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Abundance and reproduction of toads (*Bufo*) along a regulated river in the southwestern United States: Importance of flooding in riparian ecosystems

H.L. Bateman [a,*], M.J. Harner [a,1], A. Chung-MacCoubrey [b,2]

[a] *Department of Biology, University of New Mexico, Albuquerque, NM 87112, USA*
[b] *USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM 87102, USA*

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A B S T R A C T

Abundance and size of toads (*Bufo woodhousii* and *B. cognatus*) were related to precipitation, river flow, and groundwater over 7 years along the Middle Rio Grande, a regulated river in the semi-arid southwestern United States. Toads were monitored in riparian areas at 12 sites spanning 140 km of river during summers 2000–2006. Regional precipitation varied between years, with occurrence of both drought and record high precipitation. Abundance of toads was low during most of the study (mean = 11 captures/month/site). However, two sites flooded in spring 2005, resulting in a dramatic increase in captures at those sites (mean = 214 captures/month/site). Most individuals captured in 2005 were small (median body mass 0.6 g), suggesting that toads used the floodplain for breeding during the flood. Only river flows that exceeded 100 m^3/s brought groundwater close enough to the surface to create pools used by toads for reproduction and development. Such flows were once common along the Middle Rio Grande but are rare following regulation. Our results demonstrate that small, managed floods can positively affect abundance of toads by providing off-channel, aquatic habitats along regulated rivers.

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1. Introduction

Nearly all rivers with dynamic floodplains have been regulated during the last two centuries in the USA and other developed countries (Benke, 1990; Dynesius and Nilsson, 1994; Postel, 2002; Tockner and Stanford, 2002). People have regulated rivers to provide protection from flooding and to provide reliable sources of water for consumption, agriculture, and industry. Regulation of rivers often diminishes or changes the timing of seasonal flooding (Junk et al., 1989). Regulation also may disconnect the primary river channel from its surrounding floodplain and reduce interactions between surface water and groundwater (Bayley, 1995; Boulton and Hancock, 2006; Brunke and Gonser, 1997; Stanford and Ward, 1993). Reduced flooding and physical disconnection of rivers from floodplains alters adjacent, off-channel habitats, such as ponds, spring brooks, and wetlands (Gore and Shields, 1995; Nilsson and Berggren, 2000).

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[*] Corresponding author. Present address. USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM 87102, USA. Tel.: +1 505 742 3660; fax: +1 505 724 3622.

E-mail addresses: heather.bateman@gmail.com (H.L. Bateman), harner.mary@gmail.com (M.J. Harner).

[1] Present address: University of Montana, Division of Biological Sciences, Missoula, MT 59812, USA

[2] Present address: National Parks Service, Mojave Desert Network, Boulder City, NV 89005, USA

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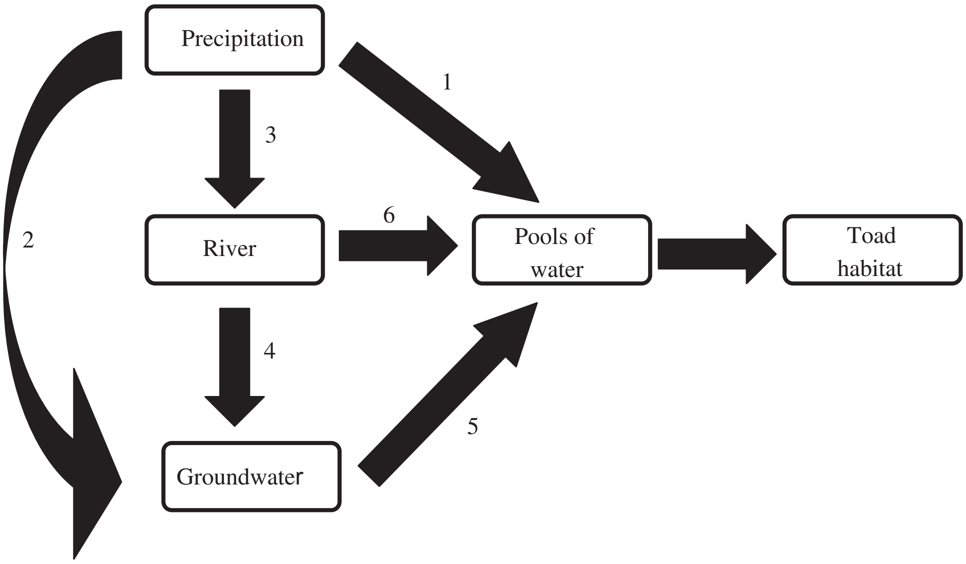

Scheme 1. Conceptual diagram of pathways by which hydrologic variables can influence the creation of toad habitat on a floodplain. Pathway descriptions include: 1) Rainfall may create pools of water on the surface of ground, 2) Rainfall that falls on other portions of the landscape may influence levels of groundwater independently of river flows, 3) Snowmelt and rainfall affect flows in the river, but upstream flood-control dams and diversions affect delivery of this water, 4) Flows in the river can influence depths to groundwater when surface water and groundwater are linked, 5) Upward seepage of groundwater can create pools of water when groundwater intercepts the surface, and 6) As river water that has inundated the floodplain recedes after a flood, pools of water may form.

Hydrologic connections between rivers and floodplains influence the availability of habitats used by amphibians and other semi-aquatic and aquatic organisms (Scheme 1). In their natural states, floodplains typically provide a mosaic of off-channel environments (Latterell et al., 2006; Stanford et al., 2005). These areas provide aquatic habitat for amphibians to deposit eggs and for tadpoles to develop (Degenhardt et al., 1996; Gilbert et al., 1994). While it is known that off-channel habitats on floodplains are important for amphibians (Tockner et al., 1999; Tockner et al., 2006), little information is available on how regulation of rivers directly alters the abundance and reproduction of amphibians, especially within semi-arid and arid environments.

Within semi-arid New Mexico, USA, regulation of the Rio Grande in the form of diversions, levees, and dams has led to a decline of wet meadows, marshes, and ponds by 40 km^2 in just over 50 years (Roelle and Hagenbuck, 1995). In this portion of the river, we studied relationships between toads (*Bufo* spp.) and local hydrology at 12 sites over 7 years. Our objective was to determine which hydrological pathways most influence abundance and reproduction of toads (Scheme 1). At two sites that experienced both flooding and record rainfall, we investigated the hypothesis that spring flooding contributes to higher abundances of toads than summer precipitation. We related abundance of toads to hydrologic variables, including precipitation, river flow, and groundwater dynamics. Our work demonstrates the importance of flooding to biotic communities along a regulated river in the semi-arid southwestern United States.

2. Materials and methods

2.1. Study sites

This study was conducted in riparian forests along the Middle Rio Grande (MRG) in central New Mexico, USA. The MRG is in the Basin-Range physiographic province, which is characterized by mountain ranges and deep river troughs (Tuan, 1962). The climate is semi-arid to arid (Tuan, 1962). Historically, flooding occurred along the MRG in spring, as snow melted in mountains of northern New Mexico and southern Colorado, and in late summer, due to precipitation from monsoonal storms. However, in the mid-20th century, construction of flood-control dams diminished the magnitude and frequency of flooding (Molles et al., 1998). Today only small areas of the historic floodplain experience flooding by over-bank river flow or by seepage of groundwater (Cartron et al., 2003; Tibbets and Molles, 2005; Valett et al., 2005). Riparian forests along the MRG contain a mix of native Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii*), non-native saltcedar (*Tamarix chinensis* and *T. ramosissima*), and non-native Russian olive (*Elaeagnus angustifolia*).

We monitored amphibians at 12 sites (approximately 20 ha each) spanning 140 km of river from Albuquerque (35°00′04N–106°41′04W) to Bosque del Apache National Wildlife Refuge (33°47′59N–106°52′59W). Our research was a component of a 7 year study by the US Forest Service, Rocky Mountain Research Station (RMRS) to monitor the effects of removing non-native plants and woody debris on vertebrates, native vegetation, and water resources (Finch et al., 2006). Sites were monitored June–September each year from 2000 to 2006.

Central New Mexico experienced high precipitation during portions of the study, especially from December 2004 to February 2005 and during summer 2006 (NOAA data). Record snowfall at high elevations in winter 2004/2005 contributed to high flows in the river in the following spring. As a result, flooding occurred in spring 2005 at two study sites near the town of Los Lunas in Valencia County (site 5: 34°50′39N–106°42′44W, Appendix A, electronic version only; site 6: 34°47′08N–106°43′46W; elevation 1475 m). These two sites (hereafter referred to as 'flood sites') were the only sites within the larger study to flood. Other sites in our study represent the typical disconnected state of most riparian areas along the MRG (long inter-flood intervals, sensu Molles et al., 1998). Such sites rarely flood under current management of flows along the MRG. Record amounts of rainfall in summer 2006 did not cause flooding at any of our sites.

2.2. Amphibian monitoring

We captured amphibians during summers 2000–2006 using pitfall and funnel traps set along drift fences (Bateman et al., 2008). Three drift fence arrays were installed approximately 320 m apart at each site. Each array consisted of three silt erosion fences with two pitfalls and two funnels per fence. Each fence was 6 m long, started 7.5 m from a central point, and positioned at an angle of 120° from the other fences. The center of each array was located at a random distance greater than 25 m from the edge of the site. Traps were open continuously from June through mid-September and checked 3 days per week. We report data from June to August. Data are not reported for September because traps were not open the entire month.

Toads (Family Bufonidae; *Bufo* spp.) were identified to species using characteristics provided by Degenhardt et al. (1996). Some individuals were distinguished only to genus because cranial crests and parotoid glands were absent on recently metamorphosed toads (hereafter, toadlets). Toads were placed in a plastic bag of known mass, weighed with a pesola scale, and then released. Not all individuals were weighed. Dead toads were not weighed, and due to high numbers of toadlets captured on some days, individuals of similar size were grouped into one bag, weighed, and then divided by number of individuals in the bag to obtain weights. We calculated the total number of toads captured each year (June–August), as well as the median body mass of toads. We report medians with ranges of values when data were skewed toward small masses or few individuals.

Our study sites were part of the larger RMRS study described above and received treatments to remove non-native plants and woody debris. Thus, we collected pre- and post-treatment amphibian data. For example, one flood site was under pre-treatment conditions for 3 years (2000–2002) and under post-treatment conditions for 4 years (2003–2006). The other flood site was under pre-treatment conditions for 5 years (2000–2004) and under post-treatment conditions for 2 years (2005–2006). Therefore, we assessed whether treatment status influenced counts of toads. Counts from all 12 sites were modeled as a function of site, treatment (control and non-native plant removal), time period (pre- and post-treatment), and year. A negative binomial regression (GLIMMIX procedure in SAS) was used to estimate the model because toad counts were not normally distributed. Site was considered the basic sampling unit and was a random effect in the model. No interaction was detected between time period and treatment ($p = 0.95$), suggesting that treatment had no effect on abundance of toads. However, abundance varied significantly among years ($p<0.001$).

2.3. Relating toads to hydrology

We analyzed two flood sites in 2005 to assess which pathways (Scheme 1) correlate with abundance of toads. We related abundance of toads to the hydrologic variables of precipitation, flow in the river, and depth to groundwater. We acquired records of precipitation for Los Lunas, New Mexico, the nearest weather station to the flood sites (NOAA data). To describe river flow, we acquired discharge data for the Rio Grande at Albuquerque, New Mexico (USGS data). Groundwater was monitored from two wells at each flood site (Campana et al., 2006). Wells were constructed from 5.1 cm diameter galvanized metal casing that extended 2.9–3.3 m below ground, with approximately 1.2–1.5 m of 0.5 mm slotted screen at the base. Depth to groundwater was determined using pressure transducers (miniTROLL, In-Situ, Inc., Fort Collins, CO, USA) that recorded depth every 15 min. Some readings were lost because data loggers failed; therefore, depth to groundwater represents measurements from 1 to 4 wells. Groundwater measurements were pooled across the two flood sites because precipitation and river flow were measured at single locales. We used a non-parametric Wilcoxon rank sum test to justify pooling counts of toads across flood sites for correlation analyses. We used a Spearman's rank correlation to identify significant correlations between three hydrologic factors (precipitation, depth to groundwater, and river discharge) and counts of toads at flood sites from 2000 through 2006.

3. Results

3.1. Amphibian captures

During our 7 year study, we captured 2721 toads, of which 60% were *Bufo woodhousii* (Woodhouse's toad), 6% were *B. cognatus* (Great Plains toad), and 34% were unidentified. We captured an additional six species of amphibians throughout

Table 1
Total number of toads (*Bufo* species) captured per site and average number of captures/month/site for June through August of each year from 2000 to 2006 along the Middle Rio Grande, New Mexico, USA

Year	Site												
	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x}$
2000	4	1	1	0	1	6	8	–	9	5	5	4	1.3
2001	4	0	2	1	6	0	0	–	16	0	3	4	1.1
2002	2	1	7	0	20	3	5	51	74	1	1	3	4.7
2003	0	0	0	2	5	0	2	5	3	0	0	38	1.5
2004	1	2	1	1	5	7	8	40	63	0	0	0	3.6
2005	15	1	2	6	947	336	1	25	34	9	15	12	39.0
2006	55	41	4	46	46	65	24	465	112	13	9	7	24.6

Data are unavailable for site 8 in 2000 and 2001 because the original site burned; a replacement site was selected in 2002.

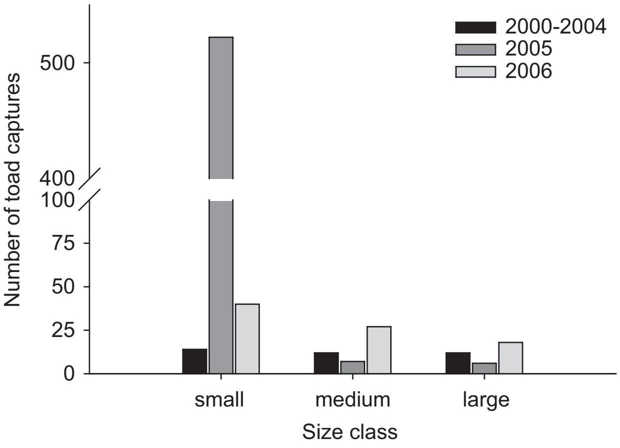

Fig. 1. Number of toads (*Bufo woodhousii* and *B. cognatus*) captured in three size classes during a flood year (2005), dry years (2000–2004), and a wet summer (2006) from two sites at Los Lunas, New Mexico, USA. Size classes include small ($\leqslant$5 g), medium (5.5–20 g), and large (>20 g).

the study (Appendix B, electronic version only). The number of toads captured across all sites through time was low, averaging 11 ±49 SD captures/month/site; $n = 246$ (Table 1).

In 2005, captures of toads increased dramatically at the two flood sites during high flows in the river (sites 5 and 6; Table 1). Water remained at these sites for several weeks and was 0.5–1 m deep in some places, thus submerging trap arrays (Appendix A, electronic version only). We observed tadpoles in pools around the arrays when floodwaters receded. Captures of toads also increased in 2006 at two non-flood sites (sites 8 and 9; Table 1) following high summer precipitation. This record rainfall in 2006 did not create pools of water near trap arrays as seen at the flood sites in 2005, but rain filled 5 gall pitfall traps on several occasions at one non-flood site (site 8).

Toads captured during the flood year weighed less than those captured in years without a spring flood (Fig. 1). Median body mass of toads captured at flood sites during 2005 was 0.6 g (range = 0.2–85.0 g, $n = 529$), and most captures (98%) were toadlets weighing less than 5 grams. At sites affected by high rainfall during 2006, median body mass of toads was 1.5 g (range = 0.5–69.0 g, $n = 364$). Conversely, median body mass across other sites through time was 5.5 g (range = 0.5–172.5 g, $n = 565$).

3.2. Flood sites

From 2000 to 2004 (pre-flood years), captures of toads were rare in flood sites (2–27 captures/year). However, we captured more than 1200 toads in 2005 (year of the flood) and over 100 toads in 2006 (the year of record summer rainfall). In 2005, toads were captured after flood waters receded, with the majority captured on 27 June (282 captures) and 18 July (573 captures). We did not detect a significant difference in the number of toads captured each year between the two flood sites ($W = 48.5$, $p = 0.61$, $n = 7$); median number of toads captured at both sites was 6 toads/year (at site 5, range = 1–947; at site 6, range = 0–336). Therefore, we pooled toad abundance from flood sites for the correlation analysis.

The region experienced variable precipitation over the period of study, with summers 2002 and 2003 among the driest on record and winters 2005 and summer 2006 among the wettest on record (Appendix C, electronic version only). River

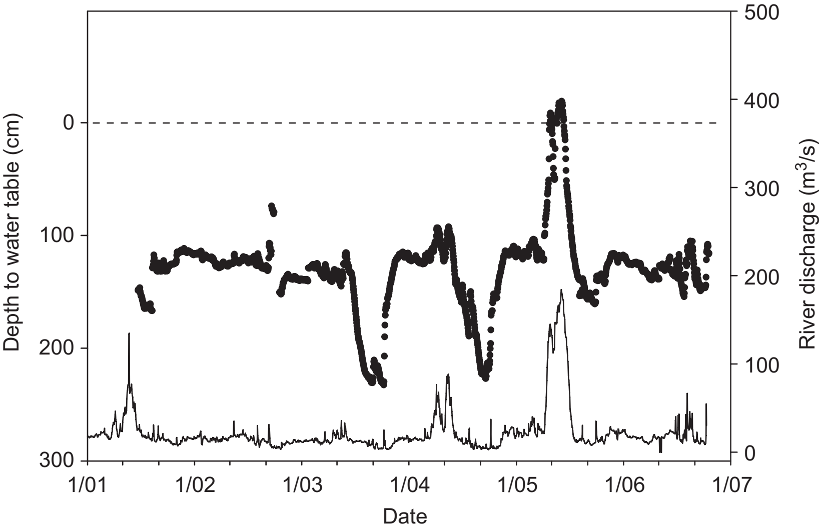

Fig. 2. Average depth to water table (dark circles) relative to the ground surface (dashed line) near Los Lunas, New Mexico, and river discharge (line) of the Rio Grande at Albuquerque, New Mexico, USA.

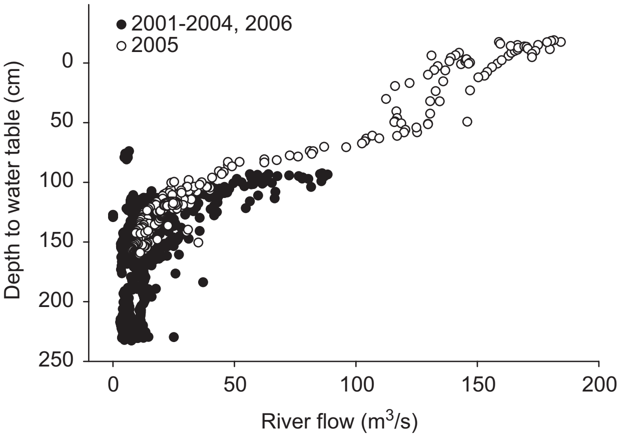

Fig. 3. Scatter plot of river flow in (m^3/s) measured at Albuquerque, NM, and average depth to water table (cm) measured at 1–4 wells at Los Lunas, NM, from 2001 to 2006. Open circles denote values in 2005, the year of spring flooding.

discharge averaged 22.3 m^3/s from 2000 through 2006 and peaked at 195 m^3/s in spring and early summer 2005 (Fig. 2). Flows also increased during a 2-day-flood pulse in spring 2001. However, flows were of greater magnitude and duration in 2005 than 2001, exceeding 100 m^3/s for 69 days in 2005 compared to only 2 days in 2001 (Fig. 2). From 2000 to 2006, average depths to groundwater (relative to the ground surface) at flood sites were 102 ± 41 SD cm and 159 ± 33 SD cm, respectively. Across both flood sites, depth to groundwater averaged 131 ± 36 SD cm and ranged over a depth of 230 cm (Fig. 2). Groundwater plummeted in late summer and early fall 2003, and again in late summer 2004, but rose dramatically in spring and early summer 2005, intersecting the ground surface at one flood site, when river flows exceeded 100 m^3/s (Fig. 2).

Abundance of toads correlated significantly with elevation of groundwater (correlation coefficient = 0.886, $p = 0.019$, $n = 6$). Average monthly depth to groundwater and annual river flow were significantly positively correlated (correlation coefficient = 0.679, $p < 0.001$, $n = 1920$; Fig. 3). Conversely, average monthly depth to groundwater and monthly precipitation were negatively correlated (correlation coefficient = −0.351, $p = 0.004$, $n = 65$).

4. Discussion

Even though we observed flooding for only 1 year during a 7-year study, our results show how a spring flood event can benefit the reproduction and activity of amphibians in riparian forests of the southwestern United States. Microhabitats conducive to reproduction and development of toads form along the MRG when high precipitation, river flows, and groundwater are linked. Historically, flows in the MRG peaked in spring following snowmelt. Today, upstream dams and reservoirs usually retain this moisture. However, water was released from Cochiti Dam in spring 2005 following high winter precipitation, thus permitting high flows in the river for several weeks (Scheme 1, pathway 3). When flows in the river increased, water infiltrated the aquifer and groundwater rose (Scheme 1, pathway 4) at two sites near Los Lunas, New Mexico. In the spring, elevated groundwater created pools in the riparian forest (Scheme 1, pathway 5) at the same time that toads (*Bufo woodhousii* and *B. cognatus*) typically breed (Degenhardt et al., 1996). The highest abundance of toads occurred at these flood sites in 2005, and most toads weighed less than 5 g. The small size of these metamorphs suggests they were recruited at the flood sites and not elsewhere.

Spring flooding had a greater positive effect on *Bufo* spp. than summer rain along the MRG. July and August 2006 were the wettest months recorded in New Mexico since 1895 (NOAA 2006). Despite this record high summer precipitation, only slightly more toads were captured in 2006 compared to 2000–2004 at the two flood sites, and most of those toads were adults rather than recent recruits. Captures of toads also increased at some non-flood sites (i.e. sites 8 and 9) during periods of heavy rain. However, summer precipitation did not create pools of water within the bounds of our trap arrays (Scheme 1, pathway 1). It is possible that toads were breeding in pools formed beyond the trap arrays; we occasionally heard advertisement calls of toads nearby. However, pools are more likely to be used for breeding April through June, the typical breeding season for toads in New Mexico (Degenhardt et al., 1996).

We did not observe rainfall immediately affecting depth to groundwater (Scheme 1, pathway 2). When precipitation was high but river flows low (2004 and 2006), groundwater remained 1 m or more below the surface at the flood sites. Conversely, during the dry summer of 2005 groundwater remained high at the flood site, and this elevated groundwater was maintained by high flows in the river. Groundwater came near the surface of the forest floor in 2005 when river flows exceeded 100 m^3/s. Flows of this magnitude were common historically along the MRG, but they are now rare. The peak in river flow in spring 2005 was the 8th highest spring flow in the river since completion of upstream Cochiti Dam in the early 1970s (Harner, 2006).

We captured only five tiger salamanders (*Ambystoma tigrinum*), one chorus frog (*Pseudacris triseriata*), and no leopard frogs (*Rana pipiens*) from nearly 3000 captures of nine species of amphibians in this study. In contrast, 20 years ago Hink and Ohmart (1984) reported that tiger salamanders, chorus frogs, and leopard frogs were common along the MRG. Scott and Jennings (1985) also recorded leopard frogs in a wide variety of habitats in the MRG, including lakes, streams, and irrigation ditches. Reduction in wetlands (Roelle and Hagenbuck, 1995) and loss of flood pulses (Molles et al., 1998) have contributed to declines in habitat used by amphibians along the MRG. Species of toads in our study also occupy adjacent agriculture lands, which provide ponds that could sustain some populations (Knutson et al., 2004).

Our observations show that in a highly regulated system like the Rio Grande, a managed flood pulse at the appropriate time of year can result in localized success of amphibians. Flows in the river in 2005 were low compared to peak annual flows prior to regulation, but the flood pulse in 2005 was enough to substantially increase abundance of toads. When these same flood sites received record amounts of rainfall in summer 2006, overall abundance of toads was lower, and fewer toadlets were captured than during the flood year. The dramatic increase in numbers of toads following the flood illustrates how managed floods, even low-magnitude floods, timed to correspond with historic spring runoff can create habitats used by toads for reproduction. Maintaining relatively small patches of off-channel, aquatic and semi-aquatic habitats could have disproportionately positive effects on regional populations of amphibians along rivers with regulated flows. We recommend that future studies report the effects of natural and regulated flooding on amphibians and other wildlife. Because flood events are rare on regulated rivers, combining results from opportunities similar to our study will add to the body of knowledge of how river regulation and managed floods affect aquatic and semi-aquatic organisms in arid ecosystems.

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Appendix. Supplementary Material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jaridenv.2008.03.009.

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