Regal Horned Lizard Translocation Effectiveness Monitoring Report – Arroyo Chico Park Avenue 2b Project

Project Report to

Pima County Regional Flood Control Department

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Figure 1. Small juvenile regal horned lizard showing early stage of head allometry with short, broad horns.

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Executive Summary

Regal horned lizards (RHL, Phrynosoma solare) were salvaged during July-November 2010 from the Arroyo Chico 2B Park Avenue Detention Basin site before excavation and construction of floodwater basins there, and translocated to three primary study sites in metropolitan Tucson. Two translocation recipient sites, an urban river preserve (West Branch of Santa Cruz River), and a revegetated detention basin on the urban fringe (Kolb Road Detention Basin), had existing horned lizard populations; the third site was an empty lot in Midtown Tucson unoccupied by horned lizards. Previous monitoring and telemetry at these sites through 2011 showed that mortality of translocated lizards was high at West Branch and low at the Midtown site, but data were lacking for the Kolb Road site. In 2012 we intensively censused all three sites using mark-recapture methods to estimate population sizes and survivorship of translocated and resident horned lizards. The objective was to understand translocation outcomes in context of the natural trajectory of horned lizards at the sites. Follow-up surveys were done through 2015.

At the highly urbanized Midtown site that originally lacked the RHL and had low predator abundance, initial survivorship of translocated adults was high. The population in 2011 and 2012 was estimated at 21-48 individuals, and RHL remained abundant in 2015. Annual survivorship of adults was estimated at 100% for the first year after the 2010 translocation, which was similar to that of resident lizards at the West Branch site (84-90%). Estimated juvenile survivorship was higher at the Midtown site (54-78%) than at West Branch (18%).

Estimated survivorship of translocated adults was low (24-38%) at West Branch and Kolb Road in the first year. In the second year, adult survivorship estimates were low for all sites (47% at Midtown, 34-39% at the other sites). Drought effects may have played a role in the reduced survivorship from 2011-2012. The estimated population at West Branch decreased significantly from 2010-2011 (30-50 individuals) to 2012 (19-20 individuals), and by 2015 the species was rare there, though apparently rare based on limited observations. Further, overall lizard abundance for all lizard species had already decreased markedly at West Branch since 2000-2001. At both West Branch and Kolb Road, predator abundance was high and also may have affected both translocation success and lizard abundance. The West Branch site had a very high abundance of roadrunners, which consumed some of the translocated horned lizards being monitored by radiotelemetry. In the Kolb Road Detention Basin, there was a high abundance of western diamondback rattlesnakes, a known predator of horned lizards, and other lizard-eating snakes of at least three species were present.

The decline of survivorship and population size at West Branch and possibly Kolb suggests that the low translocation success may have been partially determined by high-intensity predation under drought conditions. Since these factors fluctuate, different outcomes might occur under less stressful conditions. Despite the reduced survivorship of translocated RHL at West Branch, we observed them laying eggs that successfully produced hatchlings, as obviously happened also at the Midtown site. Overall, results of this experiment indicate that successful population establishment by translocation is feasible for the Regal Horned Lizard, and that translocation success may be influenced by both drought and predator abundance.
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Introduction

Project Relevance

The basis for this project are Pima County’s and the public’s interest in natural resource conservation, in a context of urban open space amenities, and the potential high utility of translocation in an era of rapid landscape change and climate warming that threatens to change to species habitat distributions. Urban biodiversity is a significant contributor to people’s recreational and educational contact with nature, which is a significant contributor to health and development (Lieberman and Hoody 1998; Louv 2005; Zhang et al. 2014; Duarte et al. 2015; Shannahon et al. 2015). Tucson is a biodiversity-rich city. It has six widespread amphibian species (Rosen 2008a; Rosen and Funicelli 2009a & b); seventeen lizard species occur within the metropolitan area (Germaine and Wakeling 2001; Rosen 2003, 2008b; Rosen et al. 2005); and approximately 240 bird species have been recorded by the Tucson Bird Count (Turner 2003, 2006; McCaffrey 2005; http://www.tucsonbirds.org/; and see Germaine et al. 1998). Large mammals including coyotes, peccaries, and bobcats are seen in the city, as are cottontail rabbits and three squirrel species. Nonetheless, many species have been lost from the city, as is true in cities globally (McKinney 2008).

Urban biodiversity will continue to decline in Tucson without active conservation. Urban infill and modernization of infrastructure and residential landscaping reduce space and habitat quality. Many native species survive primarily in parts of the environment that have not yet been fully used or developed in modern landscaping modes, such as alleys, untended yards and lots, and margins of major arroyos. The regal horned lizard (RHL, Phrynosoma solare) epitomizes this situation (Rosen and McCabe 2012). Although nearly universally liked by people (based on my interviews; and see Sherbrooke 1981, 2003), and still widespread and locally very abundant in the urban core, it has declined and may face extinction within the city (Rosen and McCabe 2012). Walls restrict its movement; ant species it eats are poisoned or starved by elimination of seed-producing wild forbs and grasses; gravel, lawn, and modern landscape architecture are largely unsuitable habitat; and open spaces are filled in or converted to new uses, as at Arroyo Chico. The RHL was reportedly still abundant in alleyways in Tempe, Arizona 50 years ago (L. Vitt, personal communication, 2012), but now occurs mostly, if not exclusively, in large desert parks in metropolitan Phoenix (R. Babb, personal communications, 2011; see Sullivan et al. 2014a). This portends an extinction trajectory for the RHL and many other species in Tucson, and globally in expanding and modernizing urban environments.

The high abundance of the RHL at the Arroyo Chico 2B floodwater control project (Rosen et al. 2011), in central Tucson, is matched by abundances of other lizards in alleys, yards, unused land, small parks, and river parks in Tucson (Rosen 2008b; and unpublished observations). My observations indicate that although several lizard species are missing from apparently suitable habitat in the city, lizards are more abundant in Tucson than in most of the surrounding desert. Global climate change models project temperature increases and exacerbated drought in the American Southwest (Garfin et al. 2013; IPCC 2013) that will negatively affect lizards (Sinervo et al. 2010; Lara et al. 2014, 2015). Highly productive, well-shaded (Kearney 2013) urban environments could be a refuge for climate-sensitive species, rather than a sink. How can we support and enhance biodiversity in urban environments, which are expected
to continue expanding (UN Habitat 2006; Grimm et al. 2008; Ellis 2011; Ahern 2013) regionally and globally?

The Arroyo Chico 2B (https://webcms.pima.gov/cms/One.aspx?portalId=169&pageId=68741) floodwater control project was poised to be yet another blow to biodiversity in Tucson. Neighborhood activists and engineers and managers at Pima County Regional Flood Control District (RFCD) recognized this, and the project design was modified to support animal habitat. RFCD sought my input and supported a project to salvage and translocate RHL from Arroyo Chico prior to project construction that would have killed nearly all of them. Salvaged RHL were experimentally translocated to three kinds of sites representing existing and potential future habitat for lizards in urban Tucson: a river park preserve, a revegetated detention basin, and an empty lot unoccupied by horned lizards. Little is known about translocation success of horned lizards (Sanders 2000; Hodges 2002; Thomas 2005; Owens and Krysko 2007). This translocation experiment is of special interest in urban settings where heavy land disturbance may be followed by reestablishment of suitable habitat that is inaccessible to many species due to low dispersal ability and habitat fragmentation (Dickman 1987; Travis 2003; Ahern 2013).

Translocation (or assisted movement; Reinert 1991) is a controversial conservation tool (Griffiths et al. 1989; Dodd and Siegel 1991; Fischer and Lindenmayer 2000; Nowak et al. 2002; Sullivan et al. 2004; Seddon et al. 2007; Germano and Bishop 2009; Ricciardi and Simberloff 2009; McCrystal and Ivanyi 2011; Germano et al. 2014; Sullivan et al. 2014b). Detractors argue that translocations often fail (Bogosian 2010; Painter et al. 2008), and may damage existing populations (Brooker et al. 2011). Yet climate change projections show that many species will be unable to adapt or migrate fast enough to avoid extinction (IUCN/SSC 2013; Hancock and Gallagher 2014; Gallagher et al. 2015). Depending on the severity of climate change, many species will only be saved by moving them to new areas with suitable habitat – an even more controversial proposition (“assisted colonization”; Lawlor 2009; Hancock and Gallagher 2014); and (more controversial still; Hobbs et al. 2009; Perring et al. 2013; Murcia et al. 2014) it may become necessary to reassemble ecological communities if we are to avoid or minimize the Anthropocene (the “Human Epoch”; Monastersky 2015) extinction event currently in motion (Barnosky et al. 2011; Pimm et al. 2014; Ceballos et al. 2015). Therefore, translocation is a tool that requires testing now (Germano et al. 2014), particularly when it can be done without jeopardizing well-protected populations (IUCN/SSC 2013), as is often the case in urban environments. Pima County RFCD has supported this with the RHL from Arroyo Chico (Rosen et al. 2011; Rosen and McCabe 2012) and with other salvage and translocation studies in Tucson to test and implement new methods of biodiversity conservation, protection and enhancement in managed environments.

**Summary of Prior Work and Methodology**

The following is summarized from Rosen et al. (2011) and Rosen and McCabe (2012). We collected most of the RHL (182 individuals total) at the Arroyo Chico 2B site in 2010. We surveyed for translocation recipient sites in the urban core and in other regional detention basins during summer 2010 and moved most the Arroyo Chico RHL three sites:

- West Branch of Santa Cruz River, a natural and protected urban river preserve (Rosen and Mauz 2001; Rosen 2003; Rosen and McCabe 2012);
• Kolb Road Detention Basin, an urban fringe floodwater detention basin with mature vegetation (Rosen and McCabe 2012); and
• Midtown near Alvernon Way and 22nd Street, in untended land parcels surrounded by residential and commercial environments (Rosen and McCabe 2012).

To follow and understand the fate of translocated RHL, we conducted a telemetry study at the West Branch site comparing behavior and survival of naturally resident and translocated lizards. We measured snout-to-vent length (SVL, in mm), tail length (mm), body mass (grams), and sex, and took four standard photographs of each individual. They were marked to be individually recognizable, either by implanting PIT tags under the skin on their backs or by combining a single toe clip with photos of their unique ventral spot patterns. We wrote small numbers in permanent ink on the venter to facilitate identification of individuals recaptured before they shed these marks. Recaptured individuals without the ink marks or PIT tags were identified by comparing photographs. Photographic identification was facilitated by using year-specific toe clips. Ambiguous identifications, due to natural toe loss, mark-reading errors, or fading of ventral spots, were resolved by comparing other details from the photographs. One individual was identified as unmarked despite having a missing toe.

As previously reported (Rosen and McCabe 2012), telemetry demonstrated that the behavior of translocated RHL at West Branch was very similar to that of originally resident individuals, but translocated RHL suffered higher mortality. In contrast, at the Midtown site, where horned lizards were initially absent due to previous use of the empty lot as a racetrack, translocated lizards survived well through the first year post-release. At the third site, habitat complexity prevented us from monitoring the translocation outcome successfully in the first year post-release (2011).

During fieldwork, we searched each study area thoroughly during 1-2 day census periods, visiting each site repeatedly each year. We focused our searches lizards were most likely to be found and captured, and focused on areas where the ant-filled scats of RHL were found, and periodically re-checked other areas in and around the study areas. Sampling effort was recorded as time- and location-specific GPS tracks, from which effort (time and distance searched) was determined. We recorded GPS waypoints (+3-4 m in precision) for all colonies of large ants that were potential food for the RHL, and recorded a waypoint for each potential RHL predator we observed.

In this report, I present an additional year of intensive censusing at the three translocation study areas to determine survivorship (percentage survival per year) of translocated RHL and to document population trends for the species at the three study sites. The primary objective of this work was to evaluate the possibility that the poor translocation outcome at West Branch might reflect deteriorating conditions for horned lizard there generally, which I suspected might be the case because overall lizard abundance had decreased markedly there over the preceding decade. Limited follow-up at two of the sites, in connection with other work, was done during 2013-2015.
Methods

Fieldwork

In 2012, we used the same search, measuring, marking, and photography methods as in 2010 and 2011, except that we discontinued using PIT tags. We intensively surveyed each of the primary translocation sites repeatedly, attempting to register all adult and subadult RHL (those with SVL equal to or greater than 55 mm) and as many smaller juveniles as possible. The locations of translocation releases and captures for each year are shown in Figs. 2-4. I used the 2012 results with sampling at the sites in 2010 and 2011 to calculate population size estimates for all three sites for 2011 and 2012. At West Branch, it was also possible to estimate the 2010 population because we had incidentally registered numerous originally resident RHL there while tracking the telemetered ones. Although post-2012 work was focused at Arroyo Chico (Rosen 2015), we conducted limited follow-up during 2013-2015 in connection with other work at two sites, with three censuses at the Midtown site during 2015.

Calculations

Two computational methods were used for estimating population size: the Chapman-modified Lincoln-Peterson Index method, which was corrected for bias according to Seber (1982), and the regression method of Schnabel (Krebs 1999). For the Chapman estimates, population size was calculated within years by dividing the sample into two equal parts (1st half and 2nd half of summer), and between years by estimating the year 1 population according to the recapture fraction in year 2.

In order to make the between-year calculation of adult-subadult population size, which assumes the population was closed to recruitment, it was necessary to exclude from the year 2 samples any individual that was too young and small in year 1 to be part of the year 1 adult-subadult population. This is necessary because small individuals were much less detectable and likely had lower survival rates than the larger, older ones. We identified individuals for the excluded juvenile category on the basis of information on head shape (Figs. 5-7), and growth, size, and date of initial capture (see Results). Horn length and shape changed with age, from short and flat in juveniles to elongate, more slender, and often irregularly curved with age. Two biologists independently assigned unknown-age individuals, which could not be aged unambiguously based on size at first capture, to age <1 or >1 yr based on horn shape using comparison of their head photographs to photographs of the individuals of known age based on recaptures (Figs. 6 and 7). In blind tests, we were able to correctly assign 78% of known-age 1- and 2-yr old individuals to the correct age-class and to always correctly distinguish 1-yr olds from those 3-yr and older. To test for potential effects of population estimation errors resulting from this age-determination procedure, I assigned all age-determinations we considered possibly questionable to their alternate age assignment and re-computed new population estimates. This yielded such small changes in the estimates and variances that this source of error is ignored herein.

We assumed that populations of adults and subadults were closed to immigration and emigration due to the small home ranges of the lizards (Rosen and McCabe 2012) and the absence or scarcity of horned lizards outside the relatively isolated demes (local populations) we studied (Figs. 2-4; see Rosen and McCabe 2012). Data were insufficient to test for varying detectability among individuals, which we
Figure 2. Horned lizard translocation-release and capture-recapture sites at the Midtown (Alvernon-22nd) study area.
Figure 3. Horned lizard translocation-release and capture-recapture sites at the Kolb Road Detention Basin study area
Figure 4. Horned lizard translocation-release and capture-recapture sites at the West Branch of Santa Cruz River study area.
Figure 5. Allometry (differential growth) of horns compared to head in regal horned lizards recaptured as adults or subadults after being marked as hatchlings.
Figure 6. Comparison of horn size and shape of known-age (based on recaptures) regal horned lizards at approximately 1-year and 2-years of age.
Figure 7. Comparison of horn size and shape of known-age (based on recaptures) regal horned lizards at approximately 2-years and 3 or more years of age.
therefore assumed as a constant within each year and site. This source of error is small for most estimates because we captured a large majority of all adult and subadult individuals at each site.

From the population estimates and total number of lizards actually registered, I calculated estimates of detection probabilities for each year and site, and used these to estimate survivorship for 2010 and 2011 for sites with sufficient sampling. This was based on the nearly complete registration of individuals at all sites in 2012 and at two of the sites in preceding years. Sample sizes at the Kolb Road site in 2010 and 2011 were too small to make this calculation for originally resident RHL. Survivorship was computed as estimated number of marked individuals present in year 1 divided by estimated number of them still present in year 2. Previous estimates of survivorship based on telemetered individuals (McCabe and Rosen 2012) are presented for comparison.

Results and Discussion
Weather, Habitat, Ant Populations, and Predation Regime

Severe drought conditions were absent in the 24 months preceding the June 2010 beginning of this study, with a minor seed-producing spring bloom of forbs and grasses in 2010 (Fig. 8). Winter rainfall was insufficient for another spring bloom until spring 2015. Winter-spring of 2011 was a drought episode with very low plant productivity, followed by another dry late winter and spring in 2012 that also saw weak seed production. Summer rains were sufficient to stimulate horned lizard activity and facilitate sampling in each year of study.

Figure 8. Monthly rainfall near three main translocation study sites for regal horned lizards in Tucson prior to and during the study of translocation effectiveness. Data are from http://alert.rfcd.pima.gov/perl/pima.pl

All three study sites had high density and diversity of large-bodied ants (Figs. 9-11). The association of RHL with ant colonies, particularly with its dietary staple, the rough harvester ant, is evident from the figures. Although to some extent the effect is modified and masked by the quality of certain ant colonies that had high and regular activity, it is also evident that RHLs were: (1) associated with vegetative cover; (2) scarce in the center of the Kolb site detention basin environment even though ant populations were
Figure 9. Association of regal horned lizards and larger-bodied ant species at the Midtown (Alvernon-22nd) study area in Tucson, 2011-2012.
Figure 10. Association of regal horned lizards and larger-bodied ant species at the Kolb Road Detention Basin study area in Tucson, 2010-2012.
Figure 11. Association of regal horned lizards and larger-bodied ant species at the West Branch of the Santa Cruz River study area in Tucson, 2010-2012.
Table 1. Potential predators of regal horned lizards observed at primary study sites in Tucson, 2010-2012.

<table>
<thead>
<tr>
<th>Species</th>
<th>Arroyo Chico</th>
<th>Alvernon-22nd</th>
<th>Kolb Road Detention Basin</th>
<th>West Branch</th>
<th>total</th>
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<td>1</td>
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<td>46</td>
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<td>460</td>
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<td>Observation Rate (no. / hr)</td>
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<td>0.14</td>
<td>0.45</td>
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<td>Observation Rate (no. / hr)</td>
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<tr>
<td>(excluding cats)</td>
<td>0.09</td>
<td>0.08</td>
<td>0.45</td>
<td>1.24</td>
<td>0.63</td>
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</table>
abundant there; and (3) scarce near and beyond the western part of the West Branch study, an area where ground squirrels were abundant. Observation (1) is somewhat surprising based on the species’ abundance in open habitat in some parcels and alleys; (2) may reflect avoidance of more frequently inundated parts of detention basins, or may involve recent recruitment of ant colonies; and (3) may partly reflect vegetation decrease westward, but is of concern as ground squirrels spread east during 2012-2014 at this study site.

The suite of potential predators was diverse and differed among the three translocation sites and the Arroyo Chico source site (Table 1). Predators were more abundant at West Branch than elsewhere, with roadrunners exceptionally abundant. At Arroyo Chico, cats were very abundant and other predators rare, while at Midtown predators were scarce overall. The Kolb site had an intermediate abundance of predators, but a high abundance of snakes, including many western diamondback rattlesnakes, a known predator of horned lizards (Beavers 1976; Sherbrooke and May 2008a&b; review in Sherbrooke 2008).

**Growth, Age, and Size**

During this study, hatchlings appeared in late September to mid-October at about 24-30 mm SVL, and grew rapidly to adult size at age 1-yr. Fig. 12 shows the increase of size of the youngest age-class, starting as an obviously distinct size-class, and then increasing in size and in September largely merging into the size-class of older individuals. Most young of the previous year were still less than 80 mm SVL in July and August and therefore mostly assignable to the yearling age-class. There is overlap of animals approaching 1-yr of age and those approaching 2-yr of age (Fig. 12) that is demonstrated by the variation of growth of marked individuals (Fig. 13). Size alone cannot adequately separate yearlings from older lizards in August-October, as required for some of the population size estimation calculations.

Age determination was complicated by size differences likely related to growth rate differences among study sites. RHL at Arroyo Chico averaged smaller than those from West Branch and Kolb Road (Figure 14). Adults at Kolb Road were the largest on average, perhaps due to higher gape-limited predation (i.e., limited by the mouth size and swallowing ability of predators) by snakes on smaller, younger RHL (see Sherbrooke 2008). The largest individuals were from West Branch, suggesting that rapid growth at Kolb Road may not be the reasons for the large average size there. The age structure at Midtown (Figure 14) has a mix of the smaller adults translocated from Arroyo Chico and their progeny, which appear in the 75-85 mm SVL size range following rapid growth. If predation at West Branch was also limited by predator gape (Cundall and Greene 2000; see Zimmerman 1970, and Holte and Houck 2000), the small size of translocated RHL from Arroyo Chico compared to the large size of West Branch adults may have contributed to differential survival of translocated and resident RHL (see below). The range of causes of growth and size differences among populations may be complex.

**Population Size and Trends**

Population size estimates are shown in Table 2. All of the estimates indicate small population sizes ranging from 18.1-50.6 adult-subadult individuals. None of these populations was as large as the Arroyo
Figure 12. Size-frequency histogram model showing how growth progression is inferred from size data. The hatchling age class moves rightward over the 12-month period following hatching (late September to mid-October based on 2010-2012 data in Tucson). As indicated by the imposed normal curves (and considering recapture-based growth rates; see Fig. 11), yearlings begin to overlap in size with older animals by August at the latest. The blue curve indicates the approximate position of the 10yr age class. Adults from Arroyo Chico, which were smaller than at other sites (Fig. 18), were excluded from the graphic.
Figure 13. Size increase of marked and recaptured regal horned lizards at Tucson study sites during 2010-2012.
Figure 14. Size distributions of regal horned lizards at study sites in Tucson, 2010-2012. Numbers over the bars are sample sizes.
Chico source, from which we collected 98 adults and subadults and estimated as many as 128 individuals present (Rosen et al. 2011; Rosen and McCabe 2012). Within sites and years, the different methods of calculation yielded similar values that were within the expected ranges of error variation based on computed confidence intervals.

The population estimates show that the Midtown (Alvernon-22\textsuperscript{nd}) population was growing, with the 2012 estimate significantly larger than the 19 adults and subadults released at the site (Table 2; Fig. 15). The Kolb Road population was growing or stable during 2011-2012, while the West Branch population experienced a large decline in abundance of about 50% or more by 2012 (Figure 15). At the Midtown site, 2015 observations yielded high capture rates demonstrating successful population establishment. At the West Branch study site, the RHL was present but appeared to be rare based on limited work through 2015.

**Mortality and Survivorship Rates**

Estimated annual survivorship of adult and subadult RHL (Table 3) varied from 17-100% for translocated individuals and from 39-90% for originally resident individuals. For hatchlings in their first year of life, survivorship estimates were 0-54% and 18-78% for translocated and resident individuals, respectively.

<table>
<thead>
<tr>
<th>Recensus</th>
<th>YR estimated</th>
<th>n1</th>
<th>n2</th>
<th>m2</th>
<th>POP_est Chap_corr</th>
<th>95% C.I.</th>
<th>POP_est Schnabel</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alvernon-22nd</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>2012</td>
<td>2011</td>
<td>22</td>
<td>17</td>
<td>9</td>
<td>40.4</td>
<td>24.8 - 56.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 2nd half</td>
<td>2011</td>
<td>9</td>
<td>10</td>
<td>4</td>
<td>20.9</td>
<td>9.2 - 32.6</td>
<td>28.3</td>
<td>17.9 - 68.1</td>
</tr>
<tr>
<td>2012 2nd half</td>
<td>2012</td>
<td>21</td>
<td>19</td>
<td>8</td>
<td>47.9</td>
<td>26.4 - 69.3</td>
<td>43.7</td>
<td>30.0 - 80.4</td>
</tr>
<tr>
<td><strong>Kolb Road</strong></td>
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<tr>
<td>2012</td>
<td>2011</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>18.8</td>
<td>3.0 - 34.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012 2nd half</td>
<td>2012</td>
<td>13</td>
<td>13</td>
<td>5</td>
<td>31.6</td>
<td>14.6 - 48.6</td>
<td>31.5</td>
<td>18.4 - 110.5</td>
</tr>
<tr>
<td><strong>West Branch</strong></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>2011</td>
<td>2010</td>
<td>9</td>
<td>20</td>
<td>3</td>
<td>50.6</td>
<td>13.4 - 87.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>2011</td>
<td>24</td>
<td>16</td>
<td>8</td>
<td>46.2</td>
<td>26.9 - 65.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011 2nd half</td>
<td>2011</td>
<td>16</td>
<td>17</td>
<td>6</td>
<td>42.7</td>
<td>20.4 - 65.0</td>
<td>31.5</td>
<td>21.6 - 58.5</td>
</tr>
<tr>
<td>2012 2nd half</td>
<td>2012</td>
<td>14</td>
<td>10</td>
<td>7</td>
<td>19.6</td>
<td>13.1 - 26.2</td>
<td>18.1</td>
<td>12.3 - 34.5</td>
</tr>
</tbody>
</table>
At West Branch, resident adult survivorship from 2010 to 2011 estimated by mark recapture (90%) was similar to the value calculated based on radiotelemetry (84%; Rosen and McCabe 2012), but estimated survivorship from 2011 to 2012 was less than half these values at 39%, consistent with the population decline there, and similar to survivorship estimates for other sites in 2012. It is not clear if the decline at West Branch was caused by solely by predation, drought effects on ant activity, or some combination of factors. At the West Branch site, cover for horned lizards comprised primarily ephemeral vegetation that is entirely dependent on recent rainfall, potentially exposing them to elevated predation risk during drought; however, ant activity also noticeably declined during 2011-2012 at this site.

Figure 15. Estimated population sizes of regal horned lizards at three study sites in Tucson, 2010-2012 showing each estimate and 95% confidence interval that was computed (Table 10). “Chap”, “1-yr” and “Schnabel” refer to the computational methods in Table 2. Years, indicated across top of the panel, and dots connected to dashed lines, are centered, respectively, over sets of estimates for each year and at the mean of annual abundance estimates. Dashed lines indicate the trends, which are significant statistically when the confidence intervals are non-overlapping.

Estimated survivorship of translocated adults and subadults at West Branch was 24-34% based on the mark-recapture results, which is also consistent with the independent, telemetry-based estimate of 30% (Table 3; Rosen and McCabe 2012). The smaller size of RHL translocated from Arroyo Chico compared to resident adults at West Branch may have contributed to their vulnerability to predation by roadrunners (Bryant 1916; Sherbrooke 1990; Holte and Houck 2000; Sherbrooke 2013), which were abundant at
West Branch (see Table 1). Hatchling survivorship from 2010 to 2011 was estimated at 18% at West Branch for both resident and translocated individuals. Estimates of hatchling survivorship were unavailable from 2011 to 2012 because few hatchlings were found in the drought year of 2011.

Translocated adult and subadult RHL at Kolb Road survived at an estimated rate of 38% per year, while none of the translocated hatchlings were found in subsequent years (giving an estimate of 0% survivorship). High mortality of hatchlings and juveniles at Kolb Road site may result from snake predation, as juveniles of both coachwhips and western diamondbacks were present and may be gape-limited in size of horned lizard taken. Snakes are identified as the key predators at Kolb Road site because other potential predators were infrequently observed. Our samples of resident RHL at Kolb Road in 2010 and 2011 were too small to estimate survivorship.

Table 3. Estimated survival rates of translocated RHL in Tucson, with comparisons to resident (non-translocated) individuals at one site West Branch) and progeny of translocated individuals at a second site (Alvernon-22nd). Telemetry estimates are from Rosen and McCabe (2012). Computation methods and sampling limitations are detailed in text.

<table>
<thead>
<tr>
<th></th>
<th>Translocated Individuals</th>
<th>in situ Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YEARS</td>
<td>Alv-22</td>
</tr>
<tr>
<td>Hatchlings &amp; Sm. Juveniles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. translocated</td>
<td>2010</td>
<td>18</td>
</tr>
<tr>
<td>Estimated Survivors</td>
<td>2011</td>
<td>9.7</td>
</tr>
<tr>
<td>Estimated Survivors</td>
<td>2012</td>
<td>--</td>
</tr>
<tr>
<td>Survivorship</td>
<td>2010-11</td>
<td>54%</td>
</tr>
<tr>
<td>Survivorship</td>
<td>2011-12</td>
<td>--</td>
</tr>
<tr>
<td>Overall Survivorship</td>
<td>Mean</td>
<td>54%</td>
</tr>
<tr>
<td>Adults &amp; Subadults</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. translocated</td>
<td>2010</td>
<td>19</td>
</tr>
<tr>
<td>Estimated Survivors</td>
<td>2011</td>
<td>19.4</td>
</tr>
<tr>
<td>Estimated Survivors</td>
<td>2012</td>
<td>9.2</td>
</tr>
<tr>
<td>Survivorship</td>
<td>2010-11</td>
<td>100%</td>
</tr>
<tr>
<td>Telemetry Survivorship</td>
<td>2010-11</td>
<td>--</td>
</tr>
<tr>
<td>Survivorship</td>
<td>2011-12</td>
<td>47%</td>
</tr>
<tr>
<td>Average Annual Survivorship</td>
<td>Mean</td>
<td>75%</td>
</tr>
</tbody>
</table>

The Midtown site, where predator abundance was lowest, had the highest estimated survivorship for both hatchling and adult-subadult RHL (Table 3). This is consistent with the population growth at this site, and gives credence to hypothesized predation effects on RHL at West Branch and Kolb Road. However, survivorship of adults and subadults from 2011 to 2012 at the Midtown site was reduced to
47%. We found three of the translocated adults dead of unknown cause in spring 2012, suggesting that drought effects on water balance or prey availability may have contributed to elevated mortality, which may have contributed to low survivorship at other sites for 2011-2012. However, people may have collected some of the lizards: we know that people became aware of the new presence of horned lizards. Further, people occasionally drive motor vehicles on this site, potentially killing lizards. In 2015 we found two dead individuals that appeared to have been run over by motor vehicles at the Midtown site. Although the translocated adults suffered elevated mortality during 2011-2012, estimated survivorship of juveniles hatched on-site from 2011 clutches produced by translocated adults was high at 78%, yielding numerous subadults and young adults, and the high population size, in 2012.

Conclusion

Monitoring of Regal Horned Lizards salvaged before construction of the Arroyo Chico Phase 2B project demonstrated that a new population was established by translocation at the previously unoccupied, highly urbanized Midtown recipient site, where predators were uncommon. Survivorship of translocated hatchlings and juveniles was higher at this site than elsewhere, suggesting that establishing new populations by harvesting hatchlings has promise as a low-impact method for translocation. This has positive implications for continuing conservation of this lizard species in urban Tucson. At two other translocation recipient sites, where resident horned lizards were present and predator abundance was high, mortality of translocated lizards was high and translocation to such sites may be of less value. However, these two negative outcomes may have been related to time-varying drought and predation factors. Additionally, the small size of horned lizards at the Arroyo Chico donor site, compared to size at the two previously occupied recipient sites may also have influenced the outcome. This study has wider implications for conservation and translocation of lizards in the Tucson region and for a current debate about translocation as a conservation tool in reptiles more generally. Regal horned lizards remained abundant five years post-translocation at the Midtown population, and these lizards may be available for population re-establishment or enhancement elsewhere in Tucson.

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