

ROADKILL ON ROADS IN AND ADJACENT TO SAGUARO NATIONAL PARK: A SUMMARY OF STUDY METHODS, RESULTS AND ANALYSES USED TO ESTIMATE AVERAGE ANNUAL VERTEBRATE MORTALITY

May 2005

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This summary provides background information on the methods used to collect and analyze data, and the results of Saguaro National Park's study to quantify the impacts of roads on wildlife. It is derived from a manuscript in preparation. It is important to acknowledge that this research has not yet been peer reviewed, although it has been presented at the following forums: Road Design and the Sonoran Desert Conservation Plan, sponsored by the Coalition for Sonoran Desert Protection (March 2002 in Tucson, AZ); and the International Conference on Ecology and Transportation, sponsored by the Center for Transportation and the Environment (August 2003 in Lake Placid, NY).

In 1994, Saguaro National Park staff began to investigate the impacts of roads on park wildlife as a follow up to the Park's General Management Plan (USDI 1988) by initiating "roadkill" surveys. The goal of this study was to gather data on the species, numbers, dates, and locations of vertebrates killed by vehicles on roads in and adjacent to the Park. These data were to be used to quantify vertebrate road mortality in the park, and to identify the temporal and spatial patterns of roadkill. Ultimately, these data were to be used to identify potentially significant road issues in the park, and to develop mitigation strategies to address them.

Concepts & Methods

1. Weekly Surveys

Between January 1994 and December 1999, park staff and volunteers conducted weekly "roadkill" surveys. These surveys were usually conducted by a single surveyor who drove the entire (47.6 mile) road network within and adjacent to each of the park's districts [27.3 miles in the Tucson Mountain District (TMD) and 20.3 miles in the Rincon Mountain District (RMD)] on a designated morning each week throughout the year. On each survey, we recorded all roadkilled vertebrates observed. Animal carcasses were identified to the extent possible, and the dates and locations of each observation were recorded (Kline and Swann 1997, 1998). Results of these weekly surveys were used as a basis to estimate the average annual number of roadkilled vertebrates on roads in and adjacent to Saguaro National Park (see Analysis in the Results section below).

Despite the many roadkills documented during weekly surveys, it soon became apparent that they did not fully represent overall road mortality in the Park for several reasons. In 1997 we initiated additional survey efforts to identify and account for these sources of error.

2. *Carcass Persistence*

Preliminary results indicated that many roadkilled animal carcasses were being taken off the road before we were able to record them. Generally, this was due to the scavenging activity of other animals (e.g., coyotes, turkey vultures, etc.), but occasionally humans were observed collecting certain birds, snakes, and larger mammals. Carcasses were moved off the road by other means too; however, eventually we understood that regardless of how carcasses disappeared from the road, the relevant parameter to measure was *carcass persistence*, the average length of time that a carcass remained on the road.

We developed further studies to estimate the portion of roadkills that we could detect and record in one survey, versus what was actually generated on a road in a week. Since each of our surveys represented only the carcasses present on a few hours during one day of each week, there were two relevant time periods (daily and weekly) to consider. To determine the persistence of roadkills on the road both within a day, and throughout a week, we designed both short- and long-term “mark-recapture” surveys along selected routes. In 1998 we conducted six surveys in the RMD to calculate short-term carcass persistence. For each of these, we conducted a survey of the entire survey route every four hours throughout a 24-hr period. On each “run” of the survey we flagged each new carcass observed and noted the disappearance of carcasses from previous runs. Each carcass was considered “present” until no trace of it could be discerned. Data from these surveys were combined to provide an estimate of short-term average carcass persistence rates for each relevant vertebrate class (amphibians, reptiles, birds, and mammals).

To estimate long-term carcass persistence throughout a week, we surveyed a 2.2 mile stretch of Speedway Boulevard on foot each morning for an eight day period during July 1999. Again, all carcasses were flagged and numbered as they appeared, and their persistence from day to day was noted. From these data we calculated a long-term average carcass persistence rate per taxonomic class.

Results of these short- and long-term carcass persistence studies were applied to our estimate of the average annual number of roadkilled vertebrates on roads in and adjacent to Saguaro National Park as described in Steps 2-4 under Analysis in the Results section below.

3. *Observer Error*

Another bias we recognized in our weekly survey data was an inherent observer error; that is, we simply could not see every carcass that was on the road potentially “available” for us to record. This is due to several factors. First, for a variety of reasons, it is impossible for someone driving a vehicle to detect every roadkill. In addition, the small size of many animals increases the likelihood that they will be missed. Finally, a percentage of animals that are killed by cars will end up far enough away from the road and/or obscured by vegetation that they will not be observed from a vehicle.

To estimate observer error we “ground-truthed” our weekly vehicle survey data by having paired observers simultaneously walking each side of all surveyed roads during seven weekly surveys in September and October 1998. For purposes of our model, we

made the conservative assumption that pedestrian observers found and recorded all roadkilled vertebrates that were present on the road/shoulder. We then compared the numbers of each animal group observed by both methods (driving versus walking surveys) on all surveys to calculate an average observer error for each taxonomic class. Unlike carcass persistence, the observer error calculated per taxon was applied to the model as a constant. In reality, however, observer error undoubtedly varies somewhat between observers and between roads. (Some roads, like the park loop roads, allow for slower driving and facilitate surveying better than many public roads like Picture Rocks, where it is unsafe to drive slowly or stop on the shoulder.)

Results of these studies were applied to our estimate of the average annual number of roadkilled vertebrates on roads in and adjacent to Saguaro National Park per step 5 under Analysis in the Results section below.

4. Data Analysis

Weekly survey data served as the main dataset used for analysis, including roadkill estimates for each taxonomic group. Unknowns, or animals that could not be positively identified as either amphibian, reptile, bird or mammal, were excluded from analysis. Due to inconsistencies in survey frequency and methodology from 1994-1995, these data were not used in this analysis, so estimates are based only on weekly survey data from 1996-1998 at TMD and 1996-1999 at RMD. All data were entered into an Access database and imported to MS Excel for analysis.

Mathematician Martin Pokorny, Ph.D. was contracted by the Park to develop a mathematical model that could be applied to our survey data to account for carcass persistence. To do this, he developed a formula based on a model of carcass persistence, for which he estimated its single parameter using both the short- and long-term carcass persistence data. Then he derived an equation to apply to our weekly survey data to calculate estimates of the average annual number of vertebrates killed on roads in and adjacent to the Park (Pokorny 2001). The equation is:

$$\bar{N} = [\bar{M} \mu T / (1 - e^{-\mu T})]$$

where: $\bar{N}$ = the number we seek- the *estimated* average number of roadkills per week for a given month for a specific animal class (i.e., mammals, birds, reptiles or amphibians).

$\bar{M}$ = the average number of roadkills actually recorded each week for a given month for a specific animal class (i.e., mammal, bird, reptile or amphibian).

μ = the estimated “persistence parameter” that represents the correction for roadkill that has occurred since one survey, but is gone before the following survey. Specifically, μ is the portion of a day that a carcass of a given taxon remains on the road on average. This number is a constant for each taxonomic class of vertebrates, and is derived separately from both short-term (24-hr) and

long-term (8-day) survey data. (Although these two methods for calculating μ are independent, they yield similar results, a fact that supports their accuracy.)

T = time, which is equal to 7, since surveys were conducted once a week and each survey represents seven days worth of roadkill.

e = the base of the natural logarithms, a constant equal to 2.718281. (This model assumes that roadkill follow a Poisson distribution; see assumptions below.)

Application of this model to the weekly survey data for each taxonomic class is necessary to account for the high degree of variability of roadkills between months, years and animal taxa. Resulting estimates of the number of weekly roadkills, (N), for each taxonomic class are then used to develop monthly, and then annual, estimates of roadkill for each taxon. These roadkill estimates, corrected for carcass persistence by the model (we call these numbers “observable” roadkill), are then corrected for observer error to give our final corrected roadkill estimates (see step by step calculations under Analysis in the Results section).

This model is based on the recognition that animals are killed on the road at one rate, and removed from the road at another rate. Since what we want to know is the rate at which animals are killed on the road, but what we find on the road at any given time is the net effect of both processes, we must account for the rate at which animals are removed from the road. An analogy would be trying to determine the rate at which water is flowing from the tap if you were filling the sink from the tap while the drain was partially open. Measuring the rate at which the water fills your sink is not enough to determine the rate at which water is flowing from the tap. However, if you know the rate at which water is draining, and the rate at which the water is filling the sink, you can determine the rate at which water is flowing from the tap. The expression $\mu T / (1 - e^{-\mu T})$ provides the correction to the numbers of roadkill counted on the road relative to the number of animals actually killed on the road, and is analogous to the correction provided by the rate at which water drains from the sink. Pokorny (2001) provides the derivations of the equations in the model, and their application to our data.

Like every model, ours is based on assumptions, some of which may be violated to some degree; however, we feel confident that the model and numbers we have generated are realistic. Model assumptions include:

1. Roadkills are independent events.
2. Carcass persistence is independent of the time at which the roadkill occurred.
3. The probability that a roadkill occurs in a given time interval is proportional only to the duration of the interval.
4. The number of roadkills in any time interval has a Poisson distribution (i.e., describes unlikely, independent events).
5. During “ground-truthing” surveys, pedestrian observers found and recorded every roadkilled vertebrate present.

6. Observer error is constant for a given taxon.
7. The years we conducted surveys (1996-1999) are representative.

Results

1. Weekly Surveys

We conducted 110 weekly surveys in the TMD during 1996-1998 and 160 surveys in the RMD during 1996-1999. In all, 2023 vertebrates that could be identified to class as amphibian, reptile, bird, or mammal, were observed on surveys. In addition, 215 individual roadkills that were categorized as “unknown” were recorded but not included in further analysis.

2. Carcass Persistence

During the seven 24-hour surveys that were conducted to calculate short-term persistence rates of carcasses on roads in and adjacent to the park, 248 roadkilled vertebrates were observed. Short-term carcass persistence for reptiles was calculated to be 0.89/day, 0.54/day for birds, and 0.54/day for mammals (Pokorny 2001). We could not calculate a short-term carcass persistence rate for amphibians because none of our surveys coincided with summer rains, so there was little amphibian activity during these surveys. To allow for estimation of total (all taxa) roadkill numbers for short-term persistence rates, we substituted long-term carcass persistence rates for amphibians (Table 2). We felt this was reasonable since the estimates for both types of surveys resulted in such similar numbers.

During the 8-day surveys to calculate long-term carcass persistence rates, 466 individual roadkilled vertebrates were observed along the survey area. Long-term carcass persistence was 0.40/day for amphibians and 0.80/day for reptiles (Pokorny 2001). Due to the small sample sizes of birds and mammals during these surveys, these taxa were combined to yield carcass persistence of 0.41/day. Again, we felt this was a justifiable alternative since the calculated short-term persistence rates for birds and mammals were identical.

3. Observer Error

During seven “ground-truthing” surveys comparing results of driving surveys and walking surveys on the same route, 1286 individual vertebrate roadkills were observed by walkers and 83 were observed by drivers. Drivers detected 39 of 808 individual amphibian roadkills (4.83%), 11 of 294 (3.74%) reptiles, 20 of 58 (34.48%) birds, and 13 of 126 mammals (10.32%). Thus, the multipliers (the inverses of the % of the numbers of each taxa detected) to apply to the annual numbers of roadkill for each taxa to correct for observer error are: 20.70 for amphibians, 26.74 for reptiles, 2.90 for birds, and 9.69 for mammals.

4. Data Analysis

This section describes the step by step procedures for calculating our average annual estimates for roadkill in the Park.

Step 1

Weekly survey data were used to calculate the average number of roadkills of each taxon actually found on all of our weekly surveys conducted on a given month, for all years.

For example, the average number of roadkilled reptiles found on weekly surveys in the Tucson Mountain District of the Park in June was 2.50 from 1996-1998.

Step 2

Apply the equation from Pokorny's (2001) model to weekly survey data to account for carcass persistence. (This calculation gives us an estimate of the "observable" roadkills in a week, not yet corrected for observer error.)

$$\bar{N} = [\bar{M} \mu T / (1 - e^{-\mu T})]$$

Continuing with our reptile example, if we plug in the value from step 1, and μ calculated for reptile carcass persistence, into the equation above, we get two values for the estimated average number of observable roadkilled reptiles each week in June in the Tucson Mountain District of the Park. One estimate comes from using the persistence parameter calculated from the short-term survey data ($\mu = 0.89$), and another using the persistence parameter calculated from the long-term survey data ($\mu = 0.80$).

Estimate based on short-term survey data:

$$\begin{aligned}\bar{N} &= (2.5)(0.89)(7) / (1 - [2.72^{-(0.89)(7)}]) \\ &= 15.575 / [1 - (2.72^{-6.23})] \\ &= 15.575 / 1 - 0.002 \\ &= 15.575 / 0.998 \\ &= 15.61\end{aligned}$$

Estimate based on long-term survey data:

$$\begin{aligned}\bar{N} &= (2.5)(0.80)(7) / (1 - [2.72^{-(0.80)(7)}]) \\ &= 14 / 1 - 0.0037 \\ &= 14 / 0.996 \\ &= 14.05\end{aligned}$$

So, while we found an average of 2.50 dead reptiles during our weekly surveys in the TMD in June, when we correct for carcass persistence, we estimate that this represents 14.05-15.61 observable reptiles that were actually killed on roads in the TMD during an average week in June.

Step 3

Figures obtained from Step 2 must now be multiplied by the average number of weeks in each month of the year (number of days/month divided by 7 days/week). This provides an estimate of the average number of observable roadkills of each taxon for each month.

Again, using our reptile example in the Tucson Mountain District of the Park, we multiply our two estimates (15.61 and 14.05) from Step 2 by 4.29 (30 days/June divided by 7 days/wk) to get two estimates of the average number of observable reptiles killed on the road in the Tucson Mountain District of the Park for the month June. These are: 66.97 (using the short-term survey data to calculate μ), and 60.27 (using the long-term survey data to calculate μ).

So, while we found an average of 2.50 dead reptiles during our weekly surveys in the TMD in June, we estimate that this represents 60.27-66.97 observable roadkilled reptiles in the TMD on average in June.

Step 4

The next step is to sum all of the monthly (January-December) averages calculated for each taxon in Step 3. This provides the average annual number of observable roadkilled animals of a given taxon. Again, there will be two estimates for this number, one based on μ calculated by the short-term survey data, and one based on μ calculated by the long-term survey data.

The table below provides the average monthly estimates for observable roadkilled reptiles in the Tucson Mountain District of the Park, and their sum, the average annual estimate of observable roadkilled reptiles in the Tucson Mountain District.

Table 1. Average monthly estimates for roadkilled reptiles in the Tucson Mountain District of the Park based on μ calculated by the short-term survey data (short), and long-term survey data (long). Totals give the observable (uncorrected for observer error) average annual estimate of roadkilled reptiles in the Tucson Mountain District of Saguaro National Park.

μ est.	Jan	Feb	Mar	Apr	May	Jun*	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Short	0	7.13	16.59	13.38	127.16	66.88	119.79	205.03	109.69	30.72	3.34	0	699.71
Long	0	6.42	14.94	12.04	114.50	60.22	107.87	184.62	98.77	27.66	3.01	0	630.05

* Note: June figures in the table are slightly different from those calculated above in Step 4, due to rounding error. For the purposes of this paper we used 4.29 instead of 4.28571.

Step 5

Once we have calculated the observable average annual roadkill estimates for a taxonomic class of animal in Step 4, we can apply the final correction factor that accounts for observer error. The observer error correction factor is a constant calculated for each taxon that is multiplied by the observable average annual roadkill estimates (see Observer Error in Methods section above) to give our final corrected estimates.

For reptiles, the observer error multiplier is 26.74. Thus, our final corrected estimates for the average annual number of roadkilled reptiles in the Tucson Mountain District of the Park are: $699.71 \times 26.74 = 18,710.25$ (based on μ

calculated from short-term survey data), and $630.05 \times 26.74 = 16,847.54$ (based on μ calculated from long-term survey data). Using the same methods, we estimate that 9,613 or 8,655.74 reptiles are roadkilled in the Rincon Mountain District of the Park each year (based on μ calculated from short- and long-term survey data, respectively). Combining the figures from both districts gives us our final estimates (corrected for carcass persistence and for observer error) of the average number of reptiles that are killed on roads in and adjacent to Saguaro National Park each year. These are: 28,323.25, based on μ calculated from short-term survey data; and 25,503.28, from long-term survey data. These numbers (rounded to two significant figures) are presented, along with the estimates for the three other relevant taxonomic classes of vertebrates (amphibians, birds and mammals) in the following table.

Table 2. Estimates of the average number of vertebrates (rounded to two significant figures) killed on roads in and adjacent to Saguaro National Park each year, by park district (RMD = Rincon Mountain District, TMD = Tucson Mountain District) and taxonomic class. Short-term figures are derived from 24-hr survey data, and long-term figures are derived from 8-day survey data.

Taxonomic Class	TMD		RMD		Total	
	<i>Short-term</i>	Long-term	<i>Short-term</i>	Long-term	<i>Short-term</i>	Long-term
Amphibians	12,000*	12,000	4,500*	4,500	17,000	17,000
Reptiles	19,000	17,000	9,600	8,700	28,000	26,000
Birds	550	430	690	540	1,200	970
Mammals	4,500	3,500	2,600	2,000	7,100	5,500
Totals	36,000	33,000	17,000	16,000	53,000	49,000

* Short-term carcass persistence could not be calculated for amphibians because the 24-hr surveys did not coincide with summer rains and there was little amphibian activity during that time. Therefore, we used the numbers calculated from long-term survey data for short-term amphibian estimates in order to obtain total (all taxa) estimates for short-term data.

Summary

We estimated that between 49,000 and 53,000 vertebrates are killed annually on the 47.6 miles of roads that run through or along the boundaries of Saguaro National Park (Table 2). The estimated number of amphibians and reptiles was higher than for birds and mammals. It should be noted that these estimates do not account for animals that die “off-road”, nor did we include in our analysis the many “unknowns” we recorded (about 10% of animal carcasses detected could not be positively identified as either reptile, amphibian, bird, or mammal). Thus, we feel confident that our figures are a conservative estimate of the actual number of animals killed on roads in and adjacent to the park.

Literature Cited

- Kline, N.C. and D.E. Swann. 1997. Results of roadkill surveys in Saguaro National Park. Pp 156-160 in D. Harmon, ed. Making Protection Work. Proceedings of the ninth conference on research and resource management in parks and public lands. The George Wright Society. Hancock, MI 493pp.
- Kline, N.C. and D.E. Swann. 1998. Quantifying wildlife road mortality in Saguaro National Park. Pp 23-32 in G.L. Evink, P. Garrett, D. Zeigler, and J. Berry, eds. *Proceedings of the international conference on wildlife ecology and transportation*. FL-ER-69-98. Florida Department of Transportation, Tallahassee, FL 263pp.
- Pokorny, M. 2001. Preliminary Roadkill Model. In-house technical report. National Park Service, Saguaro National Park. Tucson, AZ 6pp.
- USDI, National Park Service. 1988. Saguaro National Monument General Management Plan. Saguaro National Monument. Tucson, AZ 27pp.

