Status, Distribution, and Management Recommendations for the Narrow-headed Garter Snake (*Thamnophis rufipunctatus*) in Oak Creek, Arizona

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neonate *T. rufipunctatus* underwater

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ABSTRACT

The narrow-headed garter snake (*Thamnophis rufipunctatus*) is threatened over much of its range due to the loss of habitat due to modification of creekside microhabitats, the disappearance of native fish which appear to make up its primary diet, the introduction of non-native predators, and human predation. Oak Creek in north-central Arizona has historically contained one of the largest populations of this species in the United States. Surveys in 1985 and 1986 in Oak Creek resulted in the estimation that the creek contained fewer than 1000 sub-adults and adults. Since those surveys, no further research has been conducted. In 1999, we began a three-year study of the status and distribution of narrow-headed garter snakes in Oak Creek, as well as potential prey distribution and use and habitat use. This research was funded by the Arizona Game and Fish Department Heritage Fund's Inventory, Identification, Protection, and Management (IIPAM) program. Approximately 640 person-hours of fieldwork were spent in 11 areas of Oak Creek between August 1999 and September 2001. Narrow-headed garter snakes were found in seven of these areas, all within Oak Creek Canyon. We found a total of 129 narrow-headed garter snakes, of which three were recaptured once each. We detected lower snake numbers than those in earlier surveys. We trapped a total of nine potential prey species, including eight fish species and the lowland leopard frog *Rana yavapaiensis*. However, we palped only two or three fish species out of the stomachs of narrow-headed garter snakes. Narrow-headed garter snakes of all age classes tended to be less common in areas of Oak Creek with high silt levels, high proportions of non-native and/or spiny-rayed fish, and high crayfish populations. Subadult and adult narrow-headed garter snakes appear to favor sections of Oak Creek Canyon overhanging vegetation and/or vegetated islands for protection from predators. Neonate narrow-headed garter snakes appear to favor shallow backwaters or edges (with less current) with and abundant aquatic vegetation, especially watercress. We feel that populations of the species are either very low south of the canyon or have been extirpated. In the north-middle reaches of Oak Creek Canyon overall population numbers appear stable. It is possible that there may have been substantial population declines at Slide Rock State Park and in the Midgley Bridge area. We provide suggestions for future monitoring and management of the species.

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The Arizona Game and Fish Heritage Fund provided funding for this research. Janie Agyagos and Cavetta Green of the US Forest Service Red Rock Ranger Station provided invaluable field assistance, equipment, and logistical support. Northern Arizona University and the USGS Biological Resources Division Colorado Plateau Field Station provided administrative assistance. We are indebted to George Bradley, Phil Rosen, Charlie Painter, Lee Luedecker, Alan de Queiroz, and Tim Hoffnagle for sharing their knowledge and data with us, and for their encouragement. John Schreiber of Red Rock State Park and Bob Kittredge of Forest Houses Resort granted us access to their properties and were enthusiastic supporters of the project. Shawn Knox, Matthew Spille, Robert Feinsinger, and Trevor Persons assisted with fieldwork. John Coons, Robert Emerson, Erik Enderson, Marty Feldner, Rich Gasaway, Andy Holycross, Brian Hubbs, Katie Medina, Susan MacVean, Jay Meyers, Chad Montgomery, James O'Reilly, Roger Repp, and Mark and Chris Sogge provided additional assistance. Trevor Persons, Robyn Beck, and Janie Agyagos reviewed the manuscript.

INTRODUCTION

The narrow-headed garter snake (*Thamnophis rufipunctatus*) is found in permanent drainages of the Mogollon Rim and White Mountains of Arizona and New Mexico and in the Sierra Madre Occidental range of Mexico (Tanner 1990, Rossman et al. 1996). It is threatened over much of its range due to the loss of habitat from development, modification, and siltation of creekside microhabitats, the disappearance of native fish which appear to make up its primary diet, the introduction of non-native predators (e.g. fish and bullfrogs), and human predation (Rosen and Schwalbe 1988, Rossman et al. 1996, C. Painter, pers. comm.). The narrow-headed garter snake is considered a species "of special concern" in Arizona (Arizona Game and Fish Department in prep.) and was formerly listed under Category 2 of the Endangered Species Act. Although no longer given official federal status, it remains of concern to the US Fish and Wildlife Service (J. Howland, pers. comm.).

Oak Creek in north-central Arizona has historically contained one of the largest populations of this species in the United States (Rosen and Schwalbe 1988, Fowlie 1965). However, after intensive surveys for narrow-headed garter snakes in Oak Creek in 1985 and 1986 (Rosen and Schwalbe 1988), it was estimated that the creek contained fewer than 1000 sub-adults and adults. Since those surveys, no further research has been conducted on the Oak Creek populations of narrow-headed garter snakes. However, biologists and others who have looked for this species over the past decade report that it is increasingly difficult to find in Oak Creek (Rosen and Schwalbe 1988, J. O'Reilly, L. Luedecker, and R. Gasaway, pers. comm.).

During the 1990's, recreational use and private development in the Sedona area and along Oak Creek increased greatly. In 1995, 1.3 million people visited the Red Rock Ranger District, a 48% increase from 1974 (USDA Forest Service 1996 unpubl.). In 1999, the district received approximately six million visitors. Increased visitation has led to terrestrial and nearshore stream habitat degradation, siltation, and episodic outbreaks of coliform bacteria, particularly near Slide Rock State Park (Southam 1996, Burns et al. 1998). In response to the dramatically increasing visitation, the Red Rock Ranger District of the Coconino National Forest, in cooperation with other federal, state, and local agencies and community members, has begun a detailed planning effort for Oak Creek (Burns et al. 1998). The Oak Creek Canyon Steering Committee will develop a corridor plan for Oak Creek Canyon that will identify management problems, solutions to those issues, and an implementation timetable. To aid in completing this planning process, the Red Rock Ranger District requested that research on the current status and distribution of narrow-headed garter snakes within Oak Creek be conducted. At the same time, the Arizona Game and Fish Department Heritage Fund's Inventory, Identification, Protection, and Management (IIPAM) program also called for research on narrow-headed garter snakes within Oak Creek to determine if declines had taken place since Rosen and Schwalbe's surveys.

In 1999, we began a three-year study of the status and distribution of narrow-headed garter snakes in Oak Creek, as well as their potential prey distribution and use and habitat use. The overall goals of this project were to determine population trends in narrow-headed garter snakes in Oak Creek since Rosen and Schwalbe's 1985-1986 surveys, develop baseline information on potential prey populations and habitat use, and make management and conservation recommendations, including suggesting possible causes of snake population declines if observed.

STUDY AREA DESCRIPTION

Oak Creek is located in north-central Arizona, cutting through the Mogollon Rim in Coconino County and terminating at the Verde River in Yavapai County (Figure 1). The Creek is divided into two main physiographic areas, Oak Creek Canyon and the lower section south and west of the canyon. Approximate elevations within the canyon range from 1311 m (4300 feet) at the mouth to 1737 m (5700 feet) at the headwaters near the confluence with Pumphouse Wash. The lower reach terminates at 963 m (3160 feet) at the confluence with the Verde River.

The geomorphology of Oak Creek varies between the canyon and lower reaches. Within the canyon, Supai sandstone forms ledges, steep-sided walls, and the stream bottom as bedrock in some locations (Wilson 1982). The streambed is often lined with boulders, cobbles, gravel, and sand of various geological origin, including volcanic. The main channel alternates between pools, riffles, and runs, while braided side channels in some areas form quiet backwaters. An average Rosgen stream classification of Oak Creek Canyon would be "B"[1] although elements of the Rosgen "C"[2] and "D"[3] classifications may be present as well (Rosgen 1996). Several springs are located along the edges of the creek. Major steep-sided tributaries feeding the creek include Pumphouse Wash, West Fork (with perennial water flow), and Munds Canyon. Scouring floods are not uncommon and large flood events occurred during the winter of 1992-1993 (pers. obs.).

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1 "Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile with stable banks." (Rosgen 1996)
2 "Low-gradient, meandering, point-bar riffle/pool, alluvial channels with well-defined floodplains." (Rosgen 1996)
3 "Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks." (Rosgen 1996)

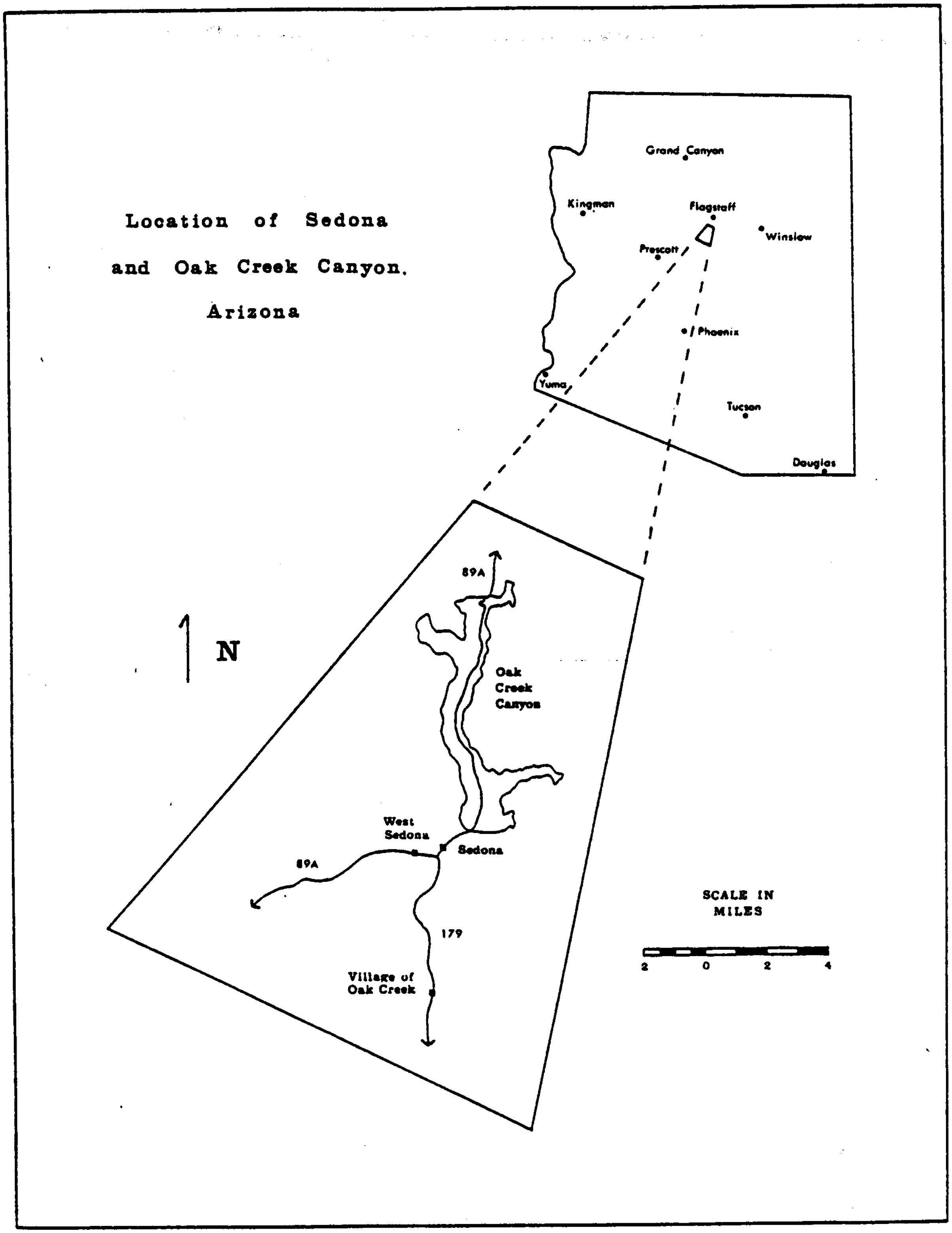


Figure 1. Location of Oak Creek in Arizona, showing a cutout of Oak Creek Canyon. (adapted from Wilson 1982).

The lower reaches of Oak Creek outside the canyon have fewer sections containing sandstone ledges and boulders. The streambed contains sections with cobbles and gravel, but is dominated by sand and silt, especially near the confluence with the Verde River. Runs and pools predominate over riffles. The stream increases sinuosity and the floodplain area becomes wide due to the lack of confining side walls. An average Rosgen stream classification of the lower reaches of Oak Creek would be “C” (Rosgen 1996).

The vegetation within Oak Creek Canyon is also different from that of the lower reaches. The major riparian vegetation community types within the canyon grade from Montane Riparian Forest to Interior Riparian deciduous forest (Minckley and Brown 1994). Dominant woody plant species include ponderosa pine *Pinus ponderosa*, velvet ash *Fraxinus velutina*, thinleaf alder *Alnus tenuifolia*, Arizona grape *Vitis arizonica*, and Arizona sycamore *Platanus wrightii*. Dominant herbaceous and/or aquatic plants include sedge *Carex* sp., grasses *Poa spp*., water hemlock *Cicuta sp*., and watercress *Rorippa nasturtium-aquaticum*. In the lower reaches, Interior Riparian deciduous forest grades to Sonoran deciduous forest. (Minckley and Brown 1994). Dominant woody species include thinleaf ash *Alnus tenuifolia*, velvet ash *Fraxinus velutina*, willows *Salix spp*., and Fremont cottonwood *Populus fremontii*. The primary herbaceous and aquatic plants are grasses, sedges *Carex spp*., cattails *Typha spp*., and milfoil *Myriophyllum sp*.

METHODS

Walking Surveys. We used a form of visual encounter survey described by Crump and Scott (1994) as our primary method of detecting narrow-headed garter snakes. We systematically walked time-recorded one-kilometer (km) transects in eleven areas along Oak Creek and its tributaries once or twice per year between June and September 1999-2001. We investigated areas where the species was suspected or known to occur, and also areas where it had not been seen. Each survey consisted of at least two people wading or walking along the edge of the creek, using auditory and visual cues to search for the snakes. We looked for the snakes basking on boulders, in rock crevices, on vegetation, or foraging in shallow water. We also flipped suitable cover (e.g. rocks) in the water and investigated wrack piles (due to personnel constraints we did not flip rocks on shore, although this method is known to be effective in detecting the species along Oak Creek in the spring and fall months, e.g. B. Hubbs, pers. comm.). Surveys occurred between late morning and late afternoon when snakes were most active.

We focused special effort on resurveying the area between Grasshopper Point and Midgley Bridge (approximately two km in length). We attempted to assess population trends of narrow-headed garter snakes in Oak Creek since Rosen and Schwalbe’s (1988) surveys by replicating their methods as closely as possible, following detailed discussions with Phil Rosen. We conducted at least three walking surveys from Grasshopper Point to Midgley Bridge between June and August each year.

Snake Trapping. We set out two alternating types of minnow traps half out of the water in areas along the creek bank that naturally funnel snakes. We installed five to ten traps in each of four one-km locations along both banks of Oak Creek, including the intensively-sampled area between Grasshopper Point and Midgley Bridge. Traps were either snap-together commercial “Gee” Minnow traps with 1/4-inch wire mesh or collapsible nylon minnow traps. Fitch (1986) and C. Painter (pers. comm.) have described the installation and use of such funnel traps to survey for aquatic or semi-aquatic snake species. The traps alternated between wire and nylon mesh, and were placed 15 meters apart along each creek bank and tethered to sturdy vegetation or other anchors. Trapping occurred twice a month from June to August 2000-2001 for three nights/four days per session. Traps were checked once a day to prevent mortality of trapped snakes and to discourage theft. They were pulled if major flood events were pending. We identified all vertebrates incidentally captured in the traps at least to genus. The location of each trap was recorded using a Trimble hand-held Geo-Explorer or Garmin GPS III Plus global positioning system (GPS) unit.

Snake Processing. Every time a narrow-headed garter snake was located, we recorded location (including GPS coordinates if possible), date, time, method of capture, behavior when first seen, sex, snout-vent length, tail length, weight, age, reproductive condition if known, presence of food bolus in digestive tract, injuries, habitat association, and any previous individual mark. If the snake appeared to have food in its stomach (as detected by gentle palpation), we gently encouraged it to regurgitate by gently palpating the bolus out for identification and measuring. Many times we were successful in re-feeding the prey to the snake.

To ensure permanent individual identification of adult and subadult snakes, we injected unique 11 to 12 mm passive integrated microchip transponder (PIT) tags (Biomark, Boise, Idaho). Due to the potential for infections (J. O’Reilly and T. Hoffnagle, pers. comm.), we decided against using scale-clipping as a permanent identification method. When properly injected into the gut cavity, PIT tags have been shown not to cause adverse effects to snakes and have low failure rates (0-1%) (Keck 1994, Camper and Dixon 1988). Using antiseptic techniques, we inserted a hypodermic needle between belly scales in the posterior third of the snake’s body, approximately 0.5-1 centimeter into the coelomic (gut) cavity, and injected a tag (after Fagerstone and Johns 1987). We sealed the injection site with veterinary skin glue. We scanned all snakes captured to determine if they had been previously tagged. Neonates were given an identifying paint mark on their backs to permit short-term identification, but were judged too small for PIT-tagging.

Fish and Tadpole Sampling. To add to our understanding of potential narrow-headed garter snake prey populations, we supplemented our sampling with trapping. We decided against using net seining due to the difficulties associated with netting over uneven substrates in Oak Creek (T. Hoffnagle, pers. comm.), and against electro-fishing due to its potential impacts on snakes and due to the difficulty in finding personnel trained in this method to sample regularly. The minnow traps used to detect fish were exactly the same as those used in four locations to detect snakes (see section above for details). All potential prey captured were identified to species and a subsample was also weighed and measured. We compared this information to that obtained by regurgitating prey from the snakes to determine prey use versus availability.

Habitat Correlates. We described habitat conditions along five-meter wide plots running perpendicular from the middle of Oak Creek and extending five m^2 onto either the randomly-selected right or left bank (after McMahon et al. 1996 and Reinert 1993). Each plot was centered on a point along the water edge, effectively making two subplots, with the terrestrial component being five by five meters (25 m^2). We recorded the following habitat variables for each plot (in part after Nowak et al. 2002): aspect (E or W side of the creek), elevation, channel and canyon width classes (five); channel type; landform type (13 classes); silt depth (five classes); stream run classification (e.g. pool, run, or riffle); water depth (five classes), temperature, and turbidity (percent visibility); if the channel was braided or not; if there were "backwater" pools present; and presence or absence of litter, crayfish, and humans. We recorded the GPS coordinates of the center of each plot where possible, and triangulated from known GPS locations in cases where the terrain and/or vegetation did not permit adequate satellite tracking. We photo-documented each plot by taking a photograph from its center, alternating up- and downstream within each one-km section.

For each of the two subplots we collected data on the basal area covered by trees, shrubs, grasses, aquatic vegetation (for the channel subplot only) and the amount of the area not covered by vegetation (called "un-vegetated area"), all expressed as percentages of the total area in the subplot. We also recorded the canopy cover class (six classes). In all, 22 habitat variables were recorded (see Appendix A).

Two types of habitat plots were designated and compared. The first type, "snake" or "non-random plots," corresponded to those locations where one or more snakes where observed and/or captured within a 10 meter radius from the center of the plot (n= 64). The second type of habitat plots were "random plots", which corresponded to five randomly selected points in each of the 11 surveyed locations along the creek (n= 55). With the "random plots" we assessed the habitat available in the area, the similarities and or differences among the 11 surveyed localities. The "snake plots" were used to assess the habitat actually used by the snakes. If one of the habitat variables measured is of particular importance for the snakes, that particular variable will be present more often in those plots associated with the snakes than with the plots associated with a random sample of the habitat available in the locality. As well, the higher or lower relative abundance of the snakes in one particular locality may be an indication of a habitat variable that has particular importance for the snakes. We determined these important habitat variables by comparing them between "random plots" and the "snake plots."

Data Analyses. The majority of statistical methods used were of a descriptive nature (e.g. mean, mode, standard deviation, etc.). Means are reported followed by $\pm$ one standard deviation. Significance was determined at the $p \leq 0.05$ level.

Methods were more detailed for habitat analyses. We performed a cluster analysis using the 22 habitat variables in order to establish the "ecological resemblance" between the eleven study sites using the statistical programs SAS and SPSS (Ludwig and Reynolds 1988). The resulting groups were compared against each other using non-parametric procedures. The Fisher Exact test was used to compare the four binary variables: aspect (east or west), crayfish (present/absent), backwater pools (present /absent), channel braided (yes/no); the Wilcoxon-Mann-Whitney U test was used to compare the 16 ordinal variables: elevation, canyon width, channel width, water depth, silt depth, canopy cover, water visibility, and the basal area covered by trees, shrubs, grasses, aquatic vegetation, "un-vegetated" for the bank and channel subplots. Finally, the two nominal variables: landform type and type of current, were compared using the Kruskal-Wallis test for independent samples (Sokal and Rohlf 1981).

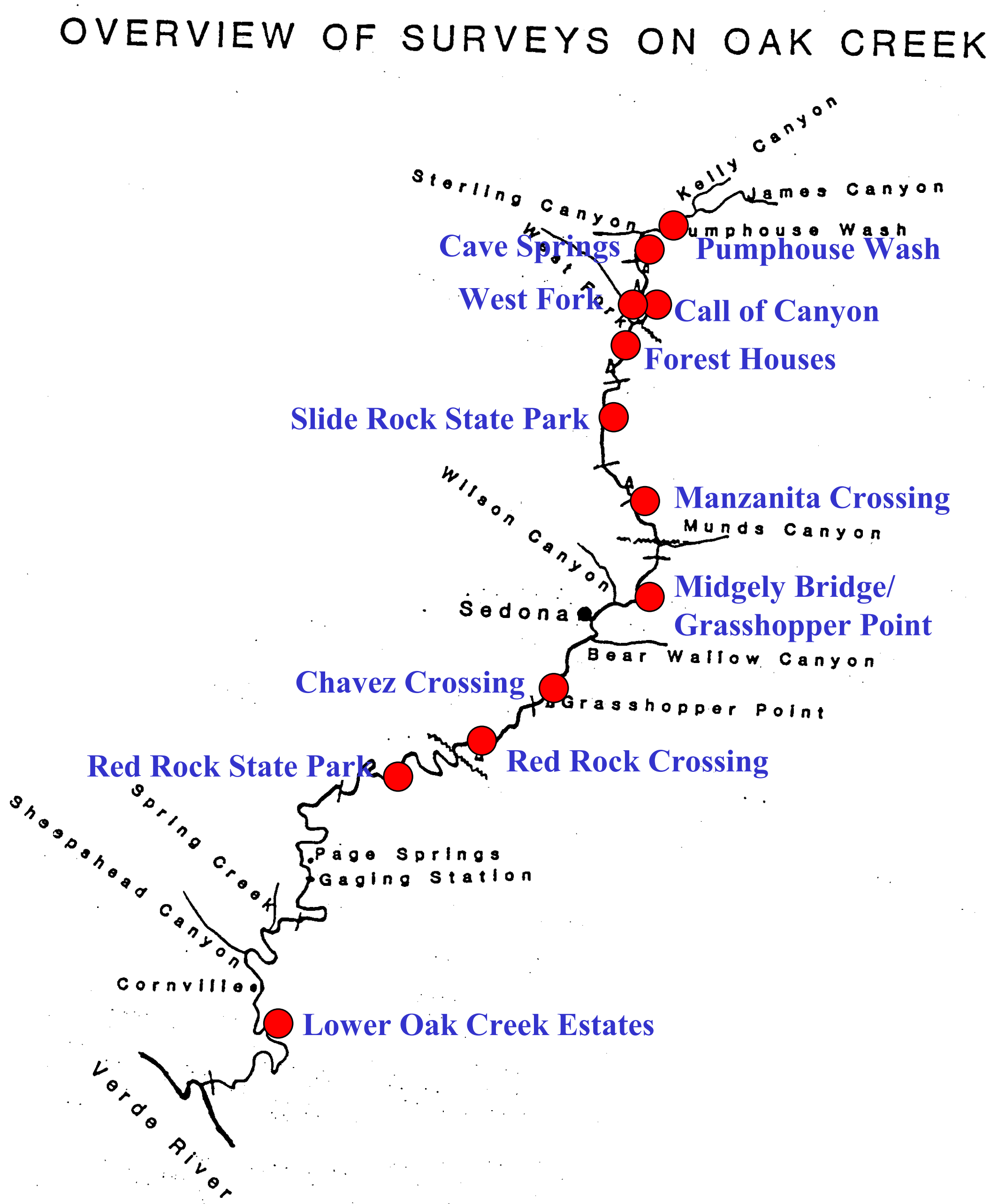
RESULTS AND DISCUSSION

Sampling Effort. We conducted at least 640 person-hours (number of hours spent in a given survey multiplied by the number of people in a survey) of fieldwork on narrow-headed garter snakes in 11 locations along Oak Creek (Figure 2). Of these, 299 person-hours were spent conducting walking surveys in 12 locations, 219 person-hours were spent setting and checking traps in four locations, and 122 person-hours were spent conducting habitat surveys at ten locations. We set a total of 50 minnow traps every other week in four locations from June-September in 2000 and 2001, for a total of 1542 trap-nights (number of traps multiplied by the number of nights they were open). In the Grasshopper Point-Midgely Bridge resurvey area, we spent a total of 184 person-hours and 632 trap-nights. The breakdown of effort for each method by location is shown in Table 1.

We focused the majority of our efforts in areas of Oak Creek where narrow-headed garter snakes historically occurred, and in the Midgley Bridge-Grasshopper Point area in an effort to duplicate the earlier efforts of Rosen and Schwalbe (1988) as closely as possible. Thus, we did not attempt to survey all areas for equal amounts of time.

Table 1. Effort spent on different methods of detecting *Thamnophis rufipunctatus* in Oak Creek, Arizona in 1999-2001. Effort is given in person-hours (number of hours spent in a survey x number of people in the survey) for walking surveys, habitat surveys, and for setting and checking traps, and in number of trap-nights (number of traps x number of nights open) for checking traps. See methods section for details. "Incl." indicates that the habitat surveys in that location could not be separated from another method at that location. An "-" indicates that the method was not used at that location.

Area Surveyed	Walking Surveys	Habitat Surveys	Checking Traps	Total Person-hours	Trap-nights
Pumphouse Wash	2.75	-	-	2.75	-
Cave Springs Campground	20.32	17.67	-	37.99	-
Call of the Canyon	96.67	22.8	13.18	132.65	99
West Fork	28.87	8.17	-	37.04	-
Forest Houses Resort	8	incl.	86.3	94.3	625
Slide Rock State Park	9.33	4.3	-	13.63	-
Manzanita Campground / Crossing	31.4	17.25	-	48.65	-
Grasshopper Point/Midgely Bridge	67.82	39.45	77.12	184.39	632
Chavez Crossing	6.63	incl.	-	6.63	-
Red Rock Crossing	17.03	3.5	-	20.53	-
Red Rock State Park	-	incl.	42.07	42.07	186
Lower Oak Creek Estates	10.22	9.1	-	19.32	-
TOTAL	**299.04**	**122.24**	**218.67**	**639.95**	**1542**



From: Schuhardt, S. 1989. Stream Survey Report: Verde River, Oak Creek, and Tributaries.

Arizona Game and Fish Department.

Figure 2. Location of 11 survey areas (indicated by circles and named) for *Thamnophis rufipunctatus* along Oak Creek, Arizona. Surveys were conducted from 1999 to 2001.

Distribution, Abundance, and Population Factors. We found a total of 129 narrow-headed garter snakes in seven locations along Oak Creek (Figure 3). There was no clear pattern of distribution and abundance in Oak Creek from higher to lower elevation, except that no snakes were found outside of the canyon. However, most of the narrow-headed garter snakes were found in the upper-middle reaches of the creek at Call of the Canyon Recreation Area and Forest Houses Resort.

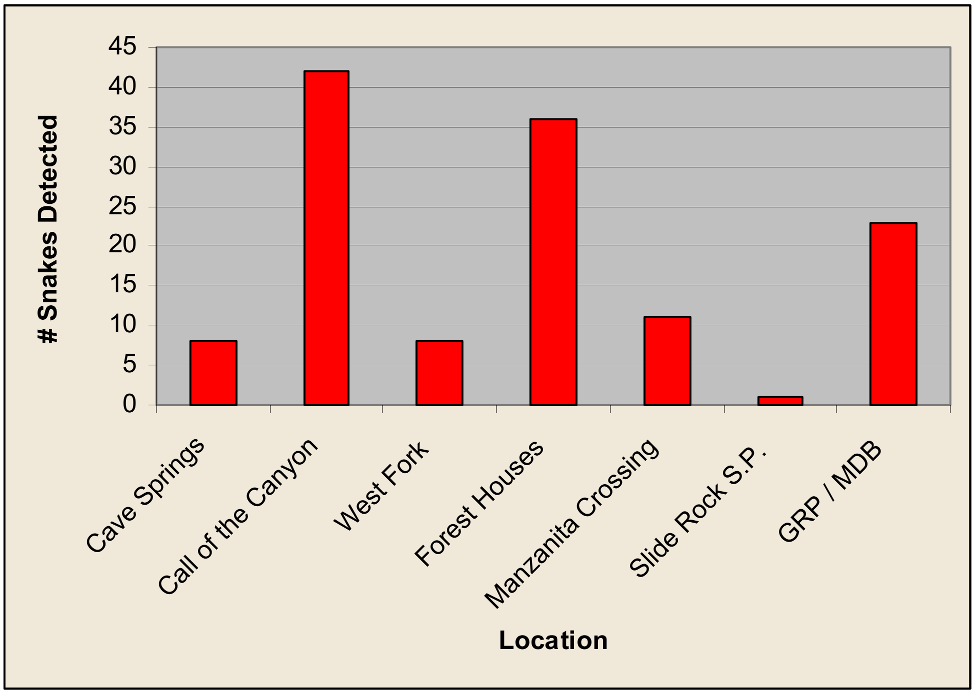


Figure 3. Number of *Thamnophis rufipunctatus* detected at each of seven locations in Oak Creek, Arizona during 1999-2001 by different methods. Methods include walking surveys, checking minnow traps (including snakes caught in traps), and habitat surveys and random encounters. “GRP/MDB” is an abbreviation for the Grasshopper Point and Midgely Bridge areas.

Although we did not find *T. rufipunctatus* south of Oak Creek Canyon, there are several records and anecdotal reports of the species occurring at Chavez Crossing, in Sedona, and other areas outside the canyon (for example, specimens collected in 1954 and 1957 “south of Sedona,” listed in Rosen and Schwalbe 1988). Fowlie (1965) lists one locality as “Maury Ranch, 7 mi. S. of Sedona.” In addition, a snake in the Yavapai College collection was collected dead on SR 89 three miles west of Sedona on June 30, 1989, although it is possible this animal was originally captured elsewhere (M. Spille, specimen verification and pers. comm.). However, George Bradley, collection manager of herpetology at the University of Arizona, also collected a *T. rufipunctatus* two miles south of Sedona on SR 179 in February 1981 and noted the species in lower Oak Creek in the 1970’s (pers. comm.). John Schreiber, park ranger at Red Rock State Park, informed us that a young *T. rufipunctatus* was found in an irrigation ditch in the park sometime in the early to mid-1990's (pers. comm.).

We PIT-tagged 60 of 129 narrow-headed garter snakes detected: 55 adults and 5 subadults. Three individuals were recaptured once each: one adult in 2000 and two (one adult, one neonate) in 2001. This extremely low recapture rate does not permit us to calculate estimated population sizes for the canyon as a whole nor for individual locations.

Of the 129 snakes detected, 41 were neonates (SVL = 18-23 cm), 26 were subadults (SVL = 24-39 cm), 61 were adults (SVL ≥ 40 cm), and one's age was not determined. Figure 4 shows the breakdown of each age class detected at each location (excluding Slide Rock State Park).

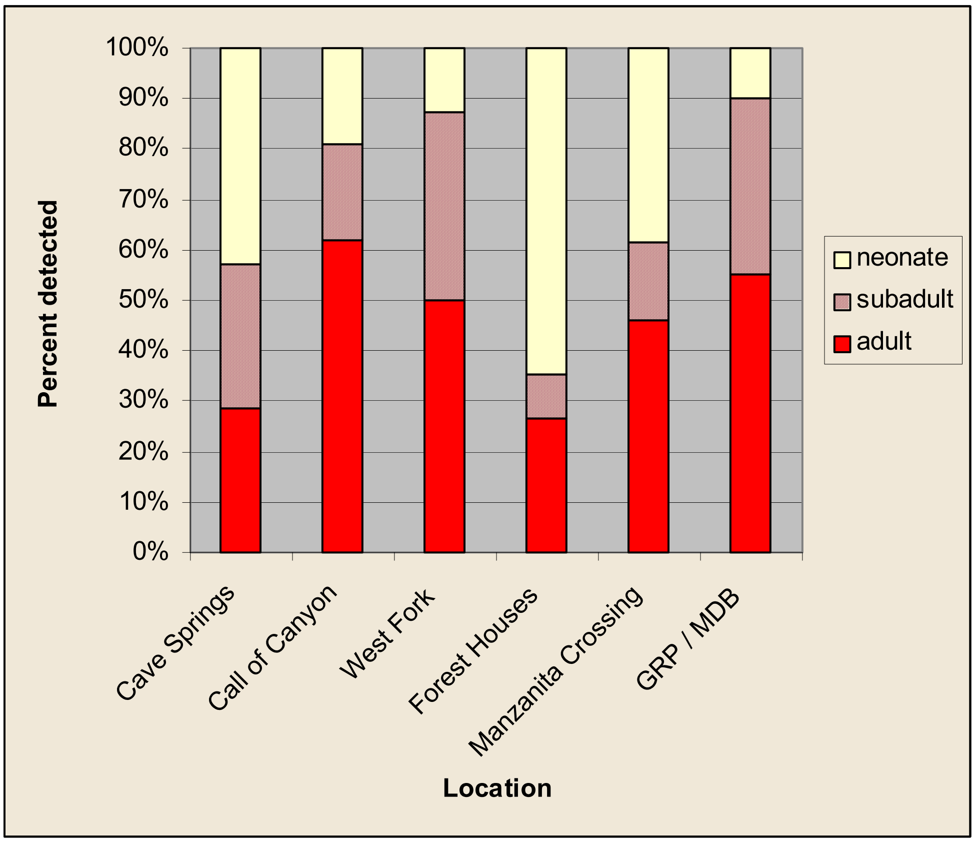


Figure 4. Percent of each age class (neonate, subadult, and adult) of *Thamnophis rufipunctatus* detected at six locations in Oak Creek, Arizona during 1999-2001. "GRP/MDB" is an abbreviation for the Grasshopper Point and Midgely Bridge area.

Cave Springs had the most even distribution of age classes. At Call of the Canyon, West Fork, and Grasshopper Point/Midgely Bridge, 50% or more of the detections were adults. West Fork and Grasshopper Point/Midgely Bridge also had the highest percent detection (30%) of subadults of the locations. At Forest Houses, over 60% of the detections were neonates. Manzanita Crossing and Cave Springs had the next highest proportions of neonates (greater than 35% each). The fewest neonates were detected at Grasshopper Point and Midgely Bridge.

These results are similar to Rosen and Schwalbe's 1988 study. They also found more adults than immature snakes at most locations sampled, with the exception of several surveys at Midgely Bridge. This is in contrast to our results of relatively few neonates in the Midgely Bridge area.

Of the snakes sexed, 50 were females and 61 were males (Figure 5). The sex ratio deviates slightly from the nearly 50:50 ratio seen by Rosen and Schwalbe (1988). Average adult female mass was 79.77 $\pm$ 32.19 g and SVL was 54.56 $\pm$ 8.01 cm. Average adult male mass was 53.01 $\pm$ 17.43 g and SVL was 48.45 $\pm$ 4.60 cm.

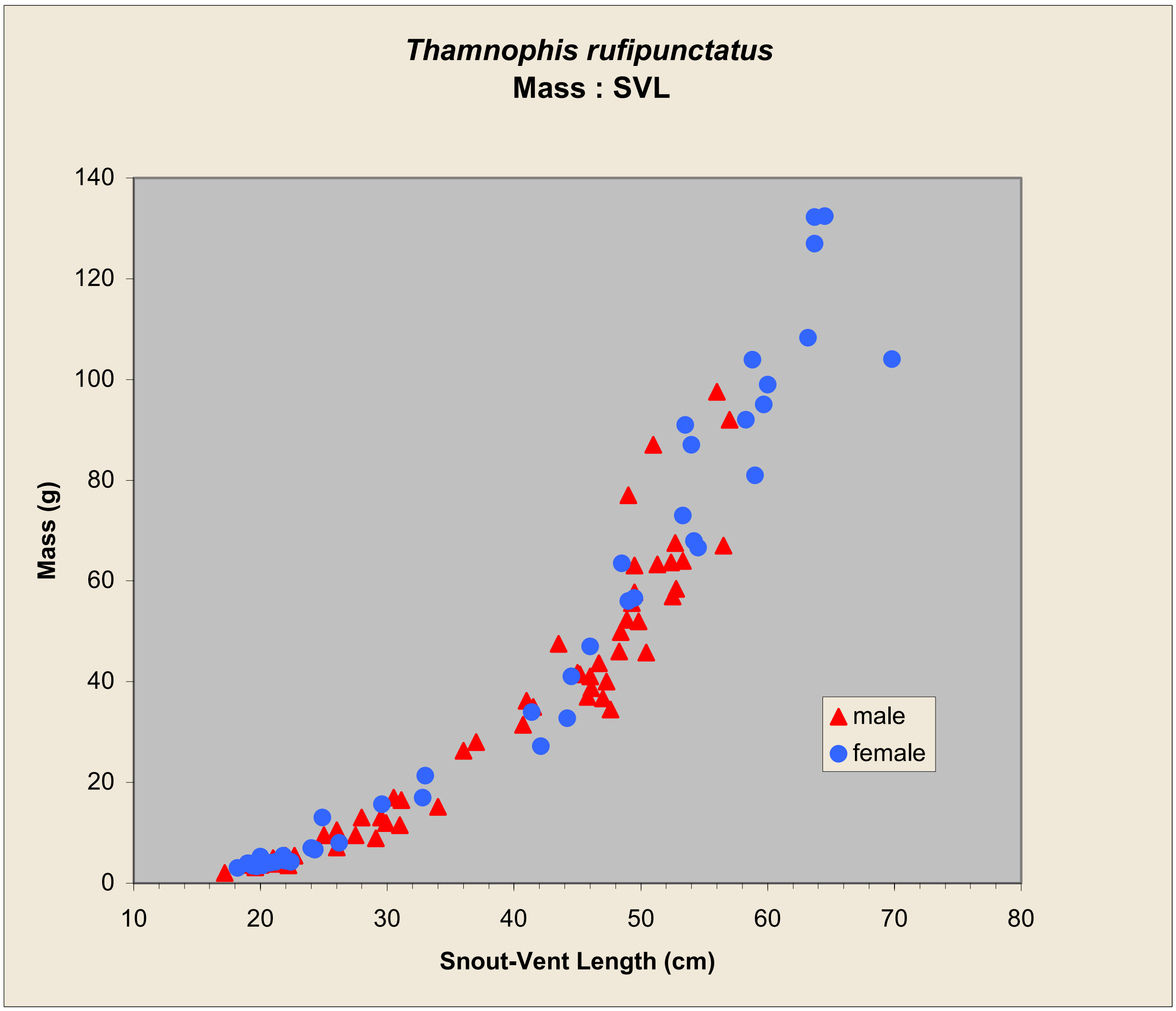


Figure 5 Sex, mass and snout-vent length (SVL) of *Thamnophis rufipunctatus* captured in Oak Creek, Arizona, 1999-2001.

Methods Comparison.

Walking Surveys and Random Encounters. When the number of snakes detected per unit effort (person-hours or trap-night) by each method was compared among all 12 locations surveyed, walking surveys were the most effective. Walking surveys in all areas detected 61 total snakes, an average of 0.20 snakes per person-hour, i.e., five person-hours of walking were needed to detect one snake. Checking traps (not including snakes encountered inside traps) detected 32 total snakes, an average of 0.15 snakes per person-hour (6.7 person-hours required to detect one snake). Finally, simply being out in the creek not especially looking for snakes was also somewhat effective: a total of 10 snakes, an average of 0.08 snakes per person-hour, were also seen during habitat surveys (i.e. 12.5 person-hours were required to detect one snake when not looking for them). As with many inventory projects, (e.g. Nowak et al. 2002), simply increasing time spent in the field increases the chances of encountering a target species through chance encounters.

When the five areas where snakes were not found (and we suspect not present) were excluded from the analyses, efficacy of all methods improved. Walking surveys in all areas detected an average of 0.23 snakes per person-hour, or four person-hours of walking to detect one snake. Checking traps detected an average of 0.18 snakes per person-hour, or 5.5 person-hours to detect a snake. An average of 0.09 snakes per person-hour were seen during habitat surveys, or 11.1 person-hours of simply being in the creek were necessary to detect one snake within their known habitat.

Trapping. Though not directly comparable because the units of effort are different, trapping detected a total of 24 snakes, an average of 0.01 snakes detected per trap-night, or 66.6 trap-nights needed to detect one snake. When only traps within known garter snake habitat are considered, trap success rises to a rounded average of 0.02 snakes detected per trap-night, or 55.5 trap-nights to detect one snake.

These results are in contrast to those from narrow-headed garter surveys in San Francisco River, New Mexico, in which minnow traps proved far more effective than walking surveys in detecting and recapturing garter snakes (C. Painter, pers. comm.). We suspect this difference may be due to differences in the type of habitat available in the two areas: the San Francisco River study area contains a large number of vertical cracks in lava flows adjacent to the creek in which the snakes hide and bask (C. Painter, pers. comm.). Oak Creek does not contain equivalent hiding places for the snakes.

The four locations did not trap snakes equally. When snakes found only in or on top of traps were considered (snakes seen outside of traps during trap-checking excluded), Call of the Canyon was the most effective area for trapping snakes, followed by Midgley Bridge (Table 2). No snakes were trapped at Red Rock State Park.

Table 2. Success in detecting *Thamnophis rufipunctatus* in Oak Creek, Arizona in 1999-2001 using minnow traps in four different areas. Effort is given in trap-nights (number of traps x number of nights open) at each location. See methods section for details. Snakes not detected in traps are excluded from these data, while those found on top of traps are included.

Area Surveyed	**Call of the Canyon**	**Forest Houses**	**Midgley Bridge**	**Red Rock State Park**
Total # trap-nights	99	625	632	186
Total # snakes trapped	5 (incl. 1 recapture)	7	12 (incl. 1 recapture)	0
# Snakes/trap night	0.05	0.01	0.02	0
# Nights/snake detection	19.8	89.3	57.4	0

Individual trap success varied within each site. Appendix C lists the total number of snakes and prey captured at each trap site at each location. Overall themes are that certain traps tended to trap more numbers of prey and snakes both years, and that certain sets (right and left bank pairs) tended to do better than others, suggesting some habitat differences in trap placement. Also, garter snakes tended to be trapped more often in traps that caught fish and frogs rather than those that did not: at Forest Houses Resort, four of seven snake captures occurred in traps that also caught fish; at Midgely Bridge nine of 12 snake captures occurred in traps that caught fish and/or frogs; and at Call of the Canyon four of five snakes were captured in traps that caught fish. At both Forest Houses Resort and Midgely Bridge, we caught snakes that were sitting on top of traps with fish (speckled dace or brown trout) in them.

Detection Success by Location. We detected the most snakes per unit effort in both walking surveys and trapping (including both trapped snakes and snakes seen outside of the traps during trap checking) at the Call of the Canyon Recreation Area (Figure 6). This area also contained the highest total number of snakes detected (42). Locations nearest this, West Fork, Forest Houses Resort, and the private crossing south of the Manzanita Forest Service Campground, followed with the next highest number of snakes detected per person-hour of walking survey. While the number of snakes trapped per unit effort was greater at Midgley Bridge than at Forest Houses, a higher number of snakes was seen outside of the traps at Forest Houses. Thus the number of snakes sighted per person-hour overall is higher at Forest Houses than at Midgley Bridge.

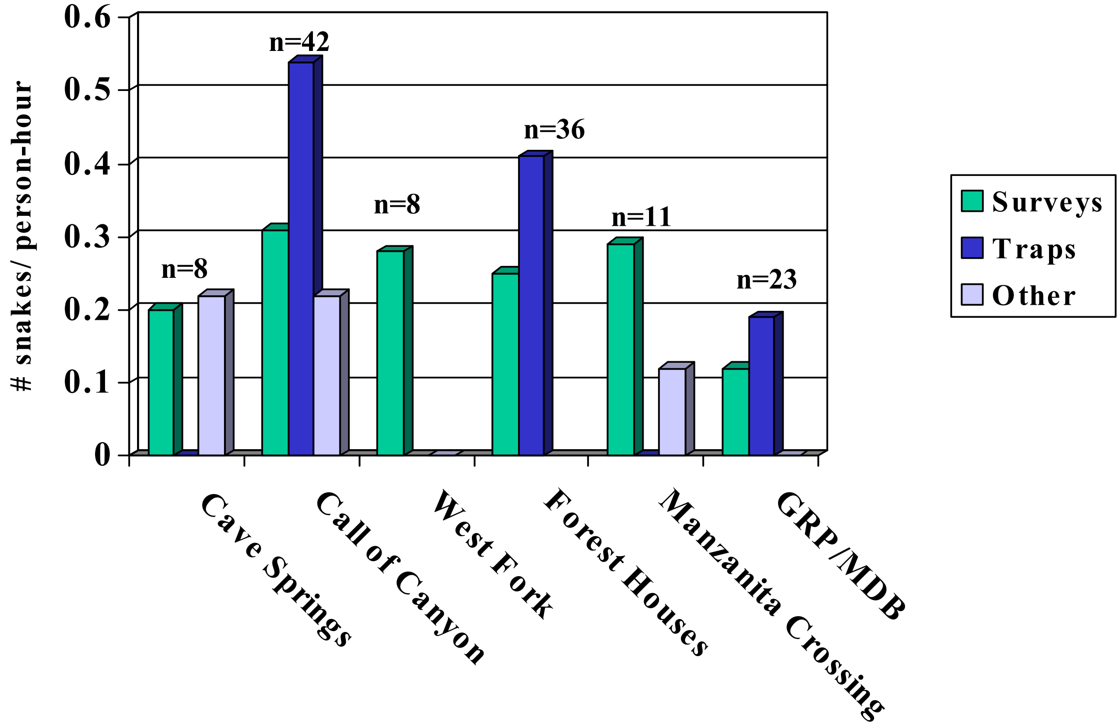


Figure 6. Number of *Thamnophis rufipunctatus* detected by unit effort (in person-hours) at each of six locations in Oak Creek, Arizona, during 1999-2001 by different methods. Methods include walking surveys, checking minnow traps (including snakes caught in traps), and habitat surveys and random encounters ("Other"). The total number of snakes caught per site is given above each set of columns, and does not include one snake seen at Slide Rock State Park.

We had higher success detecting narrow-headed garter snakes while checking traps than during walking surveys in all areas where both methods were used. This is likely due to our increasing chances of random encounters of snakes simply by being in the trapping areas more often.

Year and Month Effects. When snake detections corrected by effort were examined by year, we had the best success during walking surveys in 1999, finding an average of 0.34 snakes per person-hour (2.94 person-hours per snake). We found 0.27 snakes per person-hour of walking surveys in 2001 (3.7 hours per snake), and 0.16 snakes per person-hour in 2000 (6.25 hours per snake). In 2000, 0.33 snakes were detected per person-hour during trap checking versus 0.21 snakes per person-hour in 2001. The number of snakes trapped was the same in 2000 and 2001 (12).

When the number of snake detections was pooled across years and examined by month, we found the greatest number of snakes per unit effort of walking survey in September, 0.31 snakes per person-hour, or 3.22 person-hours per snake detected. July and August followed, with 0.24 and 0.22 snakes detected per person-hour, respectively, and October and June had the fewest numbers of snakes detected at 0.14 and 0.13 snakes per person-hour. During trap checking, the greatest number of snakes were also detected in September (0.48 per person-hour), as well as the most snakes trapped (11). August was the next most productive month with 0.25 snakes detected per person-hour (10 trapped), followed by July (0.08 snakes per person-hour and three snakes trapped) and June (0.07 snakes per person-hour and one snake trapped).

When the detection of each age class was examined by month, adults and subadults were detected most commonly in June and July. Over 50% of the snake detections were adults in June, and the first neonates were detected in July. Rosen and Schwalbe (1988) also first detected neonates in late July. By August the percent of adults detected had fallen below 50%. From August to September the number of neonates detected rose steadily. The percentage of each age class detected by month is shown in Figure 7.

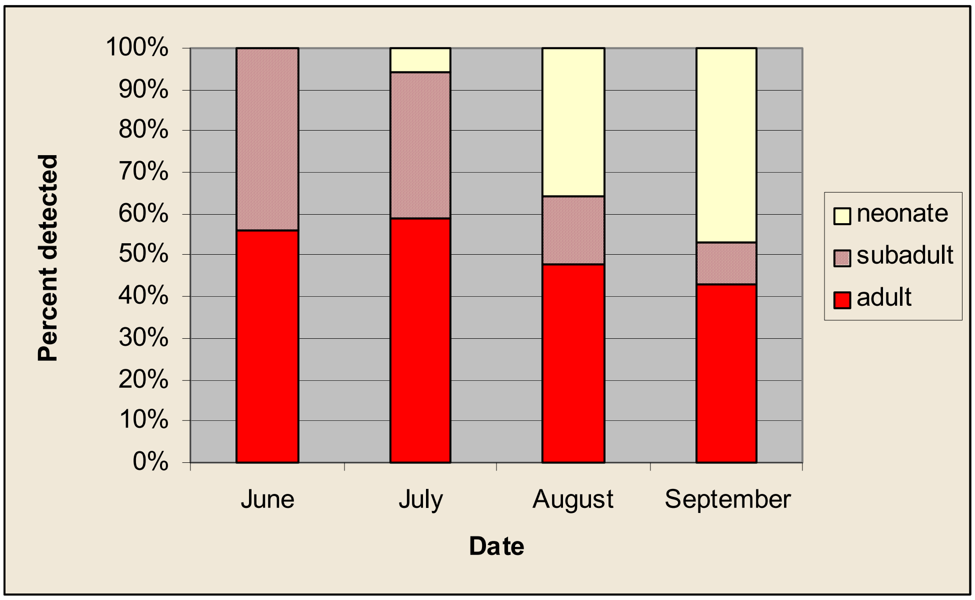


Figure 7. Percent detection of three age classes (neonate, subadult and adult) of *Thamnophis rufipunctatus* by month during surveys in Oak Creek, Arizona, during 1999-2001. Methods include walking surveys, checking minnow traps (including snakes caught in traps), habitat surveys, and random encounters.

Comparisons with Earlier Surveys. We found fewer narrow-headed garter snakes per unit effort of walking surveys in the Midgley Bridge-Grasshopper Point area when compared with other areas. These results are in sharp contrast to those of Rosen and Schwalbe (1988) and Rosen, unpubl. data. Rosen and Schwalbe conducted surveys for narrow-headed garter snakes in five of the same areas of Oak Creek as us from 1985-1988. Results from these previous surveys are compared to ours in Figure 8. They did not find any snakes at Chavez Crossing (nor did we). Rosen and Schwalbe also surveyed the Banjo Bill Campground area, which is directly south of Forest Houses Resort, and found one snake, or 0.33 snakes per person-hour there.

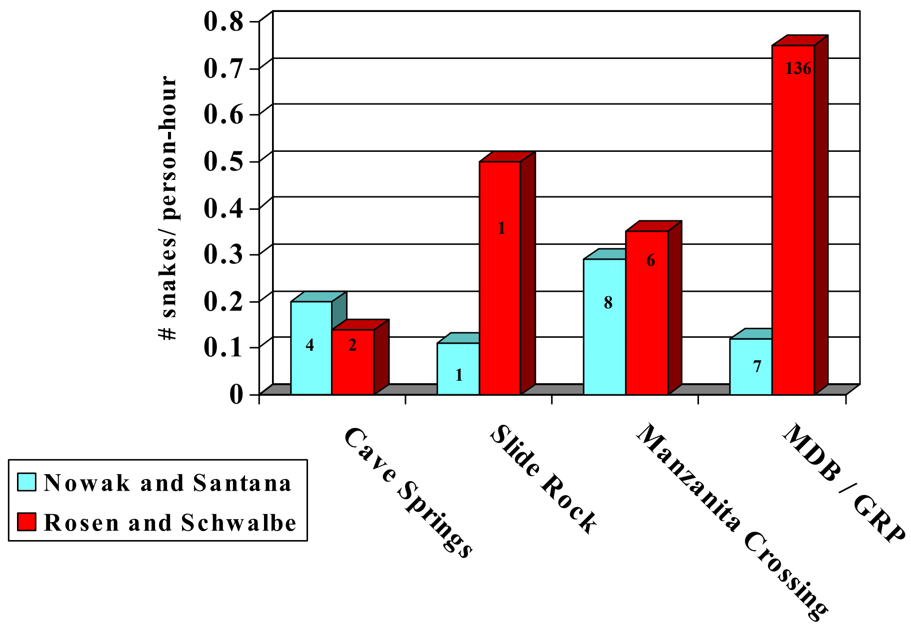


Figure 8. Number of *Thamnophis rufipunctatus* detected per person-hour of walking surveys in four areas of Oak Creek, Arizona. Comparison by Nowak and Santana –Bendix (this report, 1999-2001) and Rosen and Schwalbe (1988 and unpubl. data). Methods between the two studies are assumed to be comparable. Total number of snakes found at each location is given in each column.

Rosen and Schwalbe found more narrow-headed garter snakes per person-hour than we did in three of the four areas where we have comparable data (Rosen and Schwalbe 1988 and unpubl data), and we found more individual snakes in two of the four locations. Overall, they conducted a total of 222 person-hours of walking surveys (their only method) and found a total of 146 snakes (0.66 snakes per person-hour). They had five recaptures. To compare, we conducted a total of 299 person-hours of walking surveys and found 61 snakes, or 0.20 snakes per person-hour. We found no recaptures using this method. In the Midgley Bridge-Grasshopper Point area, we conducted a total of 68 person-hours of walking surveys and found 8 narrow-headed garter snakes (0.09 snakes/person-hour), and Rosen and Schwalbe found 136 snakes during 182 person-hours of walking surveys, or 0.75 snakes/person-hour.

Several factors may help explain this discrepancy. First, we were trained verbally in the methods of detecting narrow-headed garter snakes by Rosen (pers. comm.) and replicated his methods closely, and it is possible that differences (biases) exist between observers. As in any resurvey attempt, there may be differences in observer detection rates and/or in fine details of methods between the surveys that explain some of the differences in numbers of animals detected per person-hour.

However, even taking this caveat into consideration, Rosen and Schwalbe detected more individual garter snakes than we did. In the Midgley Bridge area, they found about six times more garter snakes than we did when combining trapping and walking surveys. It is possible that walking surveys are superior to detecting garter snakes than trapping and encountering garter snakes while trapping. We focused more effort on trapping in the Midgley Bridge area than on walking surveys (compared to Rosen and Schwalbe, who focused exclusively on walking surveys). However this is not the pattern suggested for our data by Figure 6. Those data suggests that the combination of setting and checking traps repeatedly exposed us to more encounters with narrow-headed garter snakes than walking surveys alone.

Population Status. We feel that the large differences in overall numbers of narrow-headed garter snakes detected between the two surveys suggest population declines, especially in the Midgley Bridge area and south of the canyon. Despite several historic records of the species occurring outside of Oak Creek Canyon in the Sedona area south to Red Rock State Park and "lower" Oak Creek, we did not find any snakes in those areas. For that matter, neither did Rosen and Schwalbe during their earlier surveys. We feel it is likely that populations of the species are either very low south of the canyon or have been extirpated.

In the north-middle reaches of Oak Creek Canyon, we feel that there is no evidence of decline based on comparison to earlier surveys; population numbers appear stable in these areas. Based on anecdotal evidence from long-time residents of the area, however, it is possible that there may have been substantial population declines at Slide Rock State Park. Bob Kittredge, Rich Gasaway, Brian Hubbs, and James O'Reilly (pers. comm.) all state that narrow-headed garter snakes were formerly easy to find at Slide Rock, yet we only found one there in over 13 person-hours of surveying. Rosen and Schwalbe (1988) had similar luck. Mr. Lee Luedecker of the Arizona Game and Fish Department notes that "… I used to observe narrow-heads frequently at Slide Rock and very rarely observe them now in that area." (L. Luedecker, pers. comm.). He feels that scouring flood events (most recently 1993 and 1995) and the subsequent loss of trees and root masses have degraded potential habitat for the snakes in this area. It is also possible that any declines may be due in part to the impacts of greatly-increased recreation in the area, the subsequent loss of suitable near-shore habitat, and increased direct predation of snakes by humans.

Potential Prey Distribution. We found a total of eight fish species (445 individuals), one anuran (31 individuals), and crayfish species (21 individuals) in the minnow traps at the four locations. Table 3 lists the number of individuals of each fish and frog species (potential prey species for the snakes) captured per trap-night at each location.

Table 3. Total number of individuals and number of individuals per unit effort (number of traps x number of nights open, in parentheses) of each species captured using minnow traps in four different areas in Oak Creek, Arizona, in 1999-2001 using minnow traps. See methods section for details.

Species	Call of the Canyon	Forest Houses	Midgley Bridge	Red Rock State Park	Total
Brown Trout *Salmo trutta*	4 (0.04)	33 (0.05)	2 (0.003)	0	**39** (0.02)
Gila Sucker *Catostomus insignis*	0	1 (0.002)	8 (0.13)	0	**9** (0.006)
Speckled Dace *Rhinichthys osculus*	2 (0.02)	82 (0.13)	5 (0.008)	0	**89** (0.06)
Lowland Leopard Frog *Rana yavapaiensis*	0	0	31 (0.05)	0	**31** (0.02)
Mosquitofish *Gambusia affinis affinis*	0	0	0	9 (0.05)	**9** (0.006)
Rock Bass *Ambloplites rupestris*	0	0	79 (0.12)	53 (0.28)	**132** (0.08)
Green Sunfish *Chaenobryttus cyanellus*	0	0	10 (0.01)	112 (0.61)	**122** (0.08)
Smallmouth Bass *Micropterus dolomieui*	0	0	4 (0.006)	37 (0.20)	**41** (0.03)
Largemouth Bass *Micropterus salmoides*	0	0	0	3 (0.02)	**3** (0.002)
Total	**6** (0.06)	**116** (0.18)	**139** (0.22)	**214** (1.16)	**475** (0.31)

No species was captured at all four sites. Brown trout and speckled dace were the most wide-ranging (although captured only within Oak Creek Canyon). Rock bass were the most commonly captured species, but the majority of their numbers came from Midgely Bridge. Green sunfish and speckled dace were the next most numerous species, but again their numbers were high due to disproportionately high capture numbers at single sites.

The number of potential prey individuals captured per trap night was not high; it ranged from 0.002 to 0.61 individuals per trap-night. The fewest number of trap-nights were required to detect fish at Red Rock State Park, bearing in mind that almost half of the captures were one species (green sunfish). The most trap-nights were required at Call of the Canyon. These results are in direct contrast to those for narrow-headed garter snake captures, where the most snakes were captured per unit effort at Call of the Canyon. The relatively low number of trap-nights compared to other areas may explain the lower success in detecting fishes here.

An interesting pattern of distribution emerges when the native versus non-native status of the potential prey species and their body type are examined. Of the total vertebrate species detected in traps, 67% were non-native fish (and there were a few non-native crayfish at Red Rock State Park as well). Perhaps more importantly from a predator perspective, 44% were spiny-rayed fish. These (all non-native) bass and sunfish are compressed laterally rather than ventrally, so they have tall body profiles, and they also have stiff, spiny dorsal rays and/or pectoral fins (Minckley 1973). The other fish and frog species detected are dorsal-ventrally compressed and do not have bony dorsal and/or pectoral fins, giving them a smooth, flattened appearance. We detected no native fish with spiny rays in Oak Creek. Figure 9 shows the number of fish of each of the three status and body types captured in each location.

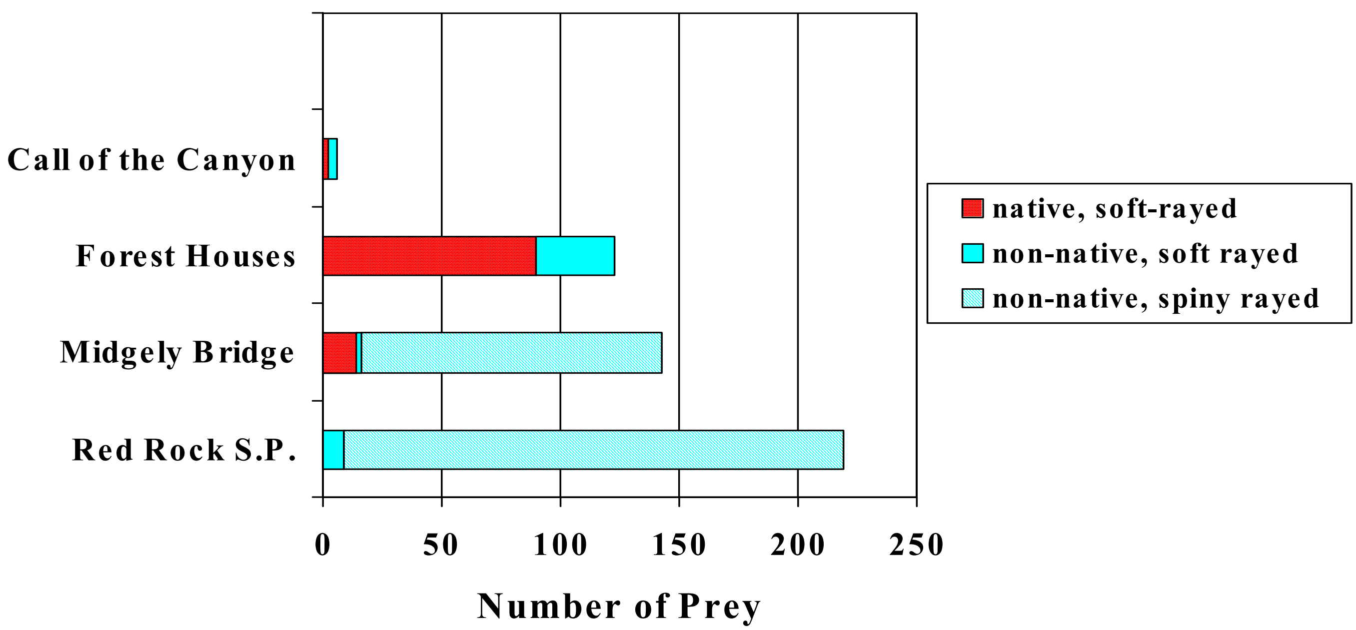


Figure 9. Total number of individual potential prey items captured in minnow traps in four locations in Oak Creek, Arizona, during 2000-2001 surveys. The species are divided into three status and body types: native, soft-rayed; non-native, soft-rayed; and non-native, spiny-rayed. Locations are arrayed from North to south along Oak Creek.

A clear pattern emerges: there are more native potential prey species higher in Oak Creek Canyon, while none were detected outside the canyon. Equally importantly, the percent of soft-rayed species of both status types declines as one moves south and out of the canyon. Native, soft-rayed species within the canyon become replaced by non-native spiny fishes as one moves from north to south in Oak Creek (also observed by Rosen and Schwalbe, 1988). This trend closely parallels narrow-headed garter snake abundance within our survey areas of Oak Creek.

There is evidence that the link between these data is not coincidental: Rosen and Schwalbe (1988, 2002) have shown that non-native fish species such as small-and large-mouth bass are major predators on garter snakes elsewhere in the state. During surveys between 1983 and 1988 across the range of narrow-headed garter snakes in Arizona, they tended to not find this snake species in locations that contained non-native fish species (Rosen and Schwalbe 2002). In addition to this negative association with exotic fishes, they also showed a significant positive association with native fishes. They pointed out that since 1973 the proportion of non-native fish species has increased in many historic *T. rufipunctatus* locations across the state, while native fish species have declined.

In at least one location in Oak Creek, comparison of fish detection data from earlier surveys (B. Denova, Arizona Game and Fish Department, unpubl. data) with our sampling suggests a large increase in non-native fish populations. Electroshocking was conducted at Red Rock State Park by the Arizona Game and Fish Department from 1989-1993. During this period, a total of 10 fish species were detected, including two native sucker species. We detected five of seven of the non-natives they detected, in similar proportions for green sunfish and smallmouth bass (Table 3). However, we detected no native species, much higher numbers of rock bass, as well as a new species, largemouth bass.

We feel that the spiny nature of the non-native fish species widespread lower in Oak Creek may make them unsuitable as narrow-headed garter snake prey. Snakes occasionally choke to death while eating spiny food, so there may be an innate or learned tendency to avoid such prey items (pers. obs.). Thus predatory behavior of some fish as well as their unsuitability as food items may influence the distribution of narrow-headed snakes: we suspect these factors may be at least partly responsible for any declines in garter snake populations within Oak Creek, e.g. in the Midgley Bridge area and reaches south of the canyon.

Another reason that non-native fishes may be unsuitable as prey items for narrow-headed garter snakes is their preferred location in the water column. De Quieroz (2002) found that narrow-headed garter snakes predominately forage by crawling on the substrate bottom and striking at prey underwater (as compared to other garter snakes which only use these behaviors in deep water). We have observed that native suckers are predominately bottom-dwellers, while non-natives such as bass appear to live higher in the water column (mosquito fish live at water surface). More work is needed to test this hypothesis.

Prey Use. No snake was found to have a spiny-bodied fish in its gut. We found a total of 12 snakes with prey in their stomach and palped these items out through induced regurgitation. Of these, eight were brown trout, two were Gila suckers, and two were fish that could not be identified. Figure 10 shows the prey species in the four locations where prey was detected in snakes.

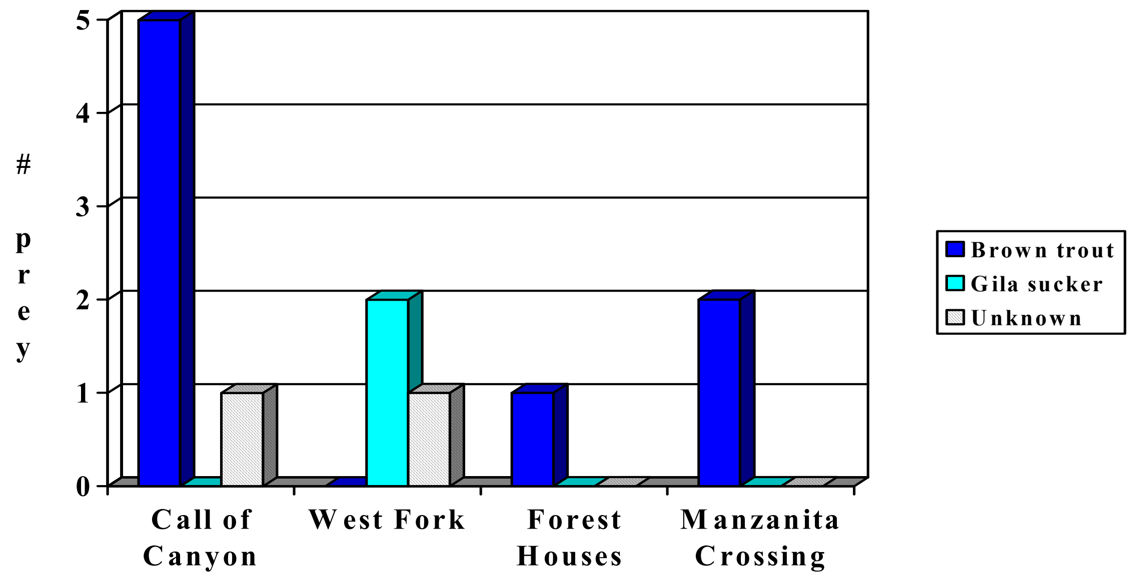


Figure 10. Number of prey items of *Thamnophis rufipunctatus* at four locations in Oak Creek, Arizona, between 1999 and 2001. Prey were detected by palping and identified after induced regurgitation.

Rosen and Schwalbe (1988) found the following prey species during their surveys of narrow-headed garter snakes in Oak Creek: speckled dace (n=7), Gila suckers (n=4), brown trout (n=1), and red shiner (*Notropis luternsis*) (n=1). The latter is a species of fish that we did not observe during our surveys in Oak Creek.

The average size of the prey items eaten by narrow-headed garter snakes during our surveys was fairly large. The average SVL of brown trout detected was 8.25 $\pm$ 3.89 cm, and their average mass was 10.89 $\pm$ 19.16 g (n=8). The fish ranged between 7 and 55 % of the snakes' body weights. While we suspect that garter snakes, like most snakes, tend to maximize the size of prey items they ingest (Rodriguez-Robles et al. 1999), it is also likely that larger or harder-bodied prey in snakes' guts were more likely to be detected visually and felt during palping.

It is extremely interesting that the major food item detected in narrow-headed garter snakes was a non-native trout species. It is likely that brown trout closely resemble in body form and ecological niche a native trout species (Apache Trout, *Salmo apache*, or a similar species) that formerly occurred in Oak Creek (Minckley 1973), so the evolutionary leap to a new food source may not have been too problematic for the snakes. Brown trout were first introduced into Oak Creek in the early 1900's (L. Luedecker, pers comm.) and breeding populations have become established, as evidenced by the presence of fingerling trout in traps and snake bellies at three locations during this study. This species may also become predators on all age classes of garter snakes when adults (Rosen and Schwalbe 1988). Twelve percent of the narrow-headed garter snakes we found had bite marks or other scars on their bodies (however, we do not know exactly how these injuries were caused), compared to 41% of the snakes Rosen and Schwalbe (1988) found during their surveys. This does not make immediate sense given that non-native fish numbers appear to have increased since the earlier surveys, and one would expect that the percentage of snakes with scars and bite marks would actually increase. More research is needed on this issue.

Habitat Use.

Habitat Types Within Oak Creek. We first examined the relationship of habitat variables to location, in an attempt to understand the distribution of the snakes within Oak Creek. The cluster analysis of habitat variables using the centroid method resulted in the grouping of all sampling plots in three distinctive clusters, consistent with their distribution along the altitudinal gradient along the creek and the distinctive vegetation types in the area (Figure 11a). Cluster 1 is comprised of Cave Springs, Call of the Canyon, West Fork, Forest Houses Resort, and Slide Rock State Park. These sites are located among ponderosa pine/oak forest (Montane Riparian Forest) in the upper middle areas of the canyon. Cluster 2 is composed of those plots located at Manzanita Crossing, Grasshopper Point, and Midgely Bridge. These locations are in the lower canyon within pinyon-juniper habitat (Interior Riparian deciduous forest). Cluster 3 is comprised of plots in Red Rock Crossing, Red Rock State Park, and Lower Oak Creek Estate, located below Sedona outside of the canyon within mesquite-grassland habitat (Sonoran deciduous forest).

The same grouping was observed when we made the same type of analysis using the snake or non-random plots: two clusters are clearly defined, one with the locations Cave Springs to Forest Houses Resort, and the other one with the locations Manzanita Crossing and Midgely Bridge (Figure 11b). We did not find any snakes in the three lower Oak Creek locations, therefore they are not represented in this second analysis.

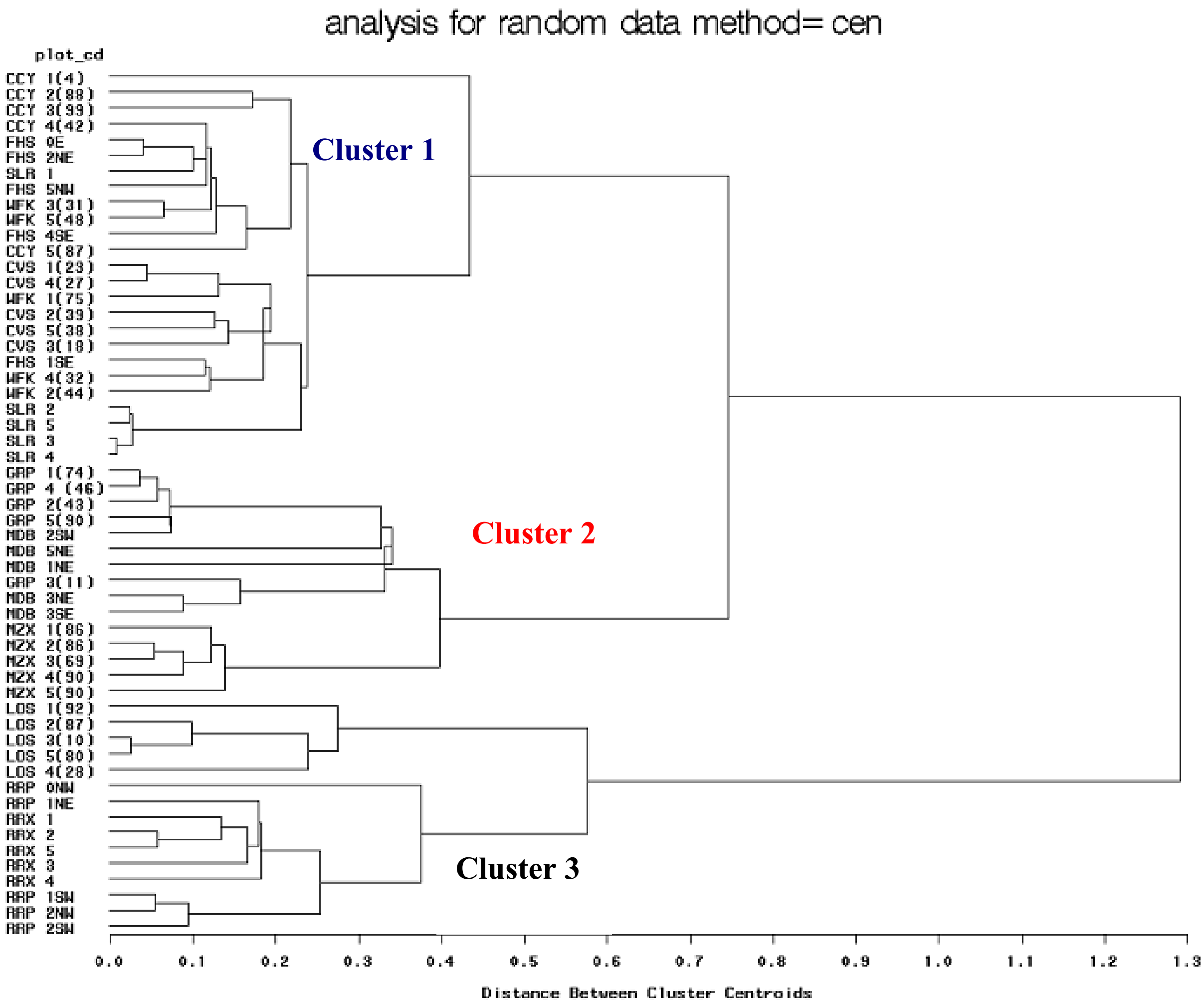


Figure 11a. Dendrogram of the cluster analysis (centroid method) for the random habitat plots (n=55) described during a survey of *Thamnophis rufipunctatus* in Oak Creek, Arizona, during 1999-2001. There are three main clusters of habitat types (see text for details and Appendix A for site codes).

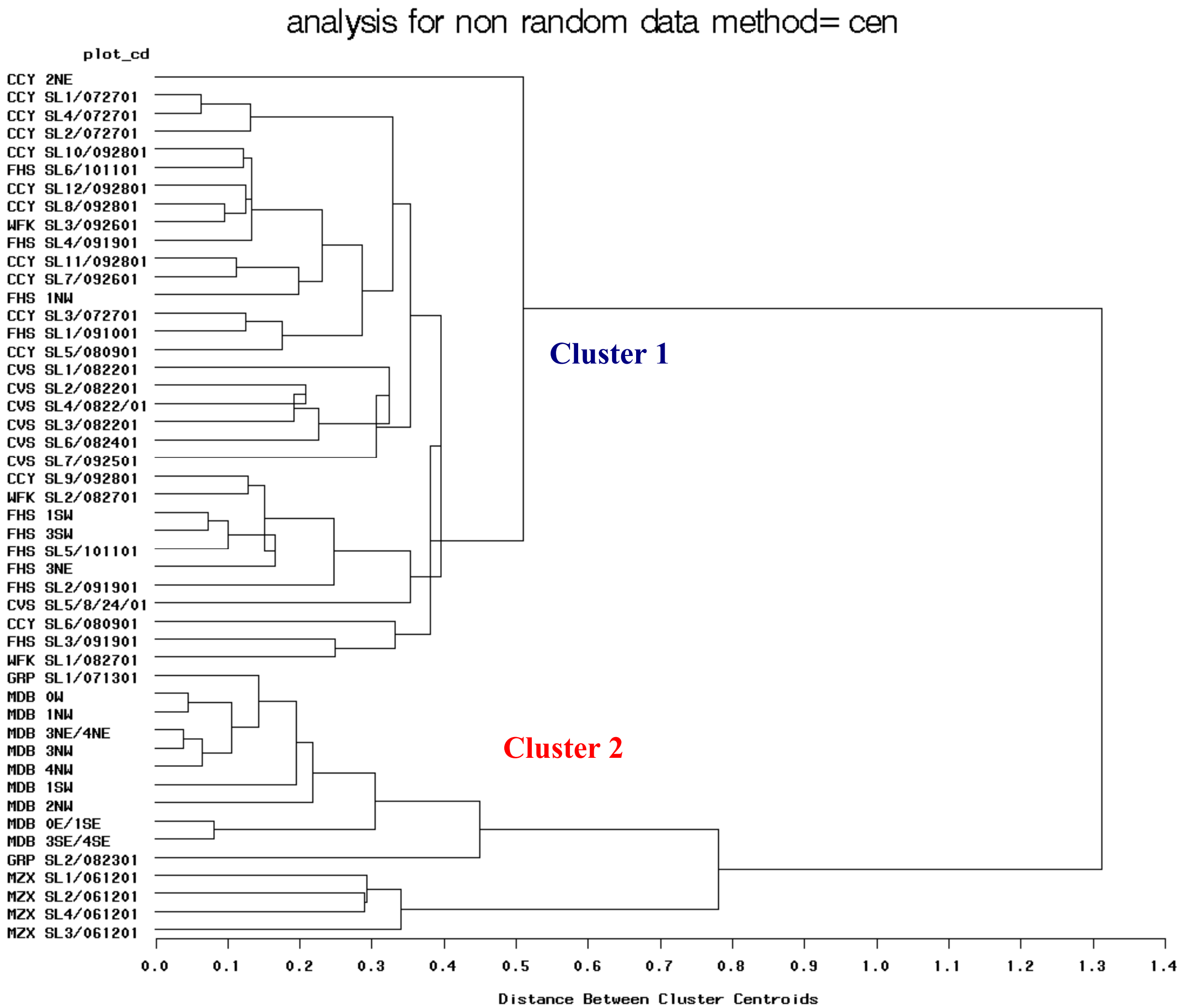


Figure 11b. Dendrogram of the cluster analysis (centroid method) for the non-random or "snake" habitat plots (n=48) described during a survey of *Thamnophis rufipunctatus* in Oak Creek, Arizona, during 1999-2001. There are two main clusters of habitat types where snakes were found (see text for details and Appendix A for site codes).

When between-cluster comparisons were made, some habitat variables were significantly different between clusters. Table 4 shows the results of comparisons between the clusters. Appendix C provides figures illustrating significant differences graphically.

Table 4. Comparisons among the 22 habitat variables between the three main clusters formed by the 55 random habitat plots in Oak Creek, Arizona, in 1999-2001. Three types of statistical tests were used: the Fisher exact test, the Mann-Whitney-U-Wilcoxon two-sample test ("WCX"), and the Kruskal-Wallis H test (KRW). Significance was determined at the $p \leq 0.05$ level; "ns" indicates that the test results were not significant. See text for details.

Habitat Variables	Cluster Comparisons			
	Statistical test	1 vs 2 (random)	1 vs 3 (random)	2 vs 3 (random)
aspect	fisher	ns	ns	ns
crayfish	fisher	p<0.001	p<0.001	ns
channel braided	fisher	ns	ns	ns
backwater	fisher	ns	ns	ns
elevation	WCX	p<0.001	p<0.001	p<0.001
canyon width	WCX	ns	p<0.001	p<0.001
channel width	WCX	ns	p<0.05	ns
water depth	WCX	p<0.05	ns	ns
current type	KRW	ns	ns	ns
water visibility	WCX	ns	p<0.001	p<0.001
silt class	WCX	ns	p<0.01	ns
landform type	KRW	ns	ns	ns
bank canopy cover	WCX	ns	ns	p<0.05
channel percent tree cover	WCX	ns	ns	ns
channel percent shrub cover	WCX	ns	ns	ns
channel percent herbaceous cover	WCX	ns	ns	ns
channel percent aquatic vegetation	WCX	p<0.01	ns	p<0.05
channel percent unvegetated	WCX	p<0.05	ns	ns p=0.0526
bank percent tree cover	WCX	ns	ns	ns
bank percent shrub cover	WCX	ns	ns	ns
bank percent herbaceous cover	WCX	ns	p<0.01	P<0.01
bank percent unvegetated	WCX	ns	ns	p<0.05

The presence of crayfish was significantly different between clusters 1 and 2, and 1 and 3, but not 2 and 3. We interpret this to mean that crayfish were significantly least abundant in Cluster 1, more abundant in Cluster 2, and significantly most abundant in Cluster 3. This distribution closely parallels that of non-native and spiny-rayed fish in the creek.

Functionally, the remaining analyses indicate that there are three main types of physical habitats available to the narrow-headed garter snakes. Each habitat cluster shares similar habitat features. Cluster 1 comprises the highest elevation in the canyon, has steeper and closer canyon walls, and tends to have the narrowest channel width and has significantly shallower water depth (e.g. Figure 12). The channel is often braided and there is minimal silt in the main stem of the creek.

Plots in this cluster had good canopy coverage, vegetated islands, and abundant streamside and significantly more aquatic vegetation to provide cover for snakes. Because the canyon walls are closer together and the trees taller, this area receives less insolation during the day than other clusters. We found the most narrow-headed garter snakes in this cluster, suggesting that this combination of habitat features (and perhaps the lack of crayfish plus the absence of spiny rayed fishes) is currently the most favorable to their distribution. However, these plots also had the fewest non-native and spiny-rayed fish, so it is likely that a combination of factors influences snake distribution.

Figure 12. Representative habitat within Cluster 1. West Fork of Oak Creek, Coconino County, Arizona, August 2001. Erika Nowak photograph.

Cluster 2 comprises mid-canyon elevations. Here the channel and canyon walls open up and get wider, and the water is deeper, with some pools over two meters in depth (e.g. Figure 13). The channel is less often braided and there is increased silt in the creek, especially in the pools, likely as a result of heavy recreation near these areas. This cluster was sunnier than Cluster 1, due to canyon walls being farther apart and to the dominant tree species being shorter. The cluster had the highest streamside canopy coverage and high vegetation cover, although there was significantly less vegetation growing in the stream. Some areas contained abundant aquatic vegetation. The number of non-native and spiny-rayed fish species increase in this cluster. We detected the remaining snakes in this cluster, in slightly lower numbers than in Cluster 1. These results are in contrast to those of Rosen and Schwalbe (1988), who found by far the most narrow-headed garter snakes in the area of Cluster 2. We suspect that this difference may be due to channel-altering (and thus habitat-altering) scouring flood events (also suggested by L. Luedecker, pers. comm.) and/or to an increase in the proportion of non-native fish species (P. Rosen, pers. comm.).

Figure 13. Representative habitat within Cluster 2. Private road crossing south of USFS Manzanita Campground, Oak Creek, Coconino County, Arizona, June 2001. Erika Nowak photograph.

Cluster 3 comprises plots that are outside the canyon proper. There are no canyon walls close to the stream, and the channel is significantly wider and deep (e.g. Figure 14). There are fewer areas of rocky run-riffle sequences; pool-run sequences are much more common. The channel is rarely braided and there is much silt throughout the creek, resulting in significantly lower water visibility. This cluster was very sunny with significantly less canopy coverage and streamside vegetation, especially grasses (graminoids) and sedges. Few areas contained abundant aquatic vegetation. We detected no native fish in our sampling area, and postulate that in lower Oak Creek the proportion of non-native and spiny-rayed fish species greatly outnumbers that of natives. We also detected no narrow-headed garter snakes in this cluster although they formerly occurred here.

Figure 14. Representative habitat within Cluster 3 near Lower Oak Creek Estates, Oak Creek, Yavapai County, Arizona, August 2001. Shawn Knox photograph.

When random plots were compared to non-random plots within each cluster where snakes were present (Clusters 1 and 2), results were similar to those in Table 4. That is, many of the same habitat variables that were significant between clusters were also important factors in snake locations. Table 5 gives test results for this comparison, as well as that for snake locations (non-random plots) between the two clusters (see earlier discussion of differences in habitat variables between clusters).

Table 5. Comparisons among the 22 habitat variables between the random and non-random (snake) habitat plots for the two cluster of locations with snakes in Oak Creek, Arizona, in 1999-2001. Three types of statistical tests were used: the Fisher exact test, the Mann-Whitney-U-Wilcoxon two-sample test ("MNW"), and the Kruskal-Wallis H test (KRW). Significance was determined at the p≤ 0.05 level; "ns" indicates that the test results were not significant. See text for details.

Habitat Variables	**Cluster Comparisons**			
	Statistical Test	Cluster 1: random v. non-random	Cluster 2 : random v. non-random	Nonrandom: Cluster 1 v. Cluster 2
aspect	fisher	ns	ns	ns
crayfish	fisher	p<0.05	ns	p<0.001
channel braided	fisher	ns	ns	ns
backwater	fisher	ns	ns	ns
elevation	MNW	ns	ns	p<0.001
canyon width	MNW	ns	ns	ns
channel width	MNW	p<0.05	ns	ns
water depth	MNW	ns	ns	p<0.01
current type	KRW	ns	ns	ns
water visibility	MNW	ns	ns	ns
silt class	MNW	p<0.01	ns	p<0.001
landform type	KRW	ns	ns	ns
bank canopy cover	MNW	ns	ns	ns
channel percent tree cover	MNW	ns	ns	ns
channel percent shrub cover	MNW	ns	ns	ns
channel percent herbaceous cover	MNW	ns	ns	ns
channel percent aquatic vegetation	MNW	ns	ns	p<0.05
channel percent unvegetated	MNW	ns	ns	ns
bank percent tree cover	MNW	ns	ns	ns
bank percent shrub cover	MNW	ns	ns	ns
bank percent herbaceous cover	MNW	ns	p<0.05 one tail	ns
bank percent unvegetated	MNW	ns	p<0.05 one tail	ns

As expected, narrow-headed garter snakes were more likely to be found in locations without crayfish. This was true within Cluster 1 and between Clusters (there were more crayfish in Cluster 2 than in Cluster 1). Snakes were more likely to be found in areas without silt, especially within Cluster 1. They were also more likely to be found in shallower areas, but this may be an artifact of our increased ability to detect them in such areas, or to the overwhelming use by neonates of this habitat. However, note that Slide Rock State Park influenced the significance of analyses in Cluster 1 by having more crayfish and a narrower channel width than the other plots within the Cluster. When we excluded these locations from the analysis, we found that the variables "crayfish presence" and "channel width" were not significant, although the above trend still held.

As mentioned earlier, there was more aquatic vegetation in plots within Cluster 1 when compared to Cluster 2. Much of the aquatic vegetation in both Clusters 2 and 3 was non-native milfoil (*Myriphyllum sp*.), compared to the native watercress (*Rorippia nasturtium-aquaticum*) and monkey flower (*Mimulus sp*.) predominate in Cluster 1. In Cluster 2, significantly more snakes were found in plots that had abundant streamside graminoid/sedge cover, and correspondingly less unvegetated cover (bare soil or rock). We found several snakes in both clusters on islands created by tussocks of a large vase-shaped *Carex spp*., or underneath these plants if they overhung the water's edge. The overhanging plants serve a similar ecological function to the undercut banks favored by narrow-headed garter snakes in the San Francisco River in New Mexico (C. Painter, pers. comm.).

<u>Habitat Use by Age Class and Sex</u>. The results of tests for habitat variables significant for adults, juveniles, and neonates, as well as for each sex, are shown for Cluster 1 in Table 6a, and for Cluster 2 in Table 6b. Variables were compared between snake locations and random plots. separately within each cluster.

Table 6a. Comparisons among the 22 habitat variables of Cluster 1, between the random plots (n=25) and the non-random (snake) plots separated for age classes (adults n=22, juveniles n=9, neonates n=13) and sex (males n=21, female n=21) in Oak Creek, Arizona, in 1999-2001. Three types of statistical tests were used: the Fisher exact test, the Mann-Whitney-U-Wilcoxon two-sample test ("MNW"), and the Kruskal-Wallis H test (KRW). "rdm" = random plots. Significance was determined at the p≤ 0.05 level; "ns" indicates that the test results were not significant. See text for details.

Habitat Variables	**Cluster 1 Comparisons**					
	Statistical Test	**Adult v. rdm**	**Juvenile v. rdm**	**Neonate v. rdm**	**Female v. rdm**	**Male v. rdm**
aspect	fisher	ns	ns	ns	ns	ns
crayfish	fisher	p<0.05 one tail	ns	ns	p<0.05 one tail	p<0.05 one tail
channel braided	fisher	ns	ns	ns	ns	ns
backwater	fisher	ns	ns	ns	ns	ns
elevation	MNW	ns	ns	ns	ns	ns
canyon width	MNW	ns	ns	ns	ns	p<0.05
channel width	MNW	p<0.05	ns	ns	p<0.05	p<0.05
water depth	MNW	ns	p<0.05 one tail	ns	ns	ns
current type	KRW	ns	ns	ns	ns	ns
water visibility	MNW	ns	ns	ns	ns	ns
silt class	MNW	p<0.01	p<0.05 one tail	ns	p<0.01	p<0.05
landform type	KRW	ns	ns	ns	ns	ns
bank canopy cover	MNW	ns	ns	ns	ns	ns
channel percent tree cover	MNW	ns	ns	ns	ns	ns
channel percent shrub cover	MNW	ns	ns	ns	ns	ns
channel percent herbaceous cover	MNW	ns	ns	ns	ns	ns
channel percent aquatic vegetation	MNW	ns	ns	ns	ns	ns
channel percent unvegetated	MNW	ns	ns	ns	ns	ns
bank percent tree cover	MNW	ns	ns	ns	ns	ns
bank percent shrub cover	MNW	ns	ns	ns	ns	ns
bank percent herbaceous cover	MNW	ns	ns	ns	ns	ns
bank percent unvegetated	MNW	ns	ns	ns	ns	ns

Table 6b. Comparisons among the 22 habitat variables of Cluster 2, between the random plots (n=15) and the non-random (snake) plots separated for age classes (adults n=10, juveniles n=7, neonates n=3) and sex (males n=10, females n=8) in Oak Creek, Arizona, in 1999-2001. Three types of statistical tests were used: the Fisher exact test, the Mann-Whitney-U-Wilcoxon two-sample test ("MNW"), and the Kruskal-Wallis H test (KRW). "rdm" = random plots. Significance was determined at the p≤ 0.05 level; "ns" indicates that the test results were not significant. See text for details.

Habitat Variables		**Cluster 2 Comparisons**				
	Statistical Test	**Adult v. rdm**	**Juvenile v. rdm**	**Neonate v. rdm**	**Female v. rdm**	**Male v. rdm**
aspect	fisher	ns	ns	ns	ns	ns
crayfish	fisher	ns	ns	ns	ns	ns
channel braided	fisher	ns	ns	ns	ns	ns
backwater	fisher	ns	ns	ns	ns	ns
elevation	MNW	ns	ns	ns	ns	ns
canyon width	MNW	ns	ns	ns	ns	ns
channel width	MNW	ns	ns	ns	ns	ns
water depth	MNW	ns	ns	p<0.05	ns	ns
current type	KRW	ns	ns	ns	ns	ns
water visibility	MNW	ns	ns	ns	ns	ns
silt class	MNW	ns	ns	ns	ns	ns
landform type	KRW	ns	ns	ns	ns	ns
bank canopy cover	MNW	ns	ns	ns	ns	ns
channel percent tree cover	MNW	ns	ns	ns	ns	ns
channel percent shrub cover	MNW	ns	ns	p<0.05	ns	ns
channel percent herbaceous cover	MNW	ns	ns	p<0.05	ns	ns
channel percent aquatic vegetation	MNW	ns	ns	p<0.05	p<0.05	ns
channel percent unvegetated	MNW	ns	ns	p<0.05	ns	ns
bank percent tree cover	MNW	ns	ns	ns	ns	ns
bank percent shrub cover	MNW	ns	ns	ns	ns	ns
bank percent herbaceous cover	MNW*	ns	ns	ns	ns	p<0.01
bank percent unvegetated	MNW	ns	p<0.05	ns	ns	p<0.01

In Cluster 1, adults of both sexes were more likely to be found in plots without crayfish. Also in Cluster 1, adults of both sexes were more likely to be found in narrower areas of the stream. In Cluster 1, adults of both sexes and juveniles were found more often in areas of the creek with less silt. The same was not true for Cluster 2, although there was a trend for snakes to be found less often in areas with increased silt and more crayfish.

We did not detect any ecologically significant habitat variables unique in importance to females or males. Perhaps there might be differences in habitat use between adult males and gravid females. However, we did not find sizeable numbers of gravid females to test that hypothesis. The juveniles and neonates tended to be found in shallower water in both clusters. On several occasions when we released neonates into deep water ($\geq$ 0.5 m), they tried to swim to the shore or to a shallower area. In at least one case, the neonate appeared to become incapacitated by the cold water and/or the swift current and sank quickly (at which point it was rescued and placed in shallow water).

Several vegetation components were significant in Cluster 2 but not in Cluster 1. Neonates in Cluster 2 were found more often in areas of higher in-stream vegetation cover. Juveniles were less likely to appear in plots with a high percentage of unvegetated bank surface. It is possible that low sample size influenced these results, but they fit with our observations of snakes in the wild. Neonate narrow-headed garter snakes appear to favor shallow backwaters or edges (with less current) with abundant aquatic vegetation, especially watercress. Subadult and adult narrow-headed garter snakes appear to favor sections of Oak Creek Canyon with overhanging vegetation and/or vegetated islands that provide protection from predators.

Threats to Habitat. We found snakes almost exclusively in the water or immediately adjacent to it during our surveys. Narrow-headed garter snakes across their range apparently spend most of their lives in or immediately adjacent to perennial streams, only emerging to bask, gestate young, and hibernate (Rossman et al. 1996, Rosen 1991, Tanner 1990, Rosen and Schwalbe 1988, Fowlie 1965). Changes in stream or bank microhabitat condition, therefore, might affect population trends and distribution of these snakes.

It is possible that recreation, especially high densities of visitors in localized areas along the creek (e.g. Slide Rock Park), may be one factor in any narrow-headed garter snake population declines because of its effects on habitat. During the 1990's, recreational use and private development in the Sedona area and along Oak Creek increased greatly. In 1995, 1.3 million people visited the Red Rock Ranger District, a 48% increase from 1974 (USDA Forest Service 1996 unpubl.). In 1999, the district received approximately six million visitors. Increased visitation has led to terrestrial and nearshore stream habitat degradation, siltation, and episodic outbreaks of coliform bacteria, particularly near Slide Rock State Park (Southam 1996, Burns et al. 1998).

Such recreation increases silt load. This leads to decreased dissolved oxygenation of interstitial areas where fish normally lay their eggs (as well as physically covering the habitat) (Minckley 1973). Siltation affects the interstitial spaces between rocks used for foraging by narrow-headed garter snakes. Rosen and Schwalbe (1988) suggest that heavy siltation will negatively affect narrow-headed garter snake populations due to this loss of prey microhabitat. Heavy siltation likely also lowers water visibility as silt is stirred up by water currents or vertebrate use of the creek. The work of de Queiroz (2002) suggests that increased silt loading in the water column could negatively affect garter snake foraging efficiency and success (also A. de Queiroz, pers. comm.). We have also observed that crayfish appear to become more abundant during periods of heavy silt load after flash flood events (pers. obs.), and over time these conditions could negatively affect snake populations.

Recreation in the form of heavy human foot traffic compacts the banks, removing suitable growing conditions for terrestrial and emergent vegetation. This recreation removes suitable cover for the snakes as well as physically destroying shallow backwater areas that neonate snakes favor. Scouring of the stream edges and removal of edge debris from some areas (e.g. Slide Rock State Park) by large spring flood events in 1993 and 1995 may also have locally impacted habitat for narrow-headed garter snakes by removing cover (L. Luedecker, pers. comm.).

Mortality Factors. We have documented mortality of narrow-headed garter snakes from wading birds, recreationists, fishing line, and roadkills at stream crossings. We suspect bullfrogs (outside the canyon proper) and non-native fish may eat all age classes, especially younger snakes (see also Rosen and Schwalbe 1988). We did not find any evidence of snake mortality from pollution or pathogens.

Recreation likely does not have a large impact on the overall creek population, but locally higher mortality occurs due to direct killing of snakes by humans, e.g. at heavily-used areas like Slide Rock State Park. One reason this species is killed in particular by humans is that it is confused with venomous “water moccasins” by visitors from other parts of the country due to its triangular head shape and propensity to be seen in the water. Rosen and Schwalbe (1988) documented mortality of narrow-headed garter snakes in Oak Creek from human predation, and estimated that a minimum of 23 neonates are eliminated (killed or taken as pets) from the population by humans in Oak Creek each year.

MANAGEMENT RECOMMENDATIONS

Population Status Summary. We feel that populations of the species are either very low south of the canyon or have been extirpated. In the north-middle reaches of Oak Creek Canyon overall population numbers appear stable. However, it is possible that there may have been substantial population declines at Slide Rock State Park and in the Midgley Bridge area. The factors most likely implicated in population declines are increases in populations of non-native and spiny-rayed fish, habitat destruction due to increased recreation, and localized mortality due to channel-altering flood events, direct predation by humans, and roadkills.

We recommend the following:

1) Continued monitoring of populations at Midgley Bridge, Forest Houses, Manzanita Campground Crossing, and Call of the Canyon. These areas have the most animals individually marked (permanently PIT-tagged).
2) Continued monitoring of fish populations within the creek, with an emphasis on the distribution of natives and non-natives, especially spiny-rayed species. As well, monitor bullfrog and crayfish populations, and develop a plan to eradicate them, especially within the canyon.
3) Involve narrow-headed garter snake biologists in planning any major change in management of brown trout and/or other fish species in Oak Creek Canyon. One management action under consideration is the re-introduction of Gila Trout (*Salmo gilae*), into the West Fork tributary region of Oak Creek (S. Rieger, Arizona Game and Fish Department, pers. comm.). This action may ultimately affect the prey base and potentially introduce new prey as well as predators.
4) Protect known habitat, especially in the north-middle reaches between Cave Springs campground and Midgely Bridge. We recommend that no further developed sites be constructed in this area of the canyon along the water, and that dispersed recreation be better monitored in that area between developed sites. Any effort that attempts to localize dispersed recreation at designated pull-outs would be useful in minimizing development of stream-side social trails. If new stream-side trails are created, the trail crews should be fully informed of the presence of narrow-headed garter snakes. The trails should be placed in areas that would minimize loss of microhabitats such as shallow edges and overhanging vegetation, and in such a way that social trails are minimized in suitable shoreline habitat. If new stream crossings are constructed, make sure that they minimize snake mortality, i.e. do not construct low-water crossings, but raise the road level above the creek. Research methods of decreasing siltation caused by heavy recreation at developed sites- this seems like a hard issue to control, but perhaps there are some diversion features that could be installed.
5) Focus on increasing public awareness of narrow-headed garter snakes to decrease human predation. Several people we met during the course of our research assumed the snakes were poisonous "water snakes" because they have slightly triangular heads, and killed them. Signs at developed areas with pictures of the snakes and information about their status and biology would be helpful. We especially recommend signs at Call of the Canyon, Manzanita Campground, the private crossing south of Manzanita Campground, Slide Rock State Park, Grasshopper Point, and Midgely Bridge. Personal contacts with anglers at known fishing sites (e.g. the crossing south of Manzanita Campground and the area north of Forest Houses Resort) would also likely decrease snake mortality.
6) Incorporate educational materials for the species and the above management recommendations into a detailed planning effort for Oak Creek initiated by the Oak Creek Canyon Steering Committee.

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Appendix C. Figures illustrating differences in habitat variables between three clusters of random plots described during surveys for *Thamnophis rufipunctatus* in Oak Creek, Arizona, from 1999-2001.

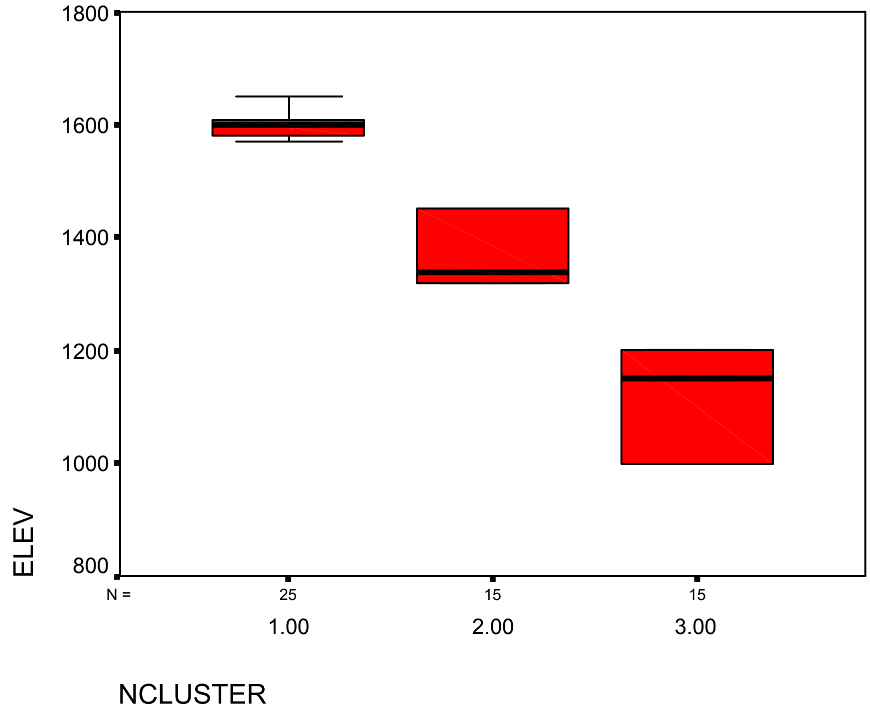

Figure I. Comparisons between mean elevation (in meters) above sea level for the random plots between the three habitat clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Cluster 1 includes plots from Cave Springs to Forest Houses Resort; Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge; Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates. See text for details.

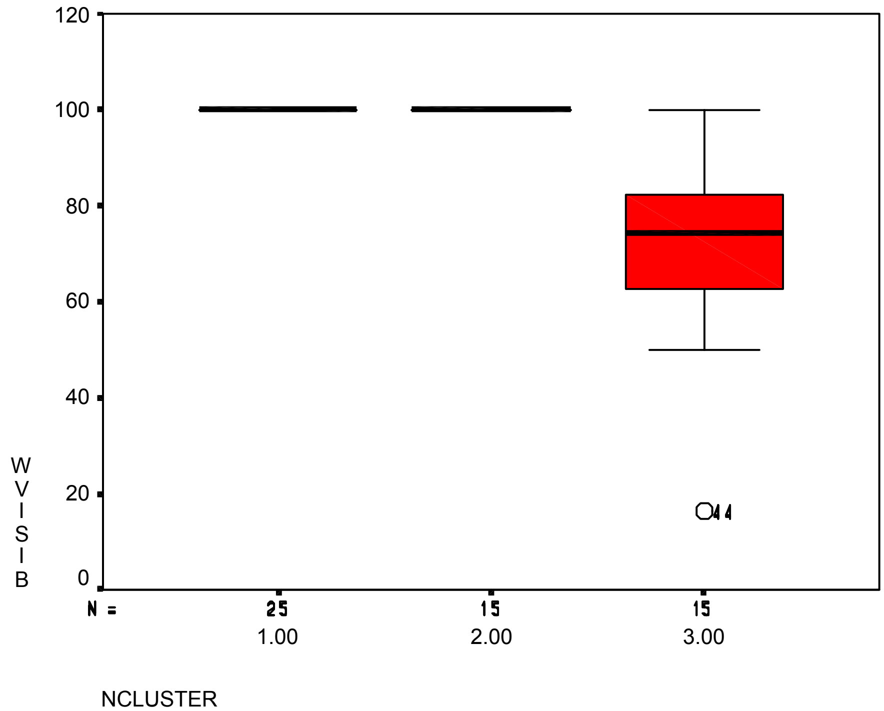

Figure II. Comparisons between mean percent of water visibility for the random plots between the three habitat clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Cluster 1 includes plots from Cave Springs to Forest Houses Resort; Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge; Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates. See text for details.

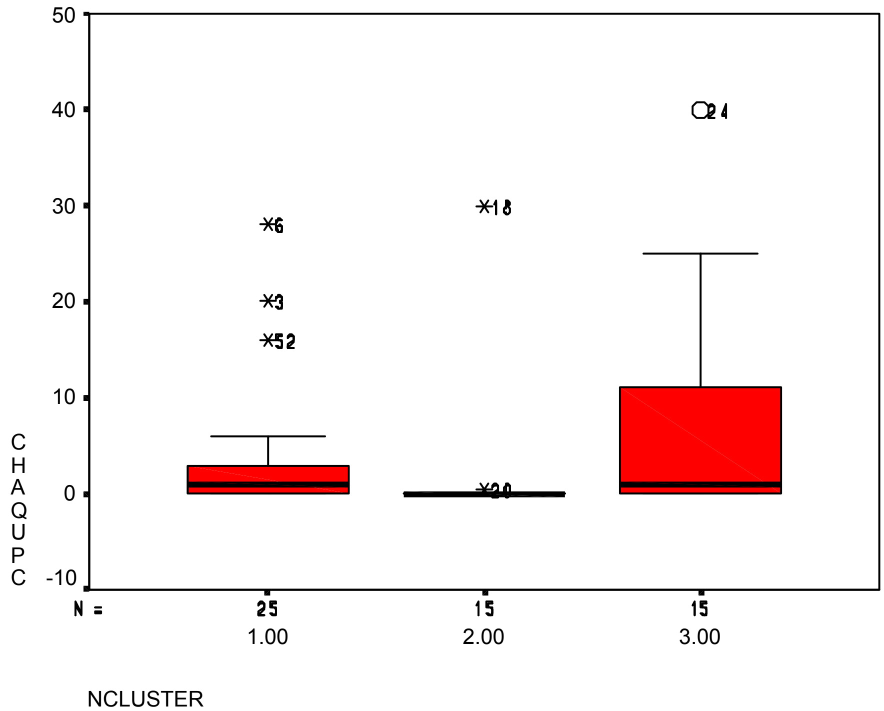

Figure III. Comparisons between mean basal area cover (in percentages) of aquatic vegetation in 25 square meter random channel subplots between the three habitat clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Cluster 1 includes plots from Cave Springs to Forest Houses Resort; Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge; Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates. See text for details.

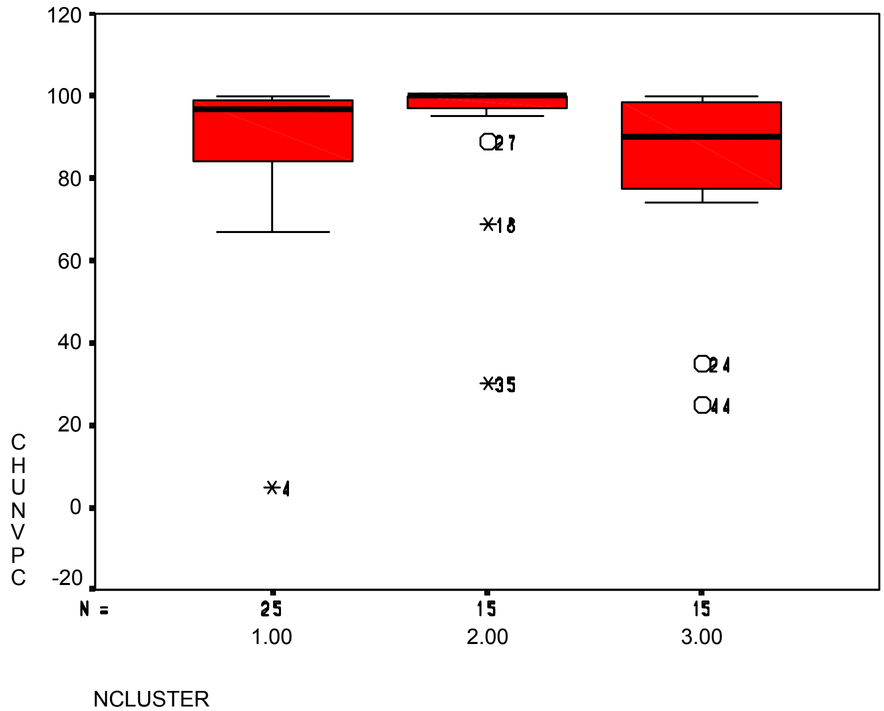

Figure IV. Comparisons between mean unvegetated area cover (in percentages) in 25 square meter random channel subplots between the three habitat clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Cluster 1 includes plots from Cave Springs to Forest Houses Resort; Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge. Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates. See text for details.

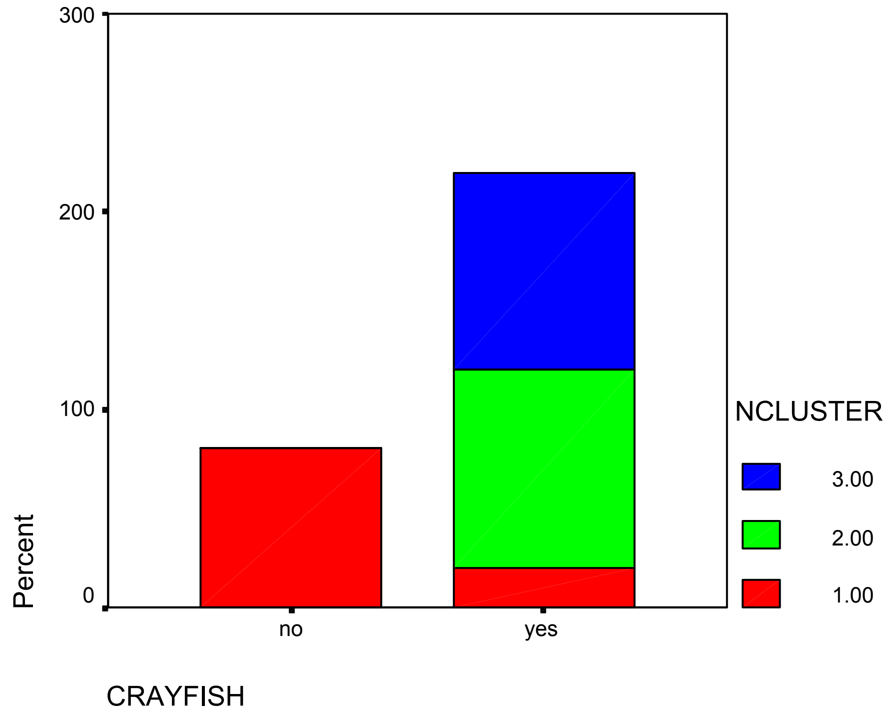

Figure V. Percent of the random habitat plots with crayfish present for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15); Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.

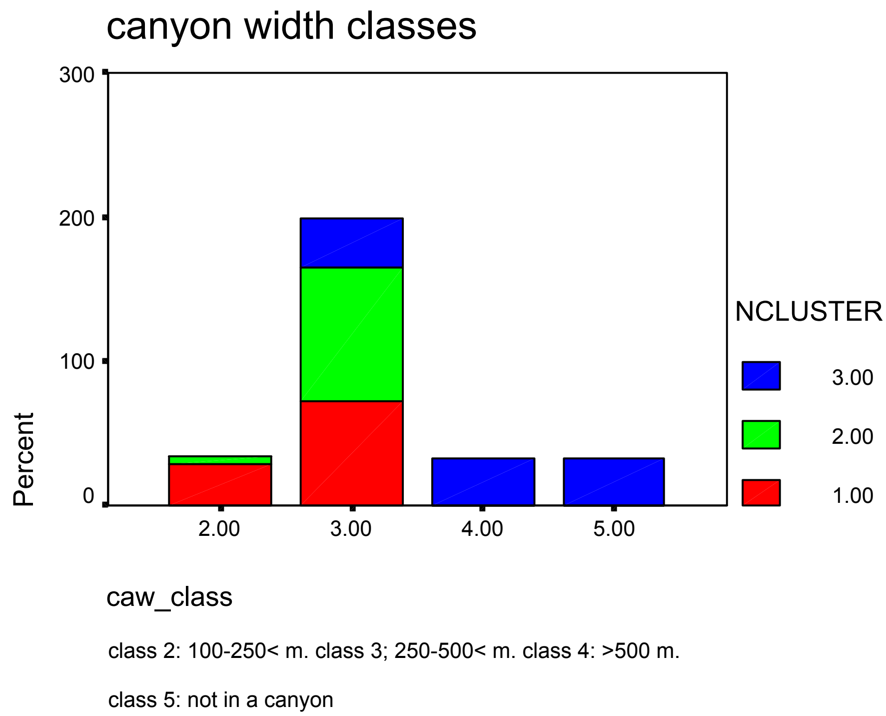

Figure VI. Percent of the random habitat plots present among the four different canyon width class intervals (in meters) for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15). Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.

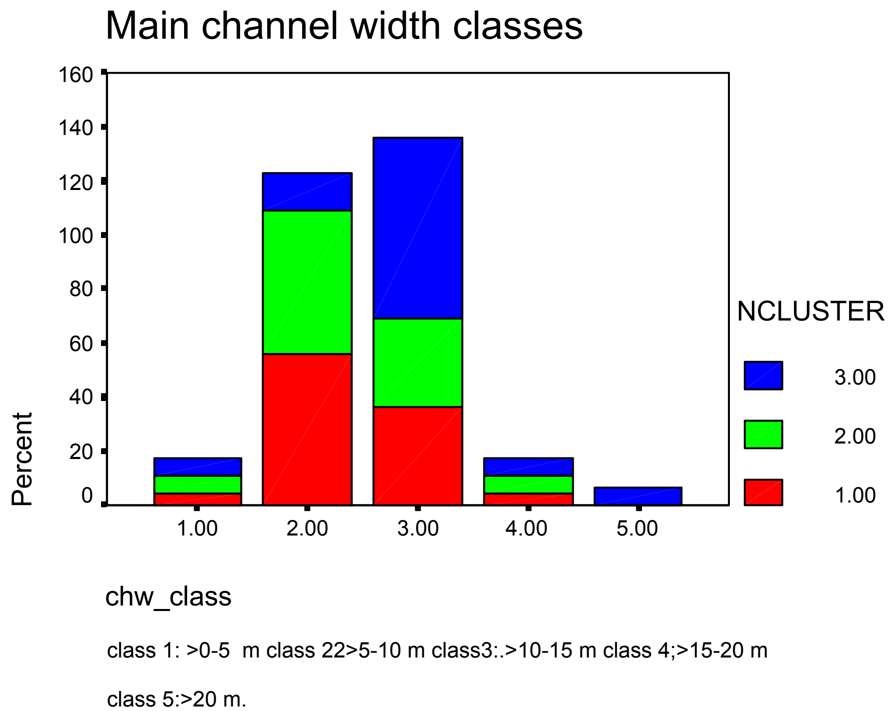

Figure VII. Percent of the random habitat plots present among the five different main channel width class intervals (in meters) for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15). Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.

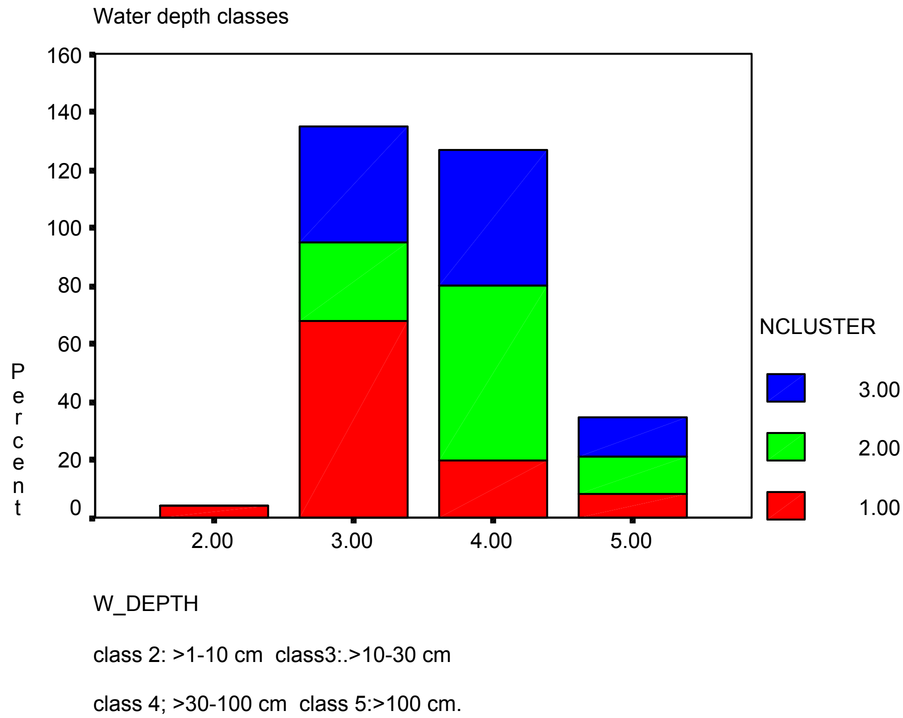

Figure VIII. Percent of the random habitat plots present among the four different water depth class intervals (in meters) for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15). Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.

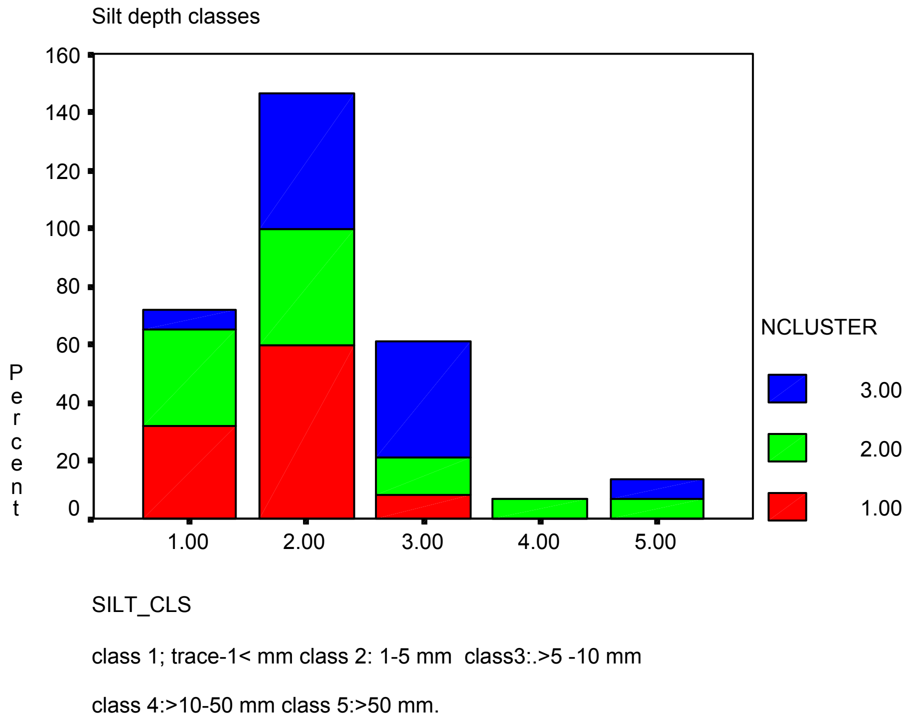

Figure IX. Percent of the random habitat plots present among the five different silt depth class intervals (in millimeters) for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15). Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.

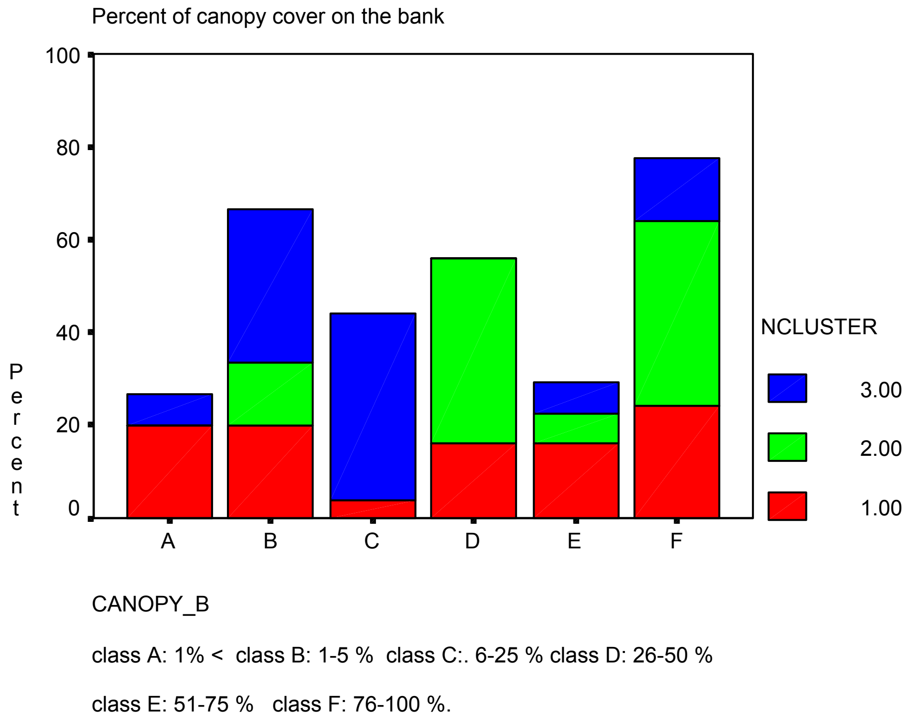

Figure X. Percent of the random habitat plots present among the among the six different class intervals (in percentages) for the three clusters determined during a study of *Thamnophis rufipunctatus* in Oak Creek, Arizona. Each color represents a different cluster, and the percentages within that color (cluster) add to 100%. Cluster 1 includes plots from Cave Springs to Forest Houses Resort (n=25). Cluster 2 includes plots from Manzanita Crossing to Midgely Bridge (n=15). Cluster 3 includes plots from Red Rock Crossing to Lower Oak Creek Estates (n=15). See text for details.