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# ABUNDANCE AND SPECIES RICHNESS OF SNAKES ALONG THE MIDDLE RIO GRANDE RIPARIAN FOREST IN NEW MEXICO

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***Abstract*.—To understand the effects of removal of non-native plants and fuels on wildlife in the riparian forest of the Middle Rio Grande in New Mexico, we monitored snakes from 2000 to 2006 using trap arrays of drift fences, pitfalls, and funnel traps. We recorded 158 captures of 13 species of snakes from 12 study sites. We captured more snakes in funnel traps than in pitfalls. The most frequent captures were Common Kingsnakes (*Lampropeltis getula*), Gopher Snakes (*Pituophis catenifer*), Plains Black-headed Snakes (*Tantilla nigriceps*), and Plains Hog-nosed Snakes (*Heterodon nasicus*). We did not detect an effect of non-native plants and fuels removal on the rate of captures; however, we recommend using other trapping and survey techniques to monitor snakes to better determine the impact of plant removal on the snake community. Compared to historical records, we did not report any new species but we did not capture all snakes previously recorded. Black-necked Gartersnakes (*Thamnophis cyrtopsis*), which are closely tied to aquatic habitats, were not captured during our study; possibly indicating the loss of off-channel semi-aquatic habitats along the Middle Rio Grande.**

*Key Words*.—exotic plants; habitat; non-native; reptiles; restoration; Rio Grande; riparian forest; snakes

## INTRODUCTION

Floodplains and riparian areas are some of the most diverse terrestrial habitats on Earth (Naiman et al. 1993; Kondolf et al. 1996) and riparian areas in the arid southwest of the U.S.A. support a diverse array of wildlife (Hubbard 1977). One of the most extensive southwestern riparian ecosystems is in New Mexico and consists of an expansive Cottonwood (*Populus deltoides*) forest, or *bosque*, along the Middle Rio Grande. Land managers chose the Middle Rio Grande for restoration because activities like damming and diverting water have altered the natural flood regime, cottonwood recruitment, and plant species composition (Molles et al. 1998). These anthropogenic activities provide opportunities for the establishment of non-native plants (Howe and Knopf 1991) coinciding with the accumulation of quantities of woody debris that facilitate catastrophic wildfires (Stuever 1997; Ellis et al. 1999).

The herpetofauna of New Mexico encompasses 123 species (Degenhardt et al. 1996), including several inhabitants of riparian forest. Because much attention focuses on reversing and repairing anthropogenic damage in riparian forest, we must understand how restoration activities affect wildlife. Snakes are important elements of ecosystems as predators of vertebrates and invertebrates (Fitch 1949). Few studies have documented how snakes respond to restoration activities that alter ground cover and understory vegetation in riparian areas. Some examples of restoration impacts on snakes and other reptiles have occurred in coniferous forests (Greenberg et al. 1994; Litt et al. 2001; Pilliod et al. 2006) and grasslands (Fitch 2006; Wilgers and Horne 2006). Many studies focus on other wildlife in the Middle Rio Grande such as arthropods (Ellis et al. 2000; Tibbets and Molles 2005), birds (Ellis 1995; Yong and Finch 1997), and small mammals (Ellis et al. 1997). However, published information on snake species richness and abundance in the *bosque* is limited to field guides (Degenhardt et al. 1996) and monitoring reports (Hink, V.C., and R.D. Ohmart. 1984. Middle Rio Grande biological survey. Final Report to the U.S. Army Corps of Engineers No. DACW47-81-C-0015. Center for Environmental Studies, Arizona State University, Tempe, Arizona, USA.; Stuart, J.N., G.H. Farley, E.W. Valdez, and M.A. Bogan. 1995. Studies of vertebrates in selected riparian and aquatic habitats on *Bosque* del Apache National Wildlife Refuge, New Mexico. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.). As part of a larger project to evaluate the effects of restoration activities on wildlife in the *bosque* (Bateman et al. 2008a), we report species occurrences and relative abundances for snakes. Our objectives were to: (1) determine if capture rate of snakes varied due to restoration activities; (2) document their abundance and morphometrics; (3) compare species richness in our study to historical records; and (4) compare capture-efficacy of pitfall and funnel traps in the riparian forest along the Middle Rio Grande.

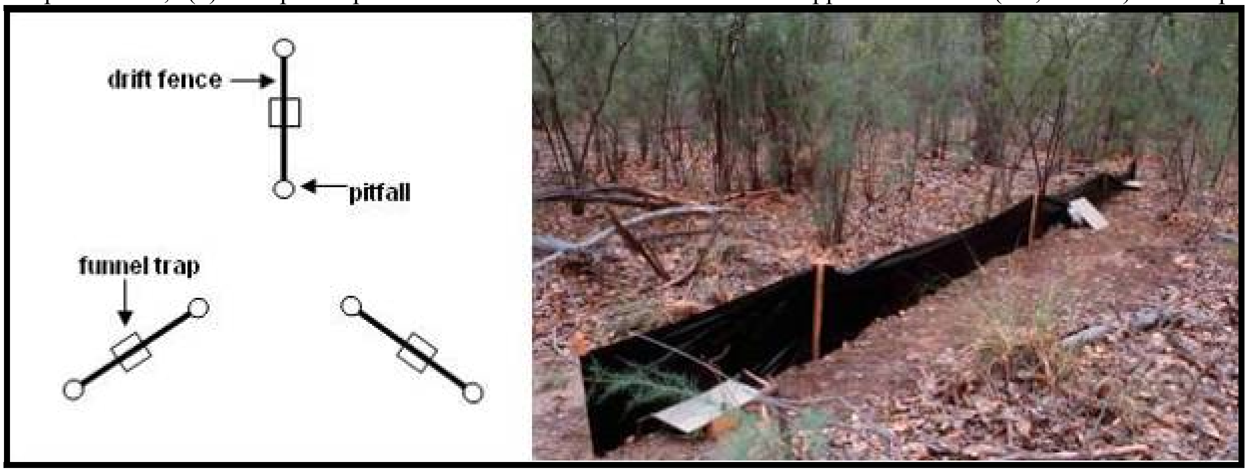


**FIGURE 1.** Trapping array in the riparian forest of the Middle Rio Grande, New Mexico, USA. Diagram illustrates one array with three 6-m long drift fences, oriented at 0, 120, and 240°. Six pitfalls (5-gallon buckets) with cover boards and six funnel traps were set along fences. Photograph shows one 'arm' of an array. (Photographed by Alice Chung-MacCoubrey).

## MATERIALS AND METHODS

***Study site***.—We captured snakes in the riparian forest (*bosque*) along the Middle Rio Grande in central New Mexico, U.S.A. The climate is semiarid to arid (Tuan 1962). Our study sites were in *bosque* that contained a mixture of native Rio Grande Cottonwood (*Populus deltoides wislizenii*), and such non-native plants as Saltcedar (*Tamarix chinensis* and *T. ramosissima*), and Russian Olive (*Elaeagnus angustifolia*).

We monitored relative abundance of snake species at 12 sites (approximately 20 ha each) from 2000 to 2006. Sites were in three regions (i.e. North, Middle, and South) from Albuquerque (35°00'04 N – 106°41'04 W) to Bosque del Apache National Wildlife Refuge (33°47'59 N – 106°52'59 W). We assigned the nine sites (three from each region) to one of three treatments of non-native plant removal and fuels reduction. The remaining three sites (one in each region) were untreated controls. Crews removed non-native plants with chainsaws and applied herbicide (i.e., Garlon) to stumps. Additional restoration activities included burning slash piles or planting native shrubs (i.e., 247 native plants per ha; NRCS 2005; see Bateman et al. 2008b for details). Non-native plant removal and fuels reduction took place in the fall or winter to reduce disturbance to wildlife. Completion of restoration activities was not simultaneous. Treatments began in 2003 and ended in 2005.

***Field techniques, analyses***.—We captured snakes using drift fence arrays with pitfall traps, cover boards, and funnel traps (Fig. 1). Our design was adopted from pitfall designs proven useful in other habitat (Jones 1981, 1987; Campbell and Christman 1982; Corn and Bury 1990). We deployed three trap arrays at each site at random distances > 25 m from the edge of each sampling site. Trap arrays were at least 320 m apart. Each 6-m long fence began 7.5 m from a central point and was positioned at 0, 120, and 240°. We checked traps three days a week and traps remained open continuously from June to mid-September each year except for a shortened season in 2000 (i.e., June and July). Experienced technicians identified snakes to species using published guides (Degenhardt et al. 1996), weighed snakes in a cloth bag of known mass with a

**TABLE 1.**—Results from repeated measures ANOVA model testing for effects of region (North, Middle, South), period (pre- vs. post-treatment), assigned treatment groups (control vs. treated sties), and period by treatment interaction for snakes captured along the Middle Rio Grande, New Mexico, USA. Capture rate numbers of snakes captured in each site divided by number of trap days multiplied by 100.

| Source | Numerator df | Denominator df | *f* | *P* | Interpretation |
|---|---|---|---|---|---|
| Region | 2 | 26.6 | 15.2 | < 0.001 | More snakes in South Region |
| Period | 1 | 47.2 | 5.3 | 0.026 | More snakes in years 2003-2006 |
| Treatment | 1 | 28.2 | 0.3 | 0.580 | No difference between treatment groups |
| Period x treatment | 1 | 48.1 | 0.3 | 0.584 | No effect of removing non-native plants |

**TABLE 2.**—Numbers of snakes captured along the Middle Rio Grande, New Mexico, USA in trapping arrays of pitfalls and funnel traps during seven years. Species are ordered by total abundance. Year 2000 had a shorter trapping period than subsequent years.

| Species | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Total |
|---|---|---|---|---|---|---|---|---|
| Common Kingsnake, *Lampropeltis getula* | 5 | 11 | 1 | 6 | 7 | 10 | 7 | 47 |
| Gophersnake, *Pituophis catenifer* | 0 | 4 | 0 | 9 | 5 | 10 | 1 | 29 |
| Plains Black-headed Snake, *Tantilla nigriceps* | 1 | 3 | 0 | 0 | 6 | 6 | 5 | 21 |
| Plains Hog-nosed Snake, *Heterodon nasicus* | 2 | 3 | 1 | 3 | 2 | 2 | 1 | 14 |
| Common Gartersnake, *Thamnophis sirtalis* | 2 | 2 | 0 | 1 | 1 | 4 | 3 | 13 |
| Prairie Rattlesnake, *Crotalus viridis* | 0 | 0 | 0 | 1 | 6 | 1 | 1 | 9 |
| Western Diamond-backed Rattlesnake, *Crotalus atrox* | 0 | 0 | 0 | 0 | 1 | 5 | 0 | 6 |
| Coachwhip, *Masticophis flagellum* | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 5 |
| Checkered Gartersnake, *Thamnophis marcianus* | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 4 |
| Unknown Gartersnake, *Thamnophis* spp. | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| Glossy Snake, *Arizona elegans* | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 |
| New Mexico Threadsnake, *Leptotyphlops dissectus* | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Terrestrial Gartersnake, *Thamnophis elegans* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Eastern Racer, *Coluber constrictor* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **Total captures** | 13 | 28 | 3 | 25 | 31 | 39 | 19 | 158 |
| **Species richness** | 6 | 8 | 3 | 8 | 9 | 8 | 7 | 13 |

spring scale (Pesola AG, Baar, Switzerland), and measured snout-to-vent length (SVL) of a subsample with a plastic ruler or string. We released snakes without assigning unique marks.

We defined capture rate as numbers of snakes captured in each site divided by number of trap days multiplied by 100. We averaged the number of trap days for the three arrays per site. We combined all snake captures into one rate because there were too few observations of individual species for analyses. We analyzed relationships among restoration treatments and capture rates using a repeated measures analysis of variance (ANOVA, $\alpha = 0.05$) with years as a repeated effect (SPSS Inc. version 13.0, Chicago, IL; Mixed procedure with first-order autoregressive, correlation among years). We tested for effects of region (North, Middle, South), period (pre- vs. post-treatment), and assigned treatment (control vs. treated sites). We tested for treatment effect on snake captures through period by treatment interaction. We defined pre-treatment years as 2000-2002 and post-treatment years as 2003-2006 for all sites except those treated in 2004 and 2005. One control site burned at the beginning of the study and was replaced in 2002. We only included data from the new control site (2002 to 2006).

We collected historical records from observations and captures reported in Hink and Ohmart (*op. cit.*) and Stuart et al. (*op. cit.*), habitat preferences described by Degenhardt et al. (1996), and records from the Museum of Southwestern Biology (Albuquerque, New Mexico, USA). We included species in historical records based on habitat preferences defined as major drainages, waterways, rivers, or marshes. We included GIS-referenced museum records defined by a 400 m buffer around the Rio Grande in Bernalillo, Valencia, and Socorro Counties in New Mexico, USA. We combined all snake captures to compare trapping methods (pitfalls and funnel traps) during the period of study using a non-parametric Wilcoxon signed rank test (alpha = 0.05).

## RESULTS

***Treatment effects***.—Treatments altered the *bosque* understory by eliminating debris heaps and thickets of non-native plants and created a more park-like, open understory (Bateman et al. 2008b). Treatments did not affect the capture rate of snakes (Table 1). However, capture rate differed by region and by period. We captured more snakes in the South region ($\bar{x} = 3.9 \pm 0.5$ SE) compared to North and Middle regions ($\bar{x} = 1.2 \pm 0.3$ SE; $\bar{x} = 1.7 \pm 0.3$ SE; Table 1). The South region had more species ($\bar{x} = 2.2 \pm 0.2$ SE) compared to North and Middle regions ($\bar{x} = 0.7 \pm 0.2$ SE; $\bar{x} = 1.0 \pm 0.2$ SE). Capture rate was lower during pre-treatment years (2000-2002; $\bar{x} = 1.6 \pm 0.3$ SE) compared to post-treatment years (2003-2006; $\bar{x} = 2.7 \pm 0.3$ SE; Table 1).

***Snake community***.—We recorded 158 captures of 13 species of snakes during seven years; not all species were captured every year (Table 2). The most commonly captured snakes were the Common Kingsnake (*Lampropeltis getula*), Gophersnake (*Pituophis catenifer*), Plains Black-headed Snake (*Tantilla nigriceps*), and Plains Hog-nosed Snake (*Heterodon nasicus*). Snake species varied in SVL and weight (Table 3). We did not encounter any previously unreported species and we did not capture four species known from historic records (Table 4).

We caught more snakes with funnel traps than with pitfalls ($T^+ = 69.7$, $P = 0.013$). Funnel traps accounted for 58% of all captures and pitfalls accounted for 42% of all captures. Funnel traps entrapped larger snakes such as Coachwhips (*Masticophis flagellum*), North American

**TABLE 3.**—Mean and standard error (SE) snout-to-vent length (SVL) and weight for five commonly captured snakes along the Middle Rio Grande, New Mexico, USA. Snakes were captured in 12 sites from 2000 to 2006. Not all snakes captured were measured; therefore we report the number measured (no.).

| | SVL (cm) | | Weight (g) | |
|---|---|---|---|---|
| **Species** | **Mean ± SE** | **No.** | **Mean ± SE** | **No.** |
| Common Kingsnake, *Lampropeltis getula* | 52.2 ± 6.6 | 19 | 47.5 ± 14.0 | 21 |
| Gophersnake, *Pituophis melanoleucus* | 56.1 ± 6.8 | 11 | 95.0 ± 30.0 | 17 |
| Plains Black-headed Snake, *Tantilla nigriceps* | 20.4 ± 0.8 | 12 | 3.9 ± 0.5 | 17 |
| Plains Hog-nosed Snake, *Heterodon nasicus* | 46.2 ± 10.9 | 3 | 120.4 ± 64.8 | 5 |
| Common Garter Snake, *Thamnophis sirtalis* | 31.5 ± 6.1 | 6 | 35.0 ± 10.1 | 12 |

Racers, (*Coluber constrictor*), Gophersnakes, and rattlesnakes (*Crotalus* spp.) more often than did pitfalls ($T^+ = 2.0$, $P = 0.094$). The smallest species, Plains Black-headed Snake, was captured more often in pitfalls (57% of captures) than in funnel traps (43% of captures).

## DISCUSSION

Our study provides basic information on trapping success, species richness, and capture rates for snakes inhabiting the *bosque* along the Middle Rio Grande in New Mexico, USA. The *bosque* is currently the focus of restoration efforts to remove non-native plants and fuels and our results did not reveal a significant effect of plant removal on snake diversity. However, this must be interpreted cautiously because of our low overall numbers of captures, potential trapping bias, and the long lag-time required for native habitat to re-establish before we can adequately observe long-term impacts.

Few studies address how removal of fuels and ground litter directly impact snake communities. Of the studies available, the results are mixed. A synthesis paper on the effects of fuels removal on wildlife in conifer forests (Pilliod et al. 2006) suggested reptiles would have species-specific responses to treatments based on habitat preferences. Some species could benefit from removal of shrubs and ground litter; whereas, removal of logs and large debris in conifer forests could detrimentally affect species like Northern Rubber Boas (*Charina bottae*). A study in the Florida sandhills suggested snakes may prefer control plots, which contained more litter and ground cover, compared to burned plots where hardwoods were removed (Litt et al. 2001). We did not identify removal and reduction effects on snakes in the first few years following treatment.

Along the Middle Rio Grande, snake captures differed by period and by region. Like other organisms in desert ecosystems, snake populations can vary in time and space due to biotic and abiotic factors (Brown and Heske 1990). Environmental factors could have influenced the observed annual and geographic variation in capture rates. Summers in 2001 and 2002 were drier than

**TABLE 4.**—Snake species documented in the riparian forest of the Middle Rio Grande, New Mexico, USA. Species are marked with an "X" if encountered in this study or other records from captures, field observations, or museum records reported in Hink and Ohmart (*op. cit.*), captures by Stuart et al. (*op. cit.*), habitat associations from Degenhardt et al. (1996), and georeferenced records from the Museum of Southwestern Biology (MSB).

| **Species** | **This Study** | **Hink & Ohmart** | **Stuart et al.** | **Degenhardt et al. (1996)** | **MSB** |
|---|---|---|---|---|---|
| Family Leptotyphlopidae | | | | | |
| New Mexico Threadsnake, *Leptotyphlops dissectus*[1] | X | | | X | |
| Family Colubridae | | | | | |
| Glossy Snake, *Arizona elegans* | X | X | | | X |
| North American Racer, *Coluber constrictor* | X | X | | X | |
| Plains Hog-nosed Snake, *Heterodon nasicus* | X | X | | | |
| Chihuahuan Nightsnake, *Hypsiglena jani* | | | | | X |
| Common Kingsnake, *Lampropeltis getula* | X | X | X | X | X |
| Coachwhip, *Masticophis flagellum* | X | X | | | X |
| Gophersnake, *Pituophis catenifer* | X | X | | X | X |
| Long-nosed Snake, *Rhinocheilus lecontei* | | X | | | X |
| Plains Black-headed Snake, *Tantilla nigriceps* | X | X | X | | X |
| Black-necked Gartersnake, *Thamnophis cyrtopsis* | | X | | X | |
| Terrestrial Gartersnake, *Thamnophis elegans* | X | | | X | X |
| Checkered Gartersnake, *Thamnophis marcianus* | X | X | | X | X |
| Common Gartersnake, *Thamnophis sirtalis* | X | X | | X | X |
| Family Viperidae | | | | | |
| Western Diamond-backed Rattlesnake, *Crotalus atrox* | X | X | | | X |
| Prairie Rattlesnake, *Crotalus viridis* | X | X | | | X |
| Massasauga, *Sistrurus catenatus* | | X | | | |

[1]Refered to as Texas Blind Snake, *Leptotyphlops dulcis* in Degenhardt et al. (1996)

average and summers in 2004 and 2006 were wetter than average (Appendix A). Rainfall may affect a snakes' water balance or prey populations (Brown and Parker 1982); therefore, conditions could have been more favorable in some years and locations.

Our results support previous studies that suggest funnel traps are more effective than pitfalls in capturing snakes (Campbell and Christman 1982; Bury and Corn 1987) and funnel traps target larger snakes better than smaller snakes (Greenberg et al. 1994). Our findings suggest that abundance of large snakes can be underestimated when using pitfalls (Greenberg et al. 1994). For example, we saw but rarely captured Coachwhips (one of the longest snakes in New Mexico, USA). We used drift fences in combination with pitfalls and funnel traps to capture snakes (Dunham et al. 1988). However, our capture rates in pitfalls may underestimate abundances of large snakes like Coachwhips, North American Racers, and Rattlesnakes.

We did not record any new species; however, several species may have relative abundances that changed from 20 years ago. The Common Kingsnake was our most commonly captured snake; whereas, Hink and Ohmart (*op. cit.*) found only one during two summers of surveys. Common Kingsnakes feed on lizards and other snake species (Degenhardt et al. 1996). On seven occasions, we found that Common Kingsnakes had ingested common species while in a trap. These included New Mexico Whiptails (*Aspidoscelis neomexicana*), Desert Grassland Whiptails (*A. uniparens*), and Desert Shrews (*Notiosorex crawfordi*). The dichotomy between our captures of Common Kingsnakes and those by Hink and Ohmart (*op. cit.*) may result from prey species attracting snakes into traps. Gophersnakes were abundant both in our study and in accounts from Hink and Ohmart (*op. cit.*). Common Gartersnakes (*Thamnophis sirtalis*) common twenty years ago, dropped to the fifth most common species in our study.

We did not capture four species previously recorded from the Middle Rio Grande. Three of these species are characteristic of shrubland habitats and uncommon in riparian forests. The fourth species, the Black-necked Gartersnake (*T. cyrtopsis*), uses aquatic habitats and feeds on tadpoles and adult amphibians (Fleharty 1967; Jones 1990; Degenhardt et al. 1996). We captured three species of Gartersnakes of similar length to Black-necked Gartersnakes, which suggests that size-related trap bias was not an issue. The absence of this species from our study may reflect the loss of suitable aquatic habitat described in earlier studies (Roelle and Hagenbuck 1995). Similarly, we captured few aquatic or semi-aquatic amphibian species (Bateman et al. 2008c). We captured no Northern Leopard Frogs (*Rana pipiens*), one Western Chorus Frog (*Pseudacris triseriata*), and five Eastern Tiger Salamanders (*Ambystoma tigrinum*). Historically, spring and summer flooding occurred along the Middle Rio Grande. However, more recently constructed dams and levees now reduce the magnitude and frequency of flooding in this region (Molles et al. 1998). Ecosystems changed considerably from these human alterations during this century (Howe and Knopf 1991). Regulation of the Rio Grande reduced available wet meadows, marshes, and ponds by 40 km$^2$ in just over 50 years (Roelle and Hagenbuck 1995). Today only small areas of the historic floodplain experience flooding (Cartron et al. 2003; Tibbets and Molles 2005; Valett et al. 2005). The poor representation of semi-aquatic species in our survey suggests that as off-channel aquatic habitats that maintain populations from the *bosque* are lost, some reptile and amphibian species may be extirpated.

Successful restoration activities require a firm understanding of habitat requirements, and population and community structure of herpetofauna (Bury 2006; Fitch 2006; McCallum and McCallum 2006). The restoration activities along the Middle Rio Grande are no exception. To evaluate the impact of non-native plant removal on the snake community, we recommend the use of pitfall and funnel traps in conjunction with other techniques for collecting snake population and community data (i.e., night surveys, walking transects, and artificial cover-objects; Campbell and Christman 1982; Engelstoft and Ovaska 2000). Knowledge of the natural history of these species can help the scientific community and resource managers make wise management decisions (Bury 2006) to protect existing native herpetofauna of the Middle Rio Grande *bosque*.

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## LITERATURE CITED


Bateman, H.L., A. Chung-MacCoubrey, D.M. Finch, H.L. Snell, and D.L. Hawksworth. 2008a. Impacts of non-native plant removal on vertebrates along the Middle Rio Grande (New Mexico). Ecological Restoration 26:193–195.

Bateman, H.L., A. Chung-MacCoubrey, and H.L. Snell. 2008b. Impact of non-native plant removal on lizards in riparian habitats in the southwestern U.S.A. Restoration Ecology 16:180–190.

Bateman, H.L., M.J. Harner, and A. Chung-MacCoubrey. 2008c. Abundance and reproduction of toads (*Bufo*) along a regulated river in the southwestern United States: Importance of flooding in riparian ecosystems. Journal of Arid Environments 72:1613–1619.

Brown, J.H., and E.J. Heske. 1990. Temporal changes in a Chihuahuan desert rodent community. Oikos 59:290–302.

Brown, W.S., and W.S. Parker. 1982. Niche dimensions and resource partitioning in a Great Basin Desert snake community. Pp. 59–81 *In* Herpetological Communities. Scott, N.J. Jr. (Ed.) U.S. Fish and Wildlife Service, Wildlife Research Report 13. Washington, D.C., USA.

Bury, R.B. 2006. Natural history, field ecology, conservation biology and wildlife management: Time to connect the dots. Herpetological Conservation and Biology 1:56–61.

Bury, R.B., and P.S. Corn. 1987. Evaluation of pitfall trapping in the northwestern forests: Trap arrays with drift fences. Journal of Wildlife Management 51:112–119.

Campbell, H.W., and S.P. Christman. 1982. Field techniques for herpetofaunal community analysis. Pp. 193–200 *In* Herpetological Communities. Scott, N.J. Jr. (Ed.) U.S. Fish and Wildlife Service, Wildlife Research Report 13. Washington, D.C., USA.

Cartron, J.L.E., M.C. Molles, Jr., J.F. Schuetz, C.S. Crawford, and C.N. Dahm. 2003. Ground arthropods as potential indicators of flooding regime in the riparian forest of the middle Rio Grande, New Mexico. Environmental Entomology 32:1075–1084.

Corn, P.S., and R.B. Bury. 1990. Sampling methods for terrestrial amphibians and reptiles. USDA Forest Service, General Technical Report PNW-GTR-256. Portland, Oregon, USA

Degenhardt, W.G., C.W. Painter, and A.H. Price. 1996. Amphibians and Reptiles of New Mexico. The University of New Mexico Press, Albuquerque, New Mexico, USA.

Dunham, A.E., P.J. Morin, and H.M. Wilbur. 1988. Methods for the study of reptile populations. Pp. 330–386 *In* Biology of the Reptilia, vol. 16. Gans, C., and R.B. Huey (Eds). Alan R. Liss, New York, New York, USA.

Ellis, L.M. 1995. Bird use of Saltcedar and cottonwood vegetation in the Middle Rio Grande Valley of New Mexico. Journal of Arid Environments 30:339–349.

Ellis, L.M., C.S. Crawford, and M.C. Molles, Jr. 1997. Rodent communities in native and exotic riparian vegetation in the Middle Rio Grande Valley of central New Mexico. Southwestern Naturalist 42:13–19.

Ellis, L.M., M.C. Molles, Jr., and C.S. Crawford. 1999. Influence of experimental flooding on litter dynamics in a Rio Grande riparian forest, New Mexico. Restoration Ecology 7:193–204.

Ellis, L.M., M.C. Molles, Jr., C.S. Crawford, and F. Heinzelmann. 2000. Surface-active arthropod communities in native and exotic riparian vegetation in the Middle Rio Grande Valley, New Mexico. Southwestern Naturalist 45:456–471.

Engelstoft, C., and K.E. Ovaska. 2000. Artificial cover-objects as a method for sampling snakes (*Contia tenuis* and *Thamnophis* spp.) in British Columbia. Northwestern Naturalist 81:35–43.

Fitch, H.S. 1949. Study of snake populations in central California. American Midland Naturalist 41:513–579.

Fitch, H.S. 2006. Ecological succession on a natural area in northeastern Kansas from 1948–2006. Herpetological Conservation and Biology 1:1–5.

Fleharty, E.D. 1967. Comparative ecology of *Thamnophis elegans*, *T. cyrtopsis*, and *T. rufipunctatus* in New Mexico. Southwestern Naturalist 12:207–230.

Greenberg, C.H., D.G. Neary, and L.D. Harris. 1994. A comparison of herpetofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. Journal of Herpetology 28:319–324.

Howe, W.H., and F.L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. Southwestern Naturalist 36:218–224.

Hubbard, J.P. 1977. Importance of riparian ecosystems: biotic considerations. Pp. 14–18 *In* Importance, Preservation and Management of Riparian Habitat. USDA Forest Service, General Technical Report RM-43. Tucson, Arizona.

Jones, K.B. 1981. Effects of grazing on lizard abundance and diversity in western Arizona. Southwestern Naturalist 26:107–115.

Jones, K.B. 1987. Amphibians and reptiles. Pp. 267–290 *In* Inventory and Monitoring of Wildlife Habitat. Cooperrider, A.Y., R.J. Boyd, and H.R. Stuart (Eds.). U.S. Bureau of Land Management, Denver, Colorado, USA.

Jones, K.B. 1990. Habitat use and predatory behavior of *Thamnophis cyrtopsis* (Serpentes: Columbridae) in a seasonally variable aquatic environment. Southwestern Naturalist 35:115–122.

Kondolf, G.M., R. Kattelmann, M. Embury, and D.C. Erman. 1996. Status of riparian habitat. Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildlife Resources.

Litt, A.R., L. Provencher, G.W. Tanner, and R. Franz. 2001. Herpetofaunal responses to restoration treatments of longleaf pine sandhills in Florida. Restoration Ecology 9:462–474.

McCallum, M.L., and J.L. McCallum. 2006. Publication trends of natural history and field studies in herpetology. Herpetological Conservation and Biology 1:62–67.

Molles, M.C., Jr., C.S. Crawford, L.M. Ellis, H.M. Valett, and C.N. Dahm. 1998. Managed flooding for riparian ecosystem restoration: Managed flooding reorganizes riparian forest ecosystems along the middle Rio Grande in New Mexico. BioScience 48:749–756.

Naiman, R.J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209–212.

Pilliod, D.S., E.L. Bull, J.L. Hayes, and B.C. Wales. 2006. Wildlife and invertebrate response to fuel reduction treatments in dry coniferous forests of the Western United States: a synthesis. USDA Forest Service, General Technical Report GTR-173. Fort Collins, Colorado, USA.

Roelle, J.E., and W.W. Hagenbuck. 1995. Surface cover changes in the Rio Grande floodplain, 1935-89. Pp. 290–292 *In* Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. LaRoe, E.T., G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (Eds.). U.S. Department of the Interior, National Biological Service, Washington, D.C., USA.

Stuever, M.C. 1997. Fire induced mortality of Rio Grande cottonwood. M.S. Thesis, University of New Mexico, Albuquerque, New Mexico, USA. 85 p.

Tibbets, T.M., and M.C. Molles. 2005. C:N:P stoichiometry of dominant riparian trees and arthropods along the Middle Rio Grande. Freshwater Biology 50:1882–1894.

Tuan, Y.F. 1962. Structure, climate, and basin land forms in Arizona and New Mexico. Annals of the Association of American Geographers 52:51–68.

Valett, H.M., M.A. Baker, J.A. Morrice, C.S. Crawford, M.C. Molles, C.N. Dahm, D.L. Moyer, J.R. Thibault, and L.M. Ellis. 2005. Biogeochemical and metabolic responses to the flood pulse in a semiarid floodplain. Ecology 86:220–234.

Wilgers, D.J., and E.A. Horne. 2006. Effects of different burn regimes on tallgrass prairie herpetofaunal species diversity and community composition in the Flint Hills, Kansas. Journal of Herpetology 40:73–84.

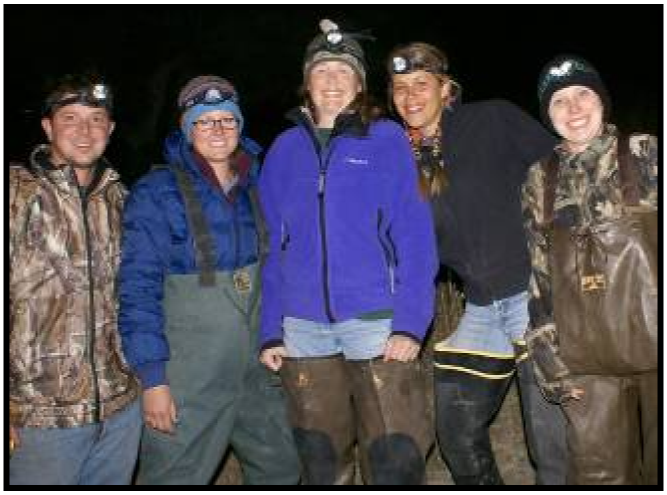
Yong, W., and D.M. Finch. 1997. Migration of the Willow Flycatcher along the middle Rio Grande. Wilson Bulletin 109:253–268.

**Appendix A**.—Precipitation along the Middle Rio Grande, New Mexico, USA, reported as seasonal total (cm) and percent of average (%). Table from Bateman et al. 2008c.

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| **Season** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** |
| Winter | 1.14 (35 %) | 6.07 (185 %) | 1.68 (51 %) | 4.32 (132 %) | 3.07 (94 %) | 8.71 (266 %) | 0.28 (9 %) |
| Spring | 6.27 (169 %) | 3.58 (97 %) | 0.81 (22 %) | 2.51 (68 %) | 9.73 (262 %) | 3.78 (102 %) | 0.84 (23 %) |
| Summer | 9.63 (106 %) | 6.17 (68 %) | 5.21 (57 %) | 4.19 (46 %) | 11.28 (124 %) | 2.13 (23 %) [a] | 15.82 (174 %) |
| Fall | 9.50 (136 %) | 4.37 (62 %) | 11.20 (160 %) | 7.80 (111 %) | 6.91 (99 %) | 7.24 (103 %) | 4.01 (57 %) |
| Total | 26.54 (115 %) | 20.19 (87 %) | 18.90 (82 %) | 18.82 (82 %) | 30.99 (134 %) | 21.87 (95 %) | 20.96 (91 %) |

Seasons delineated as winter (December of previous year-February), spring (March-May), summer (June-August), and fall (September-November). Average precipitation based on record from 1958-2006. Data from NOAA.

[a]Data unavailable for June 2005 at Los Lunas, so precipitation total for June 2005 at Albuquerque substituted.



**HEATHER BATEMAN**.—(middle) is a field ecologist and conservation biologist interested in how human land-use affects vertebrate populations and habitats, especially in riparian ecosystems. She received her B.S. degree in Ecology at Idaho State University, a M.S. in Biology from Eastern Washington University, and Ph.D. in Biology from University of New Mexico. She has been at the Polytechnic Campus of Arizona State University since August 2008. Her research interests lie in exploring population responses to habitat alteration, with a particular interest in amphibians, reptiles, and birds. Her current research focus is exploring the impacts of leaf beetles used as Saltcedar biocontrol on herpetofauna populations along the Virgin River in Nevada and exploring impacts of riparian restoration on herpetofauna in the urban Phoenix environment. (Photographed by Mel Townsend).

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