# EFFECTS OF RED IMPORTED FIRE ANTS (*Solenopsis invicta)* ON JUVENILE HOUSTON TOADS (*Bufo houstonensis)* IN A COASTAL PRAIRIE GRASSLAND

by

Madeleine J. L. Marsh, B.A.

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Committee Members:

Michael R.J. Forstner, Chair

M. Clay Green

Thomas R. Simpson

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## ABSTRACT

The Houston toad (*Bufo houstonensis)* was first described in 1953 in Houston, Texas, but has since been extirpated from the area. Houston toad populations have been in a nearly continuous decline across their known distribution since discovery, primarily due to multiple stressors, including red imported fire ants (*Solenopsis invicta;* hereafter referred to as RIFA). In spite of the uncertainty of historical presence, the 1984 Recovery Plan attempted to reintroduce the Houston Toad into coastal prairie habitats. Although originally thought unsuccessful, the coastal prairie proved to be suitable habitat, even if only as dispersal habitat. In 2015, on Attwater Prairie Chicken National Wildlife Refuge (APCNWR), a total of forty-eight exclosures were placed in four prairie locations (12 exclosures per site) two of which were treated for RIFA and two prairie locations were used as untreated controls. Morphometric data (snout-urostyle length, head-width, and weight) were collected for all toadlets were detected on a weekly basis, slowing to bi-weekly after six weeks. A mixed-effects for repeated measures model was used in R to evaluate growth rates between treatment and control areas, which showed no difference in growth between treatments (F-value=1.747, df=42.7, 45, p=0.09) or density (t-value=-1.095, df=140.61, p>0.1). Program MARK was used to estimate survivorship and detection between treatments using a Cormack-Jolly Seiber (CJS) model. The model chosen, using $\Delta AIC_c$, assumed that detection and survivorship changed

through time but not between treatments. Because there was no difference in growth or survivorship, I fail to reject our null hypothesis that RIFA has a negative impact on the survival and growth of juvenile Houston Toads. A trend seen in the data comparing the exclosures in the open prairie to those within the drip line showed higher survival within the drip line, but much faster growth in the open prairie. This supports that connectivity of habitats is vital for the survival of juvenile Houston toads. However, because it has been shown that Houston toads are able to persist on the RIFA controlled prairies of APCNWR, the area of suitable Houston toad habitat can now be more explicitly delineated to include native grasslands, particularly for dispersal habitat. These landscape-connecting habitats are one of the most critical and least understood ecological aspects for Houston toad management. The results from this study also clearly assist with assessing new sites for reintroduction through propagation and population restoration efforts.

# I. INTRODUCTION

The Houston toad (*Bufo houstonensis)* was first described in 1953 in Houston, Texas (Sanders 1953, Peterson et al. 2004) but has since been extirpated from the area. Although reasons for that decline are not explicitly known, many believe it to be due to drought and urban expansion (U.S. Fish and Wildlife 1984, referenced as USFWS hereafter). In 1970, the Houston toad was the first species in Texas to be federally listed as endangered (Allison and Wilkins 2001) and the first amphibian federally listed under the Endangered Species Conservation Act (Gottschalk 1970, Peterson et al. 2004). In 1978, the U.S. Fish and Wildlife Service (USFWS) designated critical habitat throughout Bastrop and Burleson counties aiming to protect what they referred to as "the rarest and most endangered amphibian in the United States" (USFWS 1978).

Historically, Houston toads were found across the central coastal region of southeast Texas but now the range is primarily in the Lost Pines region of Texas and surrounding counties (USFWS 2011). The Lost Pines region encompasses all or parts of Austin, Bastrop, Caldwell, Colorado, and Fayette counties (Youngman 1965). Houston toad populations have been in constant decline due to multiple stressors, including habitat fragmentation, continued urbanization of suitable habitats, fertilizers and chemical run off, as well as red imported fire ants (*Solenopsis invicta;* hereafter referred to as RIFA). This cumulative loss or degradation of habitat has caused the Houston toad to be found in only nine of the 12 historic counties previously occupied (Forstner et al. 2007).

Predominantly made up of loblolly pine (*Pinus taeda)* and oak (*Quercus sp.)* forest, the Lost Pines region is underlain by deep sandy loam soils (Campbell 1996). Relatively high annual detection of *B. houstonensis* still occurs in the sandy loam soils of the Lost Pines region (Koepp et al. 2004). Houston toads are poor burrowers (Bragg 1960), needing the soft sandy soils to create burrows where they spend most of the year, emerging only to forage and breed. Burrows not only provide protection from the cold in winter months, but also facilitate estivation in the harsh Texas summers (Campbell 1996). Accordingly, Houston toads might not be limited to areas of pine forests, but rather areas with soft sandy soils (Brown and Thomas 1982).

Starting 4 September 2011, a wildfire ignited in Bastrop County and quickly became catastrophic due to high winds and extreme drought conditions. The fire was contained after burning approximately 40%, or 36,000 acres, of the Lost Pines eco-region and high-suitability habitat of the Houston toad (Wallace et al. 2011, Brown et al. 2013). Due to the fire, the majority of the Lost Pines region is now an altered post-burn habitat with little to no canopy cover. There is very little data on how Houston toads react and survive outside of canopied habitats.

The red imported fire ant is a highly invasive species found predominantly in the southern and southeastern US. Originally introduced into Alabama in the 1930s, RIFA populations quickly made their way west into central Texas (Callcott and Collins 1996). In the US, RIFA occur in disturbed habitats or in areas that are primarily forested and in forest/canopy gaps (Colby and Prowell 2006). RIFA also prefer edges of ponds and other bodies of water (Stuble et al. 2009); this potential for a high density of RIFA around ponds is of great concern to amphibian management, because of the potential for predation on juvenile amphibians as they emerge from the water (Freed and Neitman 1988). Freed and Neitman (1988) reported fire ants predating on juvenile Houston toads as they entered the terrestrial landscape as newly-metamorphosed toadlets, causing high mortality rates at a crucial life stage for the toad's survival.

Native invertebrates comprise the entire prey spectrum for juvenile Houston toads (Clarke 1974). Porter and Savignano (1990) found that both species richness and total number of individuals of non-ant arthropods were 30% and 75% lower, respectively, in the presence of RIFA. Red imported fire ants, where present, have repeatedly been shown to have a strong negative impact on a wide range of native vertebrate and invertebrate species (Porter and Savignano 1990, Wojcik et al. 2001, Allen et al. 2001, Stuble et al. 2009, Diffie et al. 2010, Epperson and Allen 2010, Brown et al. 2012). Many species of native ants have been displaced by infestations of RIFA (Wojcik et al. 2001), these native ants may otherwise comprise a large portion of the juvenile Houston toad's diet (Bragg 1960).

Although the largest populations of Houston toads currently are found in forested areas, in 1953, the Houston Toad was known to occur in both Austin and Colorado counties, both considered coastal prairie ecosystems (USFWS 1984, Forstner and Dixon 2010). However, there is a conflict between the historical depictions of Houston toad habitat and that of current known population locations (Forstner and Dixon 2010). Despite Kennedy (1962) placing the Houston toad in the grassland Gulf Coast Prairie region, there have been no current populations found to be associated, nor abundant, in any modern examples of native grasslands (Forstner and Dixon 2010). This conflict may simply be due to dramatic anthropogenic changes in the landscape, altering what was originally the habitat for the Houston toad, or that original conclusions of the species presence in coastal prairie were misidentified due to continuing changes to the Houston area, including sand mining and clear cutting of forested areas (Forstner and Dixon 2010). It is clear that juvenile Houston toads are able to disperse through a variety of habitats, including areas with soils considered unsuitable for adults, and across areas with limited or no canopy (Forstner and Dixon 2010).

In spite of the uncertainty of historical presence, the 1984 Recovery Plan attempted to reintroduce the Houston toad into coastal prairie habitats including Austin and Colorado counties (USFWS 1984, Forstner and Dixon 2010). Authors of the 1984 Recovery Plan did not perform, nor cite, any audio surveys of Austin or Colorado counties under the assumption that the Houston Toad had simply been eradicated from the counties surrounding Harris County, where the toad was first described (Sanders 1953; Forstner and Dixon 2010).

In 1982, the recovery project began at APCNWR. A captive propagation-release, or head starting, program was initialized at APCNWR based on the believed historic presence of the toad in the area, suitable habitat, and that the area was currently uninhabited by the Houston toad (Quinn and Ferguson 1984, Forstner and Dixon 2010). Attwater Prairie Chicken National Wildlife Refuge was also chosen due to its long-term protection of the habitat as a National Wildlife Refuge. Unfortunately, despite yearly efforts to release either wild-caught or captive-breed Houston toads at multiple life stages, the program was deemed unsuccessful without any subsequent survey efforts evaluating the outcomes (Quinn and Ferguson 1984, Dodd et al. 1991). Predation of the aquatic tadpole stage was presumed to be a primary cause of the program's failure (Quinn and Ferguson 1984), while fire ant predation was also seen on the emerging juveniles (Freed and Neitman 1988).

Although it is thought that the reintroduction into a habitat that is currently considered unsuitable was unsuccessful (Quinn and Ferguson 1984; Dodd et al. 1991), it is highly likely that the 1980s reintroduction at APCNWR was actually successful (Forstner and Dixon 2010). Over five years, ~400,000 eggs, ~7,000 juvenile metamorph toads, and ~60 adult toads were released at APCNWR and although regular monitoring of the populations was not possible, it is known that there was a successful breeding event in 1985 and adults were heard calling in both 1984 and 1986 (Quinn and Ferguson 1984; McHenry and Forstner 2009). Genetic work performed by McHenry and Forstner (2009) concluded that a self-sustaining population of Houston toads resulted from the recovery efforts at APCNWR despite otherwise "unsuitable" habitat surrounding the majority of the release sites. Individual Houston toads from Colorado County were found to be more genetically similar to the toads in Bastrop County, and specifically the subpopulation in Bastrop County where the wild toads were collected for the 1984 Recovery and Reintroduction Program, than to the Austin County toads which are geographically much closer to Colorado County (McHenry and Forstner 2009).

Because APCNWR has proven to be suitable habitat for, at minimum, supporting dispersal of the Houston toad, it is important to determine if juvenile Houston toads can survive in a native prairie landscape within their historic range in the absence of RIFA. The results are also relevant for prediction of the outcomes for the Houston toad within the post-fire habitats within Bastrop County. If Houston toads are able to persist on the RIFA controlled prairies of APCNWR, the area of suitable Houston toad habitat would be greatly expanded beyond the Lost Pines region as well as potentially enabling new sites for reintroduction through propagation and population restoration efforts as long as broad-scale RIFA control is in effect.

In this study, I aim to evaluate the effect RIFA on both the survivorship and growth of juvenile Houston toads. I hypothesize that RIFA will have a detrimental effect on both the survivorship and growth of juvenile Houston toads due to diminished prey abundance for the toad from competition from RIFA, as well as predation on the toad by RIFA. Simultaneously, I also aim to explore a nontraditional habitat of coastal prairie grassland as suitable habitat for juvenile Houston toads.

## II. METHODS

Prior to beginning this study and with the explicit goal to reduce RIFA for benefit to the prairie chicken headstarting efforts ongoing at APCNWR, two aerial applications of Extinguish® Plus were placed on the treatment areas of the APCNWR prairie. The aerial application was carried out by helicopter. Extinguish® Plus is RIFA control product and the only such approved for pasture and rangeland use. Containing both an insecticide and insect growth regulator, this bait-driven suppressant specifically targets fire ants. Four hundred seventy eight hectares of pastures were treated on 22 October 2014, providing 261.5 ha adjacent to the treated zone for use as a control.

A study done on *S. invicta* showed that ants from small colonies foraged no further than 3 m for food and those from large colonies traveled up to 17 m to forage (Stringer et al. 2011). To ensure no overlap between treatments, a 50-m buffer was placed from the edge of each treatment.

At four prairie locations within APCNWR, two were treated for RIFA and two were left untreated as a control for the study. Within a 250 meter by 500 meter area in each of the four prairies, I assigned random locations for twelve exclosures (Figure 1). I placed 10 exclosures in the open prairie and two exclosures within the drip line of the trees present along the dry riverbed (Figure 1).

Exclosures are 150 cm square, constructed with 91 cm wide, 1/8 inch 27 gauge hardware cloth. Exclosure walls extend 20 cm below ground and 50 cm above ground. A 10 cm lip of hardware cloth is folded along the length of the top and bottom of each exclosure to prevent toads from escaping and deter predators from entering. I placed deer netting on top of each exclosure to prevent predation on the juvenile toads. Each exclosure was equipped with two small plastic water tubs full of organic compost and sphagnum moss in order to provide a moist location for the toads within the artificial containment. I placed each tub under or in the shelter of the native bunch grasses within each of the exclosures.

I randomly assigned juvenile toadlets to exclosures. Six exclosures in each treatment and control had a density of six individuals per exclosure with a density of four toads in the remaining six. The densities were chosen from a prior study (Jones 2015) very recently completed in Bastrop to determine the most successful densities for survivorship for juvenile Houston toads. I marked each individual by a toe clipping (0, 1, 2, 3 and 0, 1, 2, 3, 4, 5), and weighed and measured them prior to placing them in an exclosure. Marked individuals allowed for tracking of individual weight and growth measurements.

For the first five days, which are the most critical for survival, I counted the toads in each exclosure daily to determine presence and absence and the sprayed water tubs to keep them moist. Spraying the exclosures with water can also be helpful in finding toads by motivating movement of the individuals within the exclosure.

After determining survivorship within the first week and continuing for approximately six months, I recorded a weight, snout to urostyle length (SUL), and head width for each individual found after searching the exclosure for five minutes. Measurements were taken weekly from week two until week six. After the first six weeks of the study, measurements were reduced to bi-weekly, and the last two measurements were taken at four-week intervals. Throughout the study, the water tubs in the exclosures were moistened after five days of no precipitation. Data collection was performed by a number of observers, and could not have been completed had I not had the help of Student Conservation Association (SCA) interns and APCNWR staff members.

I assessed red imported fire ants densities and sampled invertebrates at regular intervals during the study. Fire ant assessments were performed by placing pureed canned sausages in a petri-dish and placing an array of these bait traps at random intervals between the road to access prairies and exclosures so as to not attract RIFA to the exclosures. Invertebrate sampling was assayed using pitfall traps and sought to quantify the number of available prey items for the prairie chicken, but these data can be also used to extrapolate effects, if any, from RIFA treatment.

I then used the statistical program R (R Core Team 2012) and *lme4* (Bates et al. 2012), to perform a linear mixed effects for repeated measures analysis of the effect of RIFA treatment on the growth rates of juvenile Houston toads. This R-package estimates degrees of freedom and p-values for each fixed factor and runs a chi-squared test for random factors. Additionally, I used Program MARK to estimate survivorship between the two treatments.

## III. RESULTS

The data demonstrated overall survivorship percentage and overall average weight by treatment remained relatively equal between treatments throughout the experiment. The percent weight gain by treatment shows little variation for the first ten weeks of the study and then the toads in the RIFA treated prairies start to gain weight much quicker than the control prairies; this time period is during and shortly after repeated intense rains that were experienced in the area. Around week twenty, there was a drop off in weight gain for the treated prairies, which coincides with the very hot, dry months at the end of the summer. At the end of the study, the mean weight of toads increased by 621% in RIFA treated locations and 491% in untreated locations (Figure 2). The overall survivorship by treatment also showed very little variation throughout the study. The RIFA treated locations had an ending survivorship of 10% (12 toads of 120 released), while the untreated control prairie locations had a survivorship of 4.31% (5 toads of 121 released) at the end of the study (Figure 3).

Program MARK was used to estimate survivorship and detection of each treatment between data collection days using a Cormack-Jolly-Seiber (CJS) model for open populations. Based on $\Delta AIC_c$, the model assuming survivorship, φ, and detection rates, *p,* change over time ($\varphi_t\ p_t$) was chosen to be the best fit (Table 1). The other models ran in program MARK had $\Delta AIC_c$ values greater than two, which makes this model the best fit. This model showed no difference between treatments for both the survivorship, φ, and detection, *p*, but both changed with time (Table 2). Both φ and *p* at week twenty of the experiment were much lower than other weeks ($\varphi$=0.48, $p$=0.71), which correspond to the period of hot and dry weather at the end of the summer (Table 2,

Figure 4). Week twenty-four, or the final week, estimates have extremely high standard errors (~90) and very wide confidence intervals (0 - 1). This uncertainty is likely due to the small sample size at the end of the experiment.

The mixed effects for repeated measures model used treatment (RIFA treated or untreated), density (number of toads surviving in the exclosure by week), and week as fixed factors and exclosure as the single random factor. The response variable was weight, which was the averaged weight of all toads captured in each exclosure. The model used was:

$$Weight \sim Treatment + Density + Week + (1|Exclosure)$$

The analysis showed no difference in the growth between treatments ($t = 1.747$, $df = 42.7$, $P = 0.088$), density ($t = - 1.095$, $df = 140.61$, $P > 0.1$), or the first two months of the study (week 4: $t = 0.42$, $df = 139.22$, $P = 0.67$; week 8: $t = 1.751$, $df = 154.47$, $P = 0.082$) (Table 3).

Significance was found in the difference in weight in the last four months (week 12: $t = 3.154$, $df = 158.7$, $P = 0.002$; week 16: $t = 5.494$, $df = 158.8$, $P < 0.0001$; week 20: $t = 5.268$, $df = 154.4$, $P < 0.0001$; week 24: $t = 5.263$, $df = 151.37$, $P < 0.0001$), which would be expected as juvenile toads continue to grow larger through the study. Each week is compared to week zero, the release date, so there is an increase in significance of week the further into the study (Table 3).

Arthropod and RIFA sampling showed significantly lower abundance of both RIFA ($t = 4.258$, $df = 104.138$, $P < 0.001$) and other arthropods ($t = 3.194$, $df = 1607.65$, $P < 0.001$) in treated areas. For native ant species, there were nine times more individuals found in untreated area than in the treated area (Figure 5). Non-ant invertebrates were equal between treatments; total number of individuals was within 50 individuals of each other (Figure 5). The treated area contained 478 hectares and the untreated area contained 261 hectares. The total area used for invertebrate sampling in each treatment was constant, as well as equal sampling effort, so no standardization of the data was performed.

## IV. DISCUSSION

I failed to reject the null hypothesis, that there is no difference in survivorship or growth parameters for the Houston toad between areas treated and untreated for RIFA. Because the mixed effects model shows that there is no significant effect on weight due to treatment, nor density, I can assume that juvenile Houston toads survive at the same rate whether there is control for RIFA or not, as well as densities of 4 or 6 per exclosure having no effect on survival. I have no support for our hypothesis that RIFA are out competing the juvenile toads for insect prey and that will have a detrimental effect on the growth and survival of the juvenile toads. However, I can also conclude that both the RIFA treated and control groups grow and gain weight successfully; both groups have an average weight gain of over 400%. Succinctly, controlling for RIFA has no impact on the survivorship or success of juvenile Houston toads.

The results from our mixed effects model show a difference between weeks. This is to be expected as the toads are gaining weight between the weeks. Density was not found to be significant in our model; that is, I found no difference in weights between exclosures with four and six toads. Additionally, as densities declined over time due to mortalities, I found no significant effect on the growth of the toad. The starting densities of this project were chosen based on a prior project done with juvenile Houston toads in Bastrop County to determine the most successful densities for juvenile survivorship and both four and six were shown to be most successful (Jones 2015).

The best supported CJS model from Program MARK was $\varphi_t\, p_t$, where survivorship and recapture estimates vary over time, but not between treatments. With survivorship and recapture estimates constant between treatments, the best fit showed no difference in survivorship between treatments, meaning RIFA had no effect on survivorship. Survivorship and recapture estimates varying with time suggests that temporal conditions were a driving factor. This is not a surprise as I had a very wet, cool spring followed by a very hot, dry late summer, which would have an effect on successful survivorship. The drop in survivorship, and detection, at the fifth month corresponds to the hot, dry period at the end of the summer (Figure 4). The increased survivorship and detection at the beginning of the experiment are likely due to increased rainfall events which causes the toads to be above ground and active as well as minimizing desiccation due to dry conditions.

As further comparison of habitat types, two exclosures were placed within the drip line in each treatment area, for a total of eight exclosures. Although the small sample size renders them incomparable for statistical analysis, there was an interesting correlation between open prairie and shaded habitats. At the beginning of the experiment, the weights of those toads in the exclosures within the drip line increase at a much faster rate than those in the prairie. However, at about week nine of the experiment, there is a switch and the rapid increase of weight for toads in the exclosures within the drip line tapers off and at the same time, exponential growth for the toads in the prairie begins. Additionally, at week nine, the survivorship for the exclosures within the drip line stabilizes after the initial decrease, while there is a steady decrease in survivorship in the prairie exclosures (Figure 6). I presume this is due to availability of food. There is likely to be a constant high supply of food in the open prairie while the canopy does not provide that same amount of constant insect prey, regardless of the presence or absence of RIFA. Historically, the Houston toad is thought to inhabit canopied areas, and this study supports that the Houston toad juvenile survivorship is higher within a forested area than seen in open grassland, but also that open grassland is also vital for feeding and growth. However, the caveat to this is the unequal number of exclosures in the prairie (forty total exclosures) and those within the drip line (eight total exclosures) make it simply a trend that needs further exploration.

The invertebrate sampling data gives us some surprising results, seemingly going against the reported effects of RIFA on native populations (Porter and Savignano 1990) as well as creating concerns about the effectiveness of Extinguish® Plus targeting fire ants and not native ant species. Extinguish® Plus was successful in reducing the abundance of RIFA in the treated prairies, as the number of individuals was significantly less in treated areas than in untreated areas, but there was also a much smaller abundance of non-RIFA invertebrates as well. Porter and Savignano (1990) report total number of individuals of non-ant arthropods being 75% lower in the presence of RIFA, while I found the number in the untreated area (in the presence of RIFA) to be almost equal that of the treated (absence, or near absence, of RIFA) area. Additionally, with native ant species, there is also a much higher abundance in the untreated area than the treated area. This proves to be problematic because it appears that Extinguish® Plus is in fact not effective at targeting solely RIFA and has a detrimental effect on all native ant populations present in the habitat.

Despite the problematic invertebrate data, I still fail to reject our null hypothesis that RIFA has a negative impact on the successful survival of juvenile Houston toads. Thus, RIFA presence does not have a detrimental effect on the availability of food or growth, nor does it affect the number of individuals that survive.

The most successful area for survival of the juvenile toads in this study appears to be in the canopied area, which supports the long-standing statement that Houston toads are forest species and require cover to survive successfully. Additionally, this study shows also that Houston toads are able to persist outside pine forests. Further exploration of the species' ability to survive outside a pine forest is essential, in particular whether or not it is viable for adult Houston toads to be successful in a coastal prairie habitat. However, it has also been demonstrated in this study that open habitat is equally important for feeding and allowing for growth of juvenile toads. This confirms the critical need for upland habitat and connectivity for the success of juvenile Houston toads and the species as a whole.

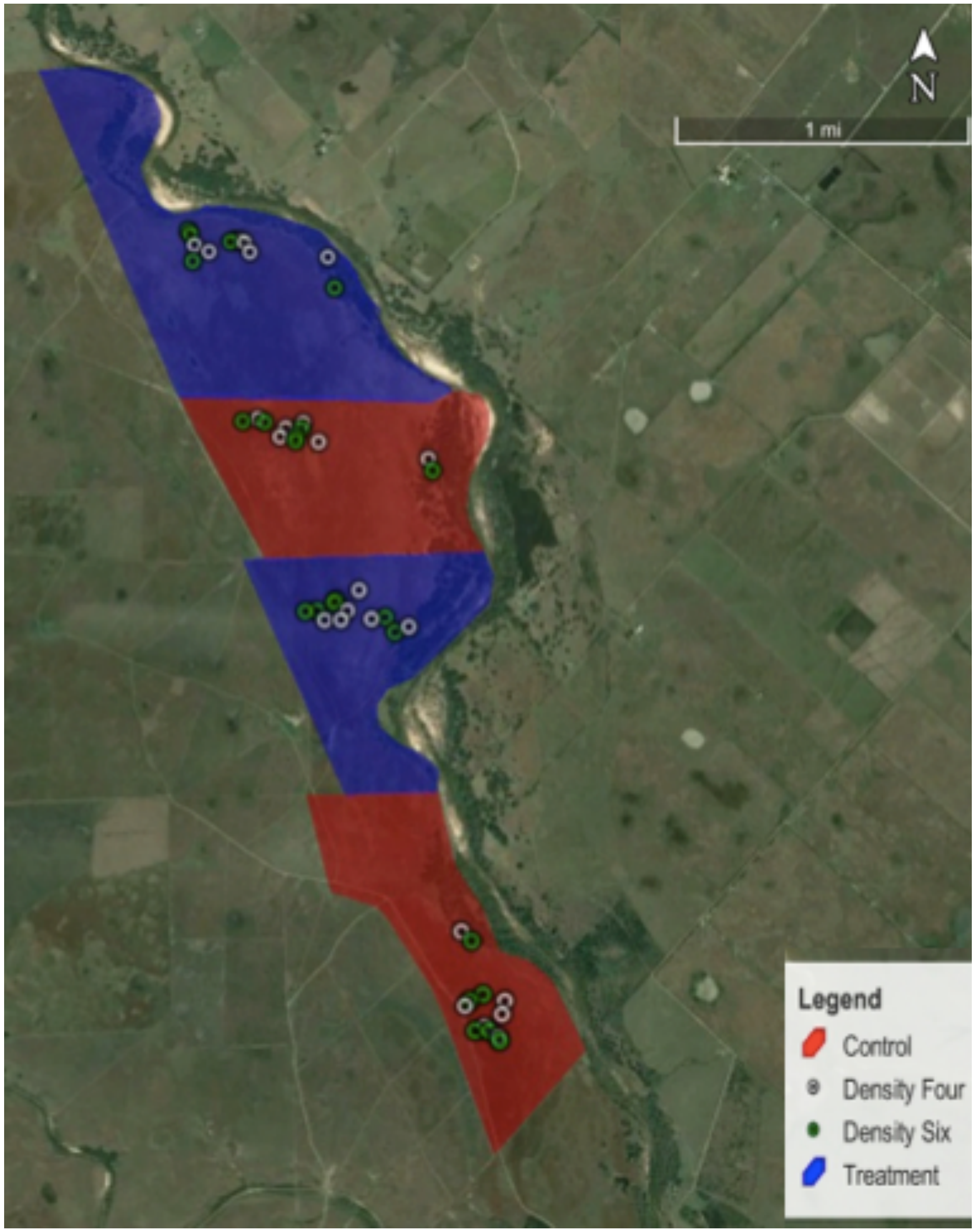


**Figure 1.** This map is of Attwater Prairie Chicken National Wildlife Refuge, near Houston, Texas. This refuge was used for a study on the effects of red-imported fire ants (RIFA) on juvenile Houston toad survivorship. It shows the four treatment areas and exclosure locations with individual toad densities of either 4 or 6. The blue areas were treated for RIFA aerially with Extinguish® Plus and the red areas were left untreated.

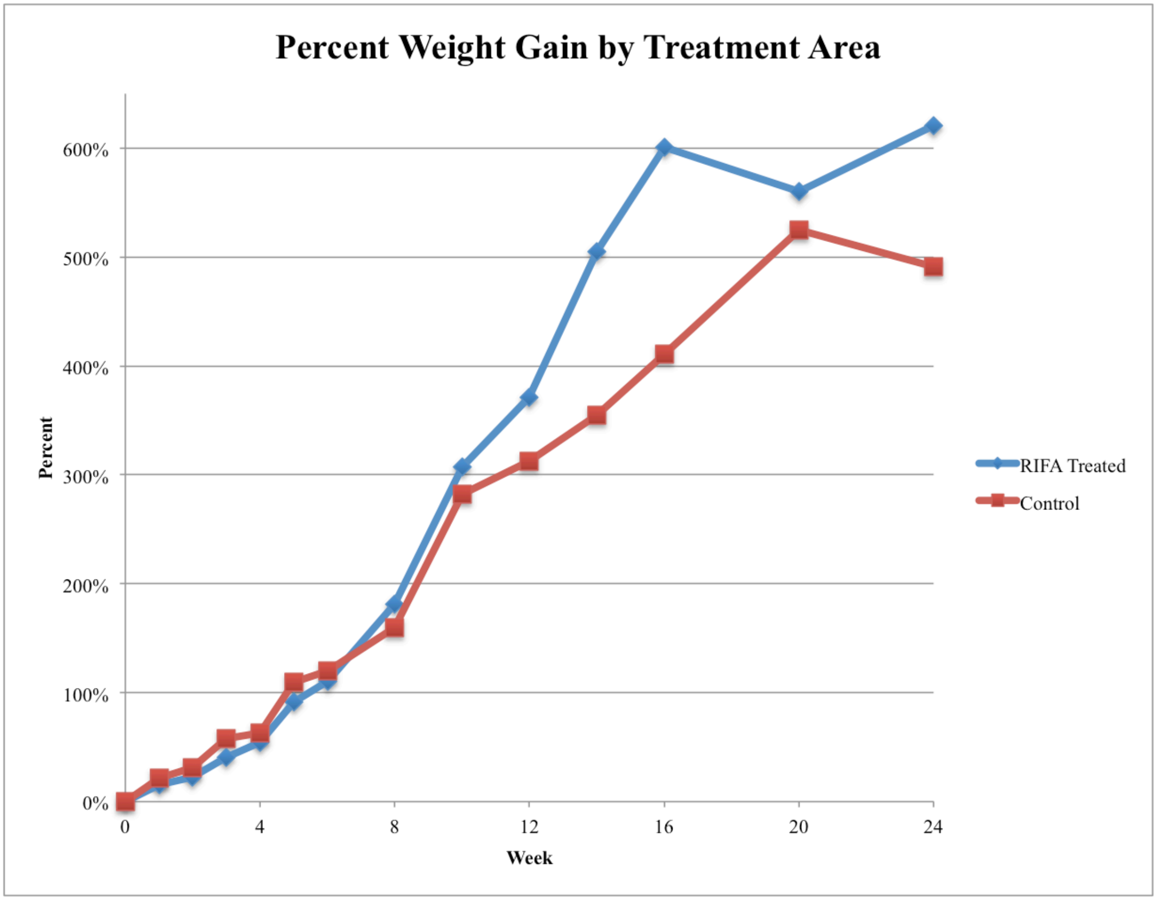


**Figure 2.** A comparison of Houston toads (*Bufo houstonensis)* cumulative percent weight gain of average weights for both treatment and control exclosures. Around week 10, toads in the RIFA treated area begin to gain weight at a faster rate than those in the control which coincides with heavy rainfall experienced in the spring. There is a drop off of that weight gained around week 20, which is during the very hot dry months during the summer.

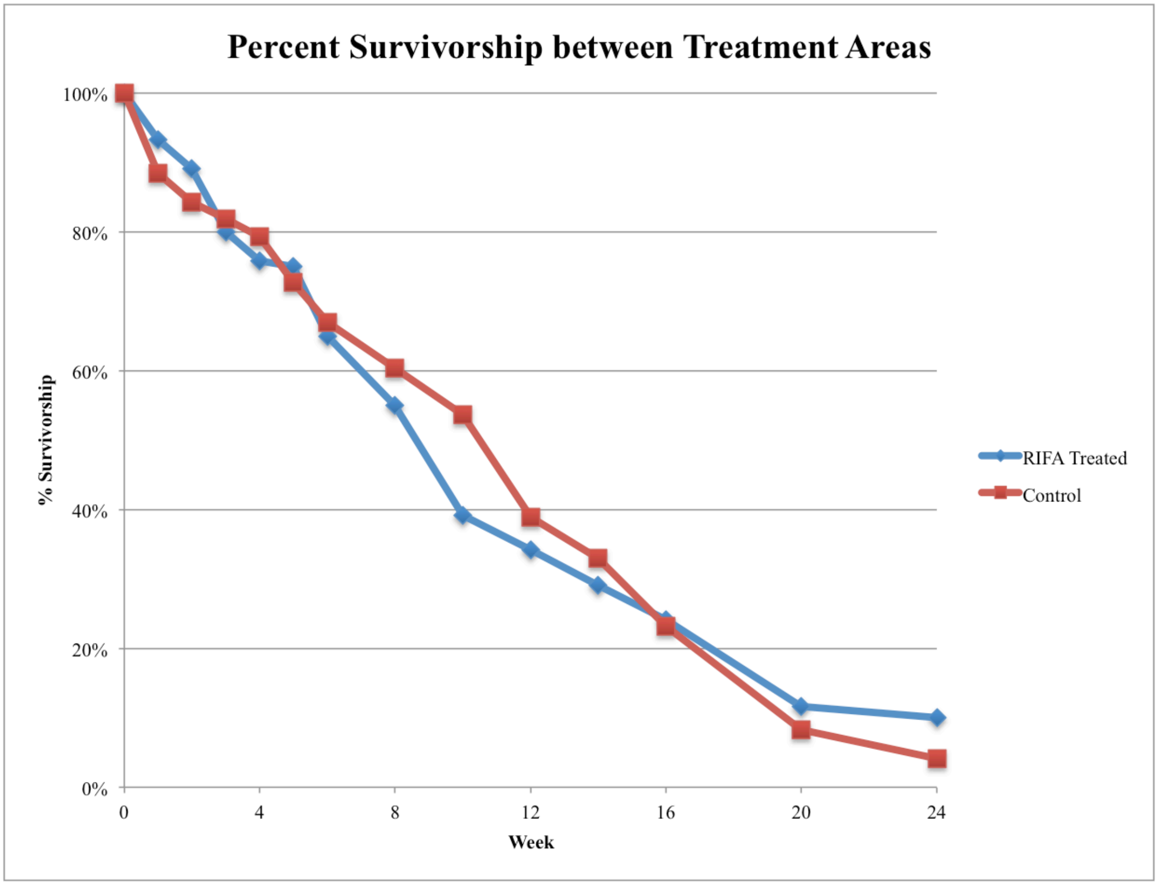


**Figure 3.** Percent survivorship of Houston toads (*Bufo houstonensis)* over all treatments for the entire 24-week experiment. There is little variation between the treatments in survivorship through the study, however around week 8 of the study there is a departure from this where the control areas begin to see a higher survivorship until week 12 when the treatments return to being very similar. Week 8 was during a very wet period, which ended around week 12 and it became very hot and dry.

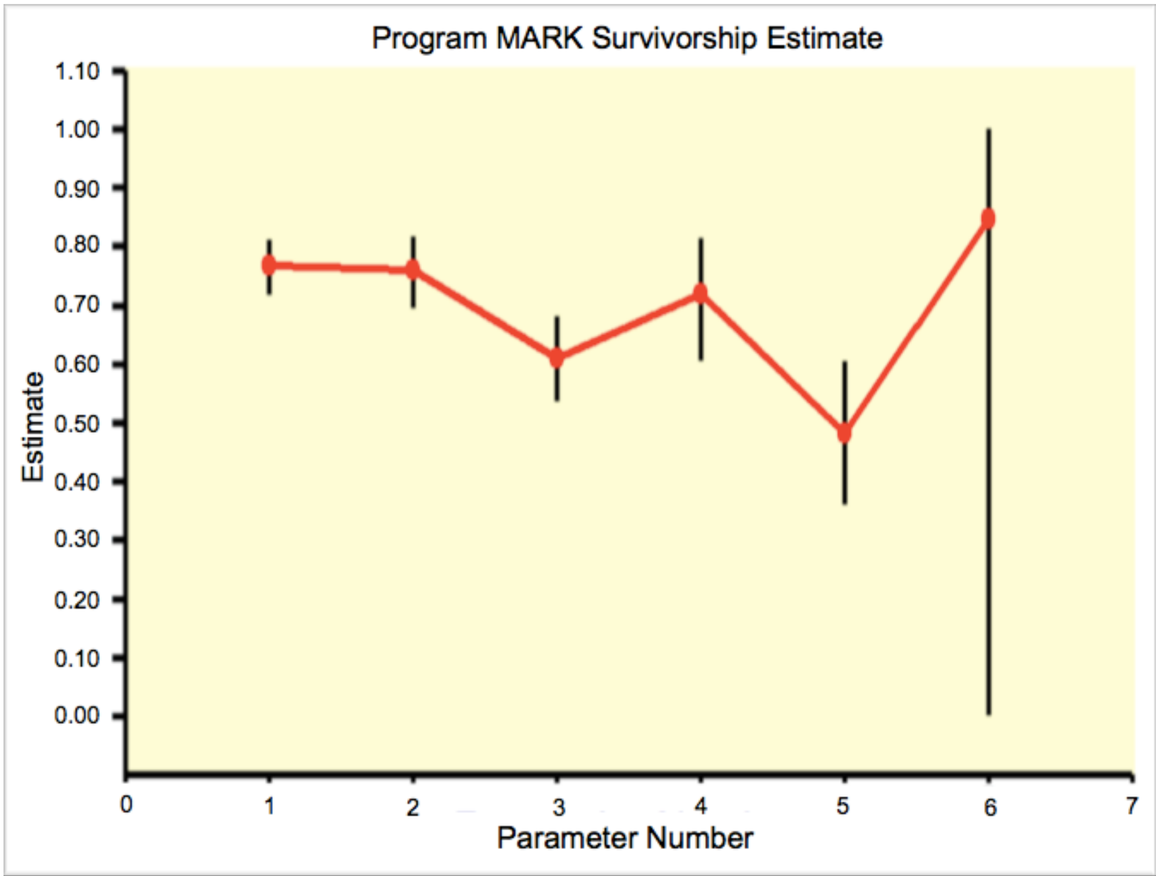


**Figure 4.** Program MARK output of survival estimates for all Houston toads (*Bufo houstonensis)* over the six-month experiment. Because the best-fit model did not show any difference between treatments, the survivorship is one single number. Parameter numbers correspond to the months of the study. The decrease seen at month 5 (parameter 5) corresponds to a period of very hot and dry weather at the end of the summer.

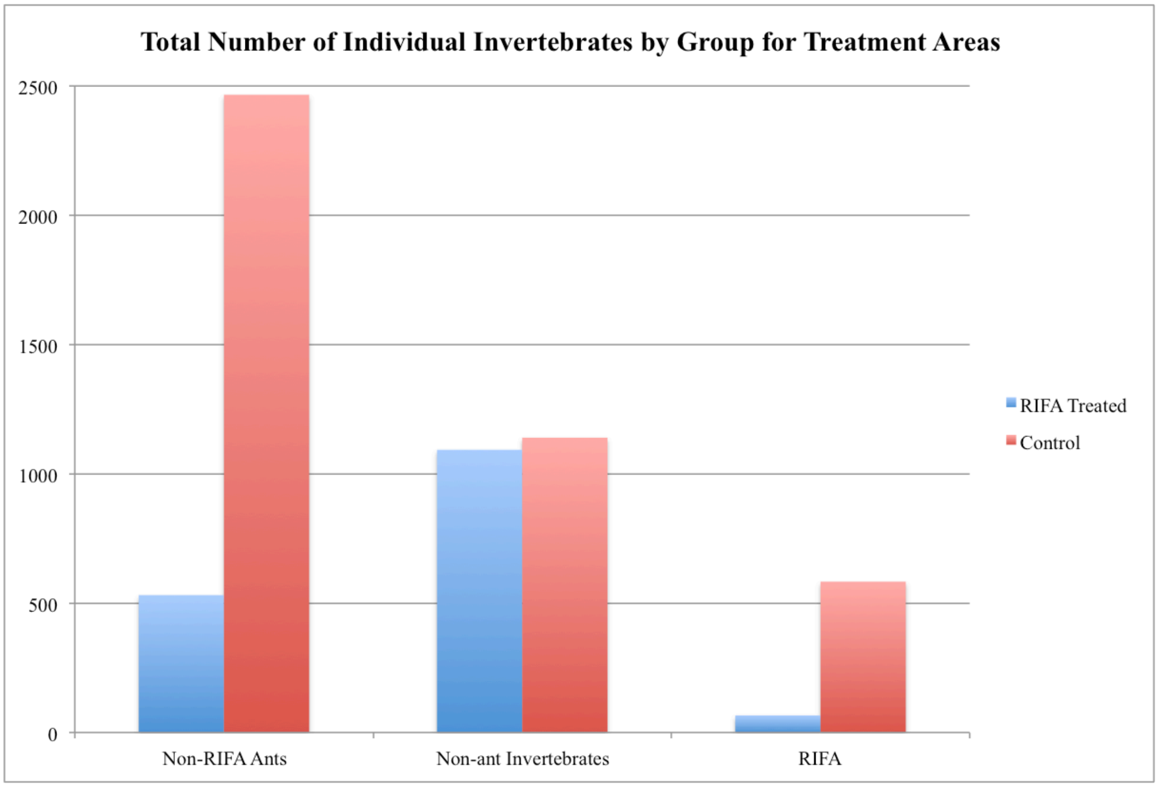


**Figure 5.** Total number of individual invertebrates for red-imported fire ants (RIFA), non-RIFA ants, and non-ant invertebrates in RIFA treated and untreated areas. Non-RIFA ants had a significantly higher abundance in the untreated area while non-ant invertebrates were very similar in numbers. The abundance of RIFA was significantly in the treated area than in the untreated.

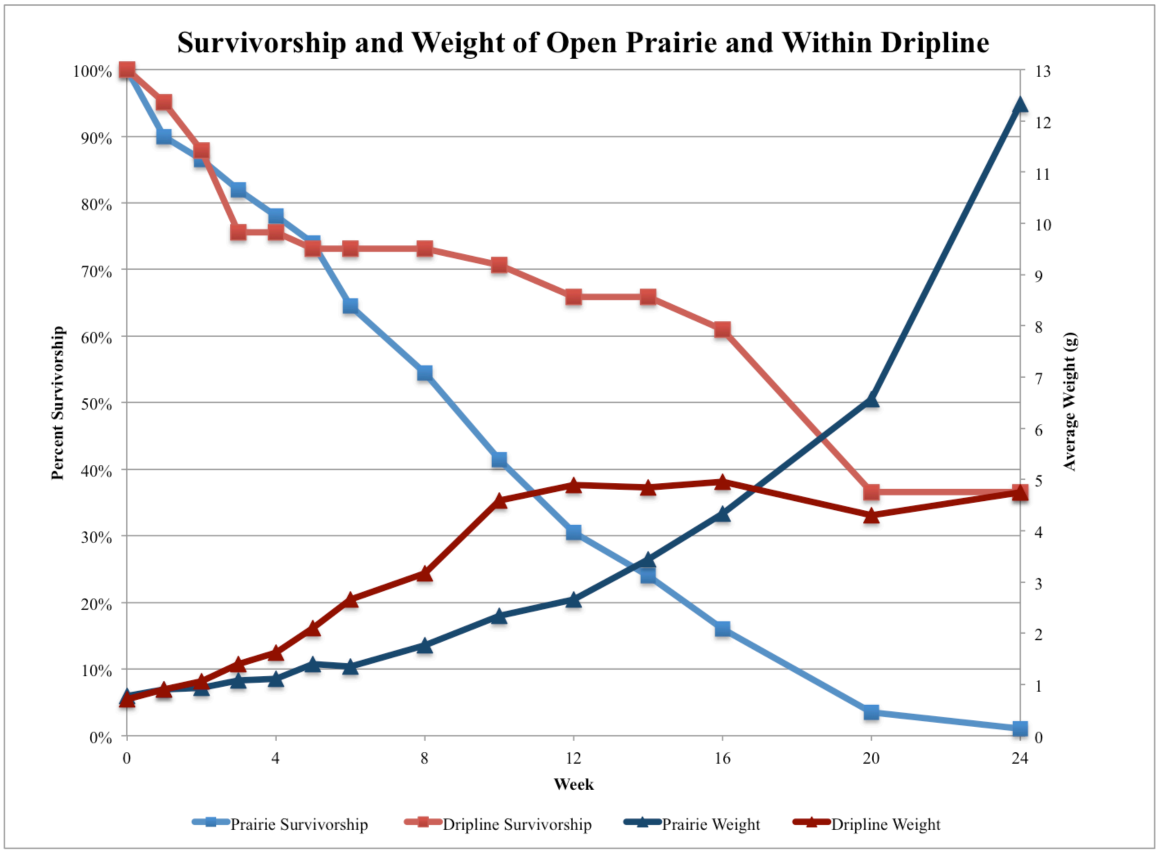


**Figure 6.** Comparison of exclosures within the drip line and open prairie exclosures, showing both average weights and survivorship of Houston toads (*Bufo houstonensis*) over 24 weeks. At week 9 the prairie weights begin to stabilize where they had been increasing at a faster rate than those within the drip line and the prairie exclosures begin exponential growth. The exclosures within the drip line see a much more stable survivorship after the initial decline while the prairie exclosures have a steady decrease in survivorship through the study.

**Table 1.** Cormack-Jolly-Seber candidate models and model selection results for estimating φ and *p* of 240 juvenile Houston toads (*Bufo houstonensis)* in prairies treated for RIFA (*Solenopsis invicta)* and untreated for RIFA. Models are listed by best fit to least fit based on $AIC_c$ scores. *t* represents time estimates, where one estimate is calculated for each sampling period, . holds estimates constant across time, and *g* represents group, for RIFA treated or untreated. The best fit model was φ and *p* differing across time, but not between groups, meaning there was no difference in survivorship or detection between treatments.

| Model | AICc | ΔAICc | AICc Weight | Likelihood | k | Deviance |
|---|---|---|---|---|---|---|
| *φ(t)p(t)* | 1640.4981 | 0 | 0.8601 | 1 | 11 | 60.3802 |
| *φ(t)p(.)* | 1644.9418 | 4.4437 | 0.09324 | 0.1084 | 7 | 72.9732 |
| *φ(t)p(g)* | 1646.9248 | 6.4267 | 0.03459 | 0.0402 | 8 | 72.9249 |
| *φ(t)p(g*t)* | 1650.443 | 9.9449 | 0.00596 | 0.0069 | 17 | 57.9802 |

**Table 2.** Estimates for *φ,* survivorship, and *p,* detection, of 240 juvenile Houston toads (*Bufo houstonensis)* in prairies treated for RIFA and untreated for RIFA, calculated using the best fit model from the AICc selection criterion using program MARK. The best fit model, and the one chosen, was *φ(t)p(t),* where survivorship and detection varied with time but not treatment.

| Parameter | Estimate | Standard Error | Lower CI (95%) | Upper CI (95%) |
|---|---|---|---|---|
| 1: *φ* | 0.768 | 0.024 | 0.718 | 0.811 |
| 2: *φ* | 0.76 | 0.032 | 0.693 | 0.817 |
| 3: *φ* | 0.61 | 0.037 | 0.535 | 0.68 |
| 4: *φ* | 0.72 | 0.054 | 0.603 | 0.813 |
| 5: *φ* | 0.481 | 0.064 | 0.36 | 0.604 |
| 6: *φ* | 0.848 | 88.99 | 0.00 | 1.00 |
| 7: *p* | 0.92 | 0.019 | 0.873 | 0.951 |
| 8: *p* | 0.873 | 0.03 | 0.803 | 0.92 |
| 9: *p* | 0.941 | 0.026 | 0.866 | 0.975 |
| 10: *p* | 0.854 | 0.055 | 0.71 | 0.933 |
| 11: *p* | 0.719 | 0.079 | 0.542 | 0.847 |
| 12: *p* | 0.848 | 89.02 | 0.00 | 1.00 |

**Table 3.** Results from a mixed effects model for repeated measures model for 240 juvenile Houston toads (*Bufo houstonensis)* in prairies treated and untreated for RIFA. The table is showing the results for the fixed factors of the study. Significant differences of weights between certain weeks were found, but no difference was found between treatments, densities, or the beginning weeks of the study.

| Variable | Estimate | df | T-value | P-value |
|---|---|---|---|---|
| Treatment | 0.6865 | 42.7100 | 1.747 | 0.088 |
| Density | -0.1472 | 140.6100 | -1.095 | 0.275 |
| Week 4 | 0.1739 | 139.2200 | 0.420 | 0.675 |
| Week 8 | 0.8459 | 154.4700 | 1.751 | 0.082 |
| Week 12 | 1.8651 | 158.7700 | 3.154 | 0.002 |
| Week 16 | 3.7036 | 158.8000 | 5.494 | <0.0001 |
| Week 20 | 5.6441 | 154.4400 | 5.268 | <0.0001 |
| Week 24 | 7.4340 | 151.3700 | 5.263 | <0.0001 |

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