which were lizards. Lizard species composition differed little between

Table 14. Numbers of individuals and hours required to encounter an individual of all reptile and amphibian species encountered incidentally at both the TVR and RK sites from 1997-2001.

Species	Number of Individuals	Hours/Individual
Arizona elegans	1	2550
Bufo alvarius	17	150
Bufo cogntus	2	1275
Bufo punctatus	13	196
Callisaurus draconoides	59	43
Chilomeniscus cinctus	1	2550
Cnemidophorus burti	1	2550
Cnemidophorus flagellicaudus	5	510
Cnemidophorus spp.	279	9
Cnemidophorus tigris	90	28
Cophosaurus texanus	80	32
Coleonyx variegatus	6	425
Crotalus atrox	62	41
Crotalus molossus	5	510
Crotalus scutulatus	1	2550
Crotaphytus collaris	9	283
Eumeces fasciatus	1	2550
Gopherus agassizi	60	43
Heloderma suspectum	37	69
Hyla arenicolor	1	2550
Hypsiglena torquata	3	850
Kinosternon sonoriense	1	2550
Lampropeltis getula	6	425
Leptotyphlops humilis	1	2550
Masticophis bilineatus	13	196
Masticophis flagellum	9	283
Micruroides euryxanthus	3	850
Phrynosoma solare	14	182
Pituophis catenifer	2	364
Rana catesbeiana	1	2550
Rana yavapaiensis	1	2550
Rhinocheilus lecontei	17	150
Salvadora hexalepis	8	319
Sceloporus clarki	80	32

Table 14 (con't.)

Species	Number of Individuals	Hours/Individual
Scaphiopus couchi	9	283
Sceloporus magister	20	128
Sceloporus spp.	4	638
Thamnophis cyrtopsis	11	232
Urosaurus ornatus	167	15
Uta stansburiana	81	31

sites; we found 15 species at TVR and 13 at RK, and only three (*Cnemidophorus burti*, *Crotaphytyus collaris*, and *Eumeces obsoletus*) were observed at one site but not the other. However, obvious differences in lizard relative abundance between sites were apparent. Lizards were much more common at RK than at TVR. Furthermore, known or potential prey species (which we defined as all species except *Heloderma suspectum* based on body size) were more abundant at RK (Table 11). This pattern held for whiptails (Table 11), an important prey item of tiger rattlesnakes (see above).

Like tiger rattlesnakes, lizards (including whiptails), were most active and most commonly observed during the monsoon season (Table 15). Although potentially biased, because we

Table 15. Relative abundance and encounter rate of tiger rattlesnake prey lizards by season (season determined by month) at the TVR and RK sites. DS = dry summer; WS = wet summer.

Season	TVR	RK	Total	Radiotracking Hours	Prey Lizards/ Tracking Hour
Spring (Mar-Apr)	40	0	40	83	0.48
DS (May-June)	63	89	152	189	0.80
WS (July-Sept)	254	390	644	562	1.15
Fall (Oct-Nov)	3	44	47	206	0.23
Winter (Dec-Feb)	4	5	9	59	0.15

often used washes to travel from site to site, lizards also seemed to favor washes (Table 16), a preference shared by tiger rattlesnakes during their active season. Tiger rattlesnake activity periods and habitat preferences may therefore have evolved at least in part to take advantage of lizard prey.

Table 16. Relative abundance of tiger rattlesnake prey lizards by habitat type at the TVR and RK sites from 1997-2001.

Habitat Type	TVR	RK	Total
Bajada	18	52	70
Ridge	11	42	53
Slope	21	113	134
Wash	116	174	290

MANAGEMENT IMPLICATIONS

In addition to studying tiger rattlesnake natural history and ecology, our objective was to use this knowledge to develop more effective management strategies for rattlesnakes in general. The results of this research have implications for rattlesnakes that live along the boundaries of parks and preserves and that move into adjacent urbanized areas. In addition, our results lead to possible management strategies for how to mitigate the effects of translocating rattlesnakes away from urbanized areas. And finally, our findings enable us to predict how the impending Rocking K development may affect rattlesnakes living in the area.

The TV site is situated along the boundary of SNP adjacent to a low-density residential housing area. Several radiotelemetered tiger rattlesnakes moved in and out of the park during the course of the study, and several more non-radiotelemetered snakes were either captured on private land or found by residents on their property (Figure 26). The community living along the park boundary at this site has been there for decades, and the residents living there are very enlightened when it comes to living with wildlife. Several residents expressed a keen interest in our research and even professed to be rattlesnake enthusiasts. However, some residents still insisted on killing rattlesnakes found in their yard. In general, however, the combination of environmentally sensitive landowners and a low density of residents may bode well for rattlesnakes. Our radiotagged snakes were found repeatedly in and around peoples' yards without incident. Most houses in the area are on lots of 5-40 acres, which seems to give the rattlesnakes plenty of space to move in without contacting people on a frequent basis. Furthermore, there is only one main road that provides access to the housing area and it is neither paved, nor does it pass through tiger rattlesnake habitat. The lack of roads in the area further allows for peaceful coexistence of rattlesnakes and humans.

When low-density housing areas abut large natural areas, it would appear that rattlesnakes have a reasonable chance of persisting indefinitely. Of course, this is not always the situation. In many areas surrounding Tucson and Phoenix, much higher density urban areas abut parks, preserves, and national forest lands. Many of the residents living in these areas are new to the desert and are unfamiliar with rattlesnakes and other wildlife. This can lead to a situation in which rattlesnakes may be killed or humans may be bitten.

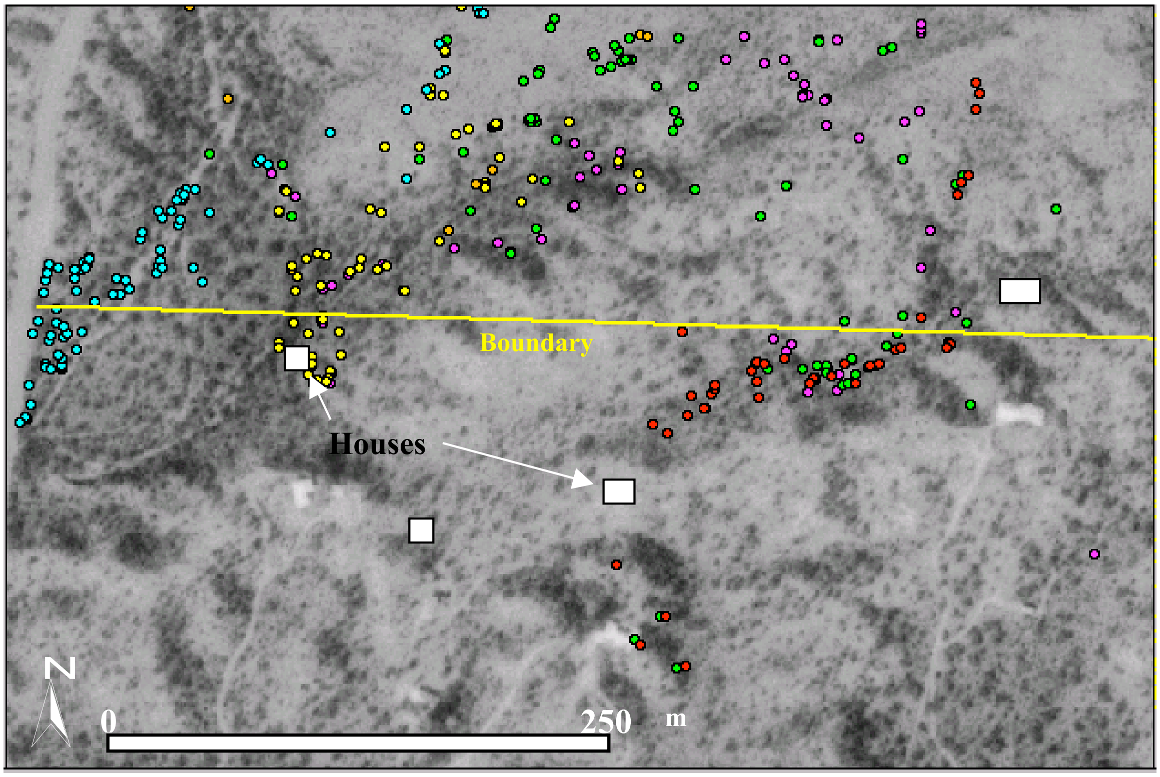

Figure 26. Digitized aerial photograph showing the movements of 6 radiotelemetered tiger rattlesnakes that moved beyond the boundaries of Saguaro National Park during the course of the study. A total of 12 tiger rattlesnakes were found outside the park boundary, including 4 snakes that were found by residents living along the edge of the park.

In the near future, SNP will experience unprecedented development along its southern boundary due to the Rocking K development (Rocking K Specific Plan 1991, 1996). It seems reasonable to apply what we have learned during the course of this study to predict the effects of the development on rattlesnakes living in the area. Our pre-development data seem to point to some obvious predictions. For example, the extensive bajada area at the north end of the main xeroriparian wash at the RK site will eventually be home to a large, high-end resort. This area is relatively flat and less rocky, making it much easier and less costly to develop. Mass grading to make room for a huge building will certainly leave this area uninhabitable by snakes. Based on movement and home range data, this bajada area has been used intensively by tiger rattlesnakes. Snakes use this area as they move from winter den sites on south-facing slopes within the park to the xeroriparian wash south of the park boundary (Figure 27). The wash is an important area where snakes congregate in the summer to forage and mate. The resort will effectively cut off this corridor between the snakes' winter and summer habitats. We expect the incidence of tiger rattlesnake observations in and around the resort to be very high because of its location between these two critical habitat areas.

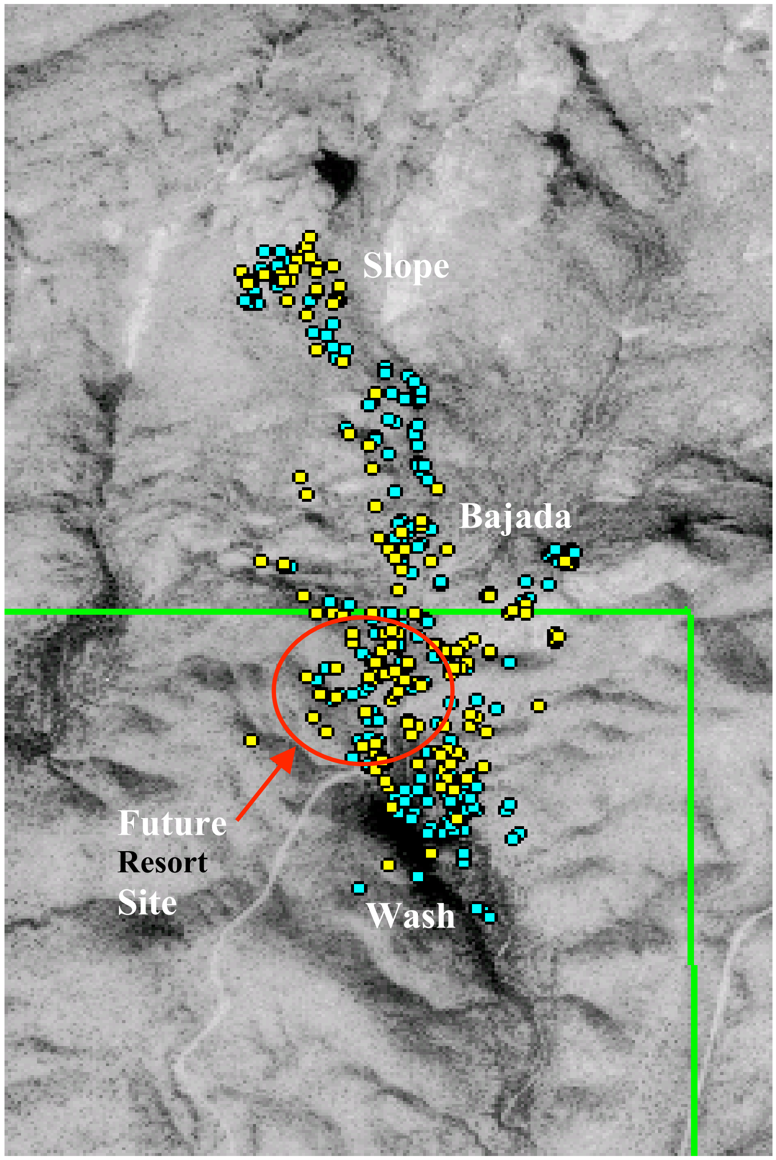

Figure 27. Digitized aerial photograph showing movements of 16 tiger rattlesnakes in relation to the park boundary and the future site of the Rocking K development resort. Snakes overwinter on steep slopes and travel through the future resort site on their way to and from wash and bajada areas.

The movement of rattlesnakes into the developed area sets the stage for what we expect to be a critical management concern in the future. The primary issue is what to do when people living, working, and recreating in the area encounter rattlesnakes. One approach has been to destroy so-called “nuisance” rattlesnakes that come in contact with people. Killing rattlesnakes is undoubtedly not good for the snakes themselves, and may pose a threat to the person attempting to kill the snake. Many rattlesnakes, which were presumed dead, have managed to bite their assailant. Therefore, killing rattlesnakes is not likely to be an effective option.

Another tactic for dealing with nuisance rattlesnakes, which is the current preferred method, is to translocate the snakes away from populated areas (Nowak and van Riper 1999). The Rural Metro Fire Department (RMFD) removes an estimated 3,000-5,000 rattlesnakes from the yards of residents living in and around Tucson every year (G. Good, RMFD, personal communication). The translocation of rattlesnakes has become an important management concern for a variety of reasons. Rattlesnakes are venomous and they may pose a serious threat to people living in areas where rattlesnakes are abundant (although the threat of snakebite is almost always exaggerated). The real victims of translocation are the snakes themselves. Translocated rattlesnakes show aberrant movement patterns, and some individuals may even succumb to being translocated (Reinert and Rupert 1999). Our data indicate that tiger rattlesnakes show remarkable fidelity to their home ranges, using the exact same rock outcrops, wood rat middens and even individual shrubs throughout the course of the year and in successive years. Aberrant movement patterns may be the result of translocating a snake out of its home range, causing the snake to become disoriented. This can result in even greater movement by snakes, thereby increasing the chance that they will find their way into someone’s backyard. Potential effects on snakes residing in areas where translocated snakes are released are unknown. However, it seems likely that the addition of new individuals into the area will be detrimental if resources cannot support an increase in the number of snakes present.

Many tiger rattlesnakes spent the winter on lower elevation slopes and rock outcrops situated in and around the area slated for development. If these rocky habitats are removed to make way for the resort and houses, then this is expected to have a negative impact on any snakes that currently use these areas as winter refugia. Because these rocky areas are so critical to the life history of tiger rattlesnakes, damage to these areas should be of heightened concern to wildlife managers and land planners.

Another specific example of how the development may be expected to impact tiger rattlesnakes is based on the location of the golf course, with fairways placed along the wash corridor. Tiger rattlesnakes use the wash corridor for foraging and breeding purposes during the summer active season. This habitat will be virtually eliminated when replaced by wide-open fairways that provide little or no cover for snakes (or wildlife in general). This ties into yet another management concern related to the potential effects of the development on tiger rattlesnake prey. If the diversity, abundance and distribution of lizards and rodents are altered by the development, then tiger rattlesnake movements and habitat use can also be expected to change. For example, the primary prey source of tiger rattlesnakes at RK is whiptail lizards (M.J. Goode, unpublished data), which prefer open desert areas with intermittent shrub cover. Fairways and parking lots are not expected to support large populations of whiptail lizards, which may result in a reduction of tiger rattlesnake prey availability. On the other hand, increased water and vegetation associated with the development may attract rodents, which may in turn attract rattlesnakes, thereby exacerbating the nuisance rattlesnake problem. In either case, the effects of the development on rattlesnake prey resources will likely be long term and subtle, making the effects more difficult to detect.

Predicting the effects of the development on tiger rattlesnakes is speculative, but may provide an important guide when developing areas in which they live. As for determining the actual effects of the development on rattlesnakes, we now have critical baseline data at RK and at the TVR control site within SNP. This will enable us to more precisely quantify the effects when the development occurs. Only through this rigorous scientific approach will we be able to make an unbiased assessment of the effects of urban development on tiger rattlesnakes. These findings can then be applied to other areas planned for development that abut natural areas such as SNP.

A MANAGEMENT PLAN FOR URBAN RATTLESNAKES

We have identified several threats facing rattlesnakes living in urban and urbanizing areas. In this section, we list these threats, followed by specific goals and strategies for removing or mitigating the threats. We also provide information on actions that have been taken to achieve these goals.

<u>THREAT</u> <u>DIRECT KILLING OF “NUISANCE” RATTLESNAKES</u>

GOAL Educate public about differences between real and perceived threats of living in proximity to rattlesnakes.

Encourage fire department personnel to inform the public about the risks (e.g., being bitten) involved in attempting to kill rattlesnakes.

Work with Arizona Poison Control Center at the University of Arizona to educate the public about the risks of living in proximity to rattlesnakes and about the proper procedures for how to deal with snakebite.

Inform public of Arizona Game and Fish regulations requiring a hunting license to kill rattlesnakes.

STRATEGY Develop an educational brochure to distribute to residents living in areas where rattlesnakes are common.

Develop an educational video depicting rattlesnake defensive behaviors and how they vary by species and ecological context (e.g., distance to cover, temperature).

Develop interpretive signage at golf courses that include information about the natural history and ecology of rattlesnakes.

ACTION The Tucson Herpetological Society has already developed a brochure entitled *Living with Rattlesnakes* that attempts to educate the public about how to deal with rattlesnakes encountered on their property.

We are currently developing a video depicting typical defensive behavior of three rattlesnake species that can be used to educate people about what to expect when they encounter a rattlesnake. It is our belief that wanton killing of rattlesnakes is mostly due to ignorance perpetuated by myths and misunderstandings associated with the true nature of rattlesnake behavior.

Our association with Jude McNally of the Arizona Poison Control Center goes back nearly 10 years. We have been featured together on several media events and have worked together to inform the public about rattlesnakes and the issue of snakebite in general.

We have approached Stone Canyon Golf Club in the foothills of the Tortolita Mountains with the idea of placing interpretive signage along the golf course. Dennis Caldwell, a graphic designed specializing in herpetofauna, has created and presented examples of signs to the development supervisor who is in the process of deciding to proceed with the project.

<u>THREAT</u> <u>TRANSLOCATION OF “NUISANCE” RATTLESNAKES</u>

GOAL Translocate rattlesnakes within their home ranges whenever possible.

Inform and educate public about the spatial ecology of rattlesnakes, including characteristics of home ranges, typical movement and activity patterns, and especially, the extreme fidelity that rattlesnakes show to their home ranges.

Encourage fire department personnel to inform the public about rattlesnake home range fidelity and to adopt a policy of translocation within home ranges whenever possible.

Work with Arizona Poison Control Center at the University of Arizona to educate the public about rattlesnake spatial ecology, and to advocate translocation within home ranges.

STRATEGY Develop an educational brochure that provides information on rattlesnake spatial ecology to distribute to residents living in areas where rattlesnakes are common.

Work with fire departments besides RMFD to educate them about rattlesnake spatial ecology and behavior, and conduct trainings for firemen to properly translocate rattlesnakes.

Develop an educational program in conjunction with the Arizona Poison Control Center that focuses on rattlesnake translocation procedures.

Data gathered during the course of this study indicate that tiger rattlesnakes show very little annual difference in home range location and use. These data can be used to bolster recommendations to translocate snakes within their home ranges.

ACTION The Tucson Herpetological Society has already developed a brochure entitled *Living with Rattlesnakes* that attempts to educate the public about how to deal with rattlesnakes encountered on their property. This brochure also contains information about translocation of rattlesnakes.

We are currently developing a video depicting typical defensive behavior of three rattlesnake species that can be used to educate people about what to expect when they encounter a rattlesnake. We could easily include information about rattlesnake spatial ecology and translocation in this video.

Our association with Jude McNally of the Arizona Poison Control Center goes back nearly 10 years. We have been featured together on several media events and have worked together to inform the public about rattlesnakes and the issue of snakebite in general. Collaborating on an educational program dealing with issues of rattlesnake translocation would be a natural next step.

We have approached Stone Canyon Golf Club in the foothills of the Tortolita Mountains with the idea of placing interpretive signage along the golf course. Again, information about rattlesnake spatial ecology and translocation procedures could be easily incorporated into the text of sign(s). We could also expand this effort to other golf courses, trailheads, parks and other outdoor venues where rattlesnakes are an issue and where the potential to reach the public is great.

THREAT RESIDENTIAL DEVELOPMENT

GOAL Design residential developments in a way that will minimize impacts to rattlesnakes and other herpetofauna.

STRATEGY Work directly with developers during the planning process to design residential developments that take into consideration relevant aspects of rattlesnake behavior and ecology.

Work with agencies that regulate residential developments to initiate regulations that are based on relevant aspects of rattlesnake behavior and ecology.

Provide movement corridors between winter areas (i.e., rock outcrops) and foraging areas (e.g., washes and bajada areas).

Establish buffers around rock outcrops and washes, and minimize destruction of rock outcrops during development.

Maintain low-density zoning in residential areas that abut parks, preserves and other natural areas.

Encourage the Arizona Game and Fish Department to provide guidelines to agencies that regulate residential developments.

Encourage developers to support research on the land they are developing that will give them information on what the effects of the development might be on rattlesnakes.

ACTION We have worked with the Rocking K Development Company to allow us to gather baseline data on their land that can be compared to post development data on rattlesnake ecology and behavior.

We are currently working with Rancho Vistoso Partners, LLC at their Stone Canyon site in the Tortolita Mountains to study the effects of this development on rattlesnakes and other herpetofauna This study was funded by the Arizona Game and Fish Department.

We have received the official endorsement of the Pima County Planning Department on this study, and on the study in the Tortolita Mountains.

THREAT GOLF COURSE/RESORT DEVELOPMENT

GOAL Design golf course and resort developments in a way that will minimize impacts to rattlesnakes and other herpetofauna.

Educate golfers and guests about differences between real and perceived threats of living in proximity to rattlesnakes.

STRATEGY Work directly with golf course and resort developers during the planning process to design golf courses and resorts that take into consideration relevant aspects of rattlesnake behavior and ecology.

Work with agencies that regulate golf course and resort developments to initiate regulations that are based on relevant aspects of rattlesnake behavior and ecology.

Provide movement corridors between winter areas (i.e., rock outcrops) and foraging areas (e.g., washes and bajada areas).

Establish buffers around rock outcrops and washes, and minimize destruction of rock outcrops during development.

Maintain low-density zoning in residential areas that abut parks, preserves and other natural areas.

Encourage the use of “desert-style” golf course designs that minimize the impact on natural areas and systems.

Maintain as much open space as possible in resort development areas to facilitate the movement of rattlesnakes.

Use native plants in landscaping along golf courses and in development areas to maintain natural vegetation communities.

Minimize the use of water developments as they attract non-native species such as bullfrogs and predatory fish.

Ensure that water developments are designed to enable rattlesnakes and other wildlife to easily escape if they become entrapped.

Encourage the Arizona Game and Fish Department to provide guidelines to agencies that regulate golf course and resort developments.

Encourage developers and golf course designers to support research on the land they are developing that will give them information on what the effects of the development might be on rattlesnakes.

Develop an educational brochure to distribute to golfers and recreationists using golf courses and resorts where rattlesnakes are common.

Develop interpretive signage at golf courses and resorts that include information about the natural history and ecology of rattlesnakes.

ACTION We have worked with the Rocking K Development Company to allow us to gather baseline data on their land that can be compared to post development data on rattlesnake ecology and behavior.

We are currently working with Rancho Vistoso Partners, LLC at their Stone Canyon site in the Tortolita Mountains to study the effects of this development on rattlesnakes and other herpetofauna. In particular, we are studying the effects of the golf course by riding golf cart paths at night and by implanting rattlesnakes with radiotelemeters that are using the golf course.

We have received the official endorsement of the Pima County Planning Department and the City of Tucson Department of Recreation on the study in the Tortolita Mountains.

We have approached Stone Canyon Golf Club in the foothills of the Tortolita Mountains with the idea of placing interpretive signage along the golf course. Dennis Caldwell, a graphic designed specializing in herpetofauna, has created and presented examples of signs to the development supervisor who is in the process of deciding to proceed with the project.

<u>THREAT</u> <u>ROAD MORTALITY</u>

GOAL Minimize death of rattlesnakes on roads.

STRATEGY Attempt to reduce the number of road that pass through areas where rattlesnakes are concentrated or through which rattlesnakes must pass, such as between rock outcrops and washes.

Use signs that inform motorists to use caution in areas where snakes are known to be abundant.

Conduct studies on the effects of roads on rattlesnakes and other herpetofauna.

ACTION Biologists at Saguaro National Park have been quantifying road mortality for the past several years and the death toll is extremely high, with an estimated 40,000 vertebrates per year dying on roads within the Park.

We have suggested that developers at the Stone Canyon site in the foothills of the Tortolita Mountains place road signs informing residents to drive with caution to avoid killing snakes and other animals. We are optimistic that the developers will take our advice when the site becomes occupied with residents.

<u>THREAT</u> <u>RATTLESNAKE-PET ENCOUNTERS</u>

GOAL Minimize the number of rattlesnake-pet encounters; pets can kill rattlesnakes and rattlesnakes can either kill pets or result in costly veterinarian bills.

STRATEGY Develop an educational brochure to distribute to residents living in areas where rattlesnakes are common that provides guidance on how to make your house rattlesnake proof.

Encourage residents to keep their pets confined to their yards to minimize rattlesnake-pet encounters.

Encourage veterinarians to inform their customers about the risks of rattlesnake-pet encounters.

ACTION The Tucson Herpetological Society has already developed a brochure entitled *Living with Rattlesnakes* that attempts to educate the public about how to deal with rattlesnakes encountered on their property. This brochure contains information about how to avoid rattlesnake-pet encounters.

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APPENDIX A

Raw data from 169 tiger rattlesnakes captured at three sites in and adjacent to Saguaro National Park, and by Rural Metro Fire Department personnel in the foothills of the Santa Catalina Mountains. LR = Loop Road, TVR = Tanque Verde Ridge, A = adult, Repro = reproductive status, NG = not gravid, G = gravid, NS = no semen present, S = semen present, SVL = snout-vent length, TL = tail length, HW = head width, HL = head length, RS = number of rattle segments, RL = rattle length, RB = rattle broken, Y = yes, and N = no. All measurements are in millimeters except mass, which is in grams.

1997

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
08/04/97	LR	F	A	NG	670	51	175	17	26	9	44	Y
08/06/97	LR	F	A	G	521	29	175	21	19	4	24	N
08/07/97	TVR	F	A	NG	592	43	259	20	26	8	40	Y
08/10/97	LR	M	A	NS	709	74	471	23	34	10	51	Y
08/12/97	TVR	M	A	NS	680	73	283	20	29	7	36	Y
08/12/97	TVR	M	A	NS	667	64	292	21	29	6	33	Y
08/13/97	TVR	M	A	NS	778	71	380			7	35	Y
08/17/97	LR	M	A	S	713	73	369	23	30	7	18	Y
08/26/97	TVR	F	A	NG	636	45	186	21	28	8	35	Y
08/26/97	LR	M	A	NS	635	72	316	20	29	8	38	Y
08/26/97	LR	M	A	NS	712	46	214	22	30	8	29	Y
08/26/97	LR	M	A	S	656	66	346		28	7	29	Y
08/26/97	LR	M	A	S	673	69	310		31	8	38	Y
08/27/97	TVR	F	A	NG	637	45	261	21	25	7	29	Y
08/27/97	TVR	F	A	NG	600	46	291	21	30	7	30	Y
08/27/97	LR	M	A	NS	730	73	337	22	32	10	49	Y
08/27/97	TVR	M	A	S	650	65	261	20	31	5	27	Y
09/02/97	TVR	F	A	NG	688	47	226	20	27	8	33	Y
09/05/97	TVR	M	A	S	680	66	325	20	31	9	43	Y
09/12/97	TVR	F	A	NG	627	45	251	18	26	7	38	N
09/27/97	TVR	M	A	NS	694	65	317	19	29	9		Y
10/02/97	TVR	M	A	S	687	71	355	26	28	7	32	Y
10/15/97	TVR	M	A	NS	647	58	236	22	29	6	30	Y

1998

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
05/23/98	TVR	M	A	NS	694	63	348	21	29	7	32	Y
07/03/98	TVR	F	A	NG	647	43	275	19	27	8	35	Y
07/08/98	TVR	M	A	NS	612	43	263	26	17	9	43	Y
07/17/98	LR	M	A	NS	741	72	357	21	30	9	40	Y
08/02/98	LR	F	A	NG	659	50	231	19	27	10	45	Y
08/02/98	LR	M	A	S	728	67	356	18	28	9	41	Y
08/02/98	LR	M	A	S	629	56	257	20	26	7		Y
08/09/98	RK	M	A	S	699	70	388	22	29	10	49	Y
08/10/98	LR	M	A	NS	687	74	400	23	26	9	44	Y
08/12/98	TVR	M	A	S	627	58	299	22	27	8	32	Y
08/12/98	LR	M	A	S	732	65	496	23	28	6	30	Y
08/12/98	TVR	M	A	NS	738	67	433	22	28	9	49	Y
08/12/98	TVR	M	A	S	693	68	401	22	29	7	44	Y
08/20/98	LR	M	A	S	697	63	357	23	30	12	51	Y
08/20/98	LR	M	A	S	602	60	260	21	27	7	35	N
08/21/98	TVR	M	A	NS	553	51	185	19	25	6	31	N
08/23/98	LR	M	A	S	772	69	512	21	29	10	43	Y
08/25/98	TVR	F	A	NG	650	51	264	20	27	9	40	Y
08/27/98	LR	F	A	G	610	42	236	21	30	10	43	Y
08/27/98	LR	M	A	NS	602	67	395	22	30	7	35	Y
08/30/98	TVR	F	A	NG	635	45	243	20	29	8	34	Y
08/31/98	TVR	F	A	NG	658	42	326	19	28	10	45	Y
09/02/98	LR	M	A	S	636	66	291	20	26	7	31	Y
09/04/98	RMFD	M	A	S	730	70	474	23	28	6	34	Y
09/04/98	RMFD	F	N	NG	252	18	18	13	17	1		
09/11/98	TVR	F	A	NG	564	35	158	17	24	3	20	Y
09/12/98	LR	M	A	S	725	65	390	19	28	10	49	Y
09/21/98	LR	M	A	S	729	71	400	18	28	10	50	Y
10/21/98	RMFD	M	A	S	659	56	281	19	25	10	46	Y
10/21/98	RMFD	F	A		577	46	239	19	23	7	40	N
10/21/98	RMFD	F	A	G	669	46	369	20	25	10	31	Y
10/24/98	TVR	M	A	NS	601	55	215	19	23	7	36	Y

1999

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
05/27/99	TVR	M	A		682	60	285	19	27	8	38	
05/01/99	LR	F	A	G	597	43	362			6		Y
06/30/99	RMFD	M	A		700	64	360				33	
07/03/99	RMFD	M	A		713	67	384				43	Y
07/26/99	RK	M	A	NS	682	66	305	21	27	9	45	Y
07/30/99	RK	F	A	NG	634	50	148	16	25	8	30	Y
08/04/99	TVR	F	A	NG	537	41	156	17	22	5	25	N
07/28/99	RMFD	M	A	S	767	73	469	24	30	4	25	Y
07/26/99	RMFD	F	A		511	41	156	18	23	5	24	N
07/26/99	RMFD	F	A		534	39	160	19	24	5	24	N
08/02/99	RMFD	F	A	NG	584	36	278	18	27	8	33	Y
08/02/99	RMFD	M	A	S	535	58	161	18	25	5	23	N
07/15/99	RMFD	M	A	S	636	55	165	17	25	5	24	N
08/31/99	RK	M	A	S	684	66	288	20	28	11	50	Y
08/30/99	TVR	F	J	NG	511	38	113	17	25	5	25	N
09/01/99	TVR	M	A	S	712	66	345	21	31	10	50	Y
09/02/99	RK	M	A	S	739	71	385	21	30	10	51	Y
09/04/99	RK	M	A	NS	636	74	378	22	29	9	46	Y
09/05/99	RK	M	A	NS	761	70	426	24	31	10	46	Y
09/05/99	RK	M	A	S	638	59	246	19	27	5	27	Y
09/05/99	RK	F	A	NG	596	41	179	19	26	7	32	Y
09/05/99	RK	M	A	NS	686	68	234	22	29	6	30	Y
09/06/99	RK	M	A	S	753	69	415	24	33	10	49	Y
09/14/99	RK	F	A	NG	619	36	150	16	25	6	27	Y
09/14/99	TVR	M	A	S	711	64	455	26	29	8	39	Y

2000

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
06/05/00	RK	M	J	NS	394	34	46	15	22	1	14	N
06/05/00	RK	M	J	NS	561	52	134	22	27	5		Y
06/13/00	LR	M	A		692	68	340	21	28	12	49	Y
06/27/00	RK	M	A	NS	649	64	265	20	26	9	40	Y
06/29/00	RK	M	J		357	37	53	14	20	3	18	Y
06/29/00	LR	M	A		531	44	158	17	24	5	25	N
07/01/00	TVR	F	A	NG	681	51	249	22	29	10	40	Y
07/02/00	TVR	M	A	NS	632	55	195	17	25	6	27	Y
07/05/00	RK	M	A	NS	689	67	308	21	30	10	48	Y
07/10/00	RK	M	A	NS	712	63	298	20	29	9	39	Y
07/11/00	RK	F	A	NG	667	48	252	21	28	9	42	Y
07/11/00	RK	M	A	NS	716	62	383	21	30	9	46	Y
07/11/00	RK	M	A	S	658	59	301	22	29	10	51	Y
07/13/00	RK	M	J	S	492	48	95	18	24	5	24	Y
07/14/00	LR	M	A	S	737	73	434	23	29	7	35	Y
07/14/00	LR	F	J	NG	477	35	102	20	25	4	19	N
07/14/00	LR	M	A	NS	699	67	336	21	29	10	44	Y
07/15/00	LR	M	A	S	676	63	297	21	29	9	41	N
07/15/00	LR	M	A	NS	749	62	315	23	30	10	43	Y
07/17/00	RK	F	A	NG	569	39	183	19	26	6	29	N
07/17/00	RK	F	A	NG	614	44	141	19	26	6	20	Y
07/17/00	RK	M	A	NS	661	64	275	21	28	21	28	Y
07/17/00	RK	M	N	NS	283	24	20	14	18	1	8.1	N
07/19/00	RK	F	N	NG	286	21	19	13	18	1	9	N
07/20/00	TVR	F	A	NG	624	42	266	24	28	11	47	Y
07/22/00	RK	M	A	S	690	65	284	20	27	8	36	Y
07/24/00	RK	F	A	NG	669	46	196	21	28	5	26	Y
07/24/00	RK	M	A	NS	610	63	227			10	42	Y
07/24/00	RK	M	A	S	684	61	332	19	29	9	37	Y
07/25/00	RK	F	A	G	630	40	208	23	30	10	45	Y
07/25/00	RK	F	A	G	539	38	154	19	25	6	30	N
07/27/00	RK	M	A	S	704	70	418	25	31	9	46	Y
07/27/00	RK	M	A	S	739	65	320	23	28	13	56	
07/28/00	RK	F	A	NG	683	44	183	21	28	9	42	Y
07/28/00	RK	M	A	NS	639	62	260	23	29	8	34	
08/01/00	RK	M	A	S	542	51	147	19	25	3	18	Y
08/08/00	TVR	M	A	S	653	57	270	21	28	7	34	Y
08/10/00	RK	F	A	NS	541	41	182	18	24	6	26	N
08/10/00	RK	F	N	NG	294	25	20.5	13	19	1	8.7	N
08/12/00	TVR	M	A	S	562	53	142	25	27	6	30	N
09/02/00	RK	M	A	S	560	59	145	19	24	6	29	N

2000 (con't.)

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
09/09/00	RK	M	A	S	605	58	209	18	26	6	31	N
09/20/00	RK	M	J	S	448	39	73	16	23	4	20	N
09/20/00	RK	F	J	NG	426	35	60	14	20	4	19	N
09/25/00	RK	M	J	S	580	56	129	17	25	5	27	N
09/28/00	TVR	M	A	S	742	68	354	21	28	11	42	Y
09/30/00	RK	M	A	S	590	58	154	18	26	8	33	Y
10/01/00	RK	M	A	S	676	68	345	21	29	9	46	Y
10/25/00	RMFD	M	A	S	666	68	398	23	29	8	37	Y
11/10/00	TVR	M	A	NS	538	49	114	16	24	5	24	N

2001

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
04/28/01	RK	F	J	NG	180	29	31	18	17	1	9	N
05/24/01	RK	F	J	NG	550	38	140	18	25	8	41	N
05/27/01	RK	F	J	NG	356	26	47	17	20	2	12	N
06/10/01	LR	M	J	NS	544	49	176	22	26	6	29	N
06/17/01	RK	F	J	NG	511	34	95	18	23	5	27	N
06/18/01	RK	M	J	NS	327	27	24	14	18	2	13	N
07/04/01	TVR	M	A	S	554	56	146	17	26	6	28	N
07/09/01	LR	F	A	G	646	44	278	23	28	10	42	Y
07/09/01	LR	M	A	NS	618	68	237	19	26	6	25	Y
07/11/01	RK	M	A	NS	731	70	421	25	31	9	43	Y
07/11/01	RK	M	J	NS	645	51	164	19	25	5	25	N
07/13/01	RK	M	A	NS	553	55	180	21	27	5	24	Y
07/15/01	LR	F	A	G	599	41	225	20	28	6	31	Y
07/16/01	LR	M	A	NS	772	68	436	21	29	3	15	Y
07/16/01	RMFD	M	A	NS	607	52	177	18	25	7	33	Y
07/16/01	RMFD	M	A	NS	651	60	215	20	28	7	32	Y
07/23/01	LR	M	A	NS	607	57	196	17	26	7	34	N
07/23/01	LR	F	A	NG	599	40	219	18	26	7	36	N
07/24/01	LR	M	A	NS	696	64	313	19	28	7	35	Y
07/30/01	RK	M	A	S	646	66	247	22	28	9	42	Y
07/30/01	RK	F	A	G	554	39	167	19	23	7	32	Y
08/04/01	RMFD	M	A	NS	716	65	354	22	30	5	23	Y
08/05/01	RMFD	M	A	NS	733	65	491	22	27	11	55	Y
08/06/01	RK	M	A	NS	689	64	285	18	27	10	47	Y
08/06/01	RK	M	A	NS	703	69	383	22	26	8	38	Y
08/08/01	RK	M	J	S	496	43	86	19	22	4	22	Y

2001 (con't.)

Date	Site	Sex	Age	Repro	SVL	TL	Mass	HW	HL	RS	RL	RB
08/09/01	RK	M	A	NS	690	62	323	20	28	12	50	Y
08/09/01	LR	M	A	NS	689	67	306	20	29	6	30	Y
08/13/01	RK	M	A	NS	670	62	287	21	27	6	27	Y
08/13/01	RMFD	M	A	S	637	54	259	19	28	6	33	N
08/14/01	RMFD	M	A	NS	708	68	389	21	28	3	19	Y
08/16/01	RK	M	J	NS	545	59	157	17	25	7	33	Y
08/25/01	RK	M	A	S	578	54	184	18	25	7	28	Y
08/30/01	RMFD	M	A									Y
09/07/01	RK	M	J	S	502	52	129	17	21	5	24	N
09/08/01	RMFD	M	A	S	707	66		22	29	8	32	Y
09/23/01	RK	F	A	G	546	37	190	17	26	6	29	N
09/22/01	LR	F	A	NG	578	45	228	19	28	7	29	Y