Understanding movement and landscape use of Chiricahua leopard frogs (*Lithobates chiricahuensis*) to promote species persistence in desert ecosystems

Research Proposal

by

Ross K. Hinderer

Submitted in partial fulfillment

of the requirements for the degree

of

MASTER OF SCIENCE

in

Ecology

MONTANA STATE UNIVERSITY

Bozeman, Montana

May 2013

INTRODUCTION

Of the described species of amphibians worldwide, one-third are threatened with extinction (IUCN 2009). In North America, 26% of amphibian species are at some risk, which is five times higher than that of terrestrial fauna (Ricciardi and Rasmussen 1999). Current declines exceed the threshold that would be expected with natural population oscillations, approaching rates seen only in prehistoric mass extinctions (Blaustein and Wake 1990; Wake and Vredenburg 2008). Instead of merely occurring in degraded areas where population declines would be expected, amphibians also have shown marked decreases in protected, relatively pristine areas (Blaustein and Wake 1990, Halliday 2005). Amphibian declines are not universal, however, as populations of some species have been greatly reduced, while neighboring species seem to be unaffected (Crump 2005).

Amphibians play an essential part in many ecosystems, and may act as "canaries in the coal mine" to indicate a loss of environmental functionality (Wake 1991; Lannoo 2005). Amphibian life cycles typically consist of both aquatic and terrestrial phases, so they may be exposed to changes in either environment. Amphibian skin is moist, vascular, and highly permeable, putting them at high risk of absorbing possible contaminants. Metamorphosis from larvae to adults usually involves a switch from herbivory to carnivory and amphibians themselves are an important food source for many other animals, thus exposing them to a wide range of trophic interactions (Wake and Vredenburg 2008). For these reasons, amphibians can be a good indicator of the function of multiple ecosystem processes.

Research examining amphibian declines tends to focus on three major, habitat-level drivers: habitat destruction, habitat fragmentation, and habitat degradation (Green 2005). Many possible sources, including climate change (Wake and Vredenburg 2008), solar UV-B radiation (Blaustein et al. 1994), introduced predators (Pilliod and Peterson 2001, Adams 2000), and infection by a pathogenic fungus, *Batrachochytrium dendrobatidis* ("Bd," Berger et al. 1998) have been examined as the mechanisms driving species declines. Amphibians in the southwestern US may be subject to additional risk factors. Wallace et al. (2010) identified upland activities in desert environments (mining, grazing, or other landscape modification) as a major factor affecting downslope habitat and water permanence important to amphibians.

Amphibians may be affected negatively by the predicted changes in climate, although documenting a definitive link between past declines and climate change may be difficult (see Corn 2005 for a review). Wetland habitats in the deserts of the southwestern United States are of major importance to many species and may be affected greatly by predicted changes in temperature and precipitation. Wetlands in the Chihuahuan region of the southwest United States and Mexico have been designated as one of the "Global 200" ecosystems of highest conservation concern (Olson and Dinerstein 1998). Minckley et al. (2013) found that 19% of animal and plant species in Arizona listed under the Endangered Species Act or candidates for such listing were associated directly with permanent desert wetlands. Climate models predict vegetation in the southwestern US will recede or change composition in the face of warming temperatures and modified precipitation regimes, which will result in decreases in vegetation cover and soil moisture (Notaro et al. 2012). Amphibians require moisture on their skin for effective respiration (Wake and Vredenburg 2008), and vegetation cover at breeding sites, important for avoiding predators, is positively correlated with amphibian species richness (Shulse et al. 2012). Because of the particular susceptibility of amphibians to climate-related changes, future management actions that actively mitigate the effects of anthropogenic climate change will be essential for amphibian conservation. For example, earthen cattle tanks provide essential amphibian habitat that can be managed in Southwest ranchlands when the quantity or quality of natural water bodies declines (Rosenstock et al. 1999). Conservation strategies also might involve manipulation of water levels at breeding sites to mimic seasonal patterns that occurred prior to climate changes (Shoo et al. 2011).

In addition to conservation issues related to a changing climate, amphibians of the desert Southwest are at risk due to introduced crayfish (*Orconectes virilis* and *Procambarus clarkii*) and the spread of disease and invasive species from nearby wetlands. The detrimental effects of invasive species on amphibians due to competition, predation, and spread of disease are likely to interact with changes in climate, as invasive species may become even more dominant (Rahel 2008) and because changes in climate will influence the configuration of wetlands on the landscape. Proximity to extinct populations of conspecifics increases the chances of the spread of disease and invasive species, resulting in local extirpation, whereas increased distance to extant populations decreases the probability of new individuals being connected to the local population, resulting in increased extinction risk (Witte et al. 2008). Similar effects of population proximity have been observed in declining populations of desert fishes (Fagan et al. 2002).

Understanding movement of animals is an extremely important facet of wildlife ecology. Movement dictates changes in populations, whether through emigration or immigration. Movement between populations is responsible for gene flow and may allow for the persistence of populations over time (Turchin 1998). Studying movements of amphibians can provide clues about the location and importance of different habitat types used at various life stages. If wildlife managers only preserved breeding habitat (e.g., ponds), this may not be sufficient to support effective foraging, breeding, movement, and hibernation (Marsh and Trenham 2001); habitat used during non-breeding periods may be of equal importance to breeding sites (Fellers and Kleeman 2007). Much of the work on amphibian movement has been centered on identifying overwintering sites (Bull and Hayes 2002; Matthews and Pope 1999), microhabitat use (Tatarian 2008), habitat corridors (Baldwin et al. 2006; Fellers and Kleeman 2007; Pilliod et al. 2002; Tatarian 2008), and developing useful conservation buffers associated with each (Baldwin et al. 2006; Fellers and Kleeman 2007). In addition to identifying habitat features important to all stages of the amphibian life cycle, movement studies identify landscape attributes that affect where or how far an individual may move, such as type and amount of vegetation cover (Fellers and Kleeman 2007), the weather conditions conducive to movement (Kruse and Christman 2005), or characteristics of the individual animal that influence its propensity for movement, such as sex or size (Pilliod et al. 2002). Pond-breeding amphibians usually are portrayed as metapopulations with ponds acting as habitat patches (Marsh and Trenham 2001) and long-distance dispersing individuals may be the most important for colonization of new habitat patches (Fellers and Kleeman 2007). Understanding the factors that drive long-distance dispersal would allow managers to try to facilitate these moves to establish new populations or promote movement between existing populations. Using movement studies to identify corridors and increase connectivity between habitat patches may be especially important when patches are more isolated due to human activity (Marsh and Trenham 2001), in an attempt to decrease extinction risk (Fagan et al. 2002).

The Chiricahua leopard frog (*Lithobates* [= *Rana*] *chiricahuensis*) is a medium-sized frog native to central and southeastern Arizona, southwestern New Mexico, and northern Mexico (Platz and Mecham 1979, Stebbins 1985). The historical distribution of *L. chiricahuensis* is poorly known (Sredl and Jennings 2005), and its range in Mexico is not well studied, although there seems to be at least one healthy, robust population in Durango, Mexico at the southern edge of the animal's range (Streicher et al. 2012). The Chiricahua leopard frog's appearance is very similar to other leopard frog species (e.g. *Lithobates blairi*, *L. yavapaiensis*, and *L. pipiens*), and it may coexist with several of these species across its range. Chiricahua leopard frogs are found in natural streams with rocky pools, springs, and ponds, but man-made stock tanks also provide important habitat (Stebbins 1985). Adults are highly aquatic and are rarely found far from water, although frogs can survive periods of surface water loss via an unstudied mechanism (Clarkson and Rorabaugh 1989; Sredl and Jennings 2005). Chiricahua leopard frogs are foraging generalists (herbivores as larvae and carnivores as adults), and are consumed throughout their life by various species of birds, reptiles, amphibians, predaceous insects, and mammals (Sredl and Jennings 2005).

After being described in 1979, *R. chiricahuensis* was divided from the Ramsey Canyon leopard frog (*Rana subaquavocalis*) (Platz 1993). Subsequent genetic study recondensed the *R. chiricahuensis* – *R. subaquavocalis* complex to simply *R. chiricahuensis* (Goldberg et al. 2004), and the species now is included in the genus *Lithobates* (Crother 2008). Chiricahua leopard frogs are affected by a variety of threats common in amphibians, including Bd infection (Boykin and McDaniel 2008) and introduced predators such as American bullfrogs (Rosen and Schwalbe 1995). In 2002, Chiricahua leopard frogs were listed as threatened under the Endangered Species Act due to fragmentation of extant populations, loss of animals from former ranges, as well as threats from invasive species and disease (USFWS Final Rule 2002). Aside from some basic natural history and documentation of population declines, there is very little information available in the scientific literature about Chiricahua leopard frogs (USFWS Final Rule 2002), including a paucity of information about their movement habits.

I seek to understand factors important for the movement of Chiricahua leopard frogs. I will use radio telemetry, which may reveal many important aspects about movement, habitat use, and mortality (White and Garrott 1990). Because an animal's movement behavior is observed directly, telemetry also provides a powerful way to evaluate hypotheses about how organisms utilize their environment, whereas other techniques may provide only circumstantial evidence (Turchin 1998). Each tracked animal may be ascribed to a specific fate, unlike mark-recapture studies where study animals may be seen only once. Although mark-recapture studies are a popular way to study animal movement, they are limited by the time between observations and the resulting gaps in information about the specific path the organism has taken or the habitats used in the interim (Turchin 1998).

OBJECTIVES

I seek to examine the movement patterns of Chiricahua leopard frogs by radio-tracking individual animals over several weeks during monsoon season when movement is greatest. I specifically want to:

1. **Identify patterns in timing or environmental cues for movement by Chiricahua leopard frogs**

I seek to understand if environmental cues such as rainfall or water or air temperature may be important signals that cue Chiricahua leopard frogs to move. A previous radio-telemetry study of Chiricahua leopard frogs on the Ladder Ranch in Caballo, New Mexico showed a seemingly positive correlation between rain events and dispersal of Chiricahua leopard frogs from earthen cattle tanks, despite a small sample size (Kruse and Christman 2005). I predict this study may show a similar relationship between rainfall and the movement of frogs out of cattle tanks.

2. **Quantify the average and maximum distance Chiricahua leopard frogs move**

The Chiricahua leopard frog Recovery Plan provides several examples of frog movement distances, but only one is based on a direct observation, where a telemetered frog moved 2.2 miles in one direction (USFWS 2007). Other examples provided are from cases where frogs were found some distance away from the nearest known population, and were presumed to have covered the intervening distance. Based on these few indirect observations, the Recovery Plan enumerates a rule-of-thumb that Chiricahua leopard frogs can move 1 to 5 miles, depending on the availability of water (USFWS 2007). I hope to provide information that may be useful in determining typical and maximum distances moved by the species and could inform these guidelines.

3. **Identify individual characteristics important in affecting Chiricahua leopard frog movement distances and direction**

Fellers and Kleeman (2007) found that a higher proportion of female California red-legged frogs (*Rana draytonii*) moved away from breeding areas, relative to males. Although not yet studied in Chiricahua leopard frogs, variation in sex, size, and age class may dictate an individual's movement patterns. I predict that there will be a large bias in favor of smaller individuals moving away from pools during the summer season. Information from this and the previous objective will help to inform reintroduction efforts by providing guidance about where Chiricahua leopard frogs are able to move, and which individuals are more likely leave sites where they are introduced.

4. **Identify landscape features that facilitate Chiricahua leopard frog movement**

Because Chiricahua leopard frogs are an extremely aquatic species (Clarkson and Rorabaugh 1989), I predict individuals may be attracted to movement corridors with vegetation cover that reduces evaporation and solar exposure. Frogs may prefer lowlands in washes and stream channels after a rain event, where damp soils could prevent desiccation during longer moves. I will use data on the substrate and vegetation characteristics (plant species and estimated cover within 1 meter) recorded at frog locations to determine if animals show preferences. I will overlay locations on a map that includes elevation and other landscape features (e.g., slope, directional aspect) to determine whether frogs prefer to use corridors with certain characteristics.

METHODS

Study Area and Site Selection

Study sites are within the boundaries of the Ladder Ranch ("the Ladder") in Sierra County, New Mexico. Populations of Chiricahua leopard frogs on the Ladder constitute 33% of the known extant populations in New Mexico (Kruse and Christman 2005).

Because of this high proportion, conservation of Chiricahua leopard frogs on the Ladder is of high priority to the property owners and cooperating agencies and stakeholders.

The Ladder is a functioning bison operation and includes various types of livestock watering tanks, which provide important habitat for Chiricahua leopard frogs. Based on data from visual encounter surveys in 2012, the largest numbers of frogs on the Ladder are found in the earthen stock tanks at Johnson Well and North Seco Well, which also produced the highest numbers of egg masses of all sites (M. McCaffery, unpub. data; Fig. 1). These sites represent the east and west ends of the reach of a creek drainage flowing through the Ladder (Seco Creek), which allows study across a range of elevations and habitat types. I will concentrate my efforts at these sites to increase the number of animals available for study, and because of the potential that due to their high rates of frog reproduction, Johnson Well and North Seco Well may represent source populations for colonization of other sites on the Ladder.

Pitfall trapping

I will encircle the earthen tanks at Johnson and N. Seco Wells with drift fences (mesh silt fence) and pitfall traps (5-gallon, plastic buckets) (Dodd and Scott 1994). I will bury silt fence 20-cm deep in the substrate and secure it to stakes with removable fasteners. In this way, the fence can be laid down when conditions are not appropriate to hold frogs in pitfall traps or when pitfall trapping is no longer required. I will bury pitfall traps at 10-m intervals paired on the inside and outside of the drift fence, and attach removable lids when traps are not in use. I will construct shade structures to prevent desiccation of animals trapped in the buckets by elevating a small piece of wood over the trap opening (Dodd and

Scott 1994), which will be padded on the underside to prevent injury to animals inside. I will install drift fences and pitfall traps before the onset of summer monsoons in mid-July and maintain them through August, and I will check and empty traps twice daily, reducing to once daily as necessity dictates. As animals are captured in pitfall traps, I will determine sex based on the presence or absence of swollen nuptial pads on the first digit of the anterior limb, measure snout-urostyle length and weight, photograph them, and release them on the opposite side of the drift fence. I will add photographs to a database to identify recaptured individuals by assigning a unique identifying code to the pattern of dorsal spots on each individual. I will use a computer program to analyze frog photographs and assign codes (I^3S Manta; http://www.reijns.com/i3s/index.html). A subset of animals captured while leaving ponds will be selected for radio telemetry.

<u>Radio Telemetry</u>

I will attach radio transmitters to 40 Chiricahua leopard frogs in each of two years. By transmittering individuals captured in pitfall traps as they begin to leave ponds, I seek to maximize my ability to observe movements. I will attach radio transmitters (Holohil Systems BD-2, www.holohil.com) to study animals with a small, flexible belt secured around the frog's waist (e.g. Muths 2003; Burow et al. 2012; Bartelt and Peterson 2000) to minimize the effects on normal behavior of the study animals (Blomquist and Hunter 2007). Total transmitter mass will not exceed 10% of the tracked animal's body mass to prevent negative impacts on amphibians' survival and behavior (Richards et al. 1994). 20 transmitters will weigh .75g each and 20 will weigh .9g each, allowing the radio tracking of frogs as small as 10.5g and tracking periods of approximately 4-6 weeks. Blomquist and

Hunter (2007) found little effect on the vagility of *Rana* [*Lithobates*] *pipiens*, a closely related leopard frog species, with transmitters up to 10% of frog body mass. I will locate animals via radio telemetry every 1-2 days and record the frog's position with a GPS unit. Spatial locations will allow analysis of movement distances, and comparing those distances to frog physical characteristics will allow me to correlate those distances with differences in individual characters. I will record physical features within 1 meter of the frog's location including substrate type, presence of water, and vegetation cover (species and an estimate of cover percentage). These data will allow me to analyze the preference of frogs for specific habitat corridor types. I will capture individuals every 7 days to assess general body condition and adjust the transmitter belt to prevent injury or discomfort to the animal. I will treat any minor abrasions with vitamin E oil, which has been shown to heal dermal abrasions in amphibians (Bartelt and Peterson 2000; Burow et al. 2012). Belts will be removed at the end of the expected transmitter lifespan (approximately 6-8 weeks), and I will release animals at the site of capture.

Other Data Collected

I will record weather conditions for the duration of the study in an effort to correlate environmental conditions with frog movements. A fixed weather station at Ladder Ranch headquarters will record rainfall, air temperature, and wind speed. Waterproof data loggers (Onset Hobo pendants; www.onsetcomp.com) will record water and air temperatures at Johnson and North Seco Wells. I will record the temperature at each frog's location via a handheld digital thermometer, as time allows.

TIMELINE

Field Work 2013

13 May	Committee meeting for research proposal
13 May-22 June	Field prep in Bozeman, collect gear, and finalize research methods
22-23 June	Travel to Ladder Ranch
24 June-01 July	Construction of drift fences and pitfall trap arrays at N. Seco and Johnson Wells
01 July-23 August	Pitfall trapping and radio telemetry
24-25 August	Remove drift fences and pitfall traps
26-27 August	Return to Bozeman

Degree Timeline

Spring 2013	Course work, proposal, and committee meeting
Summer 2013	Field work (see schedule above)
Fall 2013	Course work, develop plan of study, qualifying exam, data analysis, present at the Montana Chapter of the Society for Conservation Biology meeting
Spring 2014	Course work, present at the Montana Chapter of The Wildlife Society meeting
Summer 2014	Field work
Fall 2014	Course work, data analysis, present at a national conference
Spring 2015	Course work, thesis writing and defense

LITERATURE CITED

Adams, M. J. 2000. Pond permanence and the effects of exotic vertebrates on anurans. Ecological Applications 10(2): 559-568.

Baldwin, R. F., A. J. K. Calhoun, and P. G. DeMaynadier. 2006. Conservation planning for amphibian species with complex habitat requirements: a case study using movements and habitat selection of the wood frog *Rana sylvatica*. Journal of Herpetology 40(4): 442-453.

Bartelt, P. E., and C. R. Peterson. 2000. A description and evaluation of a plastic belt for attaching radio transmitters to western toads (*Bufo boreas*). Northwestern Naturalist 81(3): 122-128.

Berger, L., R. Speare, P. Daszak, D. E. Green, A. A. Cunningham, C. L. Goggin, R. Slocombe, M. A. Ragan, A. D. Hyatt, K. R. McDonald, H. B. Hines, K. R. Lips, G. Marantelli, and H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. Proceedings of the National Academy of Science 95: 9031-9036.

Blaustein, A. R., and D. B. Wake. 1990. Declining amphibian populations: a global phenomenon? Trends in Ecology and Evolution 5(7): 203-204.

Blaustein, A. R., P. D. Hoffman, D. G. Hokit, and J. M. Kiesecker. 1994. UV repair and resistance to solar UV-B in amphibian eggs: a link to population declines? Proceedings of the National Academy of Science 91: 1791-1795.

Blomquist, S. M., and M. L. Hunter Jr. 2007. Externally attached radio-transmitters have limited effects on the antipredator behavior and vagility of *Rana pipiens* and *Rana sylvatica*. Journal of Herpetology 41(3): 430-438.

Boykin, K. G., and K. C. McDaniel. 2008. Simulated potential effects of ecological factors on a hypothetical population of Chiricahua leopard frog (*Rana chiricahuensis*). Ecological Modelling 218: 175-181.

Bull, E. L., and M. P. Hayes. 2002. Overwintering of Columbia spotted frogs in northeastern Oregon. Northwest Science 76(2): 141-147.

Burow, A. L., A. L. Herrick, A. C. Geffre, and P. E. Bartelt. 2012. A fully adjustable transmitter belt for ranids and bufonids. Herpetological Review 43(1): 66-68.

Clarkson, R. W., and J. C. Rorabaugh. 1989. Status of leopard frogs (*Rana pipiens* complex: Ranidae) in Arizona and southeastern California. The Southwestern Naturalist 34(4): 531-538.

Corn, P. S. 2005. Climate change and amphibians. Animal Biodiversity and Conservation 28(1): 59-67.

Crother, B. I. (ed.). 2008. Scientific and standard English names of amphibians and reptiles of North American north of Mexico, with comments regarding confidence in our understanding. Sixth edition. Society for the Study of Amphibians and Reptiles, Herpetological Circular no. 37.

Crump, M. L. 2005. Why are some species in decline but others not? Pages 7-9 in M. J. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Dodd, C. K. Jr., and D. E. Scott. 1994. Drift fences encircling breeding sites. Pages 125-130 in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, editors. Measuring and monitoring biological diversity. Standard methods for amphibians. The Smithsonian Institution, Washington, D. C.

Fagan, W. F., P. J. Unmack, C. Burgess, and W. L. Minckley. 2002. Rarity, fragmentation, and extinction risk in desert fishes. Ecology 83(12): 3250-3256.

Fellers, G. M., and P. M. Kleeman. 2007. California red-legged frog (*Rana draytonii*) movement and habitat use: implications for conservation. Journal of Herpetology 41(2): 276-286.

Goldberg, C. S., K. J. Field, and M.J. Sredl. 2004. Mitochondrial DNA sequences do not support species status of the Ramsey Canyon leopard frog (*Rana subaquavocalis*). Journal of Herpetology 38(3): 313-319.

Green, D. M. 2005. Biology of amphibian declines. Pages 28-33 in M. J. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Halliday, T. 2005. Diverse Phenomena influencing amphibian population declines. Pages - 6 in M. J. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

IUCN, International Union for Conservation of Nature. 2009. Extinction crisis continues apace. Accessed 14 April 2013. www.iucn.org/?4143/Extinction-crisis-continues-apace.

Kruse, C. G., and B. L. Christman. 2005. Distribution and movement of Chiricahua leopard frog (*Rana chiricahuensis*) on the Ladder Ranch and adjacent National Forest lands, Sierra County, New Mexico. Project completion report to the New Mexico Department of Game and Fish: 92 pp.

Lannoo, M. J. 2005. Preface. Pages xix-xxi in M. J. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Marsh, D. M., and P. C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology 15(1): 40-49.

Matthews, K. R., and K. L. Pope. 1999. A telemetric study of the movement patterns and habitat use of *Rana muscosa*, the mountain yellow-legged frog, in a high-elevation basin in Kings Canyon National Park, California. Journal of Herpetology 33(4): 615-624.

Minckley, T. A., D. S. Turner, and S. R. Weinstein. 2013. The relevance of wetland conservation in arid regions: a re-examination of vanishing communities in the American southwest. Journal of Arid Environments 88: 213-221.

Muths, E. 2003. A radio transmitter belt for small ranid frogs. Herpetological Review 34(4): 345-348.

Notaro, M., A. Mauss, and J. W. Williams. 2012. Projected vegetation changes for the American southwest: combined dynamic modeling and bioclimatic-envelope approach. Ecological Applications 22(4): 1365-1388.

Olson, D. M., and E. Dinerstein. 1998. The global 200: a representation approach to conserving the earth's most biologically valuable ecoregions. Conservation Biology 12(3): 502-515.

Pilliod, D. S., and C. R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4: 322-333.

Pilliod, D. S., C. R. Peterson, and P. I. Ritson. 2002. Seasonal migration of Columbia spotted frogs (*Rana luteiventris*) among complementary resources in a high mountain basin. Canadian Journal of Zoology 80: 1849-1862.

Platz, J. E. 1993. *Rana subaquavocalis*, a remarkable new species of leopard frog (*Rana pipiens* complex) from southeastern Arizona that calls under water. Journal of Herpetology 27(2): 154-162.

Platz, J. E., and J. S. Mecham. 1979. *Rana chiricahuensis*, a new species of leopard frog (*Rana pipiens* complex) from Arizona. Copeia 1979(3): 383-390.

Rahel, F. J., B. Bierwagen, and Y. Taniguchi. 2008. Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology 22(3): 551-561.

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13(5): 1220-1222.

Richards, S. J., U. Sinsch, and R. A. Alford. 1994. Radio tracking. Pages 155-158 in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, editors. Measuring and monitoring biological diversity. Standard methods for amphibians. The Smithsonian Institution, Washington, D. C.

Rosen, P.C., and Schwalbe, C. R. 1995. Bullfrogs: introduced predators in southwestern wetlands. Our living resources: a report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems. US Department of the Interior, National Biological Service, Washington, DC: 452-454.

Rosenstock, S. S., W. B. Ballard, and J. C. Devos, Jr. 1999. Viewpoint: benefits and impacts of wildlife water developments. Journal of Range Management 52(4): 302-311.

Shoo, L. P., D. H. Olson, S. K. McMenamin, K. A. Murray, M. V. Sluys, M. A. Donnelly, D. Stratford, J. Terhivuo, A. Merino-Viteri, S. M. Herbert, P. J. Bishop, P. S. Corn, L. Dovey, R. A. Griffiths, K. Lowe, M. Mahony, H. McCallum, J. D. Shuker, C. Simpkins, L. F. Skerratt, S. E. Williams, and J. M. Hero. 2011. Engineering a future for amphibians under climate change. Journal of Applied Ecology 48: 487-492.

Shulse, C. D., R. D. Semlitsch, K. M. Trauth, and J. E. Gardner. 2012. Testing wetland features to increase amphibian reproductive success and species richness for mitigation and restoration. Ecological Applications 22(5): 1675-1688.

Sredl, M. J., and R. D. Jennings. 2005. *Rana chiricahuensis* (Platz and Mecham, 1979) Chiricahua leopard frogs. Pages 546-549 in M. J. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Stebbins, R. C. 1985. A field guide to western amphibians and reptiles. Second edition. Houghton Mifflin, Boston, Massachusets.

Streicher, J. W., C. M. Sheehy III, O. Flores-Villela, and J. A. Campbell. 2012. Morphological variation in a polychromatic population of Chiricahua leopard frogs (*Lithobates chiricahuensis*) from Durango, Mexico. Journal of Herpetology 46(3): 387-392.

Tatarian, P. J. 2008. Movement patterns of California red-legged frogs (*Rana draytonii*) in an inland California environment. Herpetological Conservation and Biology 3(2): 155-169.

Turchin, P. 1998. Quantitative analysis of movement: measuring and modeling population redistribution in animals and plants. Sinauer Associates, Sunderland, Massachusetts.

U.S. Fish and Wildlife Service Final Rule. 2002. Endangered and threatened wildlife and plants; listing of the Chiricahua leopard frog (*Rana chiricahuensis*). Federal Register vol. 67, no. 114. 23 pp.
U.S. Fish and Wildlife Service. 2007. Chiricahua Leopard Frog (*Rana chiricahuensis*) Recovery Plan. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM. 149 pp.
Wake, D. B. 1991. Declining amphibian populations. Science 253(5022): 860.
Wake, D. B., and V. T. Vredenburg. 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proceedings of the National Academy of Science 105: 11466-11473.
Wallace, J. E., R. J. Steidl, and D. E. Swann. 2010. Habitat characteristics of lowland leopard frogs in mountain canyons of southeastern Arizona. Journal of Wildlife Management 74(4): 808-815.
White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego, California.
Witte, C. L., M. J. Sredl, A. S. Kane, and L. L. Hungerford. 2008. Epidemiologic analysis of factors associated with local disappearances of native ranid frogs in Arizona. Conservation Biology 22(2): 375-383.

Fig. 1: Map of the Ladder Ranch, New Mexico. Stock tanks are denoted with stars and study sites are circled.