

REPRODUCTIVE ECOLOGY AND STATUS OF DESERT-BREEDING ANURANS
AT SAGUARO NATIONAL PARK

by

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DEDICATION

This work is dedicated to my husband, Thomas, who has always been my best friend, and to my son, Nathaniel.

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ABSTRACT

We used calling surveys, visual encounter surveys, and visits to historical sites to locate breeding populations of desert-breeding anurans at Saguaro National Park. We found 19 breeding sites at Saguaro National Park. Numbers of calling male *Anaxyrus punctatus* ranged from 12 to 49.2 males (95% CI 42.7–55.7 males) at four sites in 2006 and 35.5 males (95% 31.1–39.9 males) at one site in 2007; male *Scaphiopus couchii* ranged from 6.0 to 15.7 males (95% CI 12.0–19.4 males) at two sites in 2006, and 26.0 males (95% CI 22.3–29.7 males) at one site in 2007. In 2005–2006, 180 of 445 (40%) anurans we found were dead. We found *A. punctatus* in most pools; however, *S. couchii* and *Ollotis alvaria* may not have persistent populations long-term at Tucson Mountain District. This study will provide the Park with baseline breeding site locations and abundances to gauge future impacts.

INTRODUCTION

Concern regarding the continued persistence of many different anuran species on Saguaro National Park (SNP) have been raised because of several events: heightened awareness of the global decline of amphibians (Blaustein and Wake 1990; Wake 1991; Blaustein and Kiesecker 2002), silting in of all of the known lowland leopard frog (*Lithobates yavapaiensis*) breeding ponds due to the effects of the box canyon fire in 1999 (Parker 2006), increased threat posed by the non-native American bullfrog (*L. catesbeianus*) (Moyle 1973; Kiesecker and Blaustein 1998) and the large number of anurans estimated killed on roads by motor vehicles (Kline and Swann 1998, Kline et al. 2005).

The Sonoran Desert near Tucson, Arizona, receives approximately 31 cm of rainfall annually at Tucson International Airport (NOAA 2008) in two distinct rainy seasons—summer and winter—with spring and autumn being generally dry (Adams and Comrie 1997). Rainfall in the Sonoran Desert is not predictable even during the rainy season because dry periods can be interspersed with wet periods during the rainy season and rainfall amounts vary widely between years (Schmidli 1986; Adams and Comrie 1997). Despite these difficulties, at least eight anuran species in three families (Bufonidae, Microhylidae, and Scaphiropodidae) breed in the Sonoran Desert.

Aridity is especially challenging for anurans as they have permeable skin (Adolph 1932), cannot create hypertonic urine (Duellman and Trueb 1986), and are tied to water for reproduction (Pough 2004). Although many species occur only near permanent water sources, many others use seasonal water sources (Mayhew 1968; Shoemaker 1988).

Desert anurans, such as red-spotted toads (*Anaxyrus punctatus*), often use their bladders to store dilute urine to assist with rehydration away from water sources; they can also tolerate loss of up to 40% of their body water (McClanahan et al. 1994). While in their winter burrows, Couch's spadefoots (*Scaphiopus couchii*) absorb water from the surrounding soil by accumulating urea in their plasma, creating an osmotic gradient (Shoemaker et al. 1992). Anurans that breed in temporary pools tend to have shorter larval periods than anurans that breed in more permanent pools. For example, *S. couchii* that breed in temporary pools have a larval period as short as seven days (Morey and Reznick 2004) whereas the *Lithobates yavapaiensis*, that breed in permanent pools, have a larval period of 3–9 months (Sredl 2005).

Desert anurans also have behaviors that allow them to inhabit deserts (Mayhew 1968). They may retreat underground (as in the case of *S. couchii*) or into moist microclimates (as in the case of *A. punctatus*) during hot, dry periods (McClanahan et al. 1994). *S. couchii* may even spend nine or ten months of the year underground (Dimmitt and Ruibal 1980). *A. punctatus* seeks favorable microclimates that allow it to regulate both moisture and temperature levels while foraging away from water, even during the hottest days (McClanahan et al. 1994). Many temporary pool-breeding anurans have evolved synchronous breeding events where males of a species all call at the same time, often after the first big rain of the summer season (Wells 1977; Sullivan 1989).

Our objectives for this study were to 1) determine the locations and durations of breeding sites, 2) determine the baseline breeding population sizes for as many species and breeding sites as possible, and 3) quantify animals killed by vehicles on roads on and

adjacent to Saguaro National Park. The information we gathered will provide data to further augment existing data on anurans at SNP, particularly the Tucson Mountain District (TMD), where information of this nature is scarce. These numbers may be important in the face of increasing urbanization, the on-going long-term drought, or global climate change.

MATERIALS AND METHODS

Study Areas

Saguaro National Park (SNP) is comprised of two districts, the Tucson Mountain District (TMD) west of Tucson, Arizona and the Rincon Mountain District (RMD) east of Tucson, Arizona. TMD consists of approximately 6,216 hectares, ranges in elevation from 664 to 1,429 m, receives an average of 26.1 cm annual rainfall, and contains two biotic communities: desert scrub and desert grassland (SNP 2008). RMD is approximately 30,743 hectares, ranges in elevation from 814 to 2,641 m, receives 32.0 cm annual rainfall, and contains six biotic communities: desert scrub, desert grassland, oak woodland, pine-oak woodland, pine forest, and mixed conifer forest (SNP 2008).

Anurans have been studied and catalogued unevenly at the two districts. More is known about the historical and current distribution of anurans on RMD than TMD (D. Swann, personal communication). According to past studies and observations, four anurans inhabit TMD—Sonoran Desert toad (*Ollotis alvaria*), Great Plains toad (*Anaxyrus cognatus*), *A. punctatus*, and *Scaphiopus couchii*—and eight on RMD—*O. alvaria*, *A. cognatus*, *A. punctatus*, canyon treefrog (*Hyla arenicolor*), *Lithobates catesbeianus*, *L. yavapaiensis*, *Scaphiopus couchii*, and Mexican spadefoot (*Spea multiplicata*) (SNP 2008). We have chosen to concentrate on the “desert breeding” anurans—those species that do not rely on sources of permanent water to breed: the desert toads (*O. alvaria*, *A. cognatus*, and *A. punctatus*) and spadefoots (*Scaphiopus couchii* and *Spea multiplicata*). We used Scientific and English names according to

Crother et al. (2008). Although some of these species will breed in permanent water if available, all of them can use pools that fill with water temporarily with onset of the summer rains during the monsoon season.

Approximately 19.3 km of paved roads and 13.7 km of unpaved roads occur on TMD, whereas approximately 12.9 km of paved road (Cactus Forest Drive) occur on RMD (SNP 2008). At both districts, roads run along some borders of the Park.

Breeding Sites

We used three methods to locate as many breeding sites as possible: visiting historical sites, daytime Visual Encounter Surveys (VES), and nighttime calling surveys. In 2005, we visited historical breeding sites at RMD to determine if they were still active. We recorded any sites that had eggs, tadpoles, or recent metamorphs of any anuran species. In 2005 and 2006, we used daytime VES to locate breeding sites by surveying at TMD for evidence of eggs, tadpoles, or recent metamorphs.

To conduct nighttime calling surveys we first needed to locate intense local rainstorms, which we did using satellite radar loops for the Tucson area at the Web sites www.intellicast.com and www.wrh.noaa.gov. We then used rain gauges shown on the Pima County flood alert page (www.rfcd.pima.gov/wrd/alertsys/index.htm) to determine how much rain was produced by the storm near our study sites. With rare exceptions, these rain gauges were updated online at least every 20 minutes, giving us real-time rainfall data for current storms. The Pima County rain gauges are placed throughout Tucson and surrounding areas, allowing us to monitor storm movement. We relied upon

the seven rain gauges closest to SNP (3 at TMD, 4 at RMD, Table 1) to determine if enough rain had fallen to likely bring anurans above ground.

Table 1. Seven Pima County Flood Control District rain gauges closest to SNP

Number	Name	Zone	UTM		Description
			Easting	Northing	
2090	Tanque Verde Guest Ranch	12S	529674	3567658	Located at Tanque Verde Wash at the Tanque Verde Guest Ranch.
2310	Well E23	12S	523462	3565137	Located at Rancho El Mirador north of Broadway Boulevard
4110	Rincon Creek	12S	535277	3554829	Located at Rincon Creek at X-9 Ranch.
4180	Pantano Houghton	12S	521497	3559014	Located at Pantano Wash at Houghton Road.
6020	SCR Cortaro/Ina Road	12S	490873	3579358	Located at Santa Cruz River and Ina Road.
6440	Brawley Mile Wide	12S	477015	3568029	Located at the intersection of Brawley Wash and Milewide Road.
6460	Picture Rocks Comm Center	12S	477784	3574733	Located at Picture Rocks Community Center.

Previous studies indicate that approximately 1.3 cm is necessary to elicit a strong breeding response by desert-breeding toads and spadefoots (C. Schwalbe, unpublished data). In 2005 and 2006, starting with the first summer rainfall and ending with the last rainfall of October, whenever rainfall registered approximately 0.5 cm or greater, we drove roads near the rain gauges and listened for calling anurans, stopping approximately once every 800 meters and listening for at least a minute. Once we heard calling, we hiked to the calling site and recorded the species calling, approximate number of animals heard, and breeding site location. We also listened for calling on some nights with less

rainfall to confirm anuran activity. During 2007, we did not look for new sites; instead, we returned to selected breeding sites to document pool duration, larval period, tadpole size, and air and water temperatures.

Biological Measures

At each visit, we counted tadpoles and metamorphs and measured representative sized ones. If tadpole density was too high to accurately count or pool visibility too poor to see all tadpoles, we estimated the number of tadpoles for that visit. To estimate tadpole numbers, we counted tadpoles in a given area and extrapolated based on the size of the pool. In 2006 and 2007, we counted or estimated eggs and egg masses during our visits.

We calculated the larval period whenever possible for all three years. The larval period began at hatching (Gosner stage 26) and ended with metamorphosis (Gosner stage 45 or 46; Gosner 1960). However, for *S. couchii*, we also calculated the larval period from oviposition to the development of first forelimb (Gosner stage 42, Gosner 1960), allowing us to compare our data to published values.

Because there were inconsistencies between years with the way SVL was measured, data from 2006 and 2007 were not pooled. We used SVL and not mass for our comparisons because anuran mass depends on the state of hydration of the individual and whether or not it has recently voided its bladder due to handling. We checked for size classes by plotting each male's SVL in a histogram, separating by species. We used t-tests to determine if male and female SVL within a species differed and to determine

whether breeding male *Scaphiopus couchii* SVL differed between sites in 2006. We used a one-way ANOVA to determine whether breeding male *A. punctatus* SVL differed among sites and Tukey-Kramer HSD ($\alpha = 0.05$) to determine which sites differed from the others. For females, TMD15 was excluded because only one female was found; TMD8 because none were.

Abundance

In 2006, we estimated abundance for anuran populations for as many breeding sites as possible (N=7); in 2007, we returned to two breeding sites. If breeding had begun, we called out volunteers if a site required them and it was prior to 2100 h.

We estimated sizes of breeding populations by conducting double mark/recapture surveys of breeding aggregations in a single night (Schwalbe et al. 2006). To eliminate individual collector bias between samples on a given night, the same people collected anurans on both surveys and the same person weighed and measured animals for the entire night. During the first sampling period, collectors captured animals until all or most anurans in the pool had been caught, and recorded the duration of that collecting period so that the same collectors could collect for exactly that same amount of time during the second sample at that same pool. We took captured anurans to a nearby processing area to be weighed, measured, and marked, then released them back into the pool of origin. We played pre-recorded calls if the males did not resume singing once we released them. We waited at least one hour before returning to the pool for the second sample, but we always returned within the same night to satisfy the assumption of

closure. We estimated anuran populations with the Lincoln-Petersen method (Seber 1986).

For purposes of SVL and mass analysis, a “breeding site” was one where we had observed eggs or tadpoles during that year, even if we did not observe eggs or tadpoles following the night we estimated abundance.

We marked *Anaxyrus punctatus* and *Scaphiopus couchii* with subcutaneous injection of VI Alpha tags (Northwest Marine Technology, 1.0 mm x 2.5 mm) injected on the upper side of hind feet to prevent tags from migrating to other parts of the body. Although tags were visible with the naked eye, we used a magnifying viewer and blue light-emitting-diode (LED) light to enhance the visibility of tags. Because VI Alpha tags are not visible through the skin of *Ollotis alvaria*, we used Passive Integrate Transponder (PIT) tags (Biomark) to mark them (Donnelly et al. 1994). To prevent tag loss, we applied vet-bond over the injection site for both VI Alpha tags and PIT tags. We clipped the distal tip of a front toe from each marked animal to help us detect short-term tag loss. We calculated the probability of an animal losing the VI Alpha tag between capture and recapture sessions in a single night (Krebs 1999). We created a separate calculation for *A. punctatus* and *S. couchii*, because they were likely to have different rates of tag loss due to differences in integument, but pooled years and sexes. We used only animals that were tagged during our mark recapture sessions because we had a reasonable expectation of recapturing those animals on the same night.

Road Mortality

During 2005 and 2006, we used road-riding surveys to quantify roadkill on roads within and adjacent to both RMD and TMD, using the same criteria to decide when ride roads as we did to search for breeding sites. In 2005, we surveyed for road mortality between 23 July and 17 October. In 2006, our road mortality surveys started with a rainfall on 27 June and ended with a rainfall event on 8 October. We drove roads generally at less than 40.2 km/hour (25 mph), pulling off the road whenever possible to allow other vehicles to pass. On most occasions we had two observers per vehicle. We identified each live (LOR) and dead (DOR) anuran on roads when possible and noted its location by GPS or vehicle odometer mileage. During 2006, we checked live animals for marks, weighed, and measured them. We checked dead animals for marks, and sometimes we clipped a toe for genetic analysis at a future date.

We divided up the roads at SNP into segments (Appendix A, Table A.1, Table A.7). For purposes of counting the number of times each segment was driven, we counted each time we drove a segment as 1 with the exception of dead end roads. We counted dead end roads (both directions) as 1, even though we removed live and dead animals from the surface on the first pass. We drove the segment in its entirety, unless otherwise noted. In some cases, we drove segments that were subsets of larger segments. When this occurred, we were careful to count only the subset so we could accurately measure the total kilometers driven. We measured segments with GPS (Garmin eTrex).

We computed the number of kilometers driven at TMD and RMD by multiplying the road segment length by the number of times that segment was driven. We then

divided the total numbers of anurans found by this number to determine the number of anurans per kilometer driven. We used the same method to calculate the number DOR per kilometer driven and for each species individually. We defined “adult” as any animal above the minimum adult size given in Stebbins (2003) (*O. alvaria* > 100 mm; *A. cognatus* > 45 mm; *A. punctatus* > 37 mm; *S. couchii* > 56 mm). “Subadults” were large juveniles or small adults that were not in breeding condition. “Juveniles” were animals smaller than the cutoff sizes. We occasionally lost live animals because they escaped into the brush at the side of the road while we were trying to exit the road safely.

Environmental Measures

We measured the water dimensions at breeding sites when we initially discovered it and on the first visit to that site in subsequent years. We also measured water dimensions when it appeared that water area had changed from our last visit due to drying or additional rainfall. Once we found a breeding site, we monitored breeding success by periodically revisiting found sites until no water remained. We tried to revisit sites every two or three days until they dried, but sometimes went as long as a week or more in between visits. During 2005, we did not check sites at RMD as regularly as those at TMD because limited accessibility to RMD sites often prevented us from checking more than one site on any given day. The closure of Cactus Forest Drive for resurfacing during summer of 2006 forced us to focus our efforts on TMD during 2006. We visited selected sites at TMD to return to in 2007. In 2007, we took water temperatures to the nearest degree with a calibrated glass bulb thermometer. We shaded the thermometer if

the pool was in the sun and typically took our reading in the top 2 cm of the pool. We took readings of air temperature, average wind speed, and relative humidity (Kestrel 3000 Pocket Wind Meter).

We gathered rainfall data from three sources: rain gauges at SNP Visitor Centers, the same seven online Pima County rain gauges (RFCD Precipitation and Streamflow Data) we used to determine whether rain was falling near our sites, and the National Weather Service Web site (NOAA 2008). Each district of the Park has a rain gauge at its Visitor Center which is recorded daily by a volunteer at about 0900 h. The Pima County Flood Control District Web site, www.rfcd.pima.gov/wrd/alertsys/index.htm, allows users to select from a system of rain gauges located throughout Pima County and get the amount of rain to the nearest 0.01 inch for any time period of any day the user specifies. Both the long-term mean rainfall for Tucson and the 2005–2007 mean rainfalls for Tucson were taken from www.wrh.noaa.gov (measured at Tucson International Airport).

Even though the Pima County rain gauge Web site allows the user to gather the amount of rain for any time period specified, we selected the rainfall data for our monsoon averages in the time period from 0900 h the previous day to 0900 h of the day for which it was recorded, to be concordant with the Visitor Center data (Appendix B).

The Pima County rain gauges sometimes show different amounts of rain for the same period of time, depending on what unit of time the user selects. For example, sometimes the hourly amounts for a given 24 hour period, when summed, will not add up exactly to the amount of rain recorded on that day; sometimes the days in a month, when

summed, will not add up exactly to the same amount of rainfall if that month was specified on the Web site.

For our analysis of the daily rainfall patterns, we used one hour increments taken only from the Pima County rain gauges because neither the NOAA Web site nor the data from the Visitor Center Web site is reported hourly. We use the six Pima County rain gauges nearest SNP (excluding data from #4110 because it was offline during most of the monsoon seasons in 2006 and 2007) for our analysis of daily rainfall patterns, excluding any times when the Pima County rain gauges were malfunctioning. We analyzed TMD and RMD patterns separately. A rainfall event that occurs at 2112 h will be reported on the Web site under the hourly heading of 2200 h. Similarly, an event at 2359 h is recorded at 2400 h.

Rain that occurred before 15 June or after 30 September was not included with the monsoon tallies for the sake of comparison because the NWS Web site does not include them in the monsoon rainfall averages. However, in 2005 and 2006, we did use these additional rainfall events to search for potential anuran breeding sites and roadkill.

RESULTS

Breeding Sites

At SNP, we saw evidence of breeding (eggs, tadpoles, or recent metamorphs) at 19 sites during 2005, 2006, and 2007; 13 sites (TMD2–9; RMD1–5) in 2005; 12 sites in 2006, six repeats from 2005 (TMD2, 4–6, 8–9) and six new sites (TMD12–15, 18–19); and nine sites during 2007 (TMD2–9, 12) (Figure 1–Figure 3). In 2005, we visited three sites that historically contained anurans (RMD6–8, Figure 4) (D. Swann, personal communication), but we found no eggs, tadpoles, or recent metamorphs. Two sites (TMD3, 7) were successful in 2005 and 2007, but not in 2006; TMD7 was a human-made concrete watering hole that dried up during 2006 due to a broken pipe that was repaired in August of 2007. We did not visit sites TMD13–15, 18–19 during 2007. Sites TMD1, 10, and 11 and RMD9 were small pools of water, (volume $<0.05 \text{ m}^3$), and each had one or two males calling, but no eggs, tadpoles, or metamorphs were ever observed. Complete site descriptions are in Appendix C.

A. punctatus bred at five sites in 2005, nine in 2006, and six in 2007 (Table 2). We believe that the unknown tadpoles (*Anaxyrus* or *Ollotis*) occurring at four sites were *A. punctatus*, based on the rocky wash habitat, with the possibility of *O. alvaria* at one particularly large and deep pool. *S. couchii* bred at six sites during 2005 and at three in 2006 and 2007 (Table 3). More TMD sites produced metamorphs in 2005 than in 2006, even though mean monsoon rainfall in from gauges near our sites gathered more rain in

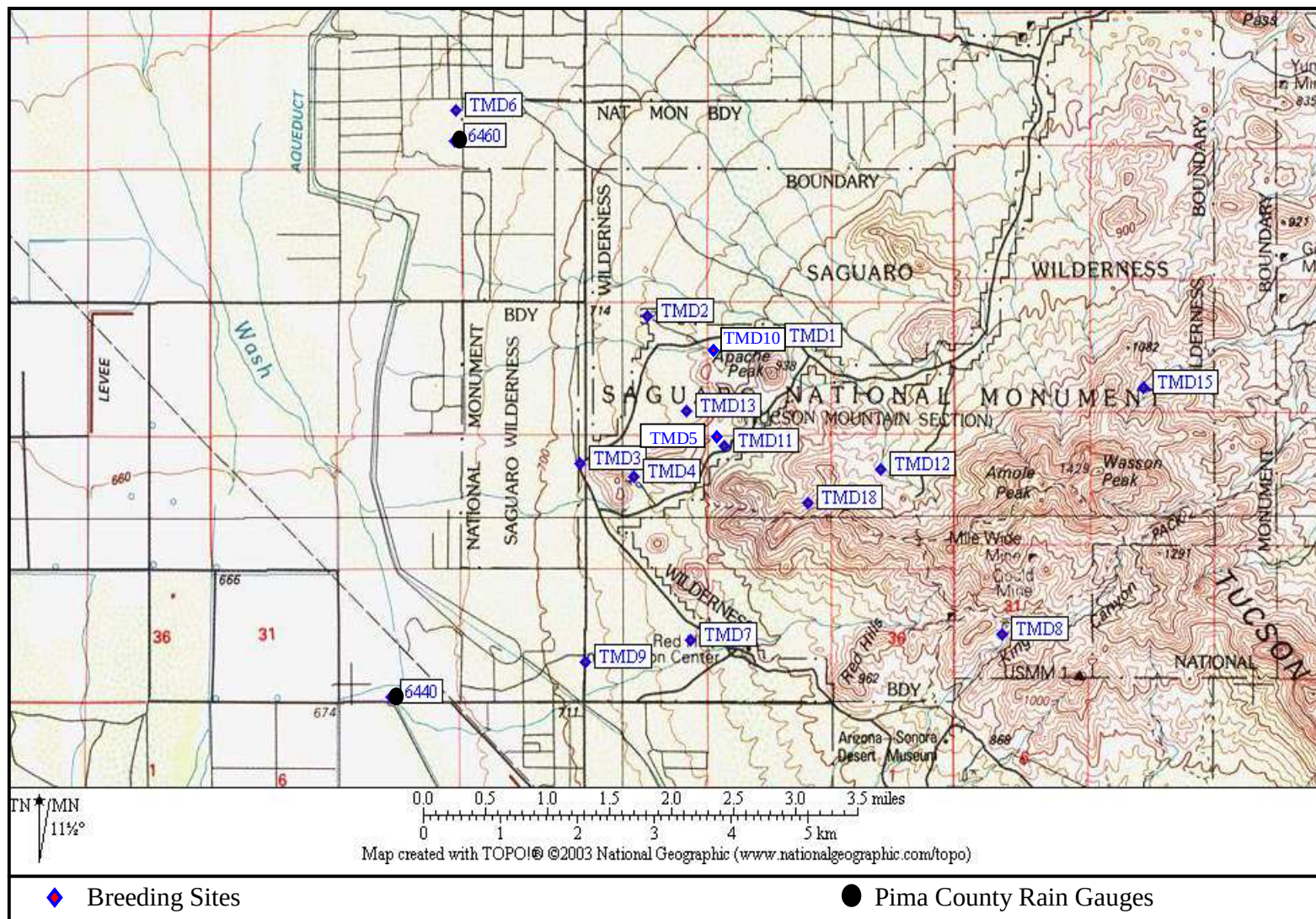


Figure 1. Breeding sites at TMD 2005–2007

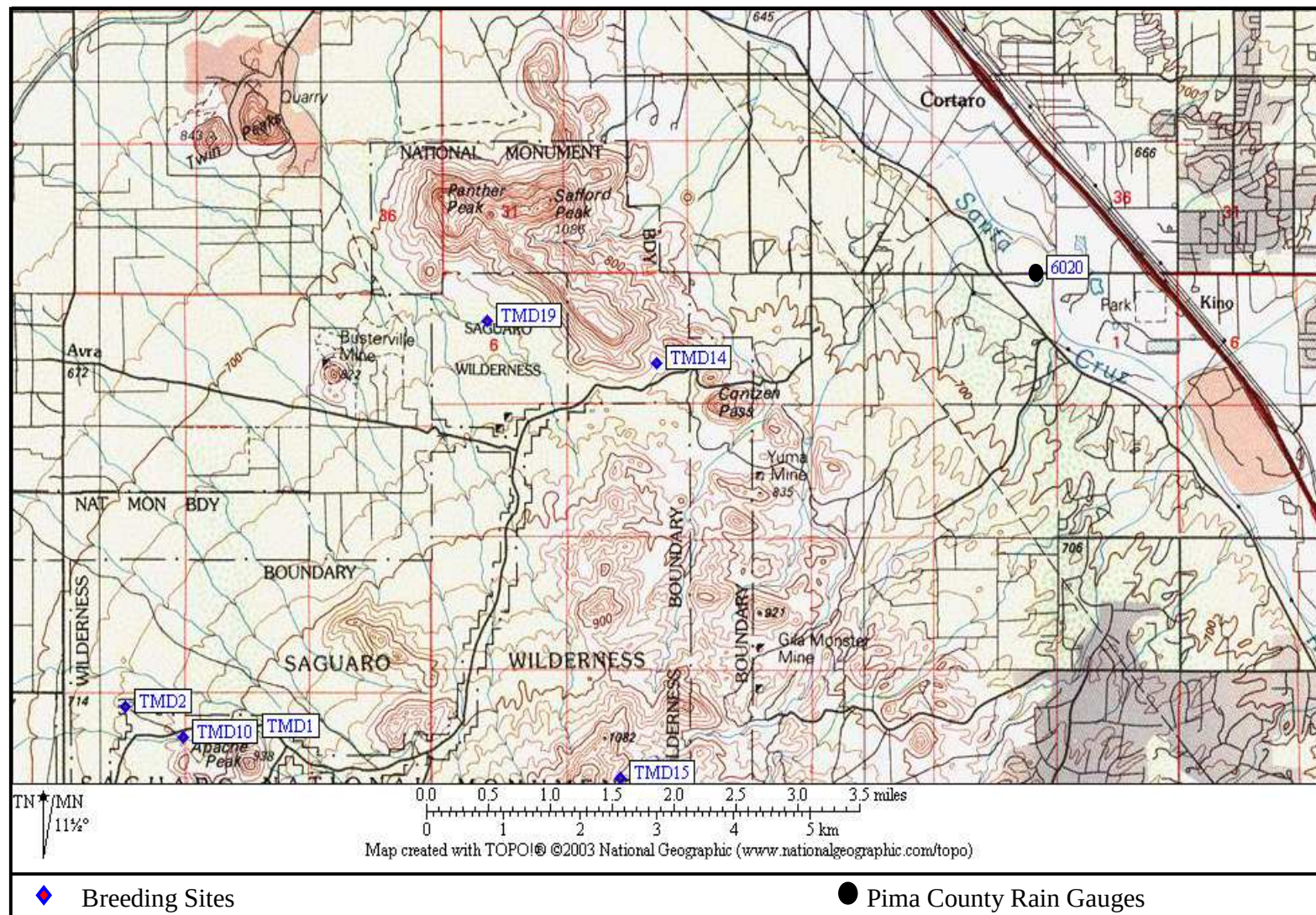


Figure 2. Breeding Sites at TMD 2005–2007 (continued)

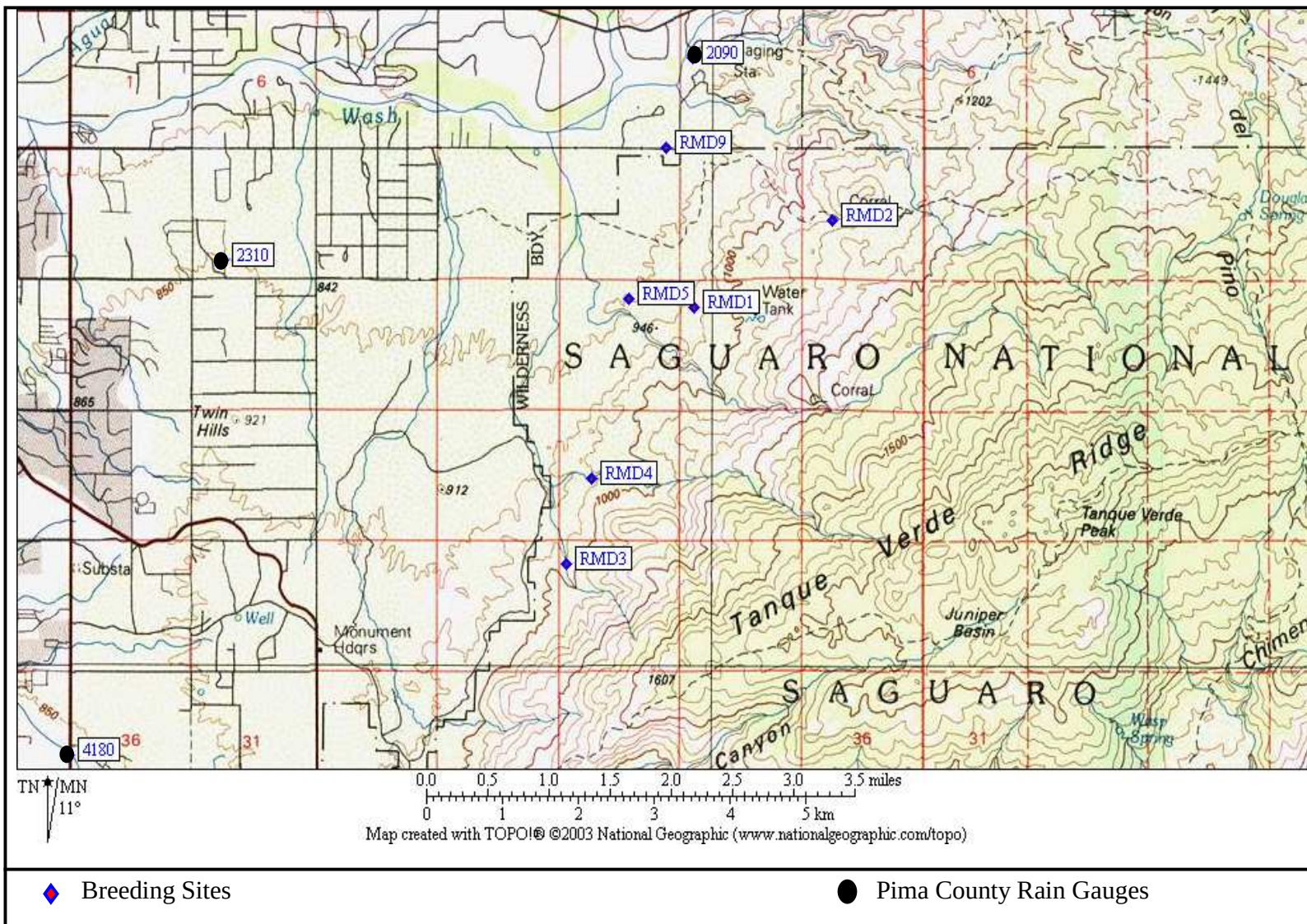


Figure 3. Breeding sites at RMD 2005

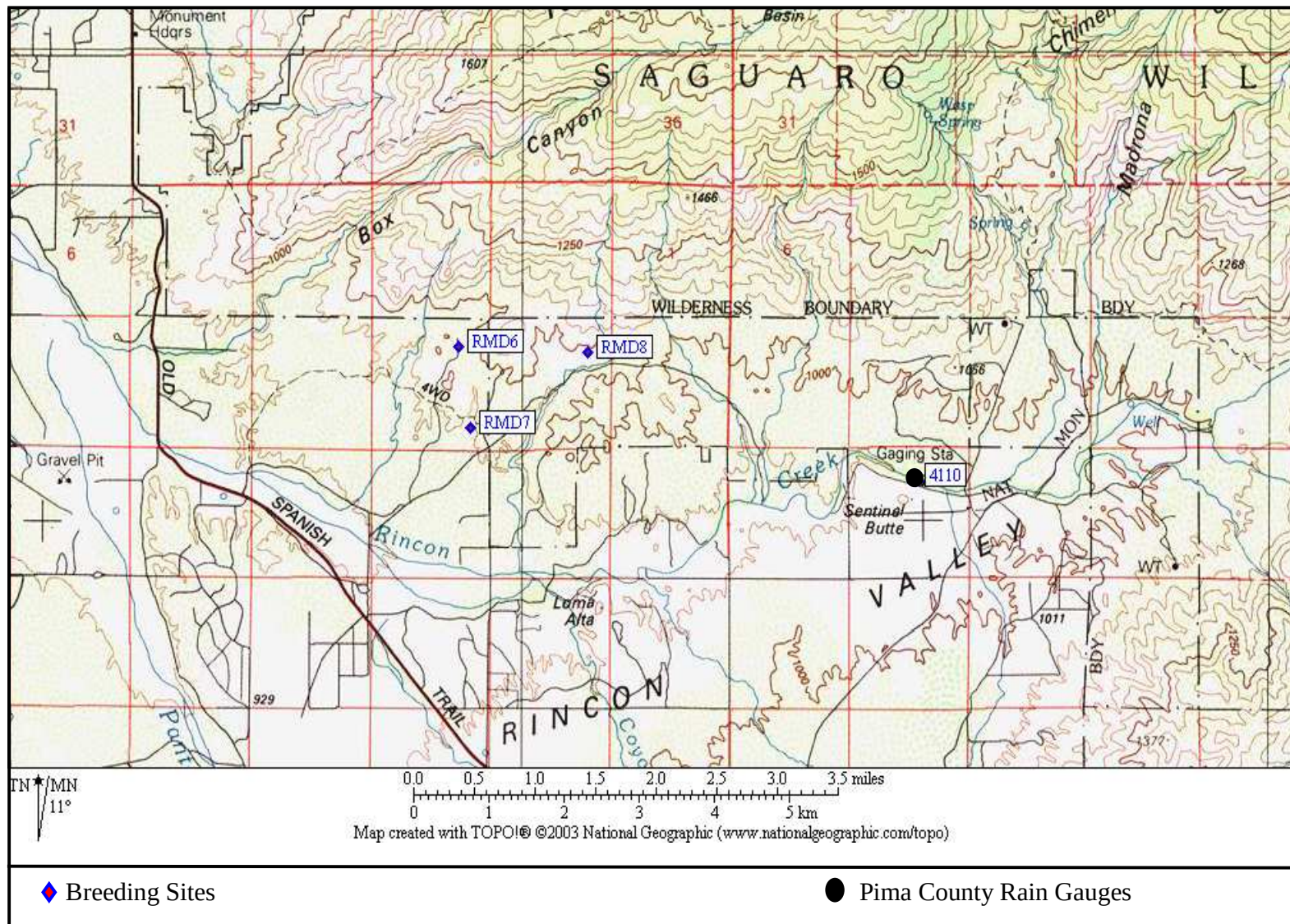


Figure 4. RMD historical sites that did not contain anurans in 2005

2006 than in 2005 (Appendix B, Table B.3–Table B.4). Rains in 2005 occurred close enough together to keep sites from drying before producing metamorphs. We did not locate a single successful *O. alvaria* breeding site, (no eggs, tadpoles, or recent metamorphs observed) although we heard *O. alvaria* calling from one site.

Table 2. Furthest observed level of *Anaxyrus punctatus* development after breeding by year

Site	2005	2006	2007
TMD3	Tadpoles	Calling only	Metamorphs
TMD4	Metamorphs	Metamorphs	Metamorphs
TMD5	Tadpoles	Metamorphs	Metamorphs
TMD7	Metamorphs	None*	Tadpoles
TMD8	Metamorphs	Metamorphs	Metamorphs
TMD12	--	Metamorphs	Metamorphs
TMD13	--	Tadpoles	--
TMD14	--	Tadpoles	--
TMD15	--	Metamorphs	--
TMD18	--	Metamorphs	--
TMD19	--	Tadpoles	--
RMD1	Tadpoles	--	--
RMD2	Tadpoles	--	--
RMD3	Metamorphs	--	--
RMD4	Metamorphs	--	--

*This site was dry during 2006 because the pipe supplying water to it broke prior to the 2006 monsoon season and was repaired in August of 2007.

Table 3: Furthest observed level of *Scaphiopus couchii* development after breeding by year

Site	2005	2006	2007
TMD2	Metamorphs	Tadpoles*	Eggs
TMD3	Metamorphs	Only calling	None
TMD6	Tadpoles*	Tadpoles*	Tadpoles*
TMD9	Tadpoles*	Metamorphs	Metamorphs
RMD3	Tadpoles	--	--
RMD5	Tadpoles	--	--
RMD9	Only calling	--	--

*Puddles dried before metamorphosis

Biological Measures

While we found *A. punctatus* eggs, tadpoles, and metamorphs throughout the monsoon season in into the fall (Table 4), we only observed *S. couchii* eggs, tadpoles, or metamorphs at potential breeding sites in July–early September (Table 5).

Table 4: Dates and stages of first and last observed *Anaxyrus punctatus* at TMD

Stage	Date First Observed			Date Last Observed		
	2005	2006	2007	2005	2006	2007
Eggs	24 July	6 July	20 July	11 Aug.	26 Aug.*	7 Sep.
Tadpoles	24 July	6 July	22 July	8 Oct.	27 Nov.	28 Sep.
Recent Metamorphs	26 Aug.	13 July	5 Aug.	16 Oct.	5 Nov.	7 Oct.

Table 5: Dates and stages of first and last observed *Scaphiopus couchii* at TMD

	Date First Observed			Date Last Observed		
Stage	2005	2006	2007	2005	2006	2007
Calling	July 23	16 July	--	Aug. 23	25 Aug	--
Amplexus	July 23	16 July	--	Aug. 14	3 Aug	--
Eggs	Aug. 10	17 July	27 July	Aug. 15	4 Aug	7 Aug
Tadpoles	July 24	17 July	28 July	Aug. 20	27 Aug	27 Aug
Recent Metamorphs	July 28	7 Aug	5 Aug	Aug. 20	16 Aug	3 Sept

In 2006, we counted 2,662 *A. punctatus* eggs in a single clutch. During 2007, the number of *A. punctatus* eggs per pool ranged from 552 to 4,299. We were unable to determine whether or not eggs in pools adjacent to one another were laid by a single female or by multiple females. We estimated that *A. punctatus* eggs hatched 30–36 hours from when they were oviposited. In 2006, we counted 1,793 *S. couchii* eggs in 44 clutches. *S. couchii* eggs hatched in an estimated 30–40 hours of being deposited. Pools that contained *S. couchii* eggs or tadpoles tended to be warmer (range from 32–42°C: mean 37.5°C, 95% CI 36.1–38.9°C) than pools that contained *B. punctatus* eggs or tadpoles (range from 17–40°C: mean 29.7°C, 95% CI 28.5–30.9°C).

In 2006, scouring events occurred on 29 July, 26 August, and 8 September at a site we monitored closely throughout the season (TMD4). In 2007, scouring events occurred on 28 July, 19 August, 1 September, and 6 September. Scouring events were a

major cause of tadpole loss for *A. punctatus* at TMD, sweeping away up to 99% of tadpoles present (range 69–99%) during a single flood event.

Estimates for the larval period for *A. punctatus* for the monsoon seasons 2005–2007 range from 16 to 28 days. Estimates for the larval period for the larval period of *S. couchii* range from 8 to 11 days (ending at Gosner Stage 45 or 46) and 9 to 10 days (ending at Gosner Stage 42).

In 2006, female *A. punctatus* were 8.4 mm Snout-Vent Length (SVL) larger than males (95% CI 6.0–10.7 mm) at breeding sites (t-test, $t_{134} = 7.77$, $p < 0.0001$). Mean male SVLs of breeding sites ranged from 56.2–58.8 mm (Table 6). In 2006, *A. punctatus* male mean SVLs were not equal (one-way ANOVA, $F_{3,122} = 6.8$, $p = 0.0003$) (Figure 5), with TMD5 being larger than TMD4 and 15. In 2006 at TMD breeding sites, there was no evidence that SVL of female *A. punctatus* differed between sites (t-test, $t_7 = 1.25$, $p = 0.34$). In 2006, mean SVL for females was 65.6 mm (95% CI 63.3–67.9 mm), mean mass, 32.46 g (95% CI 29.79–35.13 g). Snout-Vent Length for non-breeding males ranged from 51–64 mm (N = 5, at 3 sites).

Table 6: Breeding site male *A. punctatus* mean SVL and mean mass

	Mean SVL	Mean Mass
TMD4	56.2	18.56
TMD5	58.8	19.15
TMD8	58.3	20.69
TMD15	56.1	17.98

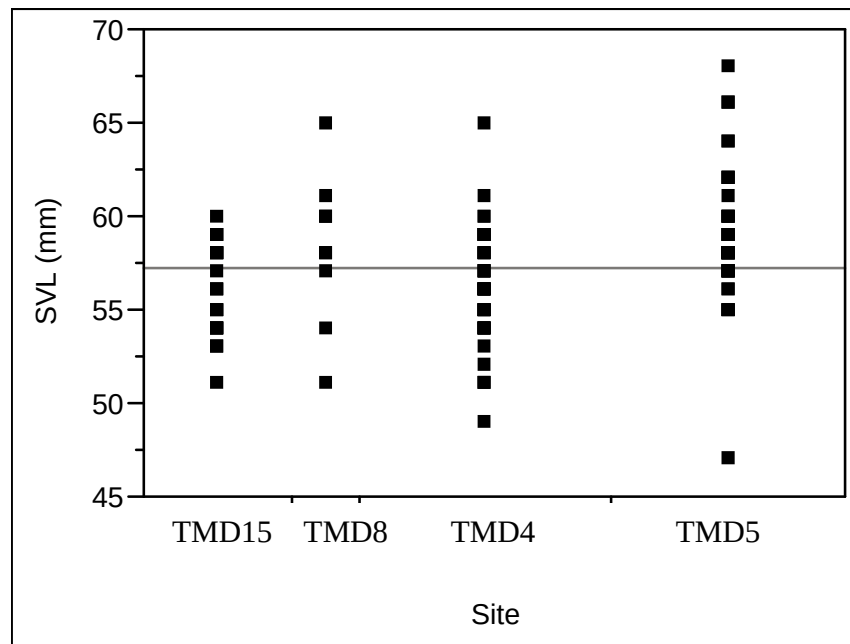


Figure 5. One-way ANOVA of male *A. punctatus* SVL by site

Mean SVL for *A. punctatus* males in 2007 was 58.1 mm (95% CI 56.9–59.2 mm); mean mass was 19.69 g (95% CI 18.58–20.79). In 2007, we only found one female (SVL 68 mm, mass 37.5 g). We found no evidence of size classes among breeding male *A. punctatus* in 2006 or 2007 (Figure 6). Although SVL appears bimodal, 11 animals occur between the peaks in 2006 and 3 occur in 2007.

In 2006, male *S. couchii* were 7.5 mm SVL bigger than females (95% CI 3.2–11.9 mm, t-test, $t_{24} = 3.89$, $p = 0.0035$). Mean SVL for breeding females in 2006 was 61.8 mm (95% CI 57.6–66.1 mm) and mean mass was 26.33 g (95% CI 21.09–31.58 g); for males, mean SVL was 69.4 mm (95% CI 67.2–71.5 mm), mean mass, 30.00 g (95% CI 27.80–32.21 g). SVL did not differ between TMD2 and 6 in 2006 for *S. couchii* males (t-test, $t_{18} = 0.90$, $p = 0.40$). In 2007, males were 5.5 mm bigger SVL than females (95% CI 3.0–8.0 mm, t-test, $t_{33} = 4.52$, $p < 0.0001$). For female *S. couchii* in 2007, mean SVL was

67.9 mm (95% CI 66.2–69.6 mm), mean mass, 38.58 g (95% CI 35.86–41.31 g); for males, mean SVL was 73.4 mm (95% CI 71.5–75.4 mm), mean mass, 36.45 g (95% CI 34.20–38.69 g). We found no evidence of *S. couchii* male size classes (Figure 7).

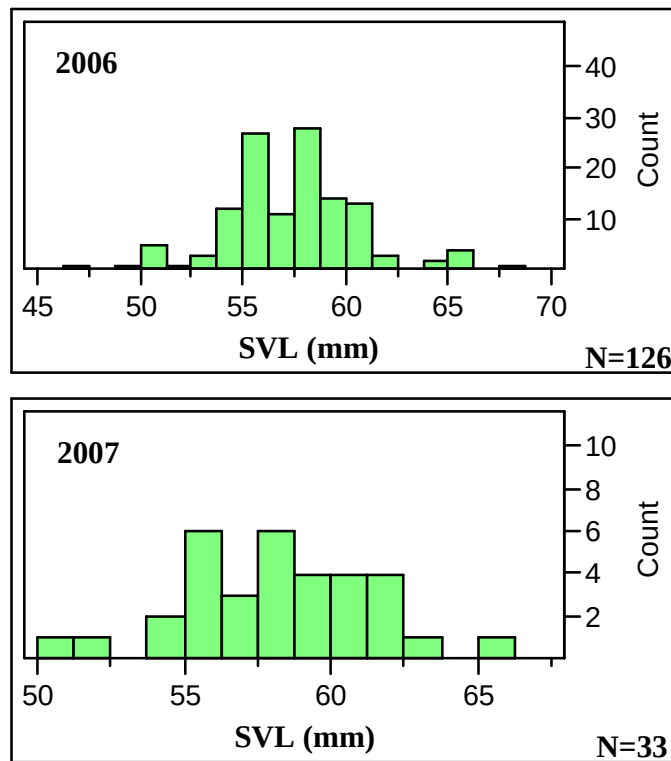


Figure 6. *A. punctatus* SVL distribution 2006 and 2007

O. alvaria mean mass was 223.80 g (95% CI 197.97–249.63) and SVL ranged from 132–154 mm (mean 141.7 mm, 95% CI 137.0–146.5 mm) with no evidence of size classes (Figure 8).

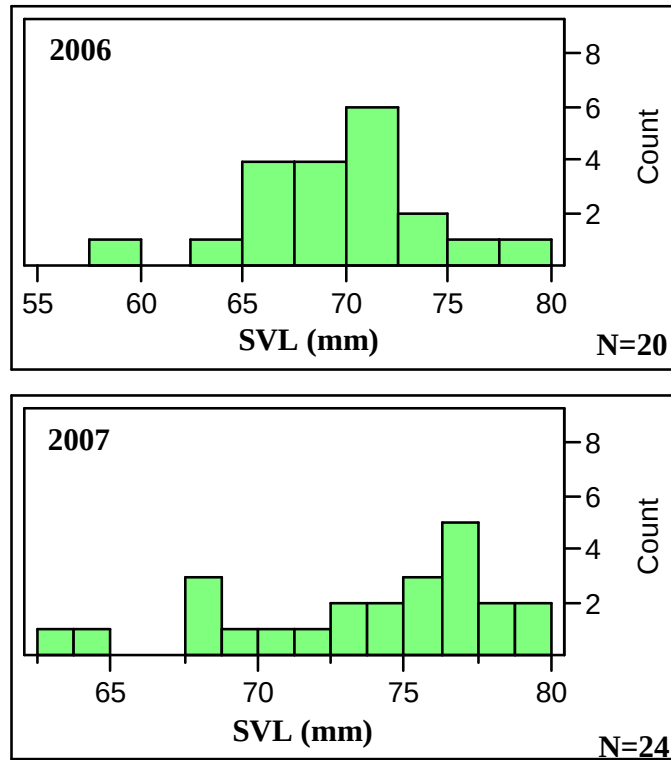


Figure 7. *S. couchii* SVL distribution 2006 and 2007

Although we heard *A. cognatus* calling at a single site, we never saw any females, eggs, or tadpoles at that site. We found two strings of unknown anuran eggs that did not appear to be *O. alvaria* (Livezey and Wright 1945; Stebbins 2003). Tadpoles found in this pond afterward were *Anaxyrus punctatus* and other tadpoles too small to identify to species.

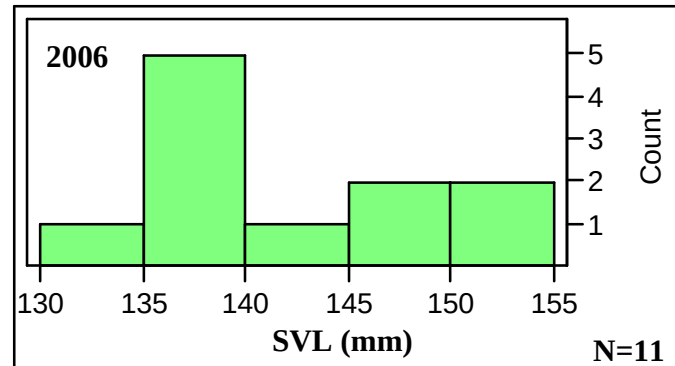


Figure 8. *O. alvaria* SVL distribution 2006 and 2007

Abundance

Population estimates of *A. punctatus* ranged from 12 to 49.2 (95% CI 42.7–55.7 males) males at four sites in 2006. We estimated 35.5 males (95% CI 31.1–39.9 males) during 2007 (Table 7). We tagged 141 (139 during abundance estimation) male and female *A. punctatus* during 2006 and 16 during 2007. In 2007, we saw 18 *A. punctatus* that had been tagged in 2006; however, one of these tags was not readable and five were hard to read. Using only males and females from breeding sites in 2006 and 2007, we estimated a 0.014 probability of *A. punctatus* losing the VI Alpha tag between capture and recapture sessions conducted in the same night (Krebs 1999). This resulted from one animal being improperly tagged (tagged too deep). Additionally, we had seven tags that were hard to see, but ultimately readable, during the second session.

Table 7: Abundance estimates for male *Anaxyrus punctatus* during 2006 and 2007 monsoon seasons, TMD

Site	Year	Date	N	var(N)	95% CI
TMD8	2006	7 Sep.	12.0	0.0	
TMD15	2006	23 Aug.	28.3	2.8	25.0 – 31.5
TMD5	2006	27 July	44.3	3.8	40.5 – 48.1
TMD4	2006	21 Aug.	49.2	11.0	42.7 – 55.7
TMD5	2007	19 Aug.	35.5	5.0	31.1 – 39.9

Numbers of male *S. couchii* varied from 6.0 to 15.7 males (95% CI 12.0–19.4 males) at two sites during 2006 (Table 8). In 2007, estimated abundance of males was 26.0 males (95% CI 22.3–29.7 males). We tagged 32 male and female *S. couchii* in 2006, and 30 in 2007. In 2007, we saw five previously tagged animals; however, two of tags had moved from the original tagging site and were only seen by chance. Using only males and females from breeding sites during 2006–2007, we estimated *S. couchii* VI Alpha tag loss between capture and recaptures sessions the same night occurring with a probability of 0.074 (Krebs 1999). In one animal, the VI Alpha tag flipped over under the skin and would not have been seen without the toe clip. The tag was lost entirely in another.

Table 8. Abundance estimates for male *Scaphiopus couchii* during 2006 monsoon season, TMD

Site	Year	Date	N	var(N)	95% CI
TMD6	2006	3 Aug.	6.0	0.0	
TMD2	2006	29 July	15.7	3.6	12.0 – 19.4
TMD2	2007	28 July	26.0	3.6	22.3 – 29.7

We estimated 11.4 (95% CI 10.0–12.8 males) *Ollotis alvaria* males at one site.

We did not experience any PIT tag loss in *O. alvaria*.

We observed differences in the daily circadian rainfall patterns during 2005–2007 using the three Pima County rain gauges nearest TMD (Appendix B, Figure B.1). A quarter of the total rainfall occurred during morning hours (25% between 0600–0800 h) during 2006, which often made it difficult to determine when anurans were going to emerge to breed.

Road Mortality

Tucson Mountain District

During the 2005 summer rains (June–October), we saw anurans on roads eight of nine nights at TMD. Two of 40 total anurans were seen dead on roads at TMD (Table 9; Appendix A, Table A.2–Table A.6). During the 2006 summer rains (June–October), we saw anurans on roads on 20 of 21 nights at TMD. Of the 145 total anurans seen on roads

on or adjacent to TMD, forty-six were dead (Table 9; Appendix A, Table A.2–Table A.6). In 2005, we found 0.24 anurans per kilometer of road driven (road segment length x number of times segment driven) and 0.01 DOR/km driven; in 2006, we found 0.25 anurans/km driven (0.08 DOR/km) (Table 10).

Table 9: Number of anurans found on roads at TMD in 2005 and 2006

Species	Dead		Live		Total		% Dead	
	2005	2006	2005	2006	2005	2006	2005	2006
<i>Anaxyrus punctatus</i>	0	1	0	4	0	5	--	20
<i>Ollotis alvaria</i>	0	17	6	43	6	60	0	28
<i>Scaphiopus couchii</i>	2	26	31	44	33	70	6	37
<i>Anaxyrus cognatus</i>	0	1	1	2	1	3	0	33
Unknown	0	1	0	6	0	7	--	14
Total	2	46	38	99	40	145	5	32

S. couchii was the most common anuran we saw on roads during both 2005 (0.19 *S. couchii*/km driven) and 2006 (0.12 *S. couchii*/km driven); *O. alvaria* was the second most common (0.04 *O. alvaria*/km driven in 2005; 0.10 *O. alvaria*/km driven in 2006) (Table 10).

Table 10: TMD anurans per kilometer driven 2005 and 2006

2005		2006	
Species	# / km	Species	# / km
<i>A. punctatus</i>	0	<i>A. punctatus</i>	0.01
<i>O. alvaria</i>	0.04	<i>O. alvaria</i>	0.10
<i>S. couchii</i>	0.19	<i>S. couchii</i>	0.12
<i>A. cognatus</i>	0.01	<i>A. cognatus</i>	0.01
Unknown	0	Unknown	0.01
Total	0.24	Total	0.25

***Anaxyrus punctatus*.** In 2005, we saw no *A. punctatus* on the roads, alive or dead; in 2006, we saw four live and one dead (Table 9; Appendix A, Table A.2).

***Ollotis alvaria*.** In 2005, we saw six *O. alvaria* on roads at TMD, all alive. During 2006, 17 of the 60 total *O. alvaria* seen on roads were dead (Table 9; Appendix A, Table A.3).

***Scaphiopus couchii*.** In 2005, two of 33 *S. couchii* we saw on roads at TMD were dead; in 2006, 26 of 70 were dead (Table 9; Appendix A, Table A.4).

Other Species. In 2005, we observed one live *Anaxyrus cognatus*; in 2006, we saw two live and one dead (Table 9; Appendix A, Table A.5). In 2005, we identified all anurans we found on the roads, but in 2006, we saw six live unidentified anurans (5.3% of the total anurans) and one dead anuran that was too mangled to identify to species (Table 9; Appendix A, Table A.6).

Rincon Mountain District

During the 2005 summer rains (June–October), we observed anurans on roads during five of the nine nights we visited RMD. Of the total 179 anurans, 92 were dead and 15 were mistakenly not classified as either alive or dead (Table 11; Appendix A, Table A.8–Table A.12). During the 2006 summer rains (June–October), we observed anurans on roads nine out of the 10 nights we visited RMD. Forty out of 81 anurans were dead on roads in 2006 (Table 11; Appendix A, Table A.8–Table A.12). In 2005, we found 0.63 anurans per kilometer driven. Excluding 15 *S. couchii* that we did not record whether they were alive or dead, we found 0.57 total anurans/km driven (0.32 DOR/km driven); in 2006, we found 0.40 (0.20 DOR/km) (Table 12). The high proportion of dead anurans found in

2005 was fueled in part by finding at least 40 dead *S. couchii* at the Rincon Creek crossing on Old Spanish Trail between the southern Park boundary and Camino Loma Alta on 31 July 2005.

S. couchii was the most common anuran seen on RMD during 2005 (0.47 *S. couchii*/km driven) and 2006 (0.35 *S. couchii*/km driven). In 2005, *A. punctatus* was the second most common anuran on RMD roads (0.05 *A. punctatus*/km driven); in 2006, *O. alvaria* was (0.05 *O. alvaria*/km driven) (Table 12).

Table 11. Number of anurans found on roads at RMD in 2005 and 2006

Species	Dead		Live		Total		% Dead	
	2005	2006	2005	2006	2005	2006	2005	2006
<i>Anaxyrus punctatus</i>	0	0	15	0	15	0	0	--
<i>Ollotis alvaria</i>	5	3	3	7	8	10	63	30
<i>Scaphiopus couchii</i>	85	37	50	34	135*	71	63	52
<i>Lithobates catesbeianus</i>	0	0	2	0	2	0	0	--
Unknown	2	0	2	0	4	0	50	--
Total	92	40	72	41	164*	81	56	49

*Does not include 15 *S. couchii* that were not classified as live or dead

Table 12. RMD anurans per kilometer driven 2005 and 2006

2005		2006	
species	# / km	species	# / km
<i>A. punctatus</i>	0.05	<i>A. punctatus</i>	0
<i>O. alvaria</i>	0.03	<i>O. alvaria</i>	0.05
<i>S. couchii</i>	0.47	<i>S. couchii</i>	0.35
<i>L. catesbeianus</i>	0.01	<i>L. catesbeianus</i>	0
Unknown	0.01	Unknown	0
Total	0.63	Total	0.40

***Anaxyrus punctatus*.** During the 2005 monsoon season, we saw 15 live *A. punctatus* at RMD; in 2006 we found none (Table 11; Appendix A, Table A.8).

***Ollotis alvaria*.** In 2005, we found eight *O. alvaria* on RMD, five of them dead. We found 10 *O. alvaria* on RMD during 2006, three of them dead (Table 11; Appendix A, Table A.9).

***Scaphiopus couchii*.** During 2005, eighty-five of the 135 *S. couchii* we saw were dead; in 2006, we saw 71 *S. couchii*, 37 of them dead (Table 11; Appendix A, Table A.10).

Other Species. During 2005, we found four unknown anurans (2 dead). Additionally, we found two live *Lithobates catesbeianus* on Speedway Boulevard east of Camino del Codorniz (Appendix A, Table A.11).

DISCUSSION

Breeding

Anaxyrus punctatus. The breeding season of *A. punctatus* is limited only by the availability of water and temperature (Tevis 1966; Ferguson and Lowe 1969), with calling or reproduction beginning from March to July (Table 13); it can also exhibit both prolonged and explosive breeding behavior (Wells 1977; Sullivan 1989), allowing it to exploit both permanent and temporary pools.

Although *A. punctatus* do not typically breed in large numbers (Table 13), the types of habitat they prefer, including rocky canyons, springs, temporary rain pools, and more permanent human-made impoundments (Johnson et al. 1948; Stebbins 1951; Parker 1973), are abundant at SNP, allowing *A. punctatus* to be the most successful desert-breeding anuran at SNP, with numbers of males at breeding sites there the largest yet reported for the species.

To succeed, clutches of desert-breeding anurans must survive scouring events, desiccation, and depredation. Scouring was the most important cause of loss, often wiping out more than 95% of tadpoles at rocky canyon sites during individual events (Table 13). Yet, we often observed *A. punctatus* breeding again in these stream sites a day or two after water flow slowed, allowing them to successfully exploit the rocky canyon habitat. While desiccation was a more important source of mortality for *S. couchii* at TMD, it also caused some clutch mortality for *A. punctatus*.

Table 13. Ecological observations of *Anaxyrus punctatus*, *Ollotis alvaria*, and *Scaphiopus couchii*

	<i>A. punctatus</i>		<i>S. couchii</i>		<i>O. alvaria</i>	
	Observation/Estimation	Notes	Observation/Estimation	Notes	Observation/Estimation	Notes
Breeding aggregation size / chorus size	37–40 toads ¹	Death Valley, CA	Up to 2497 males ⁶	BANWR, AZ	About 200 ⁸	Maricopa County, AZ
	Generally calls alone or in small groups ²	Southern AZ	6.0 to 26.0 males (95% CI 22.3–29.7 males) ⁵	TMD	< 40 males/site ⁹	Central AZ
	"Low density breeding aggregation" ³	AZ	Abundant ⁷	Sulphur Springs Valley, AZ	6–40 males/site ¹⁰	Maricopa County, AZ
	Many patches contained "tens of individuals" ⁴	Eastern Mojave Desert			11.4 males (95% CI 10.0–12.8 males) ⁵	TMD9 (2006)
	12.0 to 49.2 males (95% CI 42.7 – 55.7 males) ⁵	TMD 2006				
Egg incubation time	36 h ¹¹	Pena Blanca Springs, AZ	48 h ¹⁴	Room temperature		
	3–4 d ¹²	Laboratory (20.8–22.9°C)	15 h ¹⁵	30°C		
	2 d ¹²	Laboratory (23.6–33.4°C)	30–36 h ¹⁶	Field		
	5 d ¹³	near Riverside, CA	30–40 h ⁵	TMD		
	30–36 h ⁵	TMD				
Shortest larval period	2 mo ¹³	Oviposition to metamorphosis	7.9–12.8 d ¹⁶	Field	About 1 mo ^{20,21}	
	About 30 d ¹⁷	Hatching to metamorphosis; Laboratory	7–8 d ¹⁹	Lab		
	65–75 d ¹⁸	Chorusing to metamorphosis; Maricopa County, AZ	9–10 d ⁵	TMD (2007)		
	16–28 d ⁵	TMD 2005–2007; hatching to metamorphosis				

Table 15. Continued

	<i>A. punctatus</i>		<i>S. couchii</i>	
	Observation	Notes	Observation	Notes
Cause of mortality	Depredation on adults and juveniles ^{11, 23, 25}	Mexican garter snake (<i>Thamnophis eques</i>), West Coast garter snake (<i>T. valida</i>), black-necked garter snake (<i>T. cyrtopsis</i>)	Depredation on adults ^{26, 27}	<i>Thamnophis cyrtopsis</i> , Western hog-nosed snake (<i>Heterodon nasicus</i>), and checkered gartersnake (<i>T. marcianus</i>)
	Depredation on tadpoles ^{5, 24}	Water scavenger beetle (<i>Hydrochara lineata</i>) (larvae), <i>Thamnophis cyrtopsis</i> (potential predator), Dragonfly larvae (Odonata)	Depredation on tadpoles ¹⁶	Yellow mud turtle (<i>Kinosternon flavescens</i>), Eastern spotted skunk (<i>Spilogale putorius</i>)
	Desiccation ^{5, 13}	A major cause of clutch mortality	Desiccation ^{5, 16, 19}	Major cause of clutch mortality when pools not refilled by rain
	Scouring Events ^{5, 22}	During present study lost 69–99% of tadpoles in 5–16 clutches from scouring events in 2005–2006 at TMD4	Desiccation dependent depredation on tadpoles ²⁸	Depredation occurs when pools have almost dried; <i>T. marcianus</i> , <i>T. cyrtopsis</i> , Sonora mud turtle (<i>K. sonoriense</i>), great blue heron (<i>Ardea herodias</i>)

¹Turner 1959; ²Ferguson and Lowe 1969; ³Sullivan 1989; ⁴Bradford et al. 2003; ⁵Present Study; ⁶Schwalbe et al. 2006; ⁷Rosen and Schwalbe 1993; ⁸Blair and Pettus 1954; ⁹Sullivan and Malmos 1994; ¹⁰Sullivan and Fernandez 1999; ¹¹Campbell 1934; ¹²Ballinger and McKinney 1966; ¹³Tevis 1966; ¹⁴Mayhew 1965; ¹⁵Justus 1977; ¹⁶Newman 1987; ¹⁷Dayton and Fitzgerald 2001; ¹⁸Sullivan 2005; ¹⁹Morey and Reznick 2004; ²⁰Ruthven 1907; ²¹Musgrave and Cochran 1929; ²²Johnson et al. 1948; ²³Blazques 1996; ²⁴Livo 2000; ²⁵Meik 2007; ²⁶Dimmitt 1990; ²⁷Woodward and Mitchell 1990; ²⁸Schwalbe, personal communication

We witnessed predation and probable predation of *A. punctatus* tadpoles at TMD, but were unable to assess effects on the population, though we think it negligible for this species here. Both vertebrates and invertebrates can be sources of mortality for *A. punctatus* (Table 13).

***Ollotis alvaria*.** We did not see any evidence of *O. alvaria* breeding in any of our rocky canyon sites at TMD even though *O. alvaria* do use rocky riparian areas to breed (Degenhardt et al. 1996, C. Schwalbe unpublished data). Although these sites at TMD were very successful for *A. punctatus*, they may be too temporary or shallow to accommodate *O. alvaria* breeding. However, Sullivan and Fernandez (1999) found that over the six years of their study, *O. alvaria* persisted despite not breeding successfully most of those years. Further surveys for this species may be necessary to rule out its breeding at TMD.

Between nighttime surveys listening from roads and daytime visual encounter surveys for eggs, tadpoles, or metamorphs, we were unlikely to miss *O. alvaria* breeding sites at TMD. Although *O. alvaria* has a relatively weak call (Blair and Pettus 1954), Sullivan and Malmos (1994) were able to hear calls from about 100–150 meters away, as were we at our single calling site.

***Scaphiopus couchii*.** Our *Scaphiopus couchii* population estimates were much smaller than estimates or observations from other studies (Table 13). Although *S. couchii* will breed in pools found at SNP such as temporary pools in rocky canyons, tinajas, and pools by the side of roads (Lowe 1964; Morey 2005), it breeds in larger numbers in valley

bottoms in temporary pools formed by summer rains (Bragg 1945; Newman 1987; Morey 2005).

S. couchii is adapted to xeric conditions with its short larval period allowing it to use temporary pools formed by summer rains (Table 13). However, desiccation was often a source of clutch mortality for *S. couchii* at TMD (Table 3). Morey and Reznick (2004) found that the average duration of pools that produced metamorphs was only three days longer than tadpole development time. Thus, timing of rains can be more important to clutch survival than amount of rain (Newman 1987), as we found at TMD.

Even though predation can be a source of mortality for *S. couchii* (Table 13), we did not observe predation of *S. couchii* tadpoles at any of our sites. Dayton and Fitzgerald (2001) found that predators that occur in more permanent pools may exclude *S. couchii* tadpoles that are more active, and thus more susceptible to depredation, than co-occurring species.

Although *Anaxyrus cognatus* and Mexican spadefoot (*Spea multiplicata*) have been documented in the past at RMD (SNP 2008), we neither heard them during our nighttime calling surveys nor saw evidence of their breeding during our daytime visual encounter surveys in 2005.

Road Mortality

Kline and Swann (1998) conservatively estimated that 1,300 amphibians were killed annually on roads on or adjacent to SNP. However, they believed that this was a severe underestimate.

Although past road mortality surveys at SNP tended to miss anuran roadkill because they were conducted during the day without regard to rainfall (Kline and Swann 1998; Kline et al. 2005), we surveyed only at night during or after rain storms in an attempt to target anuran roadkill on nights when amphibian activity was expected. Because we surveyed roads as road mortality happened, we do not anticipate our numbers being affected by scavengers; counting road-killed amphibians the day after they were killed can lead to severe undercounting of their numbers because scavengers remove DOR before they are observed, as happened in past studies at SNP (Hels and Buchwald 2001; Kline and Swann 1998; Kline et al. 2005).

We found fewer DOR anurans per kilometer at TMD (0.01 in 2005; 0.08 in 2006) than previous studies (0.20); at RMD, we found similar numbers or more (0.32 and 0.20 versus 0.23) (D. Swann, unpublished data).

Because our numbers represent a snapshot of live/dead that occurred at the moment of the survey, we do not have the total number of dead that occurred on any given night, as some of the LOR we saw were undoubtedly later killed. When we combine our live and dead anurans, we have similar anurans per kilometer as found on TMD (Table 10); however, when we combine our live and dead anurans, we have many more anurans per kilometer than found on RMD (Table 12).

Sometimes amphibians are drawn to the landscape created by roads or roadside puddles themselves (Ashley and Robinson 1996). This is particularly the case for *S. couchii* which were the most common anurans on SNP roads, even though they bred at very few sites.

Vagility (or inherent tendency of an organism to move) is a measure of both movement distance and movement frequency. *Ollotis alvaria* is a large, mobile species that often can migrate long distances in one night. Individuals have moved up to four kilometers (D. Cornejo, unpublished data). Despite the fact that we recaptured *A. punctatus* up to 1,105 m from its original site, which is further than 823 meters maximum movement previously noted (Tevis 1966), *A. punctatus* is a smaller species that tends to remain near its breeding site (Turner 1959; Weintraub 1974). We seldom observed *A. punctatus* on roads compared to other species less abundant at SNP. Carr and Fahrig (2001) showed that road mortality tends to cause population declines in amphibian species that are more vagile; thus the differing vagility of these two species may be one reason why we found so many *O. alvaria* DOR and so few *A. punctatus*. Little is known about the terrestrial habits of *S. couchii*; however, they may travel at least 3.2 km between winter burrows and breeding sites (Dimmitt 1990). In areas that contain roads, increased travel distance directly relates with an increased risk of being killed on roads

CONCLUSIONS

Anaxyrus punctatus was the most abundant anuran at TMD; we found them virtually everywhere we found summer water during 2005–2007. Although we conducted no population estimates for *A. punctatus* at RMD, we found tadpoles in virtually every pool during our visual encounter surveys in summer 2005.

Several factors may endanger long-term persistence of *Scaphiopus couchii* populations on SNP. First, SNP contains little valley-bottom breeding habitat. Second, we found smaller breeding aggregations than are typical of better valley-bottom breeding habitat. Third, the landscape surrounding SNP (particularly TMD) may become less usable to *S. couchii* as urbanization increases.

Because TMD lacks reliable water at canyon sites and adequate valley-bottom breeding sites, *Ollotis alvaria* is not likely to breed there. The status of the *O. alvaria* population on RMD is less certain because we do not know how many sites exist or what size breeding populations they contain.

Our results indicate that anurans are being killed on roads at approximately the same rate or higher than studies conducted during 1996–1999 on SNP (D. Swann, unpublished data, Table 9; Table 11); however, direct comparisons between our rates of roadkill and theirs must be made cautiously because we did not calculate a rate of observer error to account for the percentage of available anurans that might be missed during driving surveys.

MANAGEMENT IMPLICATIONS

***Anaxyrus punctatus*.** Because of its strong affinity to rocky desert canyons and its relatively low vagility, which likely results in low vehicular mortality, this species appears to be thriving under present management.

***Ollotis alvaria*.** The lack of any known robust breeding populations at natural sites on TMD does not bode well for the long-term persistence of this toad on this district of the park. Searches for natural breeding sites in remote areas of the district should be continued by staff and volunteers as they conduct other activities on the park. Because this toad is known to breed in earthen cattle tanks and other human-made catchments, creation of such potential breeding sites as far away from roads as possible in TMD and enforcing the closure of the Bajada Loop road at night might allow this species to persist for decades, but continued active management would probably be required to eliminate non-native species such as the American Bullfrog (*Lithobates catesbeianus*) or the Barred Tiger Salamander (*Ambystoma mavortium*) that would also be attracted to permanent water. It would be extremely difficult to construct summer ephemeral ponds that hold sufficient water to sustain *O. alvaria* through metamorphosis that would not be perennial enough to attract invasive species—and several such ponds would be needed to support a sustainable metapopulation on the district.

Ollotis was known to breed in some of the pools in the Loma Verde drainage before those pools filled with sediment following wildfires. The park should continue its monitoring of that drainage, especially if sediment is removed again from some of the filled in pools.

Continued monitoring of Lowland Leopard Frogs (*Lithobates yavapaiensis*) since 1995, which often share some of the larger pools with *O. alvaria*, has provided and will continue to provide useful information to the park regarding breeding sites for this large toad. The sharing of observations (and the especially valuable digital photographs) of amphibians or other species of interest by field workers on other projects such as desert tortoise (*Gopherus agassizii*) studies, buffel grass (*Pennisetum cilare*) removals, etc., a practice long supported at the park, has provided useful information to the Park and other scientists at almost no additional cost.

The presence of permanent and semi-permanent water in several canyons at RMD makes the outlook for *O. alvaria* more optimistic at that district. Mapping *O. alvaria* sightings will help the park resource management staff plan future surveys to determine the status of that species at RMD.

***Scaphiopus couchii* and other valley-bottom breeders, occasionally observed on or near SNP.** Most valleys supporting robust populations of *S. couchii* have valley-bottom sites where thousands of individuals of this species and others aggregate for breeding. The two districts of SNP were originally chosen primarily to preserve populations of the saguaro cactus (*Carnegiea gigantea*), a species found primarily on the bajada, not the valley floor. Thus, it is not surprising that small populations of those valley-bottom breeding anurans occur at SNP.

With the exception of *Anaxyrus cognatus* calling at a single site at TMD, we did not observe any other valley-bottom breeding anurans, such as *Spea multiplicata* or *Gastrophryne olivacea*, on SNP. However, biologists and SNP staff should be alert for

these species so that any existing breeding sites on the Park might be identified and evaluated.

The most important step in maintaining the presence of *S. couchii* at SNP will be to preserve or enhance their current breeding habitats on the Park, particularly TMD9 and RMD5a. Creation of additional human-made impoundments at SNP may also benefit *S. couchii*, as long as they do not contain permanent water. *S. couchii* do not use permanent water to breed because the density of aquatic predators becomes too high. As previously mentioned, permanent water could lure invasive species such as *Lithobates catesbeianus* and *Ambystoma mavortium*.

APPENDIX A. ANURANS KILLED ON ROADS BY MOTOR VEHICLES

Table A.1. TMD road segments, number of times driven, and total length driven per segment 2005 and 2006

		2005		2006	
Road Segment	Segment Length (km)	# Times Driven	(Segment Length) * (# Times Driven)	# Times Driven	(Segment Length) * (# Times Driven)
Bajada Loop—north side	3.94	7	27.58	16	63.04
Bajada Loop—south side	3.71	6	22.26	13	48.23
Ezkinminzin Road	0.19	0	0	1	0.19
Golden Gate	6.07	1	6.07	6	36.42
Bajada Loop---from Sandario to Sus Picnic Area Road and back	1.50	0	0	4	6.00
Kinney Road from Bajada Loop to Sandario Road	0.33	5	1.65	17	5.61
Kinney Road from Milewide Road to Visitor Center	1.54	9	13.86	18	27.72
Kinney Road from Visitor Center to Bajada Loop	2.60	9	23.40	18	46.80
Manville Road from Sanders Road to Sandario Road	1.61	2	3.22	15	24.15
Milewide Road from Kinney Road to Sandario Road	3.18	0	0	10	31.80
Picture Rocks Road from Golden Gate Road to Park boundary sign	3.91	1	3.91	9	35.19
Picture Rocks Road from Tula Lane to Golden Gate Road	1.53	2	3.06	10	15.30
Rudasil Road from Sandario Road to Sanders Road	1.61	1	1.61	13	20.93
Rudasil Road from Sandario Road to Tula Lane	4.48	1	4.48	5	22.40
Sandario Road from Golden Gate Road to Manville Road	1.89	3	5.67	24	45.36
Sandario Road from Kinney Road to Golden Gate Road	0.43	1	0.43	23	9.89
Sandario Road from Manville Road to Rudasil Road	2.41	2	4.82	13	31.33

Table A.1. Continued

		2005		2006	
Road Segment	Segment Length (km)	# Times Driven	(Segment Length) * (# Times Driven)	# Times Driven	(Segment Length) * (# Times Driven)
Sandario Road from Milewide Road to Kinney Road	2.54	3	7.62	11	27.94
Sanders Road from Manville Road to Sweetwater Drive	1.60	4	6.40	9	14.40
Sanders Road from Rudasil Road to Manville Road	2.45	9	22.05	15	36.75
Signal Hill Picnic Area Road	0.70	8	5.60	15	10.50
Sunset Road	0.39	2	0.78	0	0
Sus Picnic Area Road	0.42	6	2.52	18	7.56
Sweetwater Drive	0.78	3	2.34	7	5.46
Total	49.81		169.33		572.97

Table A.2. TMD *A. punctatus* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Anaxyrus punctatus</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Bajada Loop—north side												
Bajada Loop—south side				3								
Ezkinminzin Road												
Golden Gate												
Bajada Loop---from Sandario to Sus Picnic Area Road and back												
Kinney Road from Bajada Loop to Sandario Road												
Kinney Road from Milewide Road to Visitor Center												
Kinney Road from Visitor Center to Bajada Loop				1								
Kinney Road -unspecified												
Manville Road from Sanders Road to Sandario Road												
Milewide Road from Kinney Road to Sandario Road												
Picture Rocks Road from Golden Gate Road to Park boundary sign												
Picture Rocks Road from Tula Lane to Golden Gate Road												
Rudasil Road from Sandario Road to Sanders Road												
Rudasil Road from Sandario Road to Tula Lane												
Sandario Road from Golden Gate Road to Manville Road												

Table A.2. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Sandario Road from Kinney Road to Golden Gate Road												
Sandario Road from Manville Road to Rudasil Road												
Sandario Road from Milewide Road to Kinney Road												
Sanders Road from Manville Road to Sweetwater Drive												
Sanders Road from Rudasil Road to Manville Road												
Signal Hill Picnic Area Road												
Sunset Road												
Sus Picnic Area Road			1									
Sweetwater Drive												
Total	0	0	1	4	0	0	0	0	0	0	0	0

<i>Anaxyrus punctatus</i>	Total 2005 Dead	0
	Total 2005 Live	0
	Total 2006 Dead	1
	Total 2006 Live	4

Table A.3. TMD *O. alvaria* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Ollotis alvaria</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Road Segment												
Bajada Loop—north side								2				
Bajada Loop—south side				2								
Ezkinminzin Road												
Golden Gate		1						1				
Bajada Loop---from Sandario to Sus Picnic Area Road and back												
Kinney Road from Bajada Loop to Sandario Road												
Kinney Road from Milewide Road to Visitor Center												
Kinney Road from Visitor Center to Bajada Loop				1				1				
Kinney Road -unspecified				1								
Manville Road from Sanders Road to Sandario Road							1	2				
Milewide Road from Kinney Road to Sandario Road				1								
Picture Rocks Road from Golden Gate Road to Park boundary sign												
Picture Rocks Road from Tula Lane to Golden Gate Road												
Rudasil Road from Sandario Road to Sanders Road								1				
Rudasil Road from Sandario Road to Tula Lane							1					

Table A.3. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Sandario Road from Golden Gate Road to Manville Road				1			2					
Sandario Road from Kinney Road to Golden Gate Road												
Sandario Road from Manville Road to Rudasil Road							2					
Sandario Road from Milewide Road to Kinney Road			5	4				2				
Sanders Road from Manville Road to Sweetwater Drive		2		5			1	10		1		1
Sanders Road from Rudasil Road to Manville Road		1		2			5	1				1
Signal Hill Picnic Area Road				1								
Sunset Road												
Sus Picnic Area Road				1								
Sweetwater Drive		1						2				
Total	0	5	5	19	0	0	12	22	0	1	0	2

<i>Ollotis alvaria</i>	Total 2005 Dead	0
	Total 2005 Live	6
	Total 2006 Dead	17
	Total 2006 Live	43

Table A.4. TMD *S. couchii* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Scaphiopus couchii</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Bajada Loop—north side												
Bajada Loop—south side												
Ezkinminzin Road												
Golden Gate												
Bajada Loop---from Sandario to Sus Picnic Area Road and back												
Kinney Road from Bajada Loop to Sandario Road												
Kinney Road from Milewide Road to Visitor Center												
Kinney Road from Visitor Center to Bajada Loop												
Kinney Road -unspecified												
Manville Road from Sanders Road to Sandario Road			1	1				1				
Milewide Road from Kinney Road to Sandario Road												
Picture Rocks Road from Golden Gate Road to Park boundary sign												
Picture Rocks Road from Tula Lane to Golden Gate Road												
Rudasil Road from Sandario Road to Sanders Road			3	3			4	4				
Rudasil Road from Sandario Road to Tula Lane				1								
Sandario Road from Golden Gate Road to Manville Road	1		5			1		1				

Table A.4. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Sandario Road from Kinney Road to Golden Gate Road												
Sandario Road from Manville Road to Rudasil Road			3	1								
Sandario Road from Milewide Road to Kinney Road			1	5								
Sanders Road from Manville Road to Sweetwater Drive		6		4		1		7				2
Sanders Road from Rudasil Road to Manville Road	1	20	3	7		1	5	3				
Signal Hill Picnic Area Road												
Sunset Road												
Sus Picnic Area Road												
Sweetwater Drive		2		1			1	2				1
Total	2	28	16	23	0	3	10	18	0	0	0	3

<i>Scaphiopus couchii</i>	Total 2005 Dead	2
	Total 2005 Live	31
	Total 2006 Dead	26
	Total 2006 Live	44

Table A.5. TMD *A. cognatus* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Anaxyrus cognatus</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Road Segment												
Bajada Loop—north side												
Bajada Loop—south side				1								
Ezkinminzin Road												
Golden Gate												
Bajada Loop---from Sandario to Sus Picnic Area Road and back												
Kinney Road from Bajada Loop to Sandario Road												
Kinney Road from Milewide Road to Visitor Center												
Kinney Road from Visitor Center to Bajada Loop												
Kinney Road -unspecified												
Manville Road from Sanders Road to Sandario Road												
Milewide Road from Kinney Road to Sandario Road												
Picture Rocks Road from Golden Gate Road to Park boundary sign												
Picture Rocks Road from Tula Lane to Golden Gate Road												
Rudasil Road from Sandario Road to Sanders Road												
Rudasil Road from Sandario Road to Tula Lane												

Table A.5. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Sandario Road from Golden Gate Road to Manville Road												
Sandario Road from Kinney Road to Golden Gate Road												
Sandario Road from Manville Road to Rudasil Road												
Sandario Road from Milewide Road to Kinney Road												
Sanders Road from Manville Road to Sweetwater Drive		1										1
Sanders Road from Rudasil Road to Manville Road												
Signal Hill Picnic Area Road												
Sunset Road												
Sus Picnic Area Road												
Sweetwater Drive							1					
Total	0	1	0	1	0	0	1	0	0	0	0	1

<i>Anaxyrus cognatus</i>	Total 2005 Dead	0
	Total 2005 Live	1
	Total 2006 Dead	1
	Total 2006 Live	2

Table A.6. TMD unknown species road mortality 2005–2006, number dead on road by segment and year

	Unknown			
	2005		2006	
	Dead	Live	Dead	Live
Road Segment				
Bajada Loop—north side				
Bajada Loop—south side				
Ezkinminzin Road				
Golden Gate				
Bajada Loop---from Sandario to Sus Picnic Area Road and back				
Kinney Road from Bajada Loop to Sandario Road				
Kinney Road from Milewide Road to Visitor Center				
Kinney Road from Visitor Center to Bajada Loop				
Kinney Road -unspecified				
Manville Road from Sanders Road to Sandario Road				
Milewide Road from Kinney Road to Sandario Road				
Picture Rocks Road from Golden Gate Road to Park boundary sign				
Picture Rocks Road from Tula Lane to Golden Gate Road				2
Rudasil Road from Sandario Road to Sanders Road				
Rudasil Road from Sandario Road to Tula Lane				
Sandario Road from Golden Gate Road to Manville Road			1	2
Sandario Road from Kinney Road to Golden Gate Road				
Sandario Road from Manville Road to Rudasil Road				
Sandario Road from Milewide Road to Kinney Road				1
Sanders Road from Manville Road to Sweetwater Drive				1

Table A.6. Continued

	2005		2006	
Road Segment	Dead	Live	Dead	Live
Sanders Road from Rudasil Road to Manville Road				
Signal Hill Picnic Area Road				
Sunset Road				
Sus Picnic Area Road				
Sweetwater Drive				
Total	0	0	1	6

unknown	2005 Dead	0
	2005 Live	0
	2006 Dead	1
	2006 Live	6

Table A.7. RMD road segments, number of times driven, and total length driven per segment 2005 and 2006

Road Segment	Segment Length (km)	2005		2006	
		# Times Driven	(Segment Length) * (Times Driven)	# Times Driven	(Segment Length) * (Times Driven)
Broadway Boulevard, east of Freeman Road	1.61	6	9.66	9	14.49
Cactus Forest Drive	12.92	2	25.84	0	0
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard	1.61	0	0	0	0
Camino Loma Alta	3.91	4	15.64	1	3.91
Freeman Road, Broadway Boulevard to Old Spanish Trail	4.21	10	42.10	11	46.31
Freeman Road, Speedway Boulevard to Broadway Boulevard	1.61	10	16.10	13	20.93
Javalina Picnic Area Road	0.76	1	0.76	0	0
Old Spanish Trail between Freeman Road and Escalante Road	0.63	2	1.26	3	1.89
Old Spanish Trail from Escalante Road to southern Park boundary	3.38	6	20.28	1	3.38
Old Spanish Trail, Freeman Road to southern Park boundary	4.01	7	28.07	4	16.04
Old Spanish Trail, southern Park boundary to Camino Loma Alta*	7.68	11	84.48	5	38.40
Old Spanish Trail—unspecified			0		0
Pre-Cactus Forest Drive Loop but within Visitor Center Parking	0.29	2	0.58	0	0
Speedway Boulevard, between Freeman Road and Camino del Codorniz	1.21	13	15.73	18	21.78
Speedway Boulevard, east of Camino del Codorniz	3.61	7	25.27	10	36.10
Total	47.44		285.77		203.23

*3 of the 5 times we drove Old Spanish Trail from the southern Park boundary to Camino Loma Alta, it is unclear whether or not we drove the entirety of this segment

Table A.8. RMD *A. punctatus* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Anaxyrus punctatus</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Broadway Boulevard, east of Freeman Road												
Cactus Forest Drive		10										
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard												
Camino Loma Alta		1										
Freeman Road, Broadway Boulevard to Old Spanish Trail												
Freeman Road, Speedway Boulevard to Broadway Boulevard												
Javalina Picnic Area Road		1										
Old Spanish Trail between Freeman Road and Escalante Road												
Old Spanish Trail from Escalante Road to southern Park boundary												
Old Spanish Trail, Freeman Road to southern Park boundary												
Old Spanish Trail, southern Park boundary to Camino Loma Alta												
Old Spanish Trail—unspecified												

Table A.8. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Pre-Cactus Forest Drive Loop but within Visitor Center Parking lot												
Speedway Boulevard, between Freeman Road and Camino del Codorniz												
Speedway Boulevard, east of Camino del Codorniz		3										
Total	0	15	0	0	0	0	0	0	0	0	0	0

<i>Anaxyrus punctatus</i>	Total 2005 Dead	0
	Total 2005 Live	15
	Total 2006 Dead	0
	Total 2006 Live	0

Table A.9. RMD *O. alvaria* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Ollotis alvaria</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Broadway Boulevard, east of Freeman Road												
Cactus Forest Drive												
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard												
Camino Loma Alta		1							1			
Freeman Road, Broadway Boulevard to Old Spanish Trail			1	1								
Freeman Road, Speedway Boulevard to Broadway Boulevard												
Javalina Picnic Area Road												
Old Spanish Trail between Freeman Road and Escalante Road												
Old Spanish Trail from Escalante Road to southern Park boundary												
Old Spanish Trail, Freeman Road to southern Park boundary												
Old Spanish Trail, southern Park boundary to Camino Loma Alta	1			2								
Old Spanish Trail—unspecified												

Table A.9. Continued

Road Segment	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Pre-Cactus Forest Drive Loop but within Visitor Center Parking lot												
Speedway Boulevard, between Freeman Road and Camino del Codorniz												
Speedway Boulevard, east of Camino del Codorniz	2		2	3	1	1				1		1
Total	3	1	3	6	1	1	0	0	1	1	0	1

<i>Ollotis alvaria</i>	Total 2005 Dead	5
	Total 2005 Live	3
	Total 2006 Dead	3
	Total 2006 Live	7

Table A.10. RMD *S. couchii* road mortality 2005–2006, number dead on roads by segment, year, and size class

	Scaphiopus couchii												
	Adult				Juvenile/Metamorph					Subadult			
	2005		2006		2005			2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	unknown	Dead	Live	Dead	Live	Dead	Live
Broadway Boulevard, east of Freeman Road	2	1		6									
Cactus Forest Drive		1									1		
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard													
Camino Loma Alta													
Freeman Road, Broadway Boulevard to Old Spanish Trail			1	1									
Freeman Road, Speedway Boulevard to Broadway Boulevard			2										
Javalina Picnic Area Road													
Old Spanish Trail between Freeman Road and Escalante Road													
Old Spanish Trail from Escalante Road to southern Park boundary													
Old Spanish Trail, Freeman Road to southern Park boundary	10	3		2							1		
Old Spanish Trail, southern Park boundary to Camino Loma Alta	42	13	4	2		1	15			1			
Old Spanish Trail—unspecified		1											

Table A.10. Continued

	Adult				Juvenile/Metamorph					Subadult			
	2005		2006		2005			2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	unknown	Dead	Live	Dead	Live	Dead	Live
Pre-Cactus Forest Drive Loop but within Visitor Center Parking lot													
Speedway Boulevard, between Freeman Road and Camino del Codorniz			3	2					1				
Speedway Boulevard, east of Camino del Codorniz	26	28	24	7	3			2	13	1		1	
Total	80	47	34	20	3	1	15	2	14	2	2	1	0

<i>Scaphiopus couchii</i>	Total 2005 Dead	85
	Total 2005 Live	50
	Total 2006 Dead	37
	Total 2006 Live	34
	Total unspecified 2005	15

Table A.11. RMD *L. catesbeianus* road mortality 2005–2006, number dead on roads by segment, year, and size class

	<i>Lithobates catesbeianus</i>											
	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Broadway Boulevard, east of Freeman Road												
Cactus Forest Drive												
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard												
Camino Loma Alta												
Freeman Road, Broadway Boulevard to Old Spanish Trail												
Freeman Road, Speedway Boulevard to Broadway Boulevard												
Javalina Picnic Area Road												
Old Spanish Trail between Freeman Road and Escalante Road												
Old Spanish Trail from Escalante Road to southern Park boundary												
Old Spanish Trail, Freeman Road to southern Park boundary												

Table A.11. Continued

	Adult				Juvenile/Metamorph				Subadult			
	2005		2006		2005		2006		2005		2006	
Road Segment	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live
Old Spanish Trail, southern Park boundary to Camino Loma Alta												
Old Spanish Trail—unspecified												
Pre-Cactus Forest Drive Loop but within Visitor Center Parking lot												
Speedway Boulevard, between Freeman Road and Camino del Codorniz												
Speedway Boulevard, east of Camino del Codorniz						2						
Total	0	0	0	0	0	2	0	0	0	0	0	0

<i>Lithobates catesbeianus</i>	Total 2005 Dead	0
	Total 2005 Live	2
	Total 2006 Dead	0
	Total 2006 Live	0

Table A.12. RMD unknown species road mortality 2005–2006, number dead on roads by segment and year

Road Segment	Unknown			
	2005		2006	
	Dead	Live	Dead	Live
Broadway Boulevard, east of Freeman Road				
Cactus Forest Drive				
Camino del Codorniz, between Speedway Boulevard and Broadway Boulevard				
Camino Loma Alta				
Freeman Road, Broadway Boulevard to Old Spanish Trail				
Freeman Road, Speedway Boulevard to Broadway Boulevard				
Javalina Picnic Area Road				
Old Spanish Trail between Freeman Road and Escalante Road				
Old Spanish Trail from Escalante Road to southern Park boundary				
Old Spanish Trail, Freeman Road to southern Park boundary				
Old Spanish Trail, southern Park boundary to Camino Loma Alta	1			
Old Spanish Trail—unspecified				
Pre-Cactus Forest Drive Loop but within Visitor Center Parking lot				
Speedway Boulevard, between Freeman Road and Camino del Codorniz				
Speedway Boulevard, east of Camino del Codorniz	1	2		
Total	2	2	0	0
Unknown			2005 Dead	2
			2005 Live	2
			2006 Dead	0
			2006 Live	0

APPENDIX B. RAINFALL AT VISITOR CENTERS AND RAIN GAUGES

Table B.1. TMD monsoon rainfall (15 June–30 September) 2005–2007 for a 24 hour period, taken at 0900 h

Rainfall in centimeters taken from 3 Pima County rain gauges and the TMD Visitor Center standardized to 0900 h to match Visitor Center's collection time												
	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
15-Jun	0	0	0	0	0	0	0	0	0	0	0	0
16-Jun	0	0	0	0	0	0	0	0	0	0	0	0
17-Jun	0	0	0	0	0	0	0	0	0	0	0	0
18-Jun	0	No data	0	0	0	0	0	0	0	0	0	0
19-Jun	0	0	0	0	0	0	0	0	0	0	0	0
20-Jun	0	0	0	0	0	0	0	0	0	0	0	0
21-Jun	0	0	0	0	0	0	0	0	0	0	0	No data
22-Jun	0	0	0	0	0	0	0	0	0	0	0	No data
23-Jun	0	0	0	0	0	0	0	0	0	0	0	0
24-Jun	0	0.71	0.41	0.15	0	0	0	0	0	0	0	0
25-Jun	0	0	0	0	0	0	0	0	0	0	0	0
26-Jun	0	0	0	0	0.10	0	0	0	0	0	0	0
27-Jun	0	0	0	0	0.20	0.20	0	0.76	0	0	0	0
28-Jun	0	0	0	0	0	0.89	0	0	0	0	0	0
29-Jun	0	0	0	0	0	0	0	0	0	0	0	0
30-Jun	0	0	0	0	1.30	1.30	0.20	0.61	0	0	0	0
June Total	0	0.71	0.41	0.15	1.60	2.39	0.20	1.37	0	0	0	0

Table B.1. Continued

	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
1-Jul	0	0	0	0	0	0	0	0.56	0	0	0	0
2-Jul	0	0	0	0	0	0	0	0	0	0	0	0
3-Jul	0	0	0	0	0	0	0	0	0	0	0	0
4-Jul	0	0	0	0	0	0	0	0	0	0	0	0
5-Jul	0	0	0	0	0.20	0.99	0.71	1.78	0	0	0	0
6-Jul	0	0	0	0	0.30	0.20	0.51	0	0	0	0	0
7-Jul	0	0	0	0	0	0	0.10	0	0	0.20	0.10	0.51
8-Jul	0	0	0	0	0.51	0.10	1.60	0.18	0	0	0	0
9-Jul	0	0	0	0	0	0	0	0	0	0	0	0
10-Jul	0	No data	0	0	0	0	0	0	0	0	0	0
11-Jul	0	0	0	0	0	0	0	0	0	0	0	0
12-Jul	0	0	0	0	0	0	0	0	0	0	0	0
13-Jul	0	0	0	0	0	0	0	0	0	0	0	0
14-Jul	0	0	0	0	0	0	0	0	0	0	0	0
15-Jul	0	0	0	0	0.10	0	0	0	0	n/a	0	0
16-Jul	0	0	0	0	0	0	0	0	0	0	0	0
17-Jul	0	0	0	0	0.20	2.79	0.10	1.24	0	0	0.10	0
18-Jul	0	0	0	0.36	0	0	0	0.13	0	0	0	0
19-Jul	0	0	0	0.84	1.50	0.79	0.20	0.58	0	0	0	0
20-Jul	0.30	1.80	0.30	0	0.51	0	0.20	0.23	1.60	1.30	1.70	1.12
21-Jul	0	0	0	0	0	0	0	0	0	0	0	0

Table B.1. Continued

	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
22-Jul	0.41	0	0	0.20	0	0	0	0	0.89	0	1.50	0.08
23-Jul	0	0	0.10	0.10	0	0	0	0	0	0.10	0	0.13
24-Jul	1.80	1.40	0.20	2.41	0	0	0	0	2.39	1.50	0.30	4.83
25-Jul	0	0	0	0	0	0	0	0	0	0	0	0.10
26-Jul	0.30	0.10	0	0	0	0	0.99	0	0	0	0.10	0
27-Jul	0	0	0	0	1.80	0.71	0.99	1.47	1.19	2.31	0	2.59
28-Jul	0.89	0.99	0	0.03	1.09	1.19	1.09	1.60	0	0	0	0
29-Jul	0	0	0	0	5.69	2.49	4.29	4.57	1.91	3.91	1.19	1.78
30-Jul	0	0	0	0	0.79	0.30	0.20	0.41	0	0	0	0
31-Jul	0	0	0.10	0.08	0.41	0	1.80	0.43	0	0	0	Trace
July Total	3.71	4.29	0.71	4.01	13.11	9.58	12.80	13.18	7.98	9.32	5.00	11.13
1-Aug	0	0	0.10	0.00	0	0	0	0	0	0.30	0.10	0.58
2-Aug	0	0	0	0	0	0	0	0	0	0	0.10	0
3-Aug	1.80	1.30	0.20	3.05	0	0	0	0	0	0	0	0
4-Aug	0	0	0	0	1.70	0.30	4.80	1.27	0	0	0	0
5-Aug	0	0	1.91	0.38	0	0	0	0.10	0	0	0	0
6-Aug	0.41	0.51	0.20	1.09	0	0	0	0	1.19	1.30	0.99	2.79
7-Aug	0.61	0.99	0.99	0.97	0	0	0	0	0.79	0.79	0.71	1.30
8-Aug	0.89	0.51	0.71	2.54	0	0	0	0	0	0	0	0
9-Aug	0	0	0	0	0.30	0.20	0.79	0.89	0	0	0	0
10-Aug	0.89	0.10	0.89	3.53	0	0	0	0.08	0	0	0	No data

Table B.1. Continued

	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
11-Aug	0	0	0	0	0	0	0	0	0.30	0	1.60	0
12-Aug	0	0	0	0	0	0	0	0	0	0	0	0
13-Aug	0	0	0	0	0	0	0	0	0	0	0	0
14-Aug	0	0	0	0	0	0	0	0	0	0.51	0	0.46
15-Aug	2.90	5.51	0.71	5.59	0	0	0	0	0.10	0.89	0.30	0.71
16-Aug	0	0	0.99	0	0	0	0	0	0	0	0	0
17-Aug	0	0	0	0	0	0	0	0	0	0	0	No data
18-Aug	0	0	0	0	0	0	0.20	0	0	0	0	0
19-Aug	0	0	0	0	0	0	0	0	0	0.10	0	0
20-Aug	0	0	0	0	0	0	0	0	0.89	1.70	0	4.83
21-Aug	0	0	0	0	0	0	0	0	0	0	0	No data
22-Aug	0	0	0	0	2.01	0.89	0	0.08	0	0	0	0
23-Aug	5.21	4.50	0.51	2.79	0	0	0	0	0	0	0	0
24-Aug	0.10	0.41	0.30	0.43	2.31	0	0	0	0	0	0	No data
25-Aug	0	0	0	0	0	0	0	0	0.51	0.20	0.71	0.15
26-Aug	0	0	0	0	0.61	0.71	0	1.27	0	0	0	0
27-Aug	0	0	0	0	0	0	0	0	0	0	0	0
28-Aug	0	0	0	0	0	0	0	0	0	0	0	0
29-Aug	0	0	0	0	0	0	0	0	0	0	0	0
30-Aug	0	0	0	0	0	0	0	0	0.10	0	0	0.03
31-Aug	0	0	0	0	0	0.10	0	0	0	0	0	0

Table B.1. Continued

	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
August Total	12.80	13.82	7.52	20.37	6.93	2.21	5.79	3.68	3.89	5.79	4.52	10.85
1-Sep	0	0	0	0	0	0	0	0	0	0	0	0
2-Sep	0	0	0	No data	0	0	0	0	0.20	0.41	0.10	0
3-Sep	0	0	0	0	0	0.30	0	0	0	0	0	0
4-Sep	0.41	0.10	0.30	0	0.79	1.50	0	1.40	0	0	0	0.86
5-Sep	0	0	0	0	0.89	1.91	0.89	0.08	0	0	0	0
6-Sep	0	0	0	0	0	0	0	0	1.30	1.09	0.20	2.29
7-Sep	0	0	0	0	1.60	0.61	3.81	2.79	0	0	0	0
8-Sep	0	0	0.20	0.30	0.10	0	0.41	0.03	0	0	0	0
9-Sep	0	0	0	0	0	0	0	0	0	0	0	0
10-Sep	0.20	0.99	0.10	0.25	0.71	0	0	0	0	0	0	0
11-Sep	0	0	0	0	0	0	0	0	0	0	0	0
12-Sep	0	0	0	0	0	0	0	0	0	0	0	0
13-Sep	0	0	0	0	0	0	0	0.13	0	0	0	0
14-Sep	0	0	0	No data	0	0	0	0	0	0	0	0
15-Sep	0	0	0	0	0	0	0	0	0	0	0	No data
16-Sep	0	0	0	No data	0	0	0	0	0	0.61	0	0.13
17-Sep	0	0	0	0	0	0	0	0	0	0	0.79	0
18-Sep	0	0	0	0	0	0	0	0	0	0	0	0
19-Sep	0	0	0	0	0	0	0	0	0	0	0	0
20-Sep	0	0	0	0	0	0	0	0	0	0	0	0

Table B.1. Continued

	2005				2006				2007			
Date	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)	#6460	#6440	#6020	Visitor Center (west)
21-Sep	0	0	0	0	0	0	0	0	0	0	0	0
22-Sep	0	0	0	0	0	0	0	0	0	0	0	0.03
23-Sep	0	0	0	0	0	0	0	0	0	0	0	0
24-Sep	0	0	0	0	0	0	0	0	0	0	0	0
25-Sep	0	0	0	0	0	0	0	0	0	0	0	0
26-Sep	0	0	0	0	0	0	0	0	0	0	0	0
27-Sep	0	0	0	0	0	0	0	0	0	0	0	No data
28-Sep	0	0	0	0	0	0	0	0	0	0	0	0
29-Sep	0	0	0	0	0	0	0	0	0	0	0	0
30-Sep	0	0	0	0	0	0	0	0	0	0	0	0
September Total	0.61	1.09	0.61	0.56	4.09	4.32	5.11	4.42	1.50	2.11	1.09	3.30
Monsoon Total	17.12	19.91	9.25	25.10	25.73	18.49	23.90	22.66	13.36	17.22	10.62	25.27
Monsoon Mean	17.84				22.69				16.62			
Standard Deviation	6.62				3.07				6.37			

Table B.2. RMD monsoon rainfall (15 June–30 September) 2005–2007 for a 24 hour period, taken at 0900 h

Rainfall in centimeters taken from 4 Pima County rain gauges and the RMD Visitor Center standardized to 0900 h to match Visitor Center's collection time															
	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
15-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
16-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
17-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
18-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
19-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
20-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
21-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
22-Jun	0	0	0	0	0	0	0.10	0.10	0.10	0.03	0	0	0	offline	0
23-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
24-Jun	0.10	0	0.10	0.30	0	0	0	0	0	0	0	0	0	offline	0
25-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
26-Jun	0	0	0	0	0	0	0.20	0	0	0	0	0	0	offline	0
27-Jun	0	0	0	0	0	0.20	0.79	0.71	0.20	0.13	0	0	0	offline	0
28-Jun	0	0	0	0	0	0	0	0.10	0	0.10	0	0	0	offline	0
29-Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
30-Jun	0	0	0	0	0	0	0.79	0	0	0.15	0	0	0	offline	0
June Total	0.10	0	0.10	0.30	0	0.20	1.88	0.91	0.30	0.41	0	0	0	n/a	0
1-Jul	0	0	0	0	0	0	0.30	0	0	0.13	0	0	0	offline	0
2-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0

Table B.2. Continued

	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
3-Jul	0	0	0	0	0	0	0.20	0	0.99	0	0	0	0	offline	0
4-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
5-Jul	0	0	0	0	0	1.70	1.50	1.19	2.11	1.19	0	0	0	offline	0
6-Jul	0	0	0	0	0	0.51	0	0	0.51	0	0	0	0	offline	0
7-Jul	0	0	0	0	0	0	0	0.20	0	0	0	0.20	0.61	offline	0.05
8-Jul	0.10	0.71	0.89	0	0.79	0.41	1.09	0.71	0.41	0.15	0.79	0.30	0.20	offline	0.20
9-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
10-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0.18
11-Jul	0	0	0	0	0	0	0	0	0	0	0.20	0.41	0.30	offline	0.15
12-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0.08
13-Jul	0	0	0	0	0	0	0	0	0	0	0.10	0	0	offline	0
14-Jul	0	0	0	0	0	0	0	0.10	1.30	0	0	0	0	offline	0
15-Jul	0	0	0	0	0	0	0.30	0	0	0.08	0	0	0	offline	0
16-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0.10	offline	0
17-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	offline	0
18-Jul	0	0	0	0	0.08	0	0	0	0	0	0.51	2.90	0	offline	0
19-Jul	0	0	0.61	0	0.58	0	1.09	1.91	0.30	1.27	0	0	0	offline	0.28
20-Jul	1.91	0.10	0	0.10	0.05	0.30	0.61	0	0.10	0.76	0.10	1.40	2.31	offline	2.08
21-Jul	0.20	0.71	0.10	0.30	0.28	0	0	0	0	0	0	0	0	offline	0
22-Jul	0	0	0	0	0	0	0	0	0	0	0	0.71	0	offline	0
23-Jul	0	0	0.20	0.20	0.10	0	0	0	0	0	0.20	0	0.30	offline	0.05

Table B.2. Continued

	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
24-Jul	0.10	0	0.30	0.30	0.15	0	0.10	0.30	0	0.05	3.71	0.61	1.50	offline	1.37
25-Jul	0	0	0	0.10	0	0	0	0	0	0	0.79	1.09	0.71	offline	1.37
26-Jul	0	0	0.20	0	0.08	0.20	0.20	0.51	0.51	1.27	0	0	0	offline	0
27-Jul	0	0	0	0	0	1.70	0.51	0.61	2.11	0.61	0	0.30	0	offline	0
28-Jul	0	0	0.41	1.09	0	0.61	1.60	0.41	0.51	0.53	0	0.20	0.20	offline	0
29-Jul	0	0	0	0	0	3.00	4.60	4.29	2.39	2.97	2.49	2.69	1.70	offline	3.28
30-Jul	0	0.61	0	0	0	2.79	3.51	4.09	2.90	6.27	0	0	0	offline	0
31-Jul	0.89	0.61	2.59	0.61	1.09	6.81	4.50	3.20	4.80	3.66	1.70	0.20	1.60	offline	0.36
July Total	3.20	2.74	5.31	2.72	3.20	18.03	20.12	17.53	18.92	18.95	10.59	11.02	9.55	n/a	9.45
1-Aug	0.61	0.20	0.99	0.30	0.53	0.10	0	0	0	1.52	0.30	0.10	0.61	offline	0.15
2-Aug	0.10	0	0	0.10	0	0	0	0	offline	0.08	0.71	0.30	0.79	offline	0.94
3-Aug	0.79	0.10	0	0.10	0	0	0	0	offline	0	0	0	0.10	offline	0.05
4-Aug	0	0	0	0	0	0.99	1.40	1.30	offline	0.97	0	0	0	offline	0
5-Aug	0.10	0.51	0.20	0.30	0.76	0	0	0	offline	0	0.20	0	0	offline	0
6-Aug	0	0	0.20	0	0.20	0	0	0	offline	0	0.51	2.01	0.10	offline	0
7-Aug	0	0.10	0	0.51	0	0.10	0	0.10	offline	0.66	0.30	0.20	0.10	offline	0.53
8-Aug	0.10	0.10	2.01	0.41	1.22	0	0	0.20	offline	0.51	0	0	0	offline	0
9-Aug	0.10	0.20	0	0.10	0.20	1.91	0.99	0.61	offline	1.07	0	0	0	offline	0
10-Aug	0.20	0.61	0	1.30	0	0.10	0	0	offline	0	0	0	0	offline	0

Table B.2. Continued

	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
11-Aug	0	0	0	0	0	0	0	0	offline	0	0	1.30	0	offline	0.25
12-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
13-Aug	0	0	0.20	0	0	0.89	0	0	offline	1.68	0	0	0	offline	0
14-Aug	0	0	0	0	0	0.30	0.51	0.41	offline	0	0	0	0	offline	0
15-Aug	0.10	0.30	0.30	0.10	1.68	0.89	0	0.20	offline	0.46	0	0.41	0.79	offline	0.74
16-Aug	0	0	0	0	0	0	0.10	0.89	offline	0.23	0	0	0	offline	0
17-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
18-Aug	0	0	0	0	0	0	0	0	offline	0	0.20	0	0	offline	0
19-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
20-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
21-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
22-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
23-Aug	3.20	2.59	2.01	0.51	2.24	0	0	0	offline	0	0	0	0	offline	0
24-Aug	0.51	0.41	0.61	1.60	0	0	0.41	0.79	offline	0	0	0	0	offline	0
25-Aug	0	0	0	0	0	0	0	0	offline	0	1.80	0.51	0	offline	0.08
26-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
27-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	offline	0
28-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
29-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
30-Aug	0	0	0	0	0	0	0	0.10	offline	0.69	0.10	0.99	0	0	0
31-Aug	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0

Table B.2. Continued

	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
August Total	5.82	5.13	6.53	5.33	6.83	5.28	3.40	4.60	n/a	7.85	4.14	5.82	2.49	n/a	2.74
1-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
2-Sep	0	0	0.41	0.51	0.08	0	0	0	offline	0	0	0	0	0.10	0
3-Sep	0	0	0	0	0	0	0.51	0	offline	0	0	0	0	0	0
4-Sep	0	0	0	0	0	0	0	0	offline	1.73	0	0	0	0	0
5-Sep	0	0	0	0	0	0.79	3.40	0	offline	0	0	0	0	0	0
6-Sep	0	0	0	0	0	0	0	0	offline	0	1.40	0.61	0.99	0.41	1.45
7-Sep	0	0	0	0	0	5.99	3.71	3.10	offline	4.29	0.20	0.20	0.10	0.20	0.18
8-Sep	1.80	0	0	0.20	0.13	0.30	0.10	0.10	offline	0.61	0	0.79	1.30	0.61	0.03
9-Sep	0.30	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
10-Sep	0.61	0.10	0	0	0	0	0	0	offline	0	0	0	0	0	0
11-Sep	0	0	0	0	0	0	0	0	offline	0	0	0.30	0	0	0
12-Sep	0	0	0	0	0	0.99	0.30	0	offline	0.79	0	0	0	0	1.85
13-Sep	0	0	0	0	0	0.20	0	0.10	offline	0.18	0	0	0.10	0	0
14-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
15-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
16-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
17-Sep	0	0	0	0	0	0	0	0	offline	0	1.50	0.61	1.40	0.41	0.89
18-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
19-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0

Table B.2. Continued

	2005					2006					2007				
Date	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)	#2090	#2310	#4180	#4110	Visitor Center (east)
20-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
21-Sep	0	0	0	0	0	0	0	0	offline	0	0.10	0	0	0	0
22-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0.08
23-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
24-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
25-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
26-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
27-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
28-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
29-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
30-Sep	0	0	0	0	0	0	0	0	offline	0	0	0	0	0	0
September Total	2.72	0.10	0.41	0.71	0.20	8.28	8.03	3.30	n/a	7.59	3.20	2.51	3.89	1.73	4.47
Monsoon Total	11.84	7.98	12.34	9.07	10.24	31.80	33.43	26.34	n/a	34.80	17.93	19.35	15.93	n/a	16.66
Monsoon Mean	10.29					31.59					17.47				
Standard Deviation	1.83					3.71					1.51				

Table B.3. Monsoon rainfall 2005, in centimeters

Site	Rain Gauge	June	July	Aug.	Sep.	Monsoon	Mean	Stand- ard Devi- ation
TMD	Visitor Center	0.15	4.01	20.37	0.56	25.10	17.84	6.62
	#6460	0	3.71	12.80	0.61	17.12		
	#6440	0.71	4.29	13.82	1.09	19.91		
	#6020	0.41	0.71	7.52	0.61	9.25		
RMD	Visitor Center	0	3.20	6.83	0.20	10.24	10.29	1.83
	#2090	0.10	3.20	5.82	2.72	11.84		
	#2310	0	2.74	5.13	0.10	7.98		
	#4180	0.10	5.31	6.53	0.41	12.34		
	#4110	0.30	2.72	5.33	0.71	9.07		
Tucson International Airport		0.03	1.80	11.50	0.10	13.50		

Table B.4. Monsoon rainfall 2006, in centimeters

Site	Rain Gauge	June	July	Aug.	Sep.	Monsoon	Mean	Stand-ard Dev-iation
TMD	Visitor Center	1.37	13.18	3.68	4.42	22.66	22.69	3.07
	#6460	1.60	13.11	6.93	4.09	25.73		
	#6440	2.39	9.58	2.21	4.32	18.49		
	#6020	0.20	12.80	5.79	5.11	23.90		
RMD	Visitor Center	0.41	18.95	7.85	7.59	34.80	31.59	3.71
	#2090	0.20	18.03	5.28	8.28	31.80		
	#2310	1.88	20.12	3.40	8.03	33.43		
	#4180	0.91	17.53	4.60	3.30	26.34		
	#4110	0.30	18.92	n/a*	n/a*	n/a*		
Tucson International Airport		0.50	13.70	7.60	4.10	25.91		

*Gauge offline

Table B 5. Monsoon rainfall 2007, in centimeters

Site	Rain Gauge	June	July	Aug.	Sep.	Monsoon	Mean	Standard Deviation
TMD	Visitor Center	0	11.13	10.85	3.30	25.27	16.62	6.37
	#6460	0	7.98	3.89	1.50	13.36		
	#6440	0	9.32	5.79	2.11	17.22		
	#6020	0	5.00	4.52	1.09	10.62		
RMD	Visitor Center	0	9.45	2.74	4.47	16.66	17.47	1.51
	#2090	0	10.59	4.14	3.20	17.93		
	#2310	0	11.02	5.82	2.51	19.35		
	#4180	0	9.55	2.49	3.89	15.93		
	#4110	n/a*	n/a*	n/a*	1.73	n/a*		
Tucson International Airport		0	13.30	2.30	1.10	16.69		

*Gauge offline

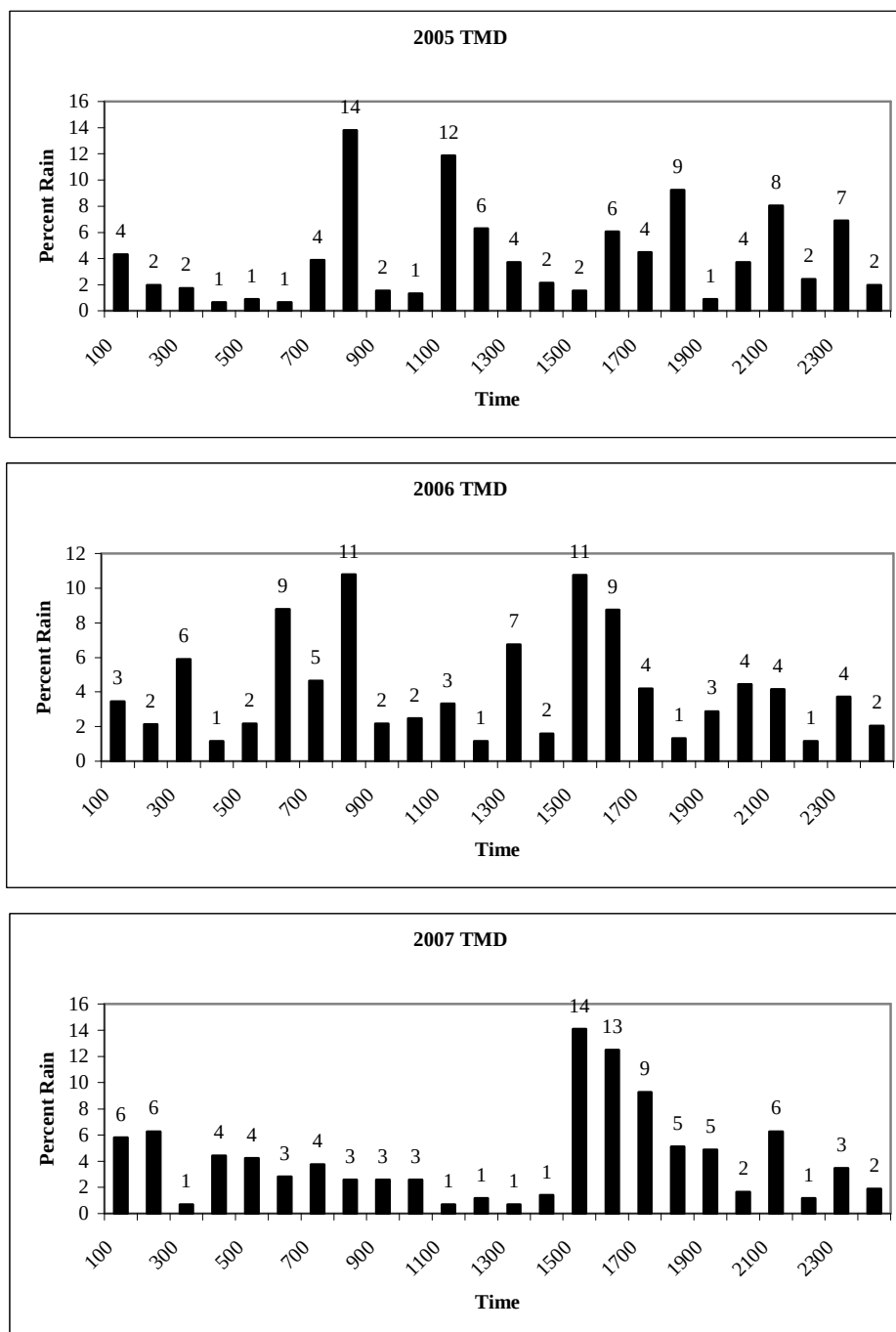


Figure B.1. TMD 2005–2007 (15 June–30 September) percent rain, from Pima County rain gauges in 1-hour increments

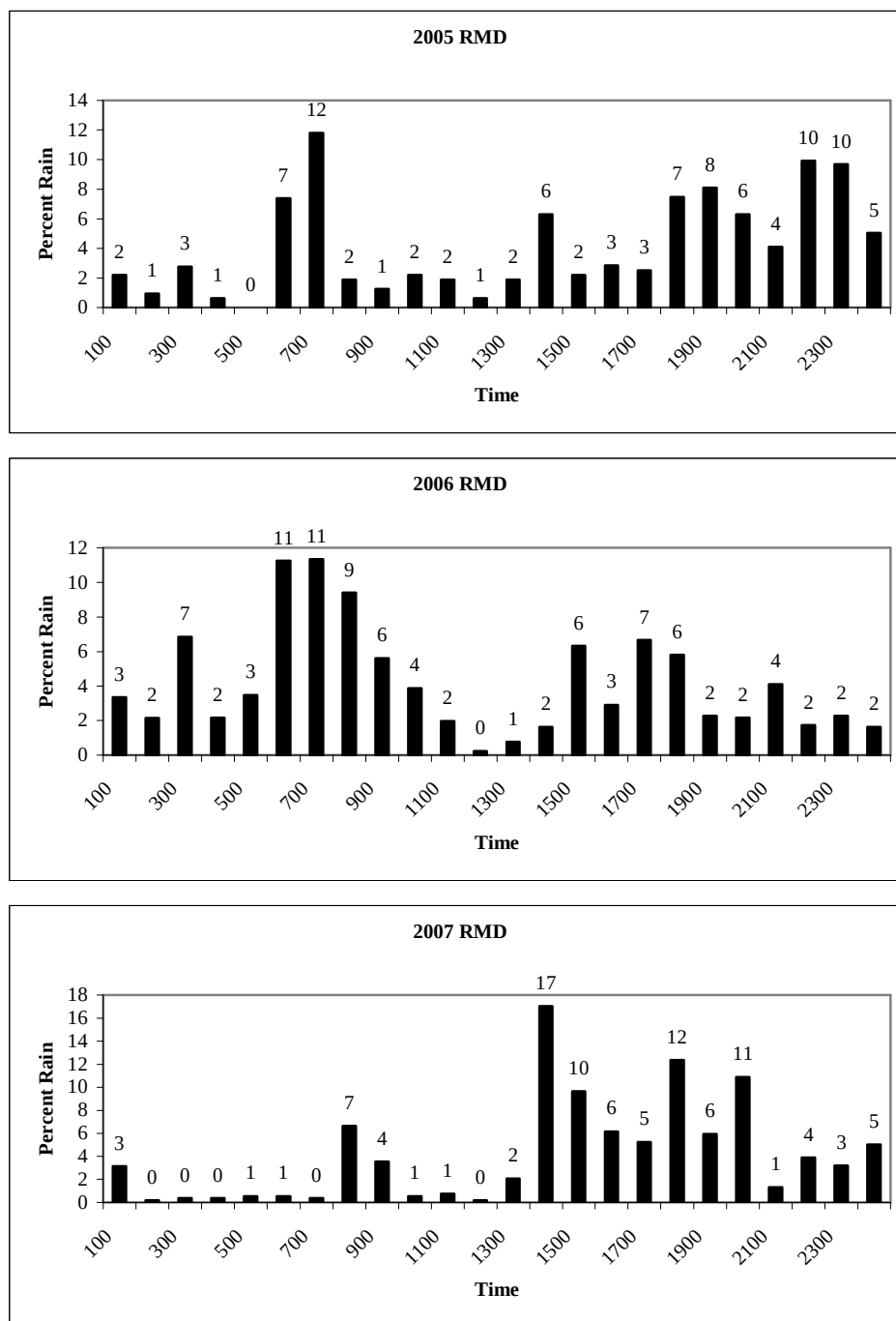


Figure B.2. RMD 2005–2007 (15 June–30 September) percent rain, from Pima County rain gauges in 1-hour increments

APPENDIX C. COMPLETE SITE DESCRIPTIONS

Table C.1. 2005–2007 TMD breeding site location, description, and species found

Key to Species: OLAL = <i>Ollotis alvaria</i> ; ANCO = <i>Anaxyrus cognatus</i> ; ANPU = <i>Anaxyrus punctatus</i> ; SCCO = <i>Scaphiopus couchii</i>					
Name	UTM			Species Observed (calling, eggs, tadpoles, or metamorphs)	Description
	Zone	Easting	Northing		
TMD1	12S	482005	3572307	ANPU	Small puddle up on side of hill near the north section of Bajada Loop Road
TMD2	12S	480330	3572622	SCCO	Signal Hill, behind a CCC dam
TMD3	12S	479443	3570840	SCCO, ANPU	Small mineshaft on hill near Sandario Road and Golden Gate Road
TMD4	12S	480140	3570685	ANPU	Canyon behind Sus Picnic Area
TMD5	12S	481121	3571183	ANPU	A drainage near Valley View parking area off Hohokam road
TMD6	12S	477834	3575103	SCCO	Two puddles on Sanders south of Rudasil
TMD7	12S	480881	3568704	ANPU	Concrete human-made wildlife watering hole
TMD8	12S	484958	3568772	ANPU	King Canyon drainage
TMD9	12S	479510	3568437	SCCO, ANCO, ANPU, OLAL	Catchment adjacent to the gate for the Tohono O’odam Saguaro fruit harvest camp, on the east side of Sandario, north of Mile Wide
TMD10	12S	481075	3572246	ANPU	Small puddle near Signal Hill
TMD11	12S	481321	3571038	ANPU	Small puddle near Valley View parking lot
TMD12	12S	483364	3570754	ANPU	Human-made watering hole near a windmill

Table C.1. Continued

Key to Species: OLAL = <i>Ollotis alvaria</i> ; ANCO = <i>Anaxyrus cognatus</i> ; ANPU = <i>Anaxyrus punctatus</i> ; SCCO = <i>Scaphiopus couchii</i>					
Name	UTM			Species Observed (calling, eggs, tadpoles, or metamorphs)	Description
	Zone	Easting	Northing		
TMD13	12S	480836	3571462	ANPU	Small puddles in a drainage on other side of hills near Valley View trail
TMD14	12S	487296	3576776	ANPU	Puddle right off of Picture Rocks Road
TMD15	12S	486810	3571745	ANPU	The breeding site we labeled TMD15 used to consist of points TMD15–17 and 20. Because they were all located in a single drainage that runs approximately east to west and crosses the Sweetwater Trail 0.15 km south of El Camino del Cerro Trailhead, we assigned one label to represent the entire drainage because seasonal water is found along much of the drainage, and toads can move easily throughout the reach.
TMD18	12S	482412	3570363	ANPU	A small puddle up near a javelina den
TMD19	12S	485079	3577288	ANPU	A puddle off of Panther Peak Wash Trail

Table C.2. 2005 RMD breeding site location, description, and species found

Key to Species: OLAL = *Ollotis alvaria*; ANCO = *Anaxyrus cognatus*; ANPU = *Anaxyrus punctatus*; SCCO = *Scaphiopus couchii*; UNK = unknown species

Name	UTM			Species Observed (calling, eggs, tadpoles, or metamorphs)	Description
	ZONE	Easting	Northing		
RMD1	12S	529711	3564609	UNK, probably ANPU	Drainage is off of Wildhorse trail near where it intersects with Three Tank Trail
RMD2	12S	531548	3565667	UNK (most probably ANPU with possible OLAL)	Drainage is off Douglas Springs Trail
RMD3	12S	527827	3562272	UNK (probably ANPU) and SCCO	Drainage parallel to the Cactus forest drive, leading up into mountains ending at 12S 528800, 3561097. Tadpoles seen in nearly every pool but SCCO tadpoles only seen in flat part at bottom of drainage
RMD4	12S	527813	3562355	UNK (probably ANPU)	Loma Verde drainage. Tadpoles seen in nearly every pool from this point to 12S 529070, 3562396.
RMD5a	12S	528700	3564944	SCCO	Drainage off Kennedy Trail: 3 ponds all in same drainage right near each other
RMD5b	12S	---	---	SCCO	Right up the drainage from the first pool; no UTM
RMD5c	12S	528964	3564782	SCCO	Right up the drainage from the second pool
RMD6	12S	529108	3556471	None	Pool found up drainage from historical location
RMD7	12S	529276	3555460	None	Historical Park location
RMD8	12S	530848	3556399	None	Historical Park location: no water, muddy in spots in nearby drainages
RMD9	12S	529346	3566561	SCCO	On side of road near Speedway Boulevard

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