HERPETOFAUNAL RESPONSES TO FIRE AND VARIATION IN AMPHIBIAN CALL INTENSITY IN AN EASTERN TEXAS POST OAK SAVANNAH LANDSCAPE

by

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A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

Major Subject: Biology

West Texas A&M University

Canyon, Texas

May 2015

ABSTRACT

Herpetofauna are critical links in the functioning of ecosystems. Despite this, herpetofauna are declining worldwide and more research is necessary to their declines and evaluate how various land management practices impact populations. Fire is a natural part of the savannahs of eastern Texas, but fire suppression has significantly altered landscapes in this region. As a result, controlled burning is being increasingly implemented in many areas to help restore the natural community. My goal was to determine how 3 burning treatments influenced the herpetofaunal community of Gus Engeling Wildlife Management Area in eastern Texas. I sampled herpetofauna with pitfall traps in summer of 2013 and both pitfall and funnel traps in summer of 2014. I captured 80 individuals of 14 species in 2013 and 109 individuals of 19 species in 2014. I then compared diversity, evenness, richness, and abundance using ANOVA with month and treatment as main effects, and found no differences among the various community characteristics across the burning treatments or months. At present, my data provides no evidence that the burning regime used by Gus Engeling WMA effects the herpetofaunal community, but further monitoring will be needed to evaluate longer term trends. I also used frog call surveys to monitor amphibians across the site. Frog call surveys are being used widely to monitor amphibian populations and their declines. I was interested in determining when during the year, as well as when throughout each night, different species call at Gus Engeling WMA in eastern Texas. For this study, I put out 7 audio

recorders in various habitat types and recorded from 23 February 2013 until 14 July 2013, with each recorder recording the first 5 minutes of every half hour from 18:00 – 07:00. Species richness was highest from the first week of April until the last week of May, and from 19:00 until 05:00 each night. With these data, I can recommend recording from late March until early June while also recording less time during each night than I did without losing detection of any species.

ACKNOWLEDGMENTS

I would like to thank the members of my committee: Dr. Rocky Ward, Dr. Richard Kazmaier, and Dr. Jim Rogers. Dr. Kazmaier has helped me with everything the past few years I have been at this school, and I would not be where I am today without his knowledge and tolerance. I would also like to thank professor Sandy Babitzke and former student Trey Barron for their guidance along the way. The staff and interns of Texas Parks and Wildlife Department at Gus Engeling WMA were incredibly helpful and accommodating, and this project would not have been possible without them. From Gus Engeling WMA, I would like to especially thank Jeff Gunnels, Tucker Slack, and Eric Woolverton. WTAMU Killgore Research Center provided me with a hefty grant to use towards my research, and for that I am very thankful. Several students took time from their busy schedules to drive all the way to eastern Texas and help me with this project, and I am very grateful to Joshua Dye, Mark Cancellare, and Korey Schroeder for their help setting up and running this project, and making it fun along the way. I would also like to thanks my officemate, Jessica Azzinnari, and roommate, Emma Browning, for putting up with hours of blaring frog calls day after day to complete this project. And finally, I would like to thank my family for the support along the way. Without all of these people, this project would not have been possible.

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INTRODUCTION

Herpetofauna are of conservation concern globally as their habitats are threatened by climate change, human interference, and other causes (Gibbons et al. 2000). Amphibians and reptiles together make up 46% of all terrestrial vertebrates, but are studied much less than birds and mammals (Lamoreux et al. 2006). These two groups occupy all terrestrial habitats aside from the high artic and Antarctica, yet they have the highest proportion of threatened species among vertebrate groups according to the International Union for Conservation of Nature (IUCN) (Lesbarrères et al. 2014). Amphibians and reptiles are declining faster than birds and mammals, but there continues to be a downward trend in the number of studies focused on herpetofauna (Stuart et al. 2004, McCallum and McCallum 2006, McCallum 2007, Christoffel and Lepczyk 2012). Herpetofauna can be the most abundant vertebrate group in the habitats they occupy, playing various roles in the ecosystem from seed dispersing to being an integral part of the food chain (Hartwell et al. 2002).

Amphibians rely on aquatic environments, especially for larval development in most species, and are not usually found more than 1000 m from at least a seasonal body of water (Pittman et al. 2013). Their reliance on an aquatic environment is one of the main reasons amphibians are declining so rapidly (Blaustein et al. 2011, Brum et al. 2013, Gibbons et al. 2000, McCallum 2007, Pittman et al. 2013). Amphibians have porous skin that is used to absorb water, and because of this, any chemicals or pollutants in the water can kill them (Jori et al. 2011, Hillyard et al. 2004). The aquatic environment is also where the fungus *Batrachochytrium* spp. are found (Bletz et al. 2013, Holden et al. 2014, Jori et al. 2011). These fungi can cause a disease known as chytridiomycosis that affects species globally by changing the chemical levels in the body and causing the heart to stop (Scheele et al. 2014, Baláž et al. 2013). Another major reason for amphibian decline is habitat loss (Mushet et al. 2014, Quesnelle et al. 2014, Harper et al. 2008, Biek et al. 2002, Gibbons et al. 2000). Because of their reliance on both terrestrial and aquatic environments, amphibians can suffer severe losses or be extirpated from an area when one of these environments is lost (Blaustein et al. 2011, Brum et al. 2013, Gibbons et al. 2000, Harper et al. 2008, McCallum 2007). Amphibians are anthropogenically important in their habitats because they are predators on terrestrial and aquatic invertebrates, helping humans to be more at ease in the outdoors (Werner and McCune 1979, Preston and Johnson 2012). Because they are sensitive towards changes in the environment, amphibians are considered to be good indicators of ecosystem health (Gardner et al. 2007, Gómez-Rodríguez et al. 2010, Scherer et al. 2012, Brum et al. 2013).

Like amphibians, many reptiles occupy both aquatic and terrestrial habitats, and thus are threatened more by habitat destruction than some other vertebrates may be (Araújo et al. 2006, Godley and Moler 2013, Gibbons et al. 2000). Reptiles can be major predators in certain habitats and can increase ecosystem health by releasing nutrients from their waste products into the soil. Herbivorous reptiles can disperse seeds and mix the soil by burrowing (McCain 2010, Smith et al. 2013, Bruton et al. 2013). Although reptiles and amphibians are critical to ecosystem functioning, their declines are largely going unnoticed, and management related research is sorely needed to help reverse declines.

Herpetofauna rely on many parts of the ecosystem to thrive, and when these areas are manipulated, it can have both positive and negative effects on the animals. Many terrestrial amphibians and reptiles rely on a leaf litter layer to seek shelter in as well as maintain much-needed higher humidity levels (Brown 2001). In many cases, flowering plants present in an ecosystem can attract more invertebrates, which can be a major food source for herpetofauna. These plants also enable them to seek shelter from predators (Diniz et al. 2011). On the other hand, some reptiles such as lizards do better in a more open, dry environment with sand rather than leaf litter covering the ground because they can better thermoregulate (Greenberg et al. 1994).

Fire in a variety of landscapes is commonly used to keep woody plant densities low (Spring et al. 2008, Polo et al. 2013, Wilgers and Horne 2007). Prescribed burning is commonly used to maintain biological diversity, improve wildlife habitat, and prevent exotic species from moving in to an area (Williams et al. 2012). Fire was a natural part of most ecosystems before settlers moved in and developed the land (Banschbach and Ogilvy 2014, Gilliam and Platt 1999). Managers restore natural processes by using fire on a regular basis to prevent the land from becoming overgrown with woody vegetation (Hu et al. 2013, Spring et al. 2008, Gilliam and Platt 1999). Burns can vary in intensity depending on whether they are done during the wet or dry part of the year, and the intensity of the burn can determine how much the landscape is being altered (Perry et al.

2009, Diniz et al. 2011). Fire suppression or too frequent burning will alter habitat beyond natural norms and can cause community shifts in species present on a site (Watson and Nicholson 2014, Hu et al. 2013).

Fire has long been used as a tool to manage wildlife, but the impacts of fire on the herpetofaunal community have been poorly studied (Greenburg and Waldrop 2008, Ruthven et al. 2008, Ashton and Knipps 2011). The studies that have looked at fire's effect on herpetofauna have found that direct mortality from fire is minimal and the herpetofaunal community as a whole can benefit from the it (Greenburg and Waldrop 2008, Perry et al. 2009, Gilliam and Platt 1999, Rochester et al. 2010, Ashton and Knipps 2011). However, indirect effects of fire on herpetofauna can result in a decline of the herpetofaunal community months or even years after the fire (Costa et al. 2013). Fire opens up the canopy, allowing more sunlight to reach the ground. This can positively impact lizards because they prefer higher temperatures, but can negatively impact amphibians by reducing humidity (Perry et al. 2009, Russell et al. 1999, Schneider and Kashian 2014). Opening up the canopy also allows for increased predation threats, especially from raptors (Perry et al. 2009, Costa et al. 2013, Wilgers and Horne 2007).

For this study, I investigated the influence of time since prescribed burn on a herpetofaunal community in eastern Texas. My hypothesis is that herpetofaunal diversity, richness, and evenness will be lowest for the months immediately following a fire. Additionally, as time since the burn increases the diversity, richness, and evenness of the herpetofaunal community should increase.

Study Area

I conducted this study at Gus Engeling Wildlife Management Area (WMA) in Anderson County in eastern Texas (Figure 1.1). Gus Engeling WMA is approximately 4465 ha and is dominated by Post Oak Savannah habitat (Singhurst et al. 2003). The land was acquired between 1950 and 1960, and is currently managed by the Wildlife Division of Texas Parks and Wildlife Department. As a research and demonstration area, Gus Engeling WMA allows opportunities for the public to hunt, fish, view wildlife, and learn about various management methods (Barron 2012). Prior to acquisition, the land was severely overgrazed, and when the state bought the property grazing was discontinued. Following cessation of grazing, the property was largely unmanaged (Singhurst et al. 2003). After decades of fire suppression, a burn regime was initiated at Gus Engeling WMA in 2005.

There are many small creeks, ponds, and marshes on site that lead to Catfish Creek, which runs along the eastern edge of the property (Barron 2012). Gus Engeling WMA has a number of habitat types ranging from flooded forests and lowland swamps to sandy, xeric grasslands. Much of the property is dominated by the 11 species of oak (*Quercus* spp.) found on site (Barron 2012, Singhurst et al. 2003). The dominant soil on Gus Engeling WMA is Queen City Sand with other areas of the WMA containing clay silt and ironstone (Singhurst et al 2003). Gus Engeling WMA is located in the subtropical humid region represented by long, hot summers and mild winters. Average yearly precipitation is 104 cm with May being the wettest month and August being the driest. Temperatures average 20°C with January being the coolest month and July and August being the hottest (Singhurst et al. 2003).

METHODS

Gus Engeling WMA is split into 25 compartments for burning purposes, with adjacent compartments not being burned at the same time. Burns were conducted during the winter months, most recently in the winters of 2011 and 2013. This study looked at the effects of 3 burning treatments: unburned, burned in winter 2011, and burned in winter 2013 (Figure 1.2). There were 3 trap arrays placed in 3 plots for each burning treatment for a total of 27 trap arrays. Additionally, this experimental design resulted in the arrangement of treatments into 3 blocks.

Year 1 Trapping

In May 2013, 27 pitfall arrays were installed. Each array consisted of an 18.9 L bucket in the center with 3 metal flashing drift fences radiating outwards at 120° angles resulting in a Y-shaped array. Each drift fence was 7.6 m long and 15.2 cm high. Each bucket had approx 5 cm of dirt in the bottom to allow animals to burrow, as well as a sponge that was wetted daily to keep humidity high. A 45.7 x 45.7 cm cover board was placed over each bucket to keep out the sun and reduce exposure-related mortality. Traps were spaced out on Gus Engeling WMA according to their burning compartments, and were all more than 50 m away from the road. Traps were checked daily for 9 consecutive days monthly in the summer of 2013 (5-15 June, 1-10 July, and 1-10 August).

Because of logistical issues, I was only able to sample all 27 pitfalls for June and the first 2 days in July, then only had access to 13 traps for the remainder of the July sampling period and the August sampling period. There was at least 1 trap kept open in each of the treatment blocks. To account for this, calculations were based on captures/trap nights as a relative abundance estimate.

Year 2 Trapping

Because of low capture success in 2013, I modified the existing 27 pitfall arrays by randomly placing 3 additional traps at the end of each drift fence arm. The additional traps include one 18.9 L pitfall trap, 1 minnow trap with 0.64 cm extracted steel mesh, and 1 minnow trap with 1.27 cm extracted steel mesh. The rectangular minnow traps are Minnie traps (J. K. Enterprises, Chantilly, VA, USA) and measure 45.7 cm length, 30.5 cm width, and 20.3 cm high. Each funnel trap also had a sponge in it that was wetted daily while traps were open along with a cover board placed over them to reduce stress associated with exposure. Traps were checked every other day for 10 consecutive days monthly in the summer of 2014 (1-11 June, 1-11 July, 1-11 August).

Specimen Processing

Any vertebrate captured was identified, measured, marked, and released > 3 m away from the trap. Measurements taken for herpetofauna included snout-vent length (SVL) and tail length if applicable. Vertebrates were weighed to the nearest 0.1 g and measurements were to the nearest mm. I used cohort marks on the specimens to identify month they were captured. For lizards and amphibians, a single toe was clipped representing the month/year the individual was captured, and the toes saved for future genetic work (Grafe et al. 2011). For snakes I used a handheld, battery-operated cauterizer to brand a cohort mark onto the subcaudal scales (Winne et al. 2006). When possible, sex and age (juvenile vs adult) were recorded. Recaptures were not included in analyses.

Toads (*Anaxyrus* spp.) in this region are known to be taxonomically confusing as many of them exhibit characteristics of multiple species (Fontenot et al. 2010, Masta et al. 2002). Additionally, many individuals captured were recent metamorphs, making character differentiation difficult. For this reason, I identified all toads only to the genus. Additionally, most of the southern leopard frogs (*Lithobates sphenocephalus*) and pickerel frogs (*Lithobates palustris*) captured were recent metamorphs and could not always be differentiated. Thus, I also lumped all true frogs captured into the genus *Lithobates* for analyses.

Analytical Methods

Richness, evenness, diversity, and abundance were calculated for each drift fence array within each month and year. Richness (s) was the total number of species captured within an array during each sampling period. Diversity was calculated with the Shannon-Weiner diversity equation (H'):

$$H' = -\sum pi \ln pi$$

Where *pi*= the proportion of the i^{th} taxon (Magurran 1988). Diversity was also calculated with the modified Simpson's index (modD).

$$\text{modD} = 1 - \Sigma\, pi^2$$

Where *pi*= the proportion of the i^{th} taxon (Magurran 1988). I chose to use 2 measures of diversity because different diversity indices often highlight different patterns Magurran 1998). Evenness was calculated as:

$$\text{Evenness} = \frac{H'}{H'_{max}}$$

Where H'_{max} = lnS. After calculating measured variables per drift fences, all variables were averaged across the 3 drift fences with each plot. Thus, the plot represented my experimental unit. Abundance was the number of captures of unique individuals made with each array during each month – year combination. I set $\alpha = 0.10$ for all comparisons. I compared richness, evenness, Shannon's diversity, modified Simpson's diversity, and abundances of common species (>5% of total captures) using analyses of variance with burning treatment and month as main affects. Because sampling methodology differed between years, I used separate analyses of variance to evaluate the 2 years individually.

RESULTS

Year 1

During the summer of 2013, there were 77 individuals of 9 species captured over 502 array nights (Table 1.1, Table 1.2). After looking at capture rates, I had sufficient captures of toads (*Anaxyrus* sp.), fence lizards (*Sceloporus undulatus*), six-lined racerunners (*Aspidoscelis sexlineata*), and true frogs (*Lithobates* sp.) to compare abundances of these species. There were also 3 mammals captured: 1 Baird's pocket gopher (*Geomys breviceps*), 1 golden mouse, (*Ochrotomys nuttalli*), and 1 least shrew (*Cryptotis parva*).

Following analysis of variance, there were no interactions between month and treatment ($F > 0.425$, $P > 0.321$) across all comparisons. There was also no detected influence of treatment on species abundance: toads ($F_{26} = 0.191$, $P = 0.828$), fence lizards ($F_{26} = 0.667$, $P = 0.526$), six-lined racerunners ($F_{26} = 0.056$, $P = 0.946$) and true frogs ($F_{26} = 0.437$, $P = 0.653$). Similarly, modified Simpson's index ($F_{26} = 0.027$, $P = 0.973$), Shannon's index ($F_{26} = 0.024$, $P = 0.977$), species richness ($F_{26} = 0.020$, $P = 0.981$), evenness ($F_{26} = 0.018$, $P = 0.982$), and total abundance ($F_{26} = 0.324$, $P = 0.727$) were not influenced by treatment (Table 1.3). There was also no detected influence of month on species abundance: toads ($F_{26} = 0.048$, $P = 0.954$), fence lizards ($F_{26} = 1.981$, $P = 0.167$), six-lined racerunners ($F_{26} = 0.264$, $P = 0.771$) and true frogs ($F_{26} = 2.380$, $P = 0.121$). Modified Simpson's index ($F_{26} = 0.803$, $P = 0.463$), Shannon's index ($F_{26} = 0.872$, $P = 0.435$), species richness ($F_{26} = 1.000$, $P = 0.387$), evenness ($F_{26} = 0.790$, $P = 0.469$), and total abundance ($F_{26} = 1.280$, $P = 0.302$) were not influenced by month (Table 1.4).

Year 2

During the summer of 2014, there were 107 herpetofauna captures of 15 species over 810 array nights (Table 1.5, Table 1.6). The most common species for analyses were fence lizards, true toads, six-lined racerunners, and true frogs. Mammals captured included 1 golden mouse and 1 hispid pocket mouse (*Chaetodipus hispidus*). I also captured 1 Carolina wren (*Thryothorus ludovicianus*). Adding the minnow traps and second pitfall for the second year of trapping increased my diversity, especially with snakes. The first year of trapping I only caught 3 flathead snakes (*Tantilla gracilis*), and the second year added many species of snake including: 1 pygmy rattlesnake (*Sistrurus miliarus*), 3 copperheads (*Agkistrodon contortrix*), 1 western ribbon snake (*Thamnophis proximus),* 3 black rat snakes (*Pantherophis obsoletus*), 3 coachwhips (*Masticophis flagellum*), and 2 plain-bellied water snakes (*Nerodia erythrogaster*). Of the different traps at each array, the large mesh traps captured 9 reptiles, 1 mammal, and 1 bird. The small mesh traps captured 8 reptiles and 2 amphibians. The center buckets captured 27 reptiles, 17 amphibians, and 1 mammal. Lastly, the side bucket traps captured 15 amphibians and 29 reptiles.

There was no detected influence of treatment on species abundances: six-lined racerunners (F_{26} = 1.738 P = 0.204), fence lizards (F_{26} = 2.422, P = 0.117), true frogs (F_{26} = 0.300, P = 0.744) and toads (F_{26} = 0.013, P = 0.987). Modified Simpson's index (F_{26} = 1.431, P = 0.265), Shannon's index (F_{26} = 1.789, P = 0.196), species richness (F_{26} = 1.033, P = 0.376), evenness (F_{26} = 1.333, P = 0.289), and total abundance (F_{26} = 1.178, P = 0.330) were not influenced by treatment (Table 1.7).There was also no detected influence of month on species abundances: six-lined racerunners (F_{26} = 0.595, P = 0.562), fence lizards (F_{26} = 1.089, P = 0.358), true frogs (F_{26} = 0.300, P = 0.745) and toads (F_{26} = 0.558, P = 0.582). Modified Simpson's index (F_{26} = 0.965, P = 0.400), Shannon's index (F_{26} = 0.708, P = 0.506), species richness (F_{26} = 1.132, P = 0.344), evenness (F_{26} = 0.422, P = 0.649), and total abundance (F_{26} = 0.586, P = 0.567) were not influenced by month (Table 1.8)

DISCUSSION

My results indicate that the current burning regime at Gus Engeling WMA appears to have minimal effect on herpetofaunal diversity, evenness, richness, or abundance. My results are largely consistent with similar studies that reported mostly a lack of significant effects of prescribed burning on reptiles and amphibian communities (Moseley at al. 2003, Ford et al. 1999, Greenberg and Waldrop 2008, Perry et al. 2009, Schneider and Kashian 2014, Langford et al. 2007). Frequent fires have been a natural part of the southeastern United States ecosystems for thousands of years (Sharitz et al. 1992, Russell et al. 1999) and the herpetofaunal community has likely adapted to these fires and the changes in the habitat that are associated with them (Greenberg 1994). That being said, weather effects have been documented to be a more important driver of herpetofaunal diversity than short-term effects of burning (Lesbarrères et al. 2014, Popescu et al. 2013, Martínez-Freiría et al. 2013, Araújo et al. 2006, Gardner et al. 2007).

In Georgia, Moseley at al. (2003) attributed a slightly lower number of amphibians captured in recently burned areas to dehydration resulting from the lack of leaf litter. Similarly, in Arkansas, Perry et al. (2009) attributed slightly higher captures of reptiles in recently burned areas to enhanced thermoregulation because of leaf litter removal. While prescribed fire is known to change the environment, other factors such as vegetation and insect abundance may affect herpetofauna more (Lindenmayer et al. 2008, Perry et al. 2012). Some vegetation communities are barely altered by a prescribed fire when the area has many fire tolerant plants and receives rainfall soon after burning, resulting in rapid regrowth (Francl and Small 2013

I suspect the main reason why I did not detect an effect with either variable (month or treatment) was because of my low capture success. Also, two years is a short amount of time to observe changes during, so continuing this study will help with looking for longer term trends. My capture rates were much lower compared to other studies, and one reason for that may be because red imported fire ants (*Solenopsis invicta*) are very abundant at Gus Engeling WMA and may be negatively affecting herpetofaunal communities by nest predation, competition for food, and direct mortality (Allen et al. 2004). I did not capture more than 20 individuals of any species within each month or treatment per year, thus making it difficult to detect significant statistical effects. My capture rates decreased throughout the summers, presumably because the temperatures increased and the precipitation decreased. Additionally, my results may not show any significant differences between treatments because there could be a lag in response time since fire, or because multiple fires need to come through an area to significantly alter the habitat before differences are noticed.

In general, my results support the idea that other factors, such as climate, may be a more important factor in altering herpetofaunal community than dormant season burning (Ruthven et al. 2008). My data from Gus Engeling WMA suggests the burning regime does not strongly influence the herpetofaunal community, and, unless additional research clarifies relationships, the managers can continue to burn the area to manage for mammals and birds without affecting the herpetofaunal community. In addition to looking at longer term trends of the current burning regime, it would also be beneficial to explore other fire variables, such as frequency or season of burning, to better evaluate the effects of controlled fire on herpetofaunal populations.

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Table 1.1. Number of individuals of each species of herpetofauna captured per burn treatment (unburned, winter 2011, winter 2013) at Gus Engeling WMA, Anderson County, Texas, during the summer of 2013.

Species	Treatment		
	Unburned	Winter 2011	Winter 2013
True toads	3	4	2
True frogs	8	3	2
Eastern narrowmouth toad (*Gastrophryne carolinensis*)	1	3	0
Hurter's spadefoot toad (*Scaphiopus hurterii*)	0	1	2
Fence lizard	6	11	6
Six-lined racerunner	5	5	3
Five-lined skink (*Plestiodon fasciatus*)	1	1	1
Ground skink (*Scincella lateralis*)	1	3	2
Flathead snake	1	0	2

Table 1.2. Number of individuals of each species of herpetofauna captured per month at Gus Engeling WMA, Anderson County, Texas, during the summer of 2013.

Species	Month		
	June	July	August
True toads	4	3	1
True frogs	13	0	0
Eastern narrowmouth toad	0	3	1
Hurter's spadefoot toad	2	1	0
Fence lizard	17	4	3
Six-lined racerunner	8	1	4
Five-lined skink	0	2	1
Ground skink	1	3	2
Flathead snake	2	0	1

Table 1.3. Relative abundances (average captures/array) and community statistics based on burn treatment (unburned, winter 2011, winter 2013) for herpetofauna at Gus Engeling WMA, Anderson County, Texas, during the summer of 2013.

Variable	Unburned		Winter 2011		Winter 2013		P-value
	mean	SD	mean	SD	mean	SD	
Toad abundance	0.148	0.170	0.148	0.170	0.074	0.021	0.828
Fence lizard abundance	0.259	0.231	0.519	0.361	0.296	0.280	0.526
Six-lined racerunner abundance	0.185	0.321	0.259	0.357	0.185	0.170	0.946
True frog abundance	0.296	0.513	0.111	0.192	0.074	0.128	0.653
Shannon's diversity	0.178	0.159	0.209	0.096	0.195	0.179	0.977
Modified Simpson's diversity	0.120	0.105	0.142	0.061	0.136	0.123	0.973
Species richness	0.926	0.231	1.000	0.289	0.944	0.536	0.981
Evenness	0.236	0.205	0.269	0.100	0.259	0.231	0.982

Table 1.4. Relative abundances (average captures/array) and community statistics based on month for herpetofauna at Gus Engeling WMA, Anderson County, Texas, during the summer of 2013.

Variable	June		July		August		P-value
	mean	SD	mean	SD	mean	SD	
Toad abundance	0.148	0.064	0.111	0.192	0.111	0.192	0.954
Fence lizard abundance	0.630	0.231	0.278	0.096	0.167	0.289	0.167
Six-lined racerunner abundance	0.296	0.232	0.111	0.192	0.222	0.385	0.771
True frog abundance	0.481	0.357	0.000	0.000	0.000	0.000	0.121
Shannon's diversity	0.294	0.065	0.112	0.116	0.175	0.155	0.435
Modified Simpson's diversity	0.199	0.041	0.080	0.084	0.120	0.104	0.463
Species richness	1.259	0.128	0.889	0.255	0.722	0.347	0.387
Evenness	0.381	0.031	0.162	0.167	0.221	0.191	0.469

Table 1.5. Number of individuals of each species of herpetofauna captured per burning treatment (unburned, winter 2011, winter 2013) at Gus Engeling WMA, Anderson County, Texas, during the summer of 2014.

Species	Treatment		
	Unburned	Winter 2011	Winter 2013
True toads	10	3	9
True frogs	4	3	2
Eastern narrowmouth toad	3	0	0
Hurter’s spadefoot toad	0	0	2
Fence lizard	3	8	16
Six-lined racerunner	4	3	11
Five-lined skink	1	0	1
Ground skink	1	4	1
Flathead snake	4	1	0
Pygmy rattlesnake	0	0	1
Copperhead	1	0	2
Western ribbon snake	1	0	0
Black rat snake	0	1	2
Coachwhip	2	1	0
Plain-bellied water snake	0	1	1

Table 1.6. Number of individuals of each species of herpetofauna captured per month at Gus Engeling WMA, Anderson County, Texas, during the summer of 2014.

Species	Month		
	June	July	August
True toads	7	8	7
True frogs	4	2	3
Eastern narrowmouth toad	3	0	0
Hurter's spadefoot toad	2	0	0
Fence lizard	5	8	14
Six-lined racerunner	8	8	2
Five-lined skink	1	1	0
Ground skink	5	0	0
Flathead snake	3	1	1
Pygmy rattlesnake	0	1	0
Copperhead	0	1	2
Western ribbon snake	1	0	0
Black rat snake	2	0	1
Coachwhip	1	0	2
Plain-bellied water snake	2	0	0

Table 1.7. Relative abundances (average captures/array) and community statistics based on burn treatment (unburned, winter 2011, winter 2013) for herpetofauna at Gus Engeling WMA, Anderson County, Texas, during the summer of 2014.

Variable	Unburned		Winter 2011		Winter 2013		P-value
	mean	SD	mean	SD	mean	SD	
Toad abundance	0.296	0.421	0.259	0.357	0.259	0.064	0.987
Fence lizard abundance	0.111	0.111	0.296	0.321	0.556	0.112	0.117
Six-lined racerunner abundance	0.148	0.128	0.111	0.111	0.444	0.223	0.204
True frog abundance	0.148	0.128	0.111	0.000	0.074	0.064	0.744
Shannon’s diversity	0.259	0.097	0.116	0.103	0.368	0.159	0.196
Modified Simpson’s diversity	0.717	0.084	0.486	0.272	0.604	0.155	0.265
Species richness	0.926	0.339	0.778	0.509	1.296	0.256	0.376
Evenness	0.275	0.081	0.145	0.126	0.390	0.164	0.289

Table 1.8. Relative abundances (average captures/array) and community statistics based on month for herpetofauna at Gus Engeling WMA, Anderson County, Texas, during the summer of 2014.

Variable	June		July		August		P-value
	mean	SD	mean	SD	mean	SD	
Toad abundance	0.370	0.357	0.111	0.111	0.333	0.334	0.582
Fence lizard abundance	0.185	0.231	0.296	0.321	0.481	0.232	0.358
Six-lined racerunner abundance	0.296	0.128	0.296	0.340	0.111	0.111	0.562
True frog abundance	0.148	0.064	0.074	0.064	0.111	0.111	0.744
Shannon's diversity	0.337	0.155	0.185	0.201	0.220	0.090	0.506
Modified Simpson's diversity	0.543	0.271	0.712	0.109	0.552	0.180	0.400
Species richness	1.296	0.128	0.741	0.632	0.963	0.064	0.344
Evenness	0.347	0.170	0.208	0.206	0.254	0.068	0.649

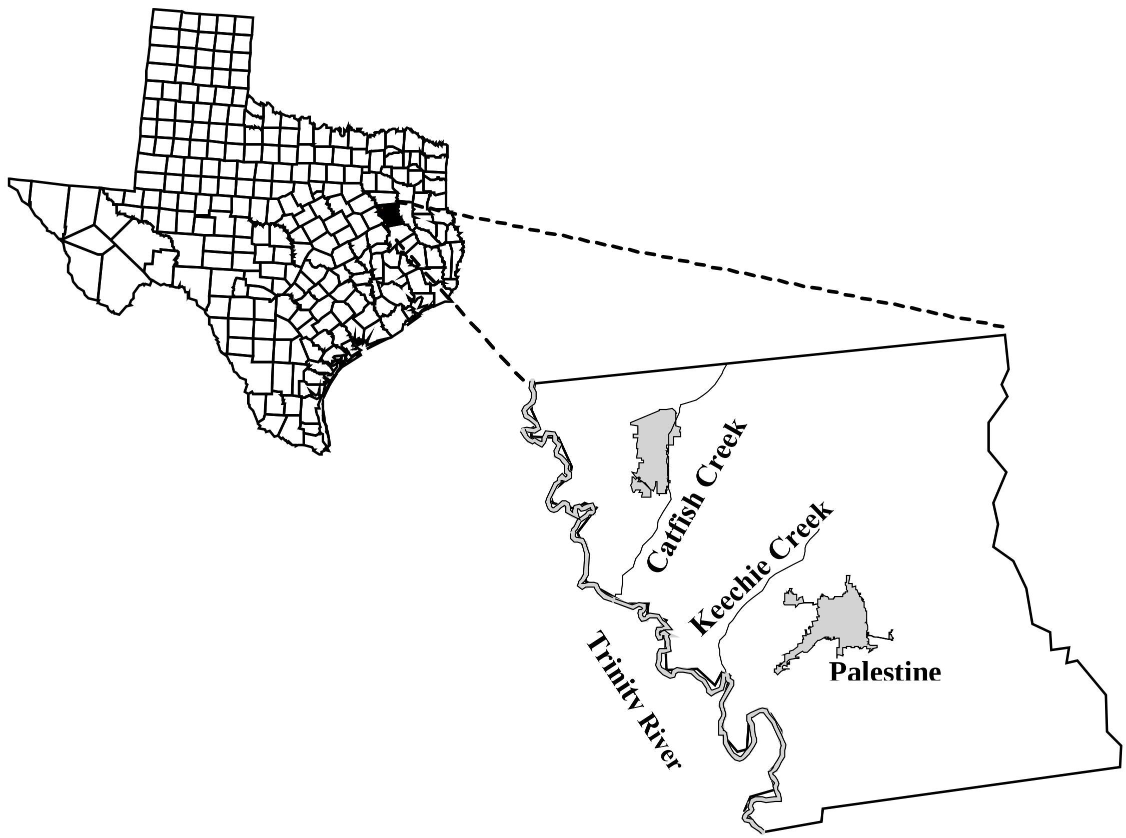

Figure 1.1. Location of Gus Engeling WMA in the northwestern corner of Anderson County, Texas along Catfish Creek.

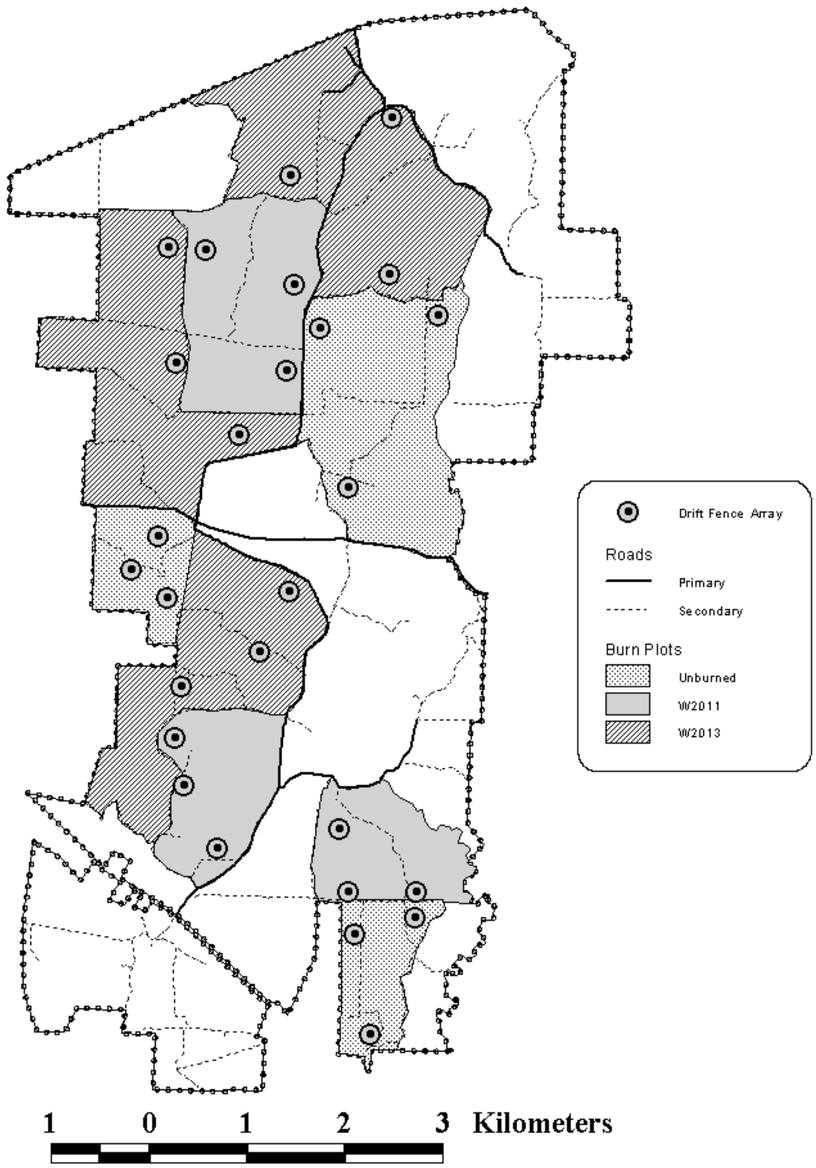

Figure 1.2. Location of trapping arrays within each burn plot at Gus Engeling WMA, Anderson County, Texas, 2013 - 2014.

CHAPTER II

AMPHIBIAN CALL DATA

INTRODUCTION

Amphibians are a taxonomically rich group of vertebrates that require both aquatic and terrestrial habitats for the various stages in their development (Blaustein et al. 2011, Brum et al. 2013, Gibbons et al. 2000, Harper et al. 2008). Thus, they are usually not found more than 1000 m from a seasonal or permanent body of water (Pittman et al. 2013). Amphibians are important in their habitats because they prey on both terrestrial and aquatic organisms, as well as being prey for many predators (Werner and McCune 1979, Preston and Johnson 2012). Amphibians are also good indicators of ecosystem health because of their sensitivity towards changes in the environment. In recent decades, amphibians have been declining globally at alarming rates because of climate change, habitat destruction, and disease (Buckley et al. 2013, Daskin et al. 2014, Pittman et al. 2014, Walls 2014, Salice 2012, Kiesecker 2011). This suggests environmental change is occurring that might ultimately affect humans (Gardner et al. 2007, Brum et al. 2013, Scherer et al. 2012, Gómez-Rodríguez et al. 2010).

These concerns have led to increased need to monitor amphibian populations. Because of the time-consuming nature of herpetofaunal surveys, there has been an increased emphasis on using acoustic monitoring to document the calls of anurans because most frogs give off a specific call when defending territory or trying to attract a mate (Milne et al. 2013, Bower et al. 2014, Acevedo and Villanueva-Rivera 2006). Such devices, often referred to as frog loggers, allow for documentation of species presence as well as estimates of abundance to monitor population trends (Acevedo and Villanueva-Rivera 2006). By recording sound at predetermined intervals and durations, researchers also have permanent vouchers of anuran choruses for future use (Fristrup and Mennitt 2012). Abundance and presence data derived from these loggers can be used to evaluate the influence of weather phenomena, habitat variables, and management treatments on anuran populations (Acevedo and Villanueva-Rivera 2006, Fristrup and Mennitt 2012).

Despite the increasingly widespread use of frog loggers, there is still considerable need to address the effectiveness of this tool and to determine appropriate protocols to best document the phenomenon of interest. Although frog loggers greatly reduce person-hours of field effort to collect data, they greatly increase the number of person-hours to process data because recorded calls must be scored. Therefore, any knowledge about the most appropriate times of day and season to document species calls would allow for a considerable reduction on labor if call recording intervals could be shortened.

I deployed frog loggers at a site in eastern Texas with 3 objectives. First, I wanted to determine species richness and seasonality of calling by frogs on the site. Second, I wanted to evaluate what times of the night were most effective for documenting the frog community at the site. Third, I wanted to determine what time of year was most effective for documenting the frog community at the site. Ultimately, these objectives should lead to the development of a more time efficient monitoring protocol for this site.

STUDY AREA

This study was conducted on Gus Engeling Wildlife Management Area (WMA) (Figure 2.1). This area is managed by the Wildlife Division of Texas Parks and Wildlife Department and is located in Anderson County in eastern Texas (Singhurst et al. 2003). The property is about 4465 ha and dominated by post oak savannah habitat (Singhurst et al. 2003). Several small creeks and streams flow into Catfish Creek which runs along the eastern portion of the property, creating several areas of flooded timber and marshes (Singhurst et al. 2003). Yearly average precipitation is about 104 cm, with the wettest month being May and the driest being August (Singhurst et al. 2003). Average annual temperature is 20°C with January being the coldest month and August being the warmest (Singhurst et al. 2003).

There have been 21 anurans recorded in Anderson County, with 17 of those being found on Gus Engeling WMA. The 17 species found on site are Hurter's spadefoot toad (*Scaphiopus hurteri*), northern cricket frog (*Acris crepitans*), green treefrog (*Hyla cinerea*), gray treefrog (*Hyla versicolor*), Cope's gray treefrog (*Hyla chrysoscelis*), spotted chorus frog (*Pseudacris clarkii*), spring peeper (*Pseudacris crucifer*), Texas toad (*Anaxyrus speciosus*), Coastal Plain toad (*Incilius nebulifer*), Fowler's toad (*Anaxyrus fowleri*), crawfish frog (*Lithobates areolata*), American bullfrog (*Lithobates catesbeianus*), green frog (*Lithobates clamitans*), pickerel frog (*Lithobates palustris*), southern leopard frog (*Lithobates sphenocephalus*), and eastern narrowmouth toad (*Gastrophryne carolinensis*) (Hines and Telfair 2004). It is also speculated that the American toad (*Anaxyrus americanus*) is found on site, but not included on the species list because of the confusion of the toads in this region. Some recognize the East Texas toad (*Anaxyrus velatus*) as being a valid species, but for this study I recognize the Fowler's toad in its place. The crawfish frog is classified as near-threatened by the IUCN (International Union for Conservation of Nature) and has not been documented on site recently (Richard Kazmaier, West Texas A&M University, Personal Communication).

METHODS

Seven frog loggers (Song Meter SM2, Wildlife Acoustics, Maynard, Massachusetts, USA) were placed in different habitat types across Gus Engeling WMA (Figure 2.2). Logger 1 was at the edge of a sphagnum bog. The bog contains many yellow pitcher plants (*Sarracenia flava*) and sundew (*Drosera* spp.), and was surrounded by moist, sparse oak woodlands. The bog received full sunlight during the days, but maintained high humidity levels. Logger 2 was at the edge of a marsh dominated by cutgrass (*Leersia* sp.). The marsh consistently held low levels of water, received full sunlight, and was surrounded by thick oak woodlands. Logger 3 was placed along a shaded creek surrounded by dense, oak woodlands. Not far past the logger the creek flowed up into a marsh. Logger 4 was placed at a small, shaded, upland pond dominated by water shield (*Brasenia schreberi*) and surrounded by sparse oak woodlands. Logger 5 was placed at the edge of a marsh. The marsh consistently held water, was open to sunlight in the middle, but the edges were covered with thick vegetation including greenbrier (*Smilax* spp.), common buttonbush (*Cephalanthus occidentalis*), and more. Logger 6 was located in flooded timber near Catfish Creek that either held low levels of water or kept moisture in the leaf litter. The flooded timber contained large oak trees without understory vegetation. Logger 7 was located at a small upland pond surrounded by oak trees and shrubs.

Loggers recorded off and on from 23 Feb 2013 until 14 July 2013 (Table 2.1). Each logger was set to record 5 minutes at every half hour from 18:00 until 07:00. Files were then listened to and given a ranking based on call intensity for each species. A rank of “0” meant no individuals of that species were calling. A rank of “1” meant a single individual of that species was calling. A rank of “2” meant <10 individuals of that species were calling. A rank of “3” meant it was a chorus (>10 individuals), but individuals were still distinct. A rank of “4” meant a large chorus of a species where individuals were not distinct. And a rank of “5” meant a chorus so loud it exceeded the capability of the microphone and made the microphone pop. Richness was calculated across week and time (every half hour throughout the night) for each logger, as well as all loggers together. Call rate by week and time were also calculated for each species. Gray tree frogs and Cope’s gray tree frogs have very similar calls and were told apart when possible. If there was uncertainty about the identity of a gray treefrog call, then I defaulted to *Hyla versicolor*. Low and high temperatures (Figure 2.3), as well as rainfall (Figure 2.4), were recorded for Palestine, TX and used to compare to results of frog calling data to determine trends. Palestine, TX is 33.8 km southeast of Gus Engeling WMA and is the closest town with weather data. Weather data were collected online from Weather Underground, Inc., San Francisco, CA, USA.

RESULTS

Technical and logistical issues resulted in incomplete records from some loggers, but 799 hours of recordings were made across the 7 loggers. Thirteen species of frog were detected, with only logger 2 picking up all 13 species (Table 2.2). Across all weeks and all species, call rates were highest from 20:00 – 23:00, but remained generally high from

23:00 – 05:00 as well (Figure 2.5). Activity was highest across all species from the first week of April until the end of May (Figure 2.6). Anurans known to occur on site, at least historically, but not detected were Texas toad, American toad, spotted chorus frog, and crawfish frog.

Hurter's spadefoot toads were detected on 43% of loggers (= loggers 1, 2, and 4). Across all weeks, detectability peaked at approximately 21:00, with a generally bimodal pattern highest from 20:30 – 22:30 and a slightly lower peak from 01:00 – 04:30 (Figure 2.7). Across all times, Hurter's spadefoots exhibited 3 peaks of activity corresponding to week 4, week 9, and week 11 (Figure 2.8). These weeks corresponded to precipitation events. When calls were detected, rates tended to be high (rate 2 – 3), which made detectability easier.

Northern cricket frogs were detected on 71% of loggers (= loggers 1, 2, 4, 5, and 7). Across all weeks, detectability was lowest from 05:30 – 07:00, and highest from 19:30 – 23:30, but there were no large peaks of activity throughout the night (Figure 2.9). Cricket frogs were not detected until the last week of March, and called regularly until the end of June when they started declining (Figure 2.10).

Green tree frogs were detected on 71% of the loggers (= loggers 1, 2, 4, 5, and 7). Across all weeks, detectability stayed consistent with a slight peak from 19:30 – 22:30, and a drop off from 04:30 – 06:00 (Figure 2.11). Green tree frogs were detected as early as the end of March and continued to call until the middle of May when they started to decline. They stopped calling by the middle of June (Figure 2.12).

Gray tree frogs were detected on 86% of the loggers (= loggers 1, 2, 4, 5, 6, and 7). Across all weeks, detectability was lowest from 05:00 – 07:00, and stayed fairly consistent throughout the rest of the night with a peak from 20:00 – 21:30 (Figure 2.13). Gray tree frogs were first detected at the beginning of March, peaked at the beginning of April and again in the middle of May, then declined rapidly at the beginning of July (Figure 2.14).

Cope's gray tree frogs were detected on 43% of the loggers (= loggers 1, 2, and 4). Across all weeks, detectability remained generally consistent throughout the night with the exception of 05:00 – 07:00 and 18:00 – 19:00 (Figure 2.15). There were 3 distinct peaks of activity from mid-March to mid-April, mid-April to end of April, and beginning of May to mid-May (Figure 2.16).

Spring peepers were detected on 86% of loggers (= loggers 1, 2, 3, 4, 5, and 6). Across all weeks, detectability stayed consistent with no dips or peaks (Figure 2.17). Spring peepers were calling strongly when loggers were first put out at the end of February, started declining the first week of April, and had completely stopped calling by the end of May (Figure 2.18).

Coastal Plains toads were detected on 43% of loggers (= loggers 1, 2, and 5). Across all weeks, calling only occurred from 18:30 – 03:00 and fluctuated little during this time (Figure 2.19). There were two distinct peaks of activity from the end of March until the end of April, and again from the end of April until the end of May (Figure 2.20).

Fowler's toads were detected on 43% of loggers (= loggers 1, 2, and 7). Across all weeks, calling was fairly consistent up until 05:30 when it dropped off (Figure 2.21).

Calling occurred very sporadically from the middle of March until end of June when it stopped completely (Figure 2.22).

American bullfrogs were detected on 57% of the loggers (= loggers 1, 2, 4, and 7). Across all weeks, calling was consistent throughout much of the night with a slight peak from 23:00 – 00:00 and dropped off from 05:00 – 07:00 (Figure 2.23). Calling only occurred in a single peak from mid-April to mid-May (Figure 2.24).

Green frogs were detected on 57% of the loggers (= loggers 1, 2, 4, and 7). Across all weeks, calling was fairly consistent with a drop from 05:30 – 07:00 (Figure 2.25). Green frogs were detected the last week of February, then not again until the end of March. Once they started calling at the end of March, they steadily increased their calling until a peak at the end of May, then decreased rapidly and were done calling by the middle of June (Figure 2.26).

Pickerel frogs were detected on 57% of the loggers (= loggers 2, 5, 6, and 7). Across all weeks, calling was generally consistent with a small peak from 19:00 – 22:00, and a drop off from 05:00 – 07:00 (Figure 2.27). Pickerel frogs had two peaks of activity, one from the beginning of March until mid-April, and the other from the beginning of May to the middle of May (Figure 2.28).

Southern leopard frogs were detected on 86% of the loggers (= loggers 1, 2, 4, 5, 6, and 7). Across all weeks, calling was generally consistent besides a drop from 05:00 – 07:00 (Figure 2.29). Southern leopard frogs sporadically called up until the middle of June when they stopped completely. In this time, there was a peak at the end of March, beginning of May, and beginning of June (Figure 2.30).

Eastern narrowmouth toads were detected on 57% of the loggers (= loggers 1, 2, 4, and 7). Across all weeks, calling stayed about level from 18:00 – 00:30, after which time it dropped lower and stayed consistent again (Figure 2.31). There were two distinct peaks of activity from mid-April until the end of April, then again from the beginning of May until the beginning of June. There were no other calls recorded outside these two peaks (Figure 2.32).

DISCUSSION

Using audio recorders, I was able to record a frog community without being physically present to document frog calls every night. Additionally, the loggers allowed for simultaneous sampling at multiple sites. Though several of the recorders malfunctioned, I still detected 13 of the 17 species of frogs that have been documented on site. Although I did not have the recorders out for an entire year, I did have them out for the breeding season and got a wide coverage of species in addition to detecting the peaks of activity for each species.

Hurter's spadefoot males enter breeding pools shortly after heavy rainfall and begin calling immediately (Bragg and Smith 1942). Temperatures at which males have been found calling in Texas were between 13 - 18°C (Wiest 1982). I observed spadefoots calling during weeks when highs and lows were 8 - 26°C, 8 - 28°C, and 7 - 29°C. All calling periods were after at least a little bit of rainfall (≥0.025 cm). Spadefoots were not observed calling until 19:00 and ceased calling by 05:00.

Northern cricket frogs call during the day and night, and in Texas have been observed calling at temperatures from 6 to 34°C (Wiest 1982). Calling has been detected as early as March in Texas, but breeding did not occur until April (Wiest 1982). I observed cricket frogs calling from the beginning of April until the beginning of July, and they called at all hours the loggers recorded during.

Green tree frogs start calling as early as late February in the South (Carr 1940). Usually, a few males start calling and more slowly join in until the chorus is nearly deafening, then all males may go silent for a few minutes. This pattern continues until the early morning hours (Dodd 2013). I observed green tree frog calling beginning the last week of March until mid-June, and they called all hours the loggers recorded.

Gray tree frogs have been recorded calling as early as March in Texas when temperatures were between 13 - 28°C (Wiest 1982). Males decrease the intensity of their calls as the breeding season goes on, as well as decrease the overall number of hours they spend calling (Runkle et al. 1994). I observed gray tree frogs calling consistently from the second weekend of March until the last weekend of June. Temperatures during that time ranged from -1 - 39°C. They also called all hours of the night.

Cope's gray tree frogs calls are normally heard in the south starting as early as February (Carr 1940). Calling usually begins at dusk unless there is diurnal rainfall, then they will call during it (Dodd, 2013). Males have been found to call as far away as 25 m from a pond (Godwin and Roble, 1983). Temperatures for calling are generally above 15°C (Godwin and Roble, 1983). I observed Cope's gray tree frogs calling from the last weekend of March until the second weekend of May. Temperatures during this time ranged from -3 - 29°C.

Spring peepers are a winter to early spring breeder depending on location (Sullivan and Hinshaw, 1990). In the south, calling is greatest from late November to February, with calls extending into April . Spring peepers are often extremely abundant at breeding ponds and tend to be the most commonly observed species calling (Gerhardt 1973). A majority of calls occur between 16:00 – 22:00. Optimum temperatures for calling are 10 - 20°C, but calls have been heard from <5 - >30°C as well (Owen 1996, Steelman and Dorcas, 2010). Spring peepers were calling in force when I first put my loggers out the last week of February. They started to decline in calling the second week of April, and completely stopped calling by the second week of May. Temperatures during this period ranged from -3 - 30°C. There was a slight peak in activity from 18:00 – 23:00 when all nights were averaged together, but spring peepers remained consistently high throughout all hours loggers recorded.

Coastal Plains toads have been recorded calling as early as March in Texas (Wiest 1982). Temperatures generally need to be above 17°C for males to begin calling (Thorton 1960). Some males have been noted to only call early in the season, where others call only later in the season (Dodd, 2013). I first observed them calling in the first week of April, and they stopped calling by the third week of May. Temperatures during this time ranged from 0 - 29°C.

Fowler’s toad choruses form in late spring to early summer, and temperatures must be above 10°C (Breden 1988, Green 1989). Males should prefer to call at cooler temperatures or in a cooler microclimate because it influences the frequency of the call to make them sound larger, which is something females prefer (Sullivan et al. 1996). I observed them calling from the last week of March until the second week of June. During this time, temperatures ranged from -3 - 34°C.

Bullfrogs call beginning in late spring and continue through mid-summer (Dodd 2013). Males have an inverse relationship between size and resonance of his call, thus telling the female how large the calling male is. Males are also able to recognize calls of nearby males to know if there is an intruder or if the one calling is just the male with territory adjacent to his own (Bee and Gerhardt 2002). Calling begins when air temperatures are above 21°C (Fitch 1956, Oseen and Wassersug, 2002). Calls start in late afternoon, but peaks are after midnight and tapers off at dawn (Mohr and Dorcas, 1999). I observed bullfrogs calling from the third week of April until the second week of May. Calling only occurred throughout the night from 18:00 – 05:30. There is a short peak at midnight, but overall calling was fairly consistent from 20:00 until 04:30. Temperatures during this time ranged from 0 - 29°C.

Green frogs will call both diurnally and nocturnally, but peak activity is generally from shortly after midnight until dawn (Mohr and Dorcas, 1999). In Louisiana, calling usually started in March, but has been heard as early as January (Dundee and Rossman, 1989, Meshaka et al. 2009). Temperatures will be between 11 - 29°C for calling, with activity peaking at temperatures from 22 -24°C (Meshaka et al. 2009). I had a small peak of calling the last week of February (temperatures 0 - 18°C), then did not hear them again until the first week of April. They continued to call until the first week of June. Temperatures during this time ranged from 0 - 33°C. They were observed calling all hours of the night with a peak from 23:00 - 03:00.

Pickerel frogs began calling as early as February in Louisiana (Dundee and Rossman, 1989). Calling begins shortly after dusk and at least some individuals will call throughout the night until dawn (Todd et al. 2009). Temperatures need to be above 10°C for males to start calling (Given 2005). I observed them calling the second week of March until the second week of April, with another small peak the second week of May. Temperatures during the first period of activity ranged from -3 - 30°C, then ranged from 7 - 29°C the second week of May. Calling started at 19:00 and stopped at 06:30 and was fairly consistent throughout this time period.

Southern leopard frogs can begin calling in January in Arkansas (Trauth 1989). Calling happens anytime throughout the day, but intensifies from 19:00 until dawn (Todd et al. 2003). Optimum calling temperature is 10°C, with the range being 5 - 30°C (Steelman and Dorcas, 2010). When I set out recorders the last week of February, they were already calling and continued until the second week of June. Temperatures during this time ranged from -3 - 34°C. They called throughout the entire night, but remained consistently higher from 19:00 – 05:00.

Eastern narrowmouth toads call at temperatures above 19.5°C (Dundee and Rossman, 1989). In the south, calls begin as early as March, but increase with intensity into April and May (Gaul and Mitchell, 2007, Trauth et al. 2004). Males make daily movements to and from breeding sites, usually at dusk, but have been observed calling during the daytime if humidity is high (Dodd and Cade, 1998). I first detected narrowmouths calling the third week of April, then again the second week of May until the fourth week of May. Temperatures during the April calling period ranged from 0 - 28°C, then from 7 - 33° during the May calling period.

Audio recorders were easy to install and required very little maintenance while out in the field, but transcribing 799 hours of frog calls was very time intensive. Shirose et al (1997) documented that a 3 minute recording was sufficient in monitoring most species present, and if another species was heard it was not until the ~15 minute mark. If I had recordings only lasting 3 minutes instead of 5 minutes, I would have had 479 hours of calls versus 799 hours, and saved 40% of time on transcribing calls and would not have lost any species I detected. I made sure all species detected had at least one recording where they occurred in the first 3 minutes of the recording. Most species did not start calling until 19:00 or 20:00, so being able to cut out the first hour or two would have saved me time. However, eastern narrowmouth toads tended to call earlier in the night, and when the other species started joining in the chorus around 20:00, the narrowmouths got masked out by the louder calls of other species very easily. Thus, it is possible that eastern narrowmouth toads could be missed with only later recordings. That was the only calling species I consistently heard right at 18:00 when the loggers started recording. Ending the loggers early in the morning around 03:00 would also have saved transcription time and I would not have lost any species that had not already been detected earlier in the night. So if I had cut down my recording time to start at 20:00 instead of 18:00, then end at 03:00 instead of 07:00, I would have reduced my time transcribing calls by 46% and not missed any species I detected.

Monitoring frogs by calling provides reasonable estimates for species presence, but may not estimate abundance well (Genet and Sargent 2003, Shirose et al. 1997). Audio recorders being used to monitor frog species can be much more practical than spending the man hours in the field listening at different ponds, in addition to allowing monitoring frogs at different locations at the same time. Another benefit to not being present while the frogs are calling is that you do not disturb them. Studies have shown that noises, lights, and blocking moonlight can all have an effect on calling species (Penman et al. 2005, Granda et al. 2008). Audio recorders also allow for a permanent record of the call in case it is challenged or if taxonomy changes. For species with very similar calls, more expensive software can be added to map out the call and determine which species it is (Penman et al. 2005). After the initial cost of the audio recorders, this method is less expensive than driving to a site daily to listen for frogs in the same area the recorders are in (Penman et al. 2005). The downside of audio recorders is they can malfunction because of weather conditions, technical problems, or animal damage (Penman et al. 2005, Shearin et al. 2012). You also have to change batteries before they die and change memory cards before they fill up. Additionally, frog loggers are ineffective in sampling for species that are present on the area but not calling. Under such situations, there is no substitution

Overall, audio recorders were very useful and I would recommend researchers who are using them to do so for almost half the time throughout each night than I did to save time in the lab. At least in this region of eastern Texas, having recorders out from the middle of March until the end of May should be the minimum, and recording from 20:00 – 05:00 should be the minimum for times throughout the night. This is an excellent way to determine species present at breeding locations with minimal disturbance to the animals while also collecting much-needed data.

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Table 2.1 Days within each month frog loggers successfully recorded data at Gus Engeling WMA, Anderson County, Texas in 2013.

	February	March	April	May	June	July
Logger 1	23-28		3-30	1-14		
Logger 2	23-28	1-31	1-30	1-14		
Logger 3	23-28	1-10				
Logger 4	23-28	1-26	14-21, 26-30	1-14		
Logger 5	23-28	1-27	14-20			
Logger 6	23-28	1-27				
Logger 7			12-30	1-31	1-30	1-14

Table 2.2. Species present on each frog logger at Gus Engeling WMA, Anderson County, Texas in 2013.

	Logger 1	Logger 2	Logger 3	Logger 4	Logger 5	Logger 6	Logger 7
Hurter's spadefoot	x	x		x			
Northern cricket frog	x	x		x	x		x
Green tree frog	x	x		x	x		x
Gray tree frog	x	x		x	x	x	x
Cope's gray tree frog	x	x		x			
Spring peeper	x	x	x	x	x	x	
Gulf coast toad	x	x			x		
Fowler's toad	x	x					x
Bullfrog	x	x		x			x
Green frog	x	x		x			x
Pickerel frog		x			x	x	x
Southern leopard frog	x	x		x	x	x	x
Eastern narrowmouth toad	x	x		x			x

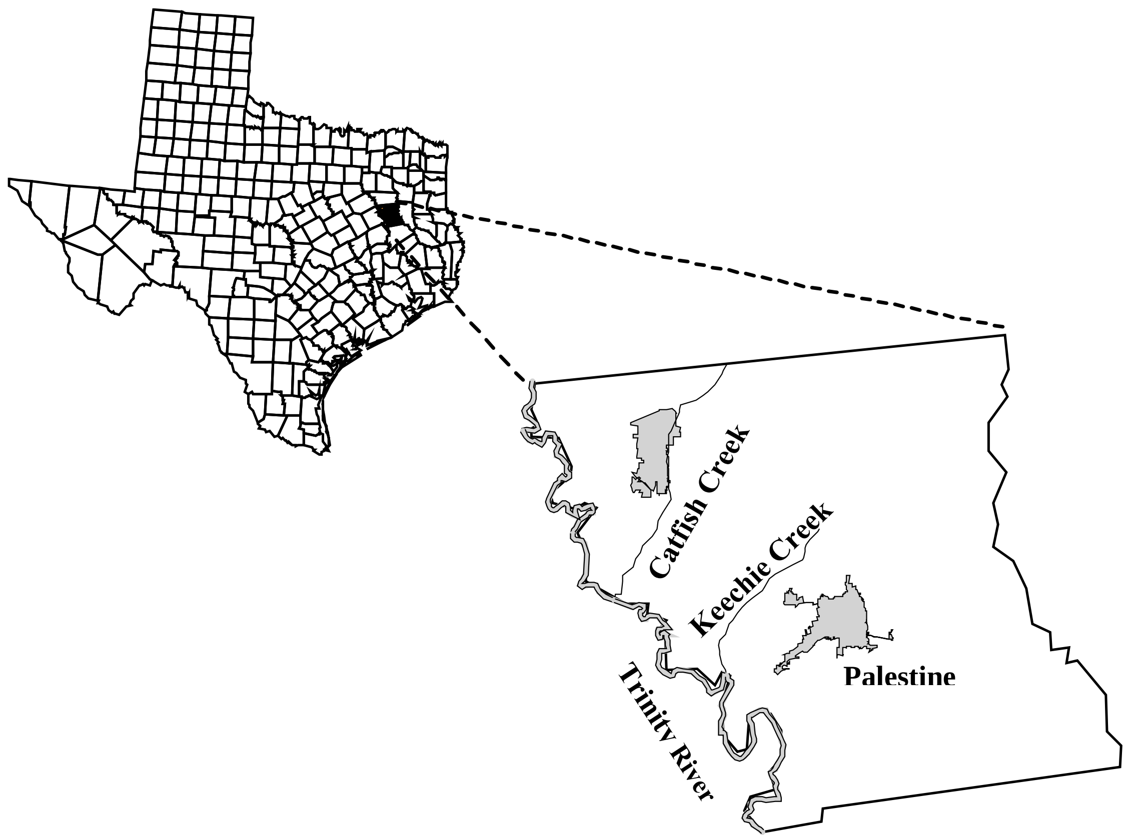

Figure 2.1. Location of Gus Engeling WMA in the northwestern corner of Anderson County, Texas along Catfish Creek.

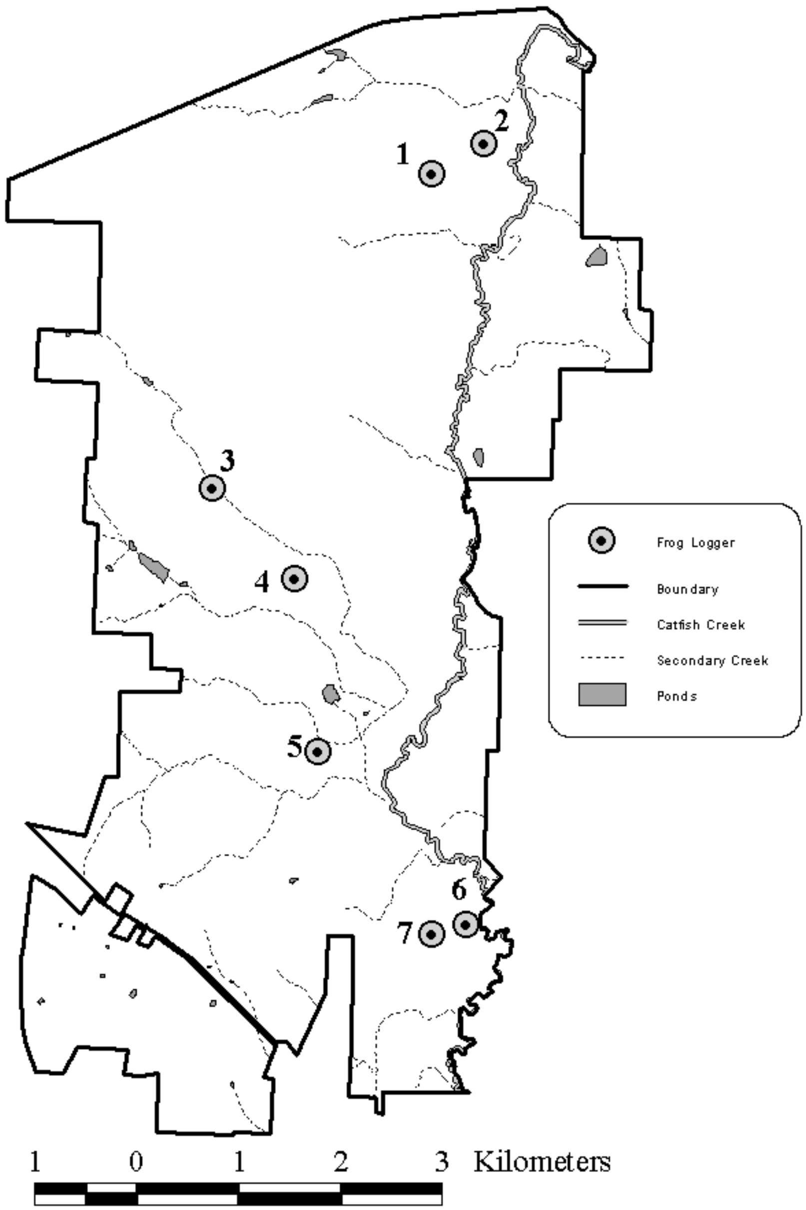

Figure 2.2. Frog logger locations within Gus Engeling WMA, Anderson County, Texas, 2013.

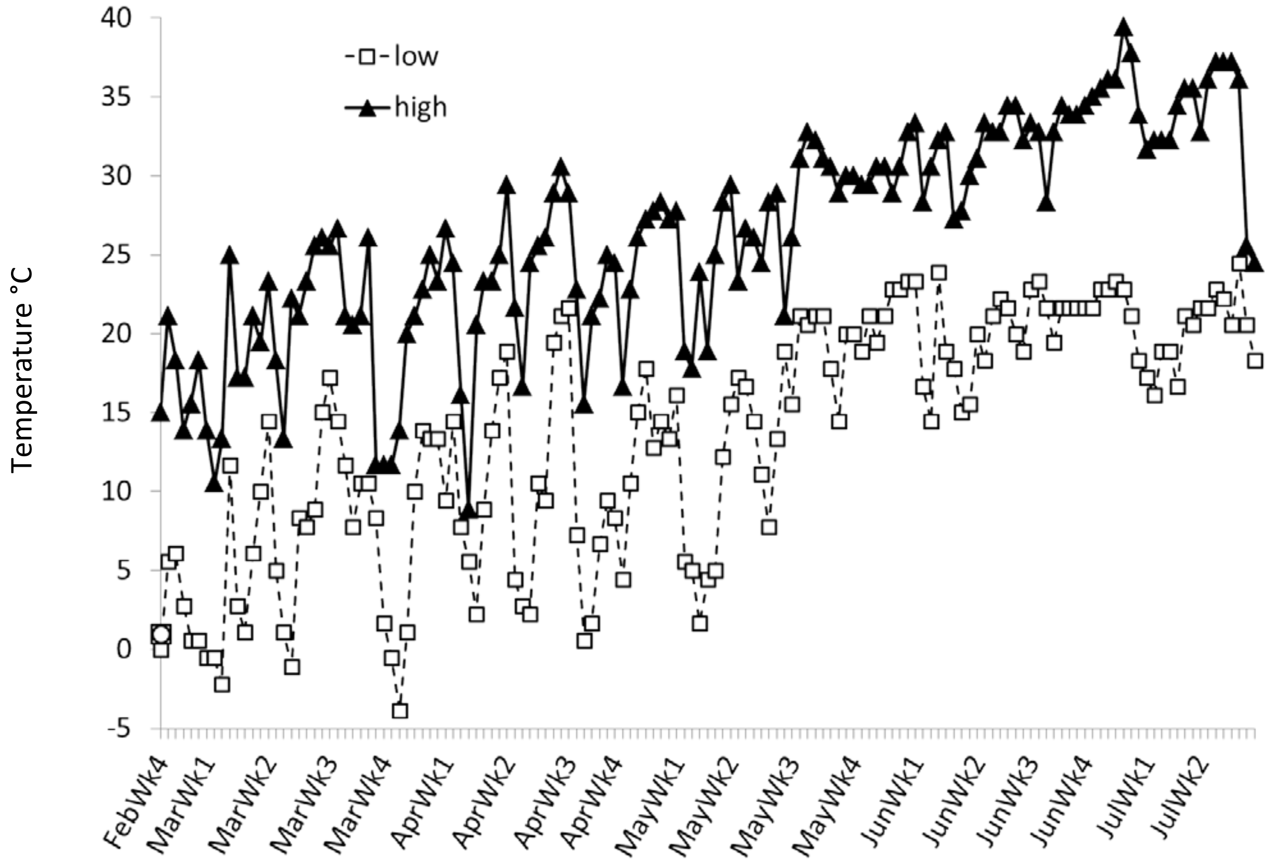

Figure 2.3 High and low temperatures by week for Palestine, Texas in 2013.

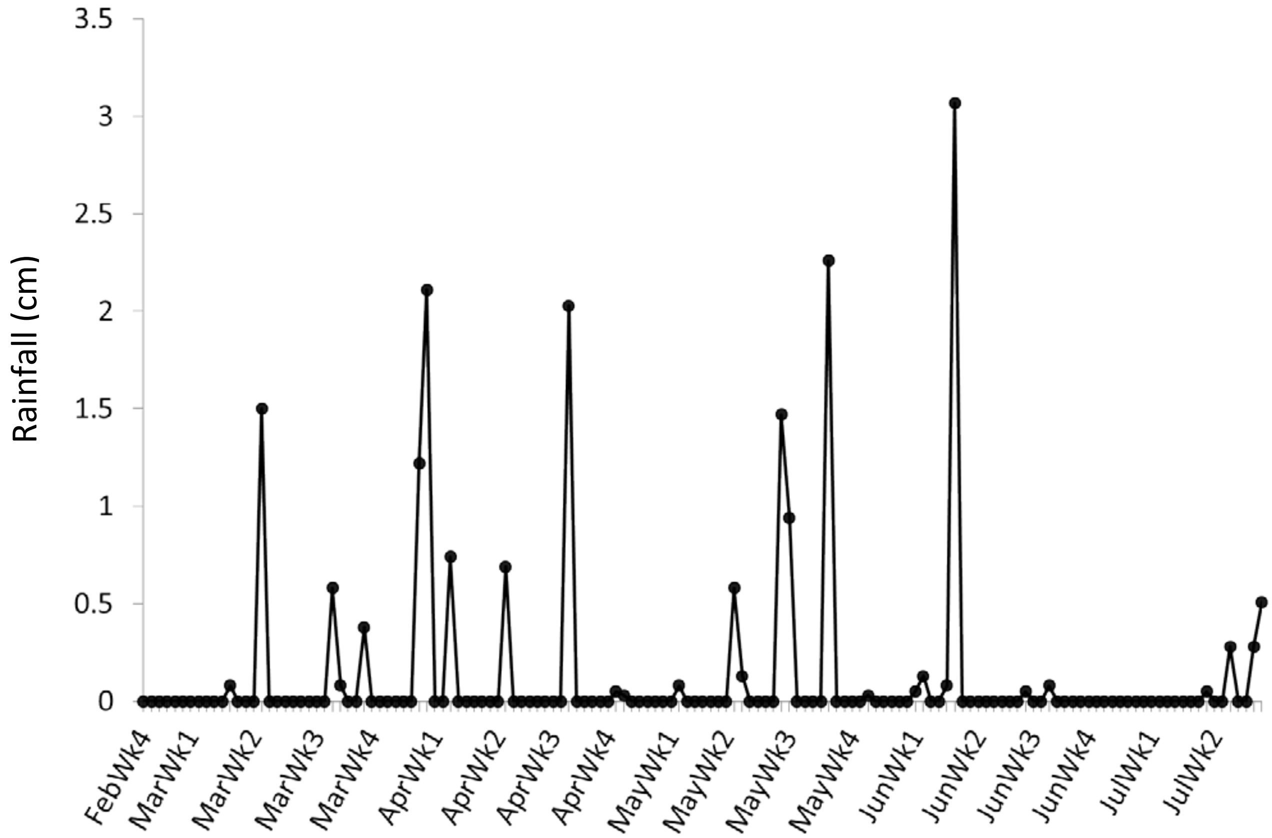

Figure 2.4. Rainfall amounts from the 4th week of February until the 2nd week of July for Palestine, Texas in 2013.

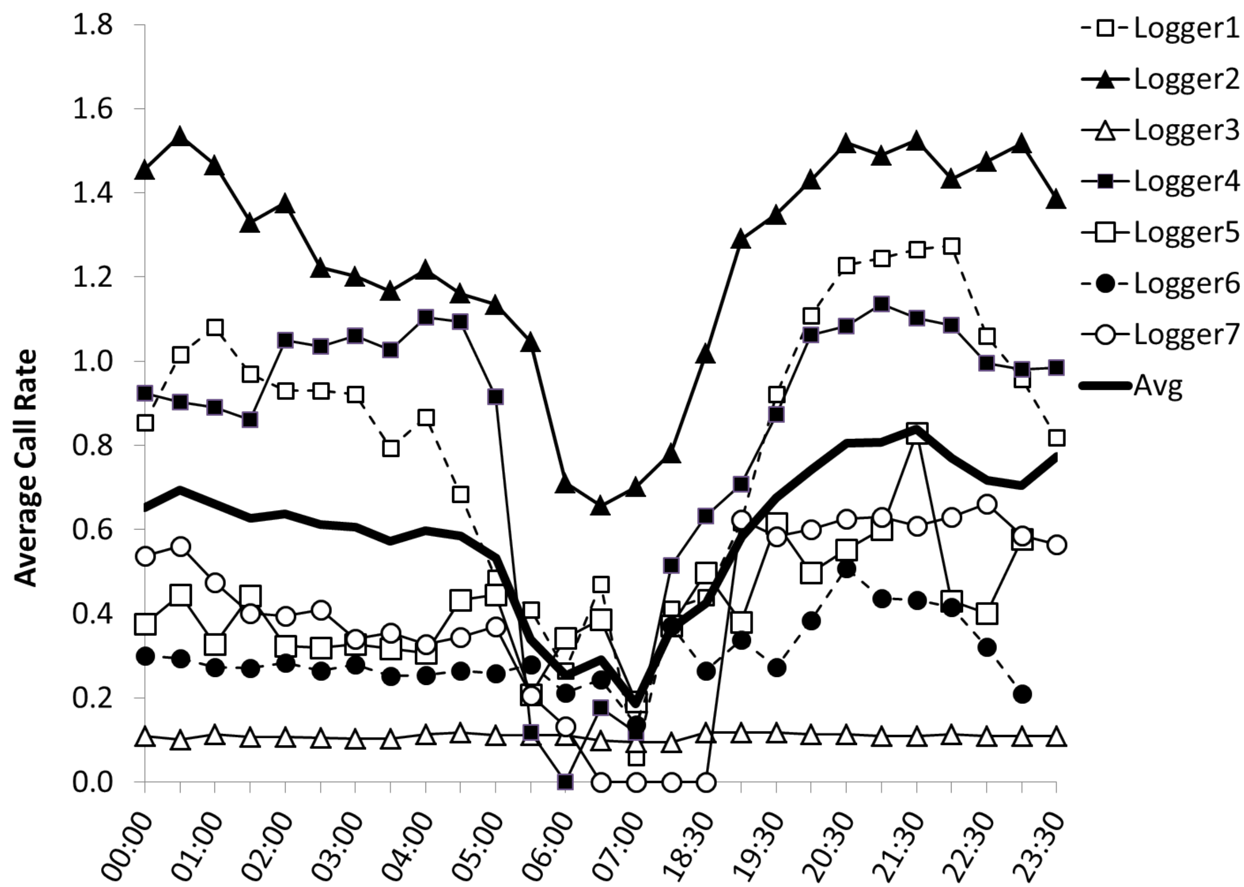

Figure 2.5. Average call rate for all species present across all frog loggers from 18:00 – 07:00 throughout the duration of the study at Gus Engeling WMA, Anderson County, Texas in 2013.

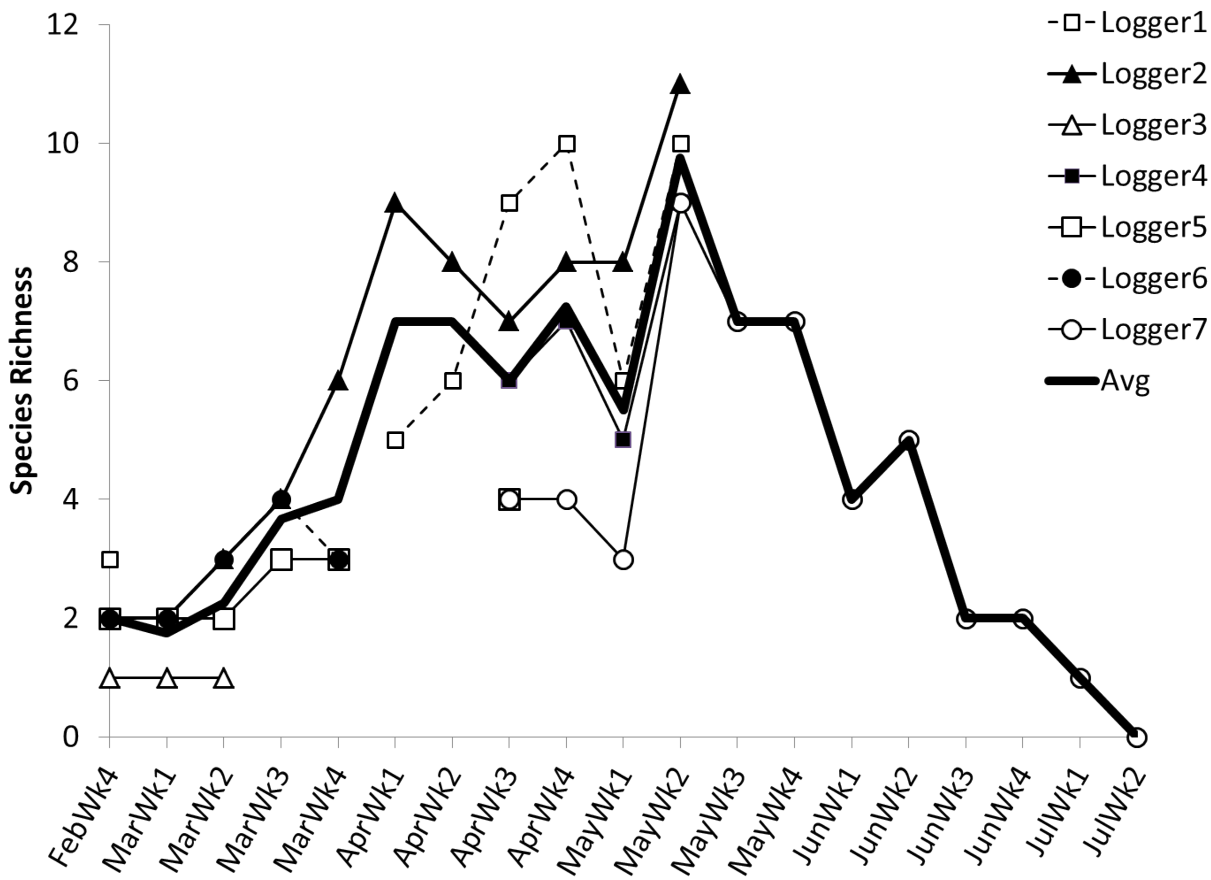

Figure 2.6. Species richness across all frog loggers from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

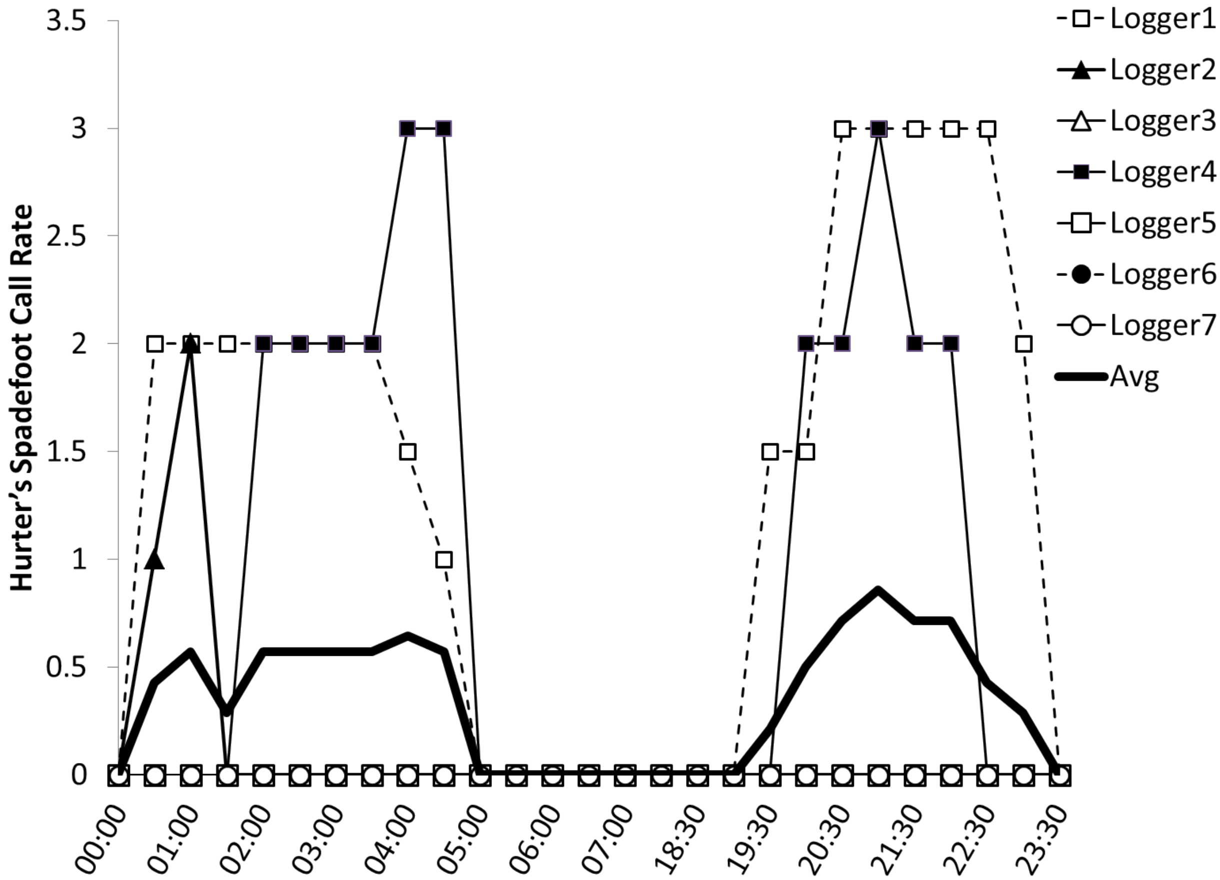

Figure 2.7. Hurter's spadefoot call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

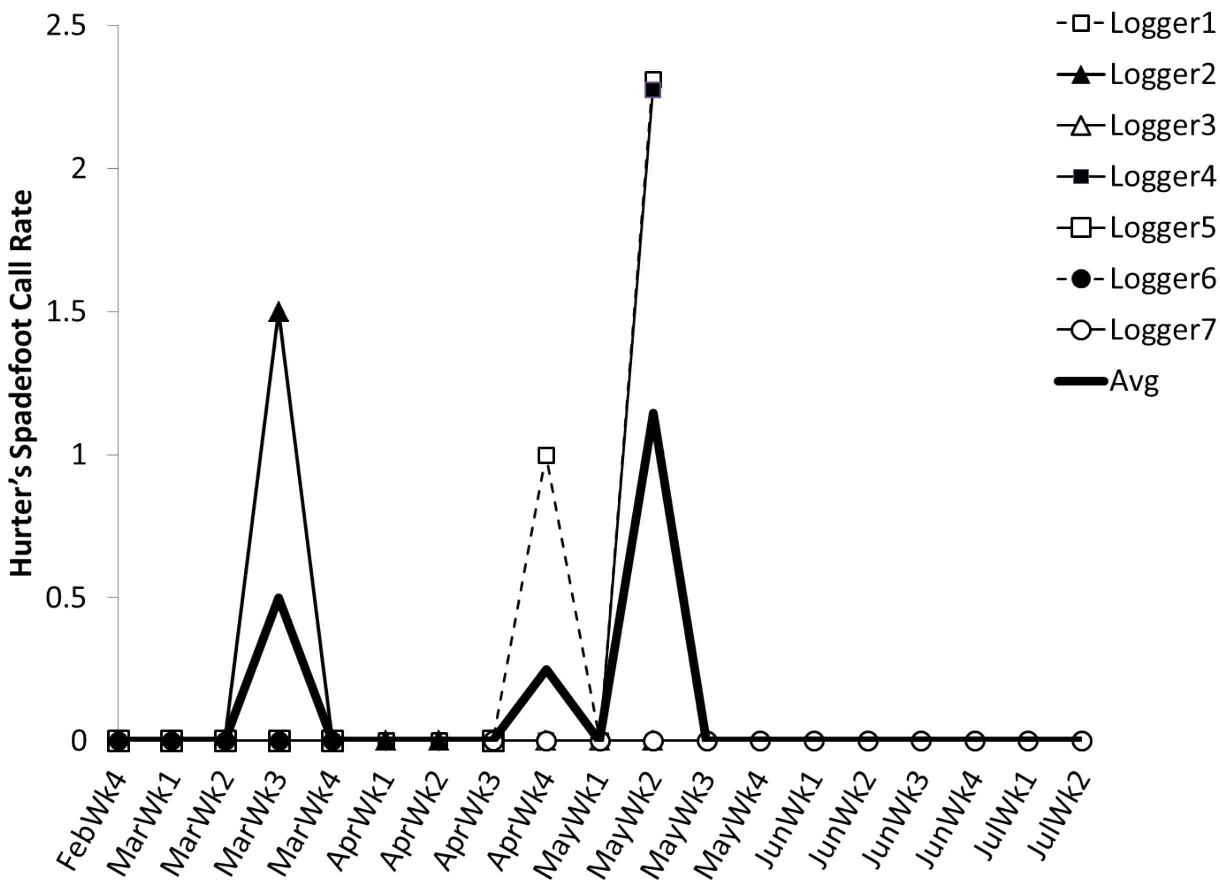

Figure 2.8. Hurter's spadefoot call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

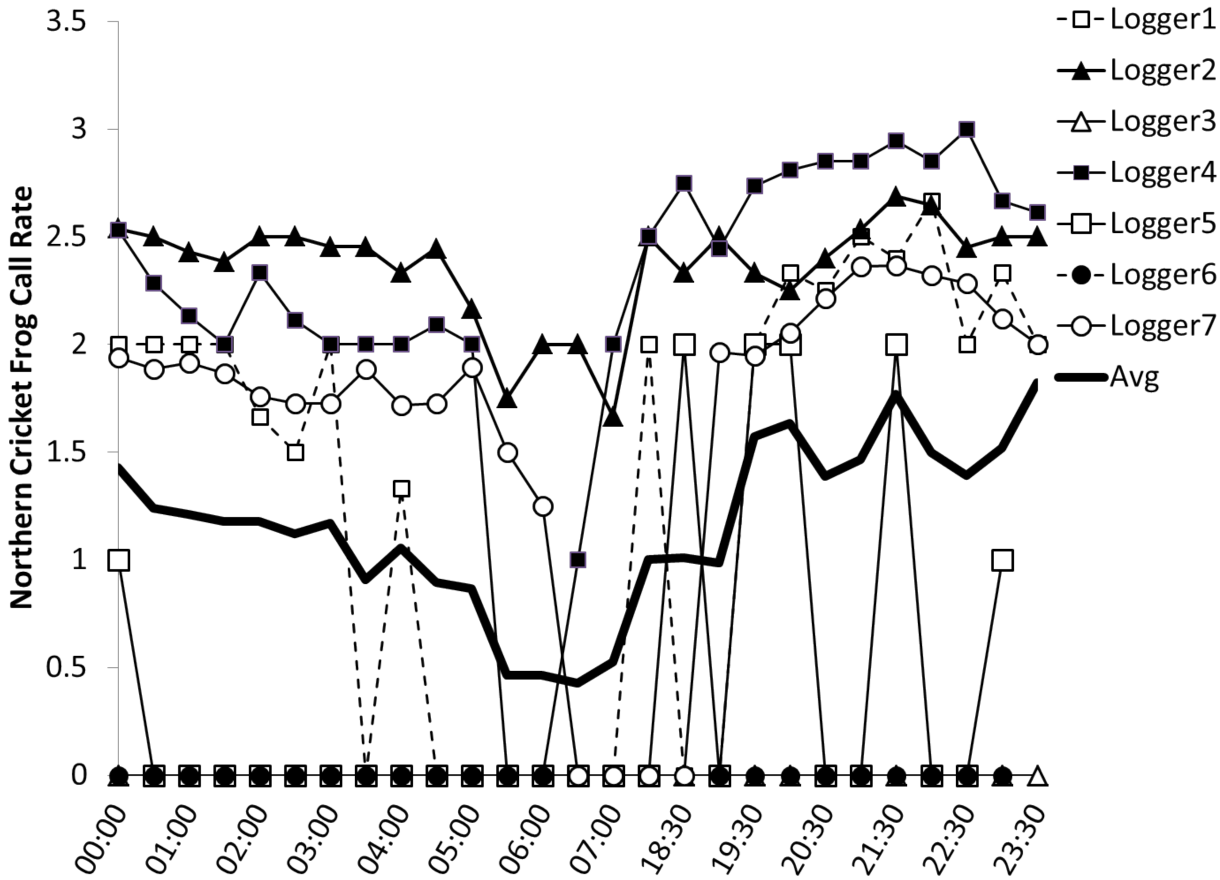

Figure 2.9. Northern cricket frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

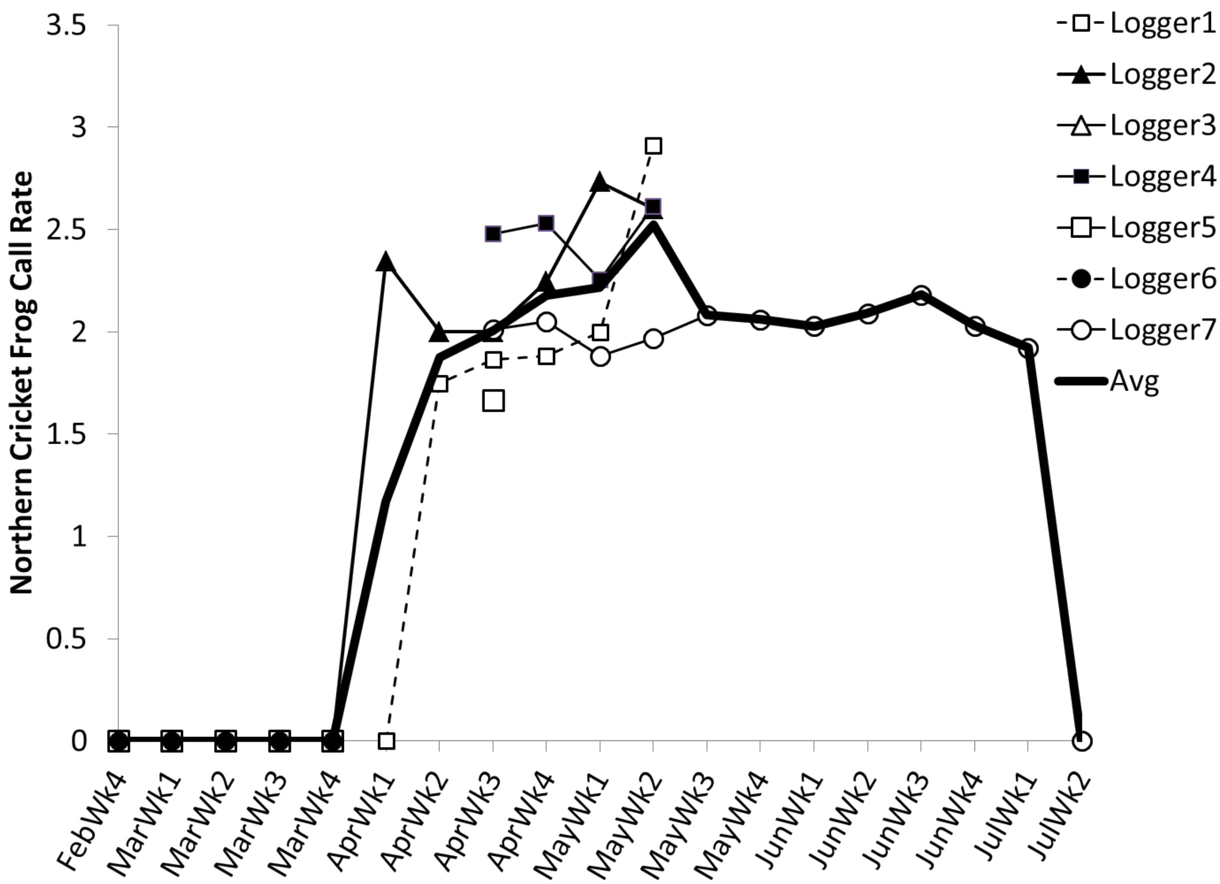

Figure 2.10. Northern cricket frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

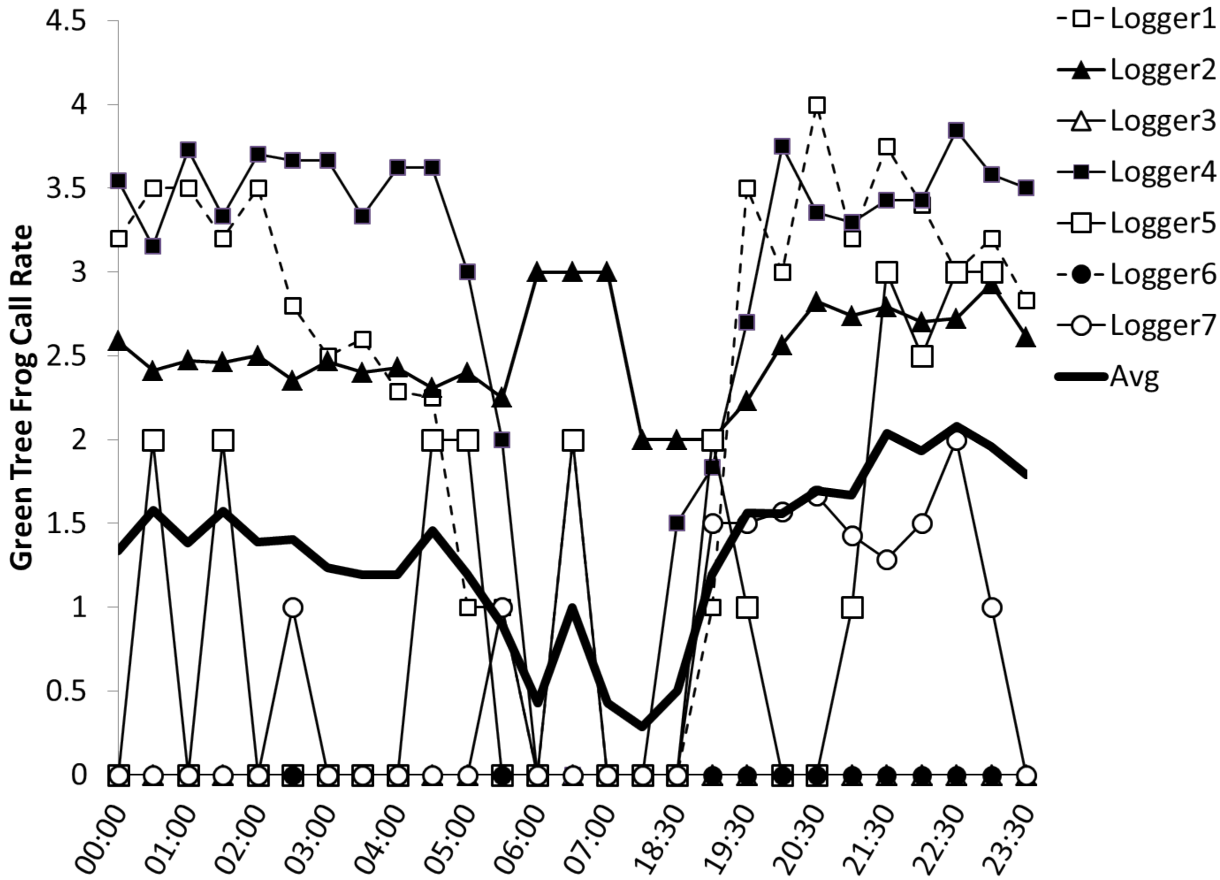

Figure 2.11. Green tree frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

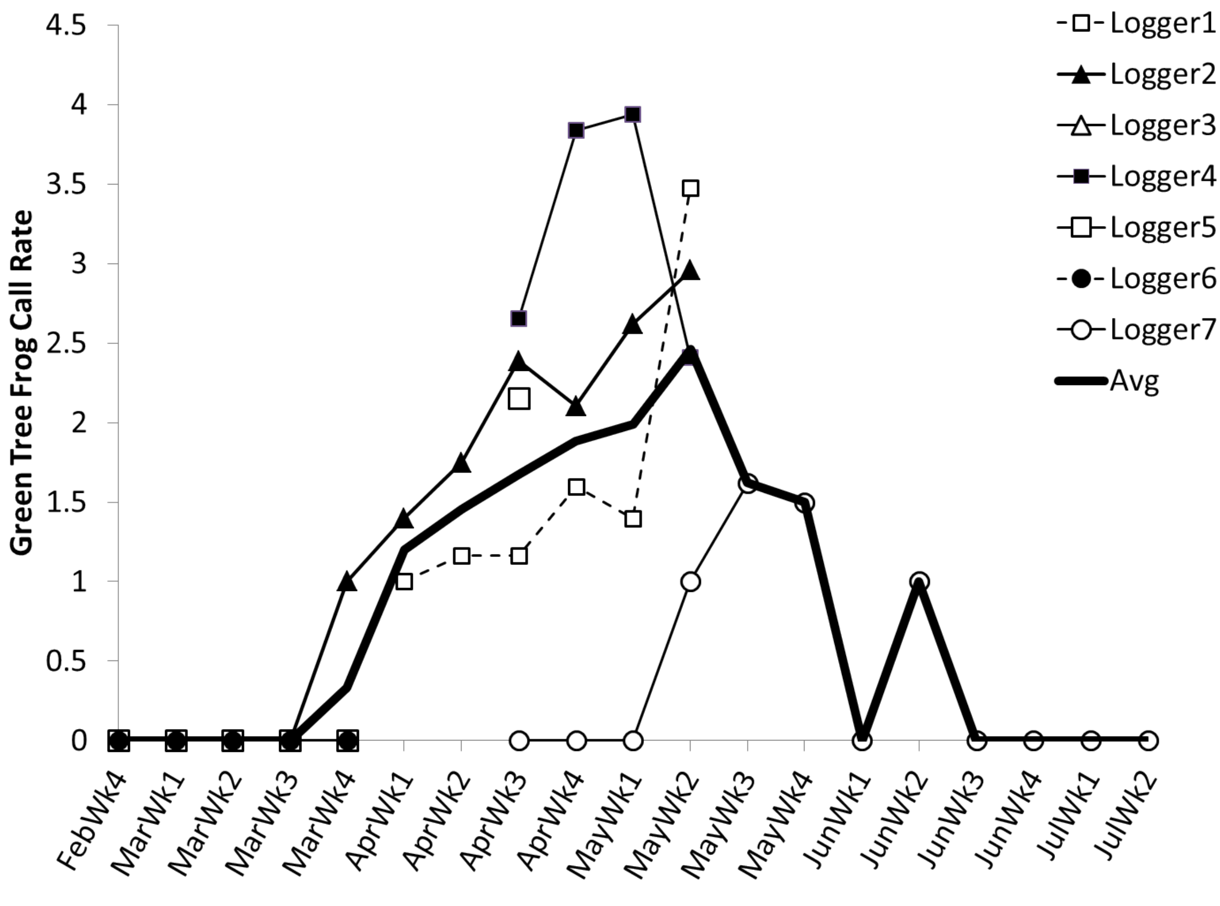

Figure 2.12. Green tree frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

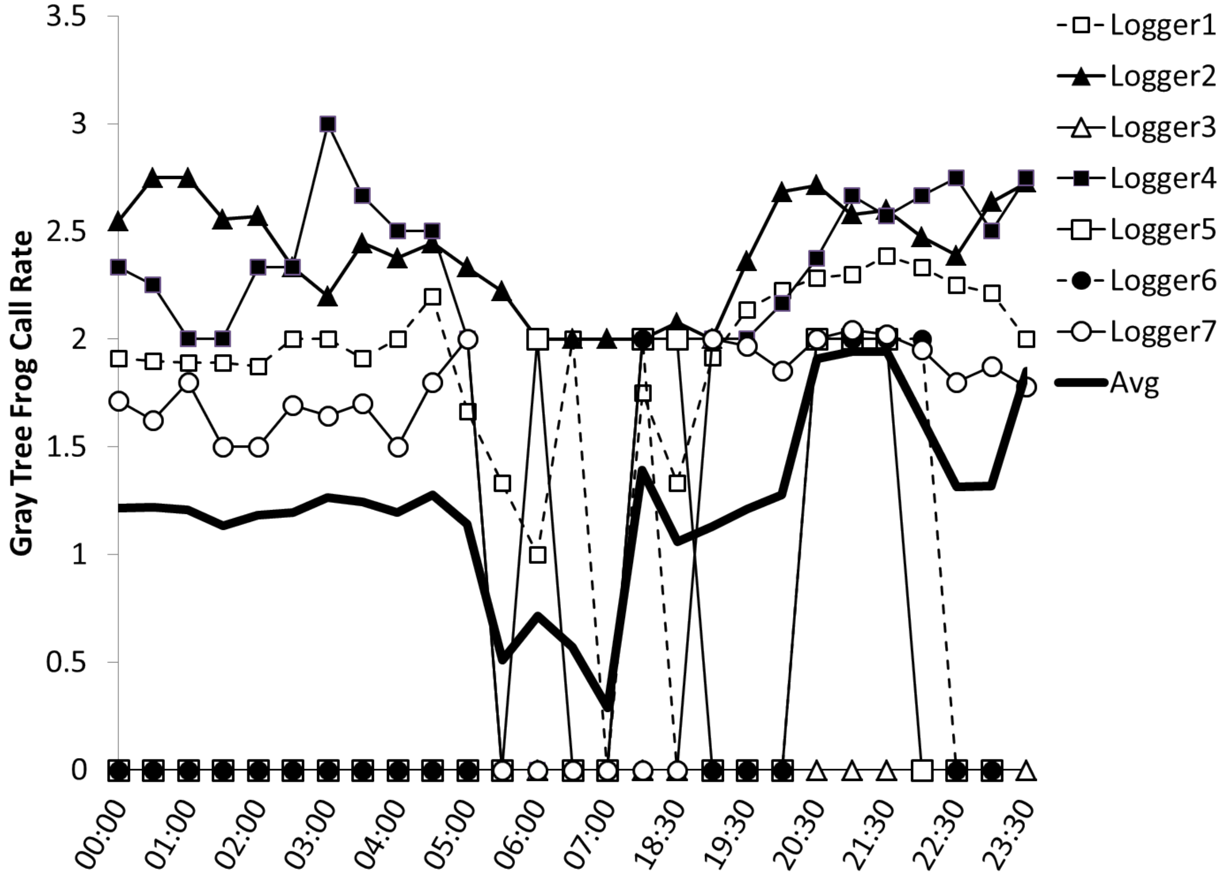

Figure 2.13. Gray tree frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

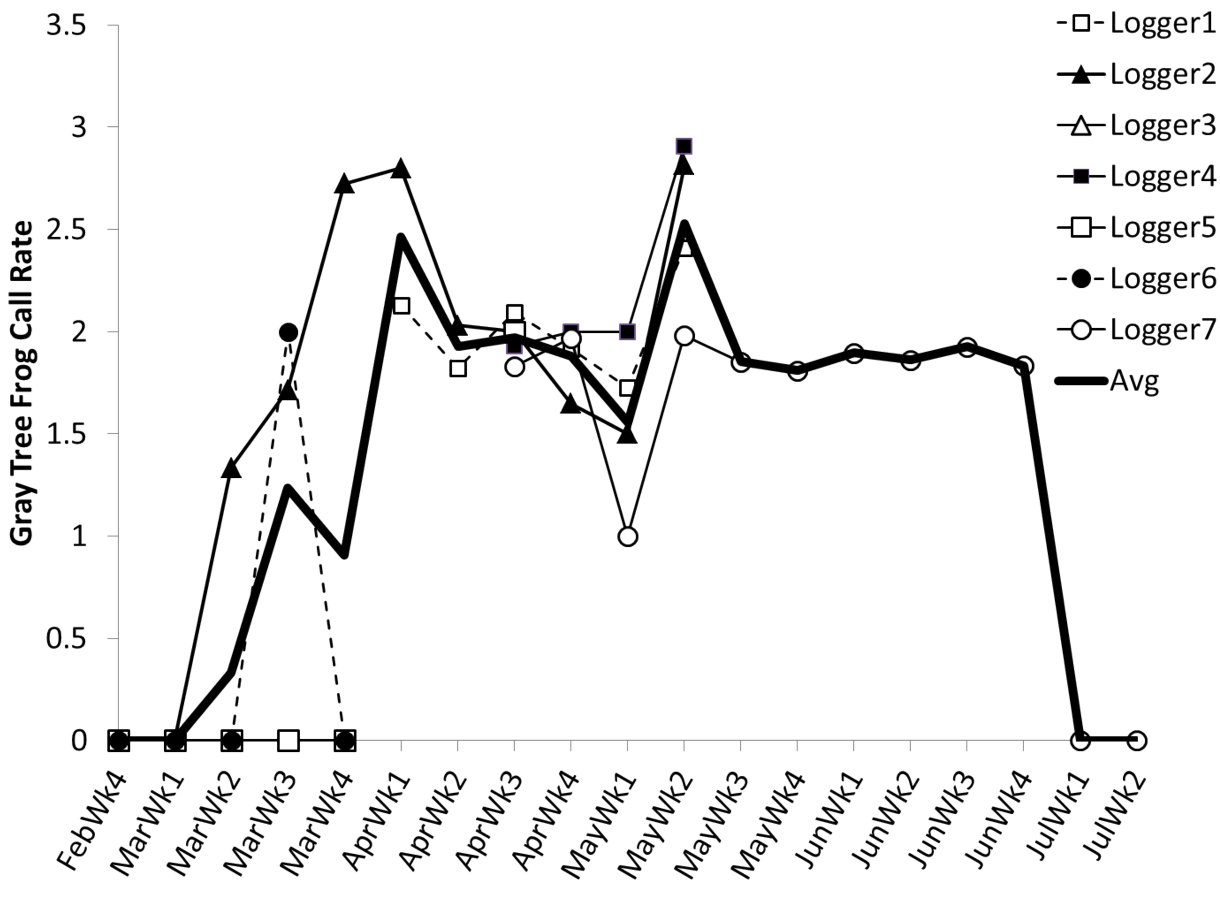

Figure 2.14. Gray tree frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

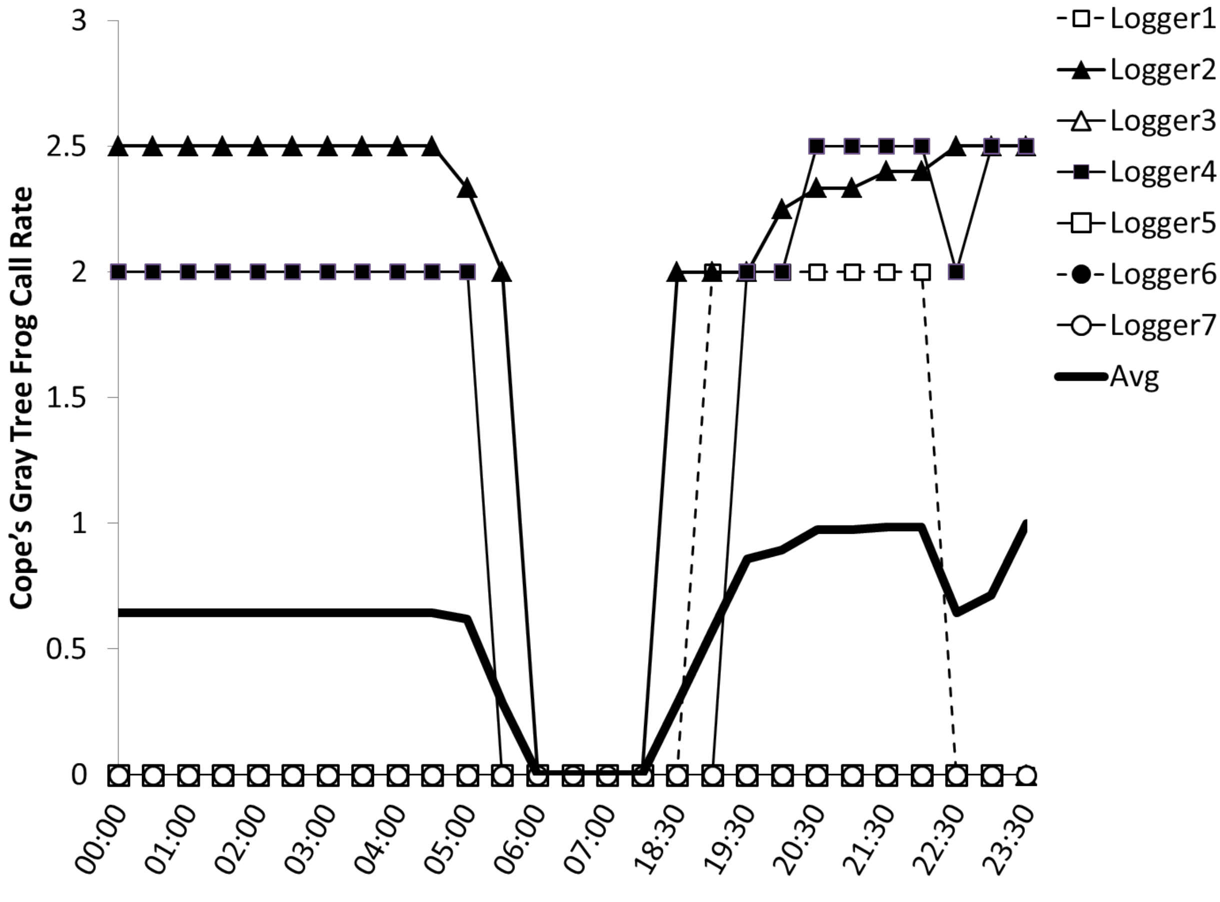

Figure 2.15. Cope's gray tree frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

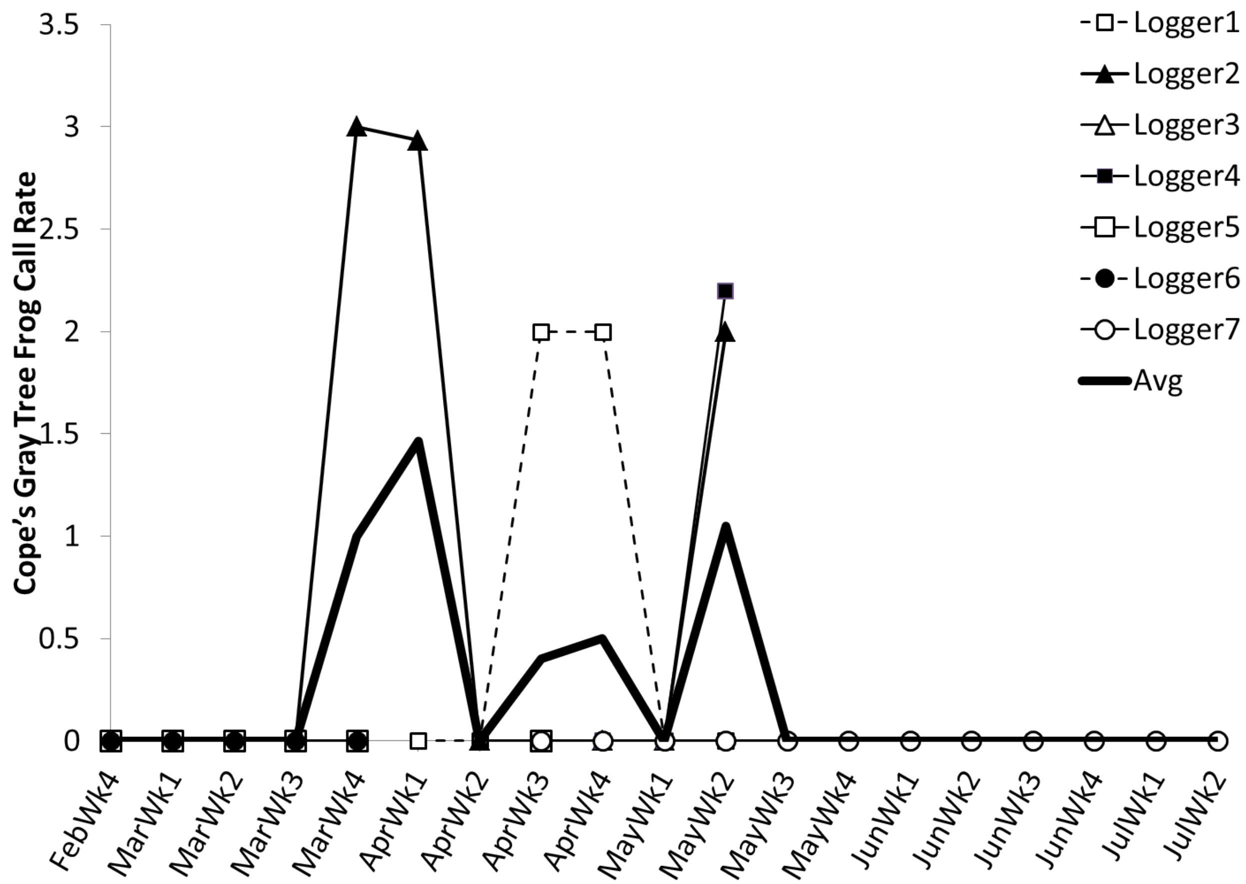

Figure 2.16. Cope's gray tree frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

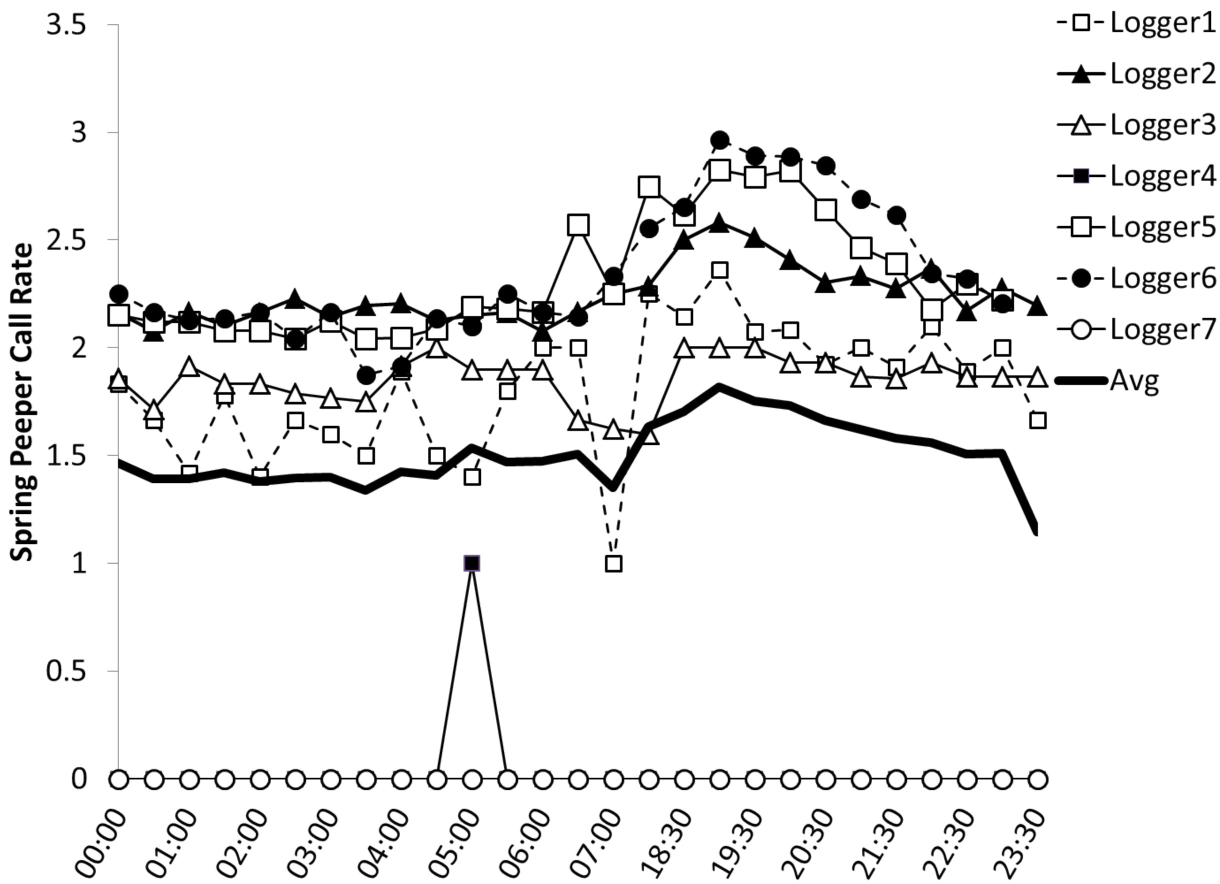

Figure 2.17. Spring peeper call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

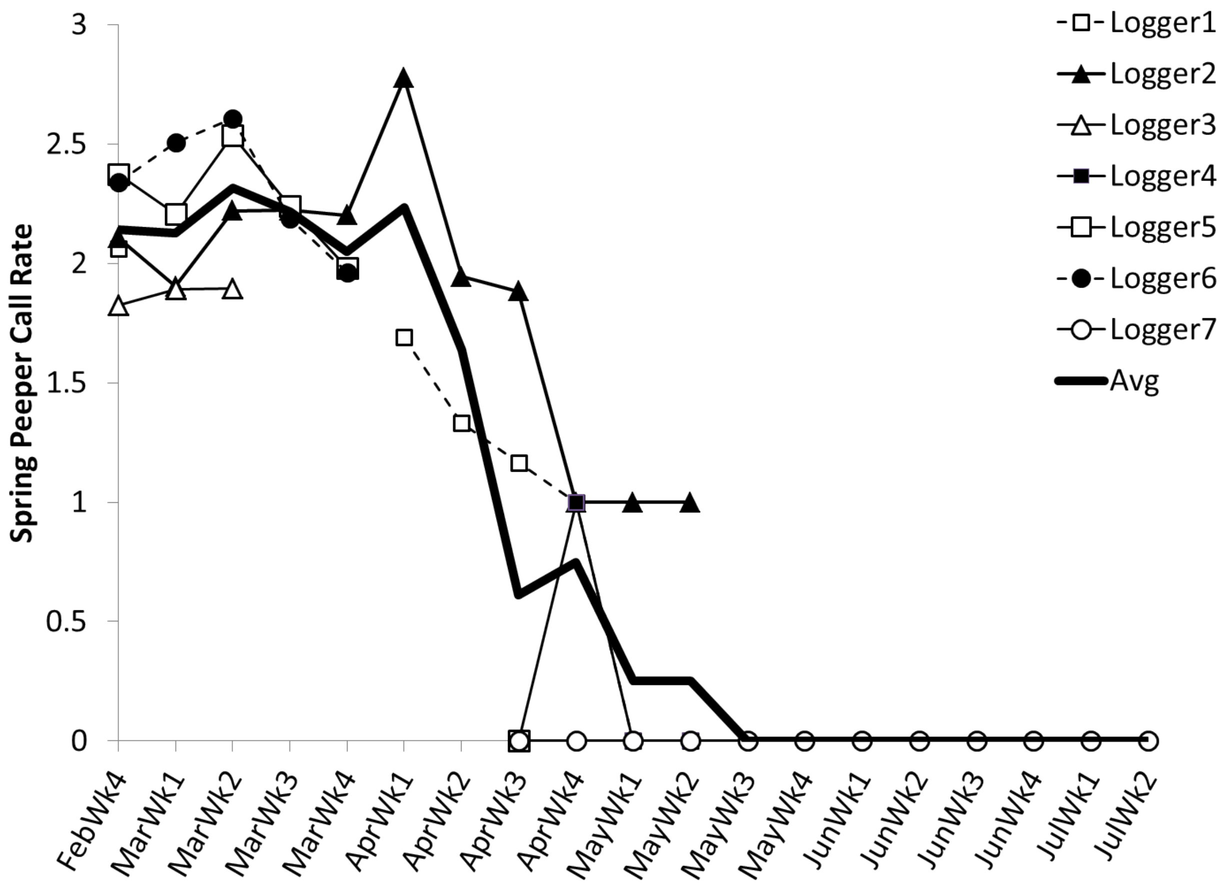

Figure 2.18. Spring peeper call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

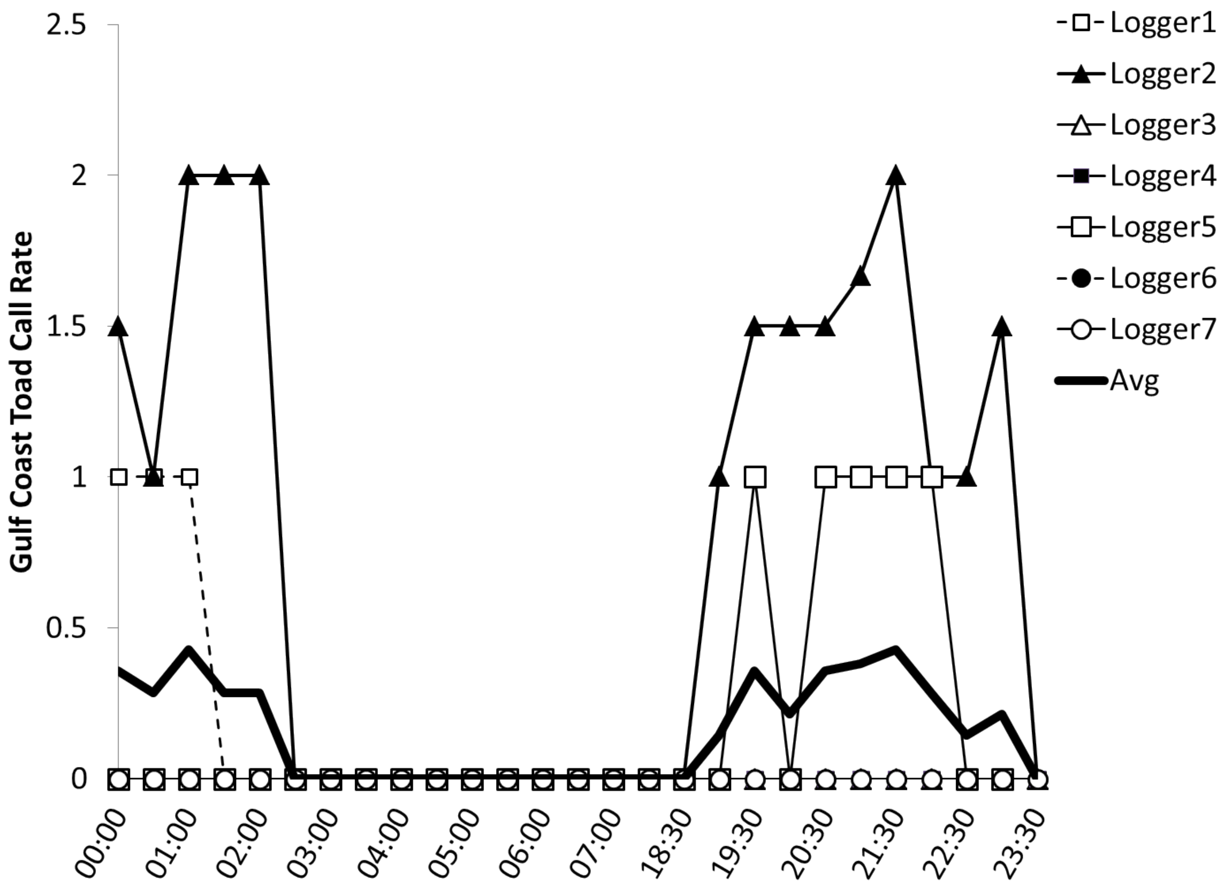

Figure 2.19. Gulf Coast toad call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

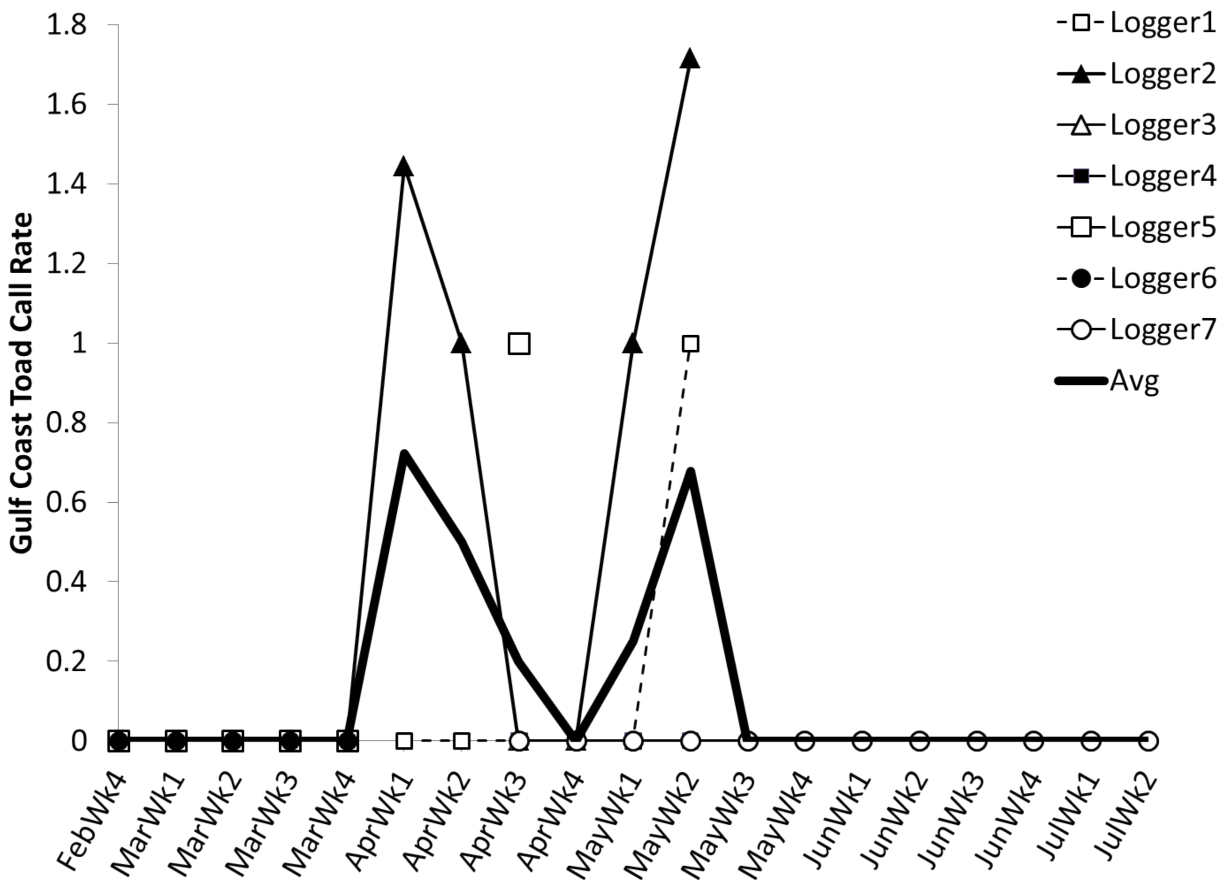

Figure 2.20. Gulf Coast toad call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

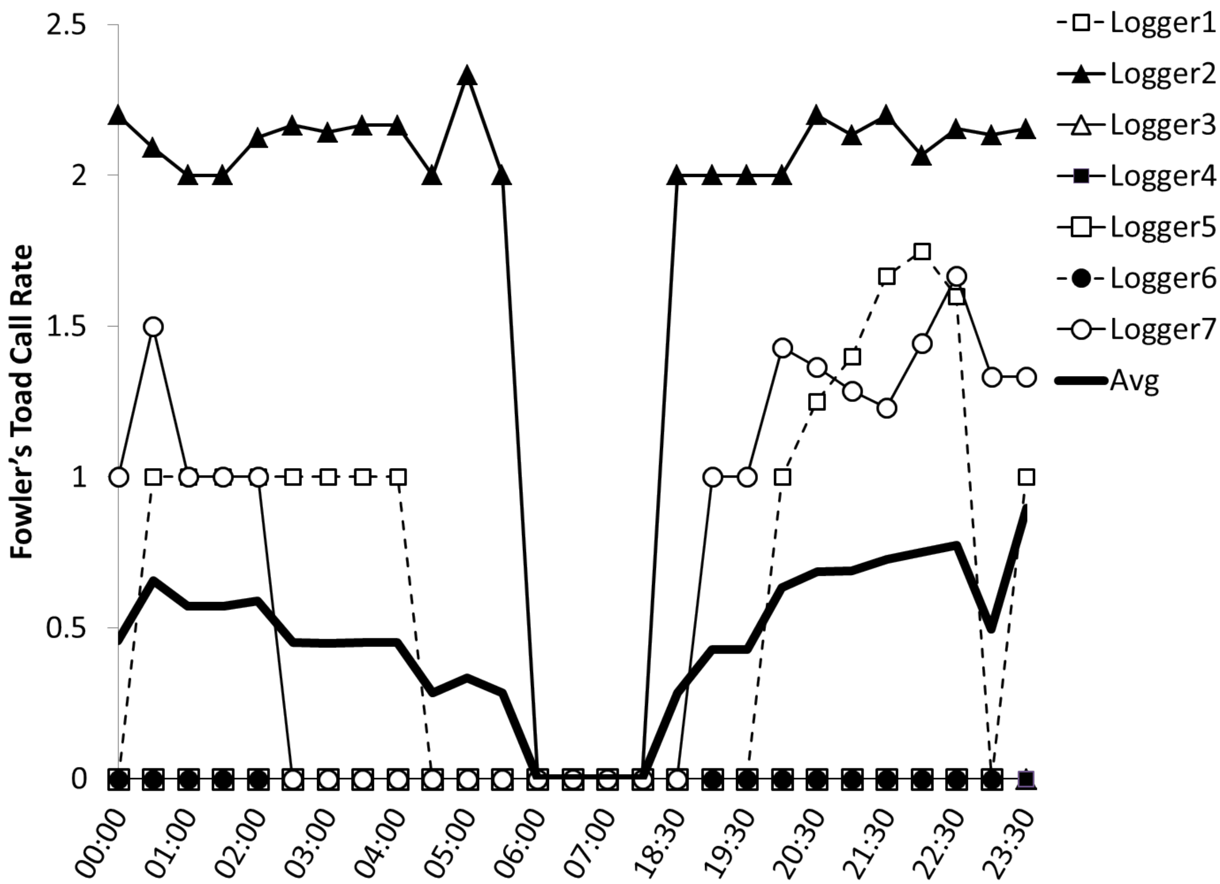

Figure 2.21. Fowler's toad call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

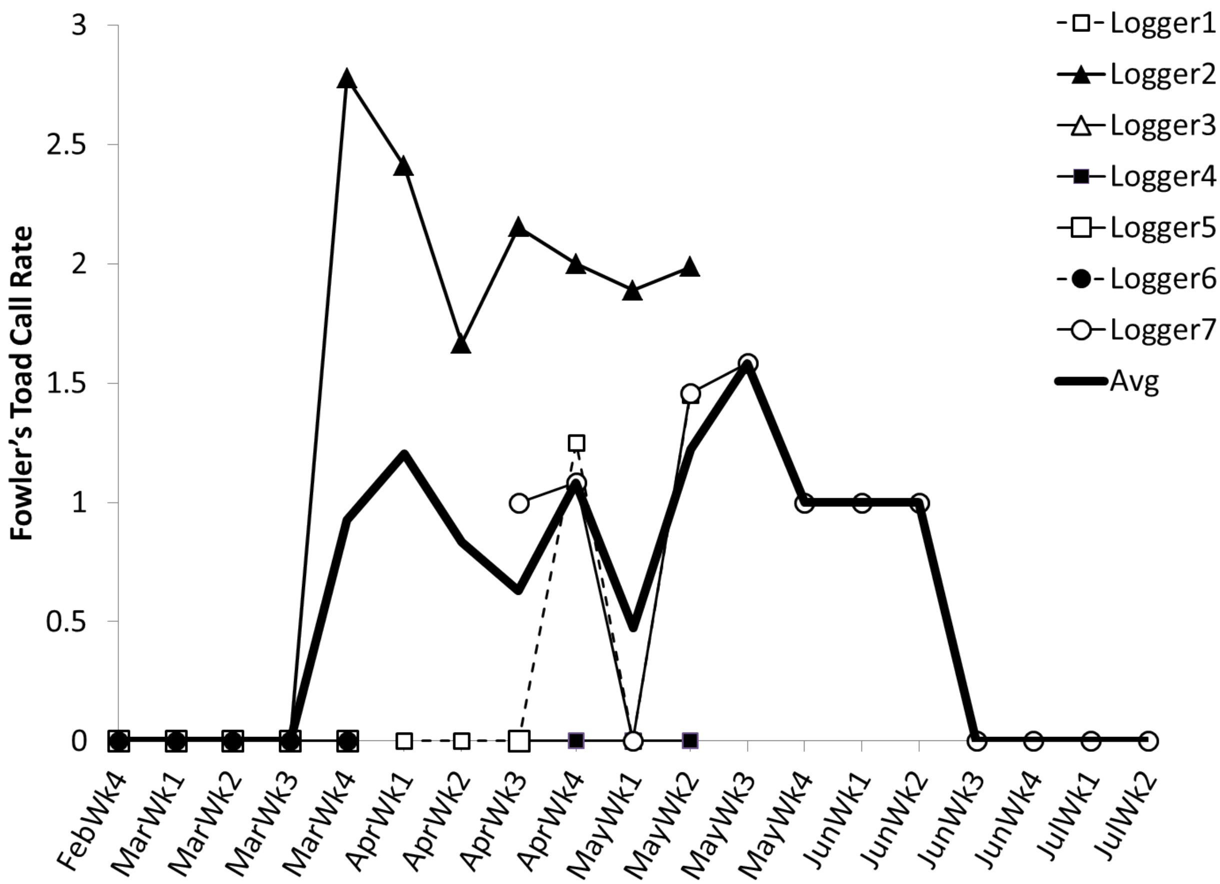

Figure 2.22. Fowler's toad call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

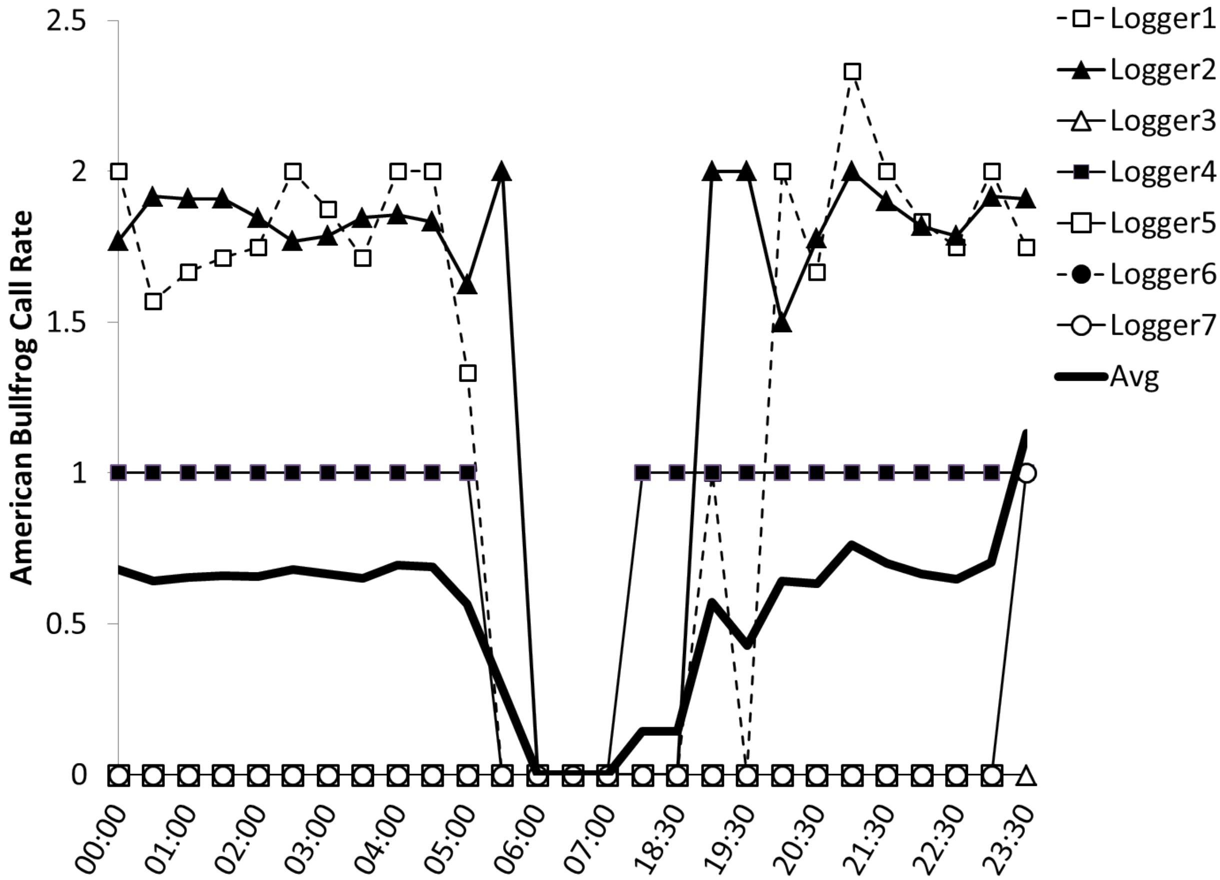

Figure 2.23. American bullfrog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

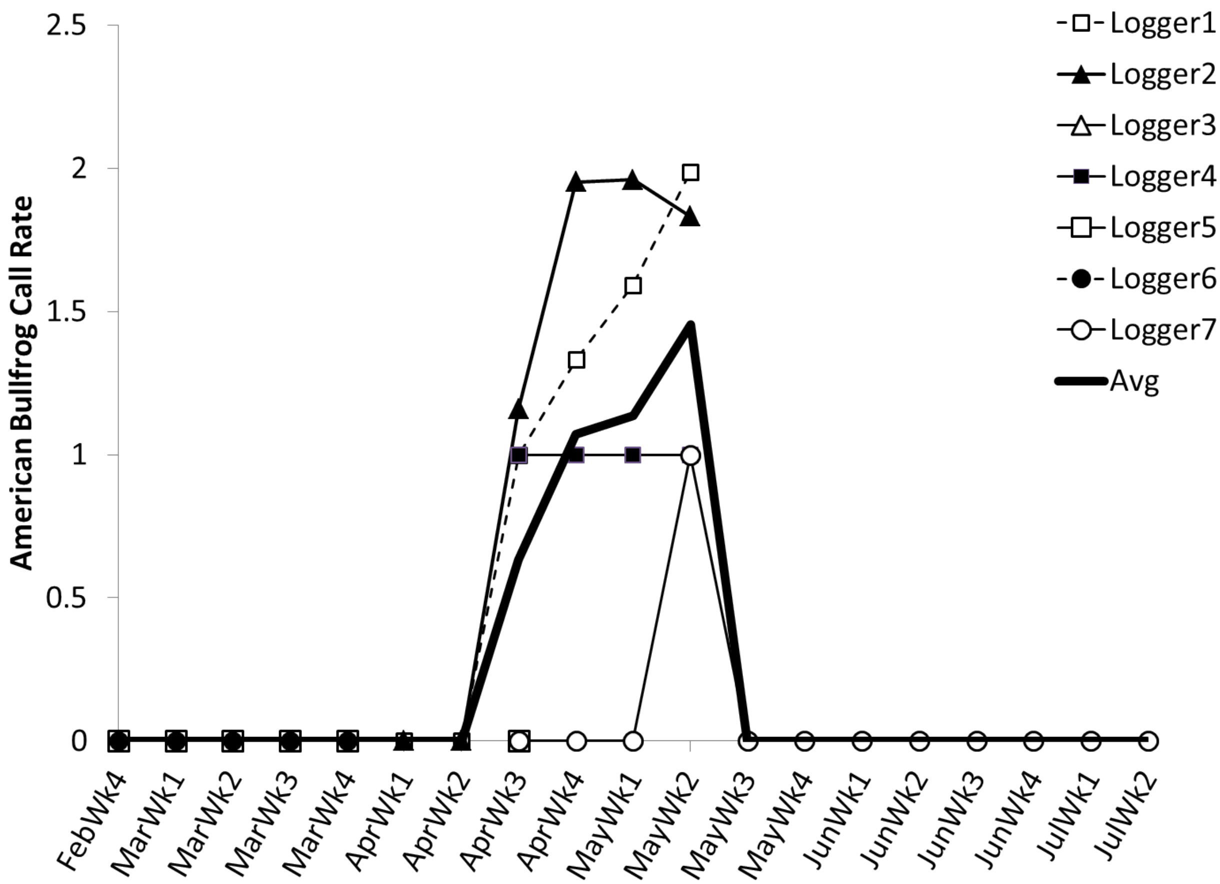

Figure 2.24. American bullfrog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

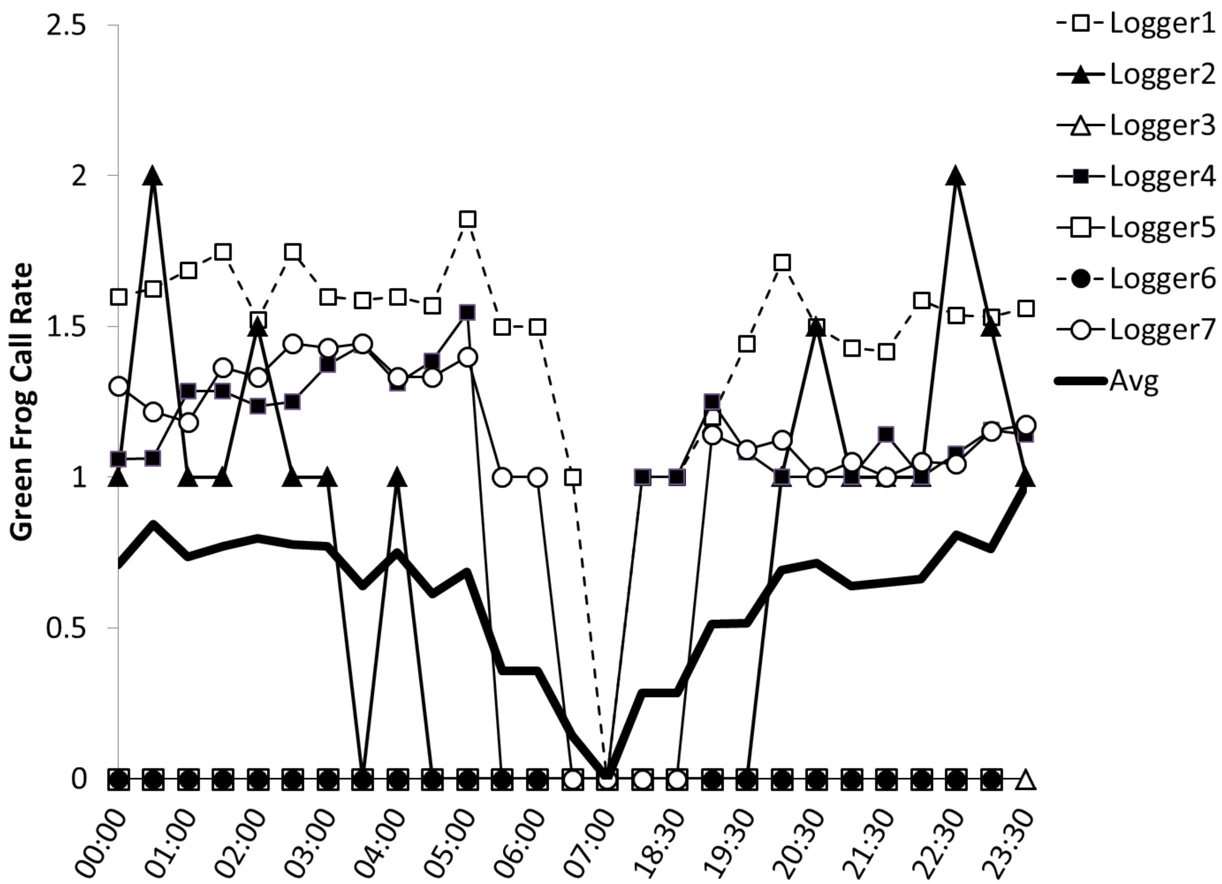

Figure 2.25. Green frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

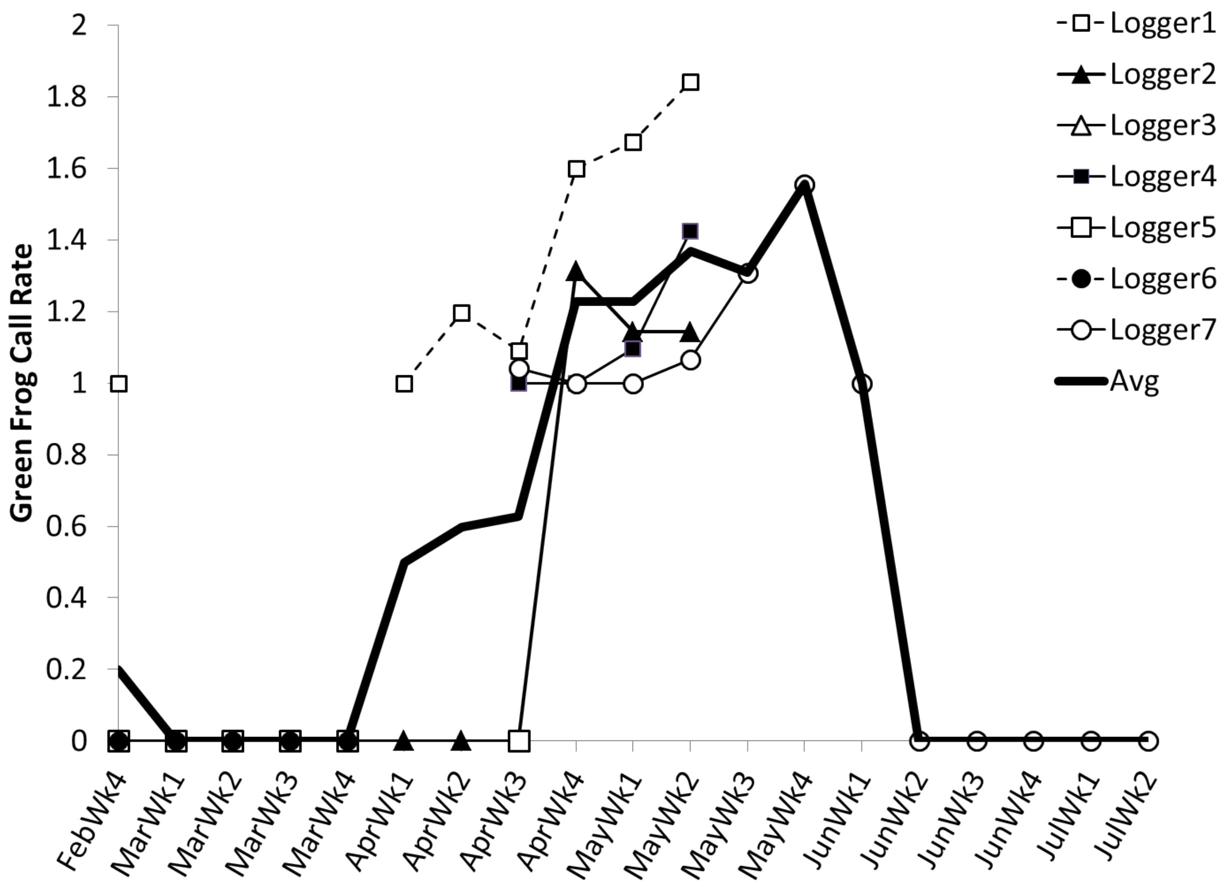

Figure 2.26. Green frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

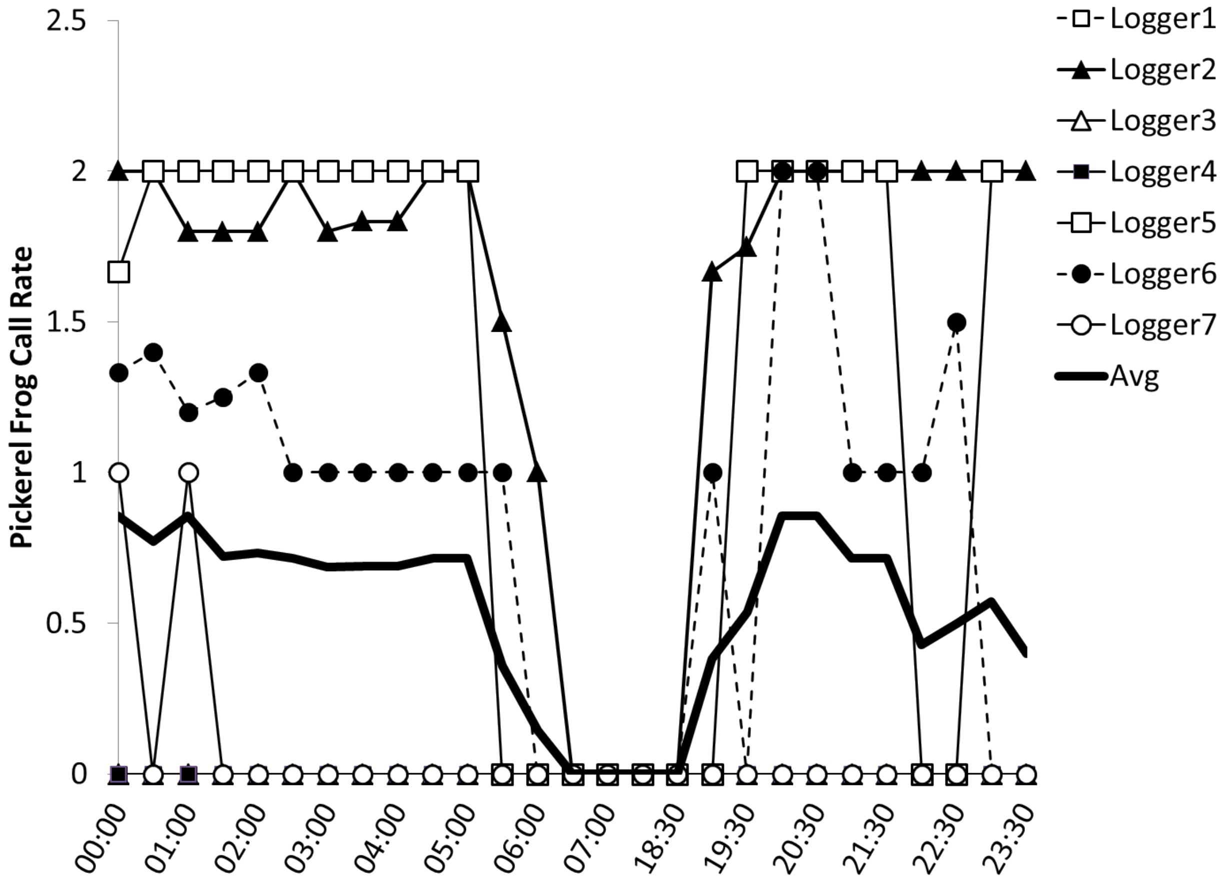

Figure 2.27. Pickerel frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

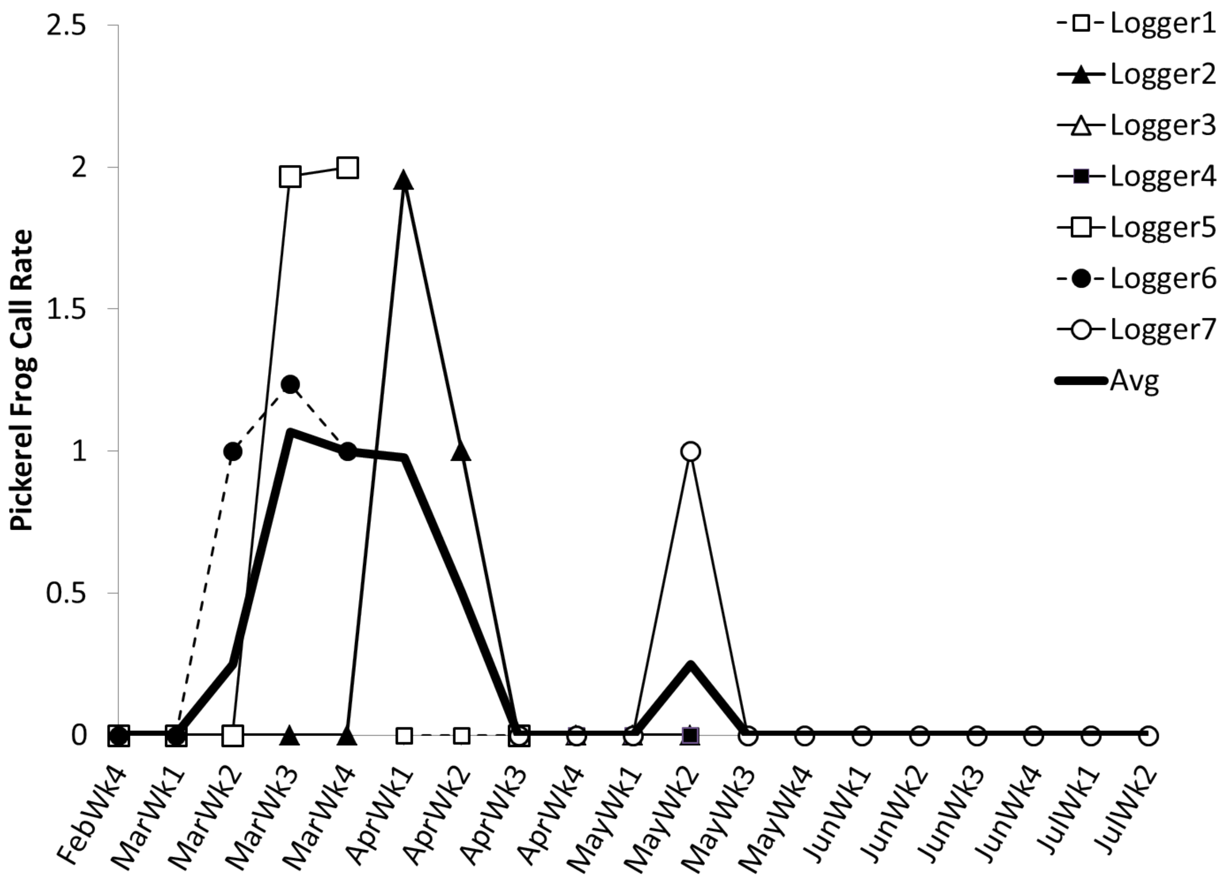

Figure 2.28. Pickerel frog call call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

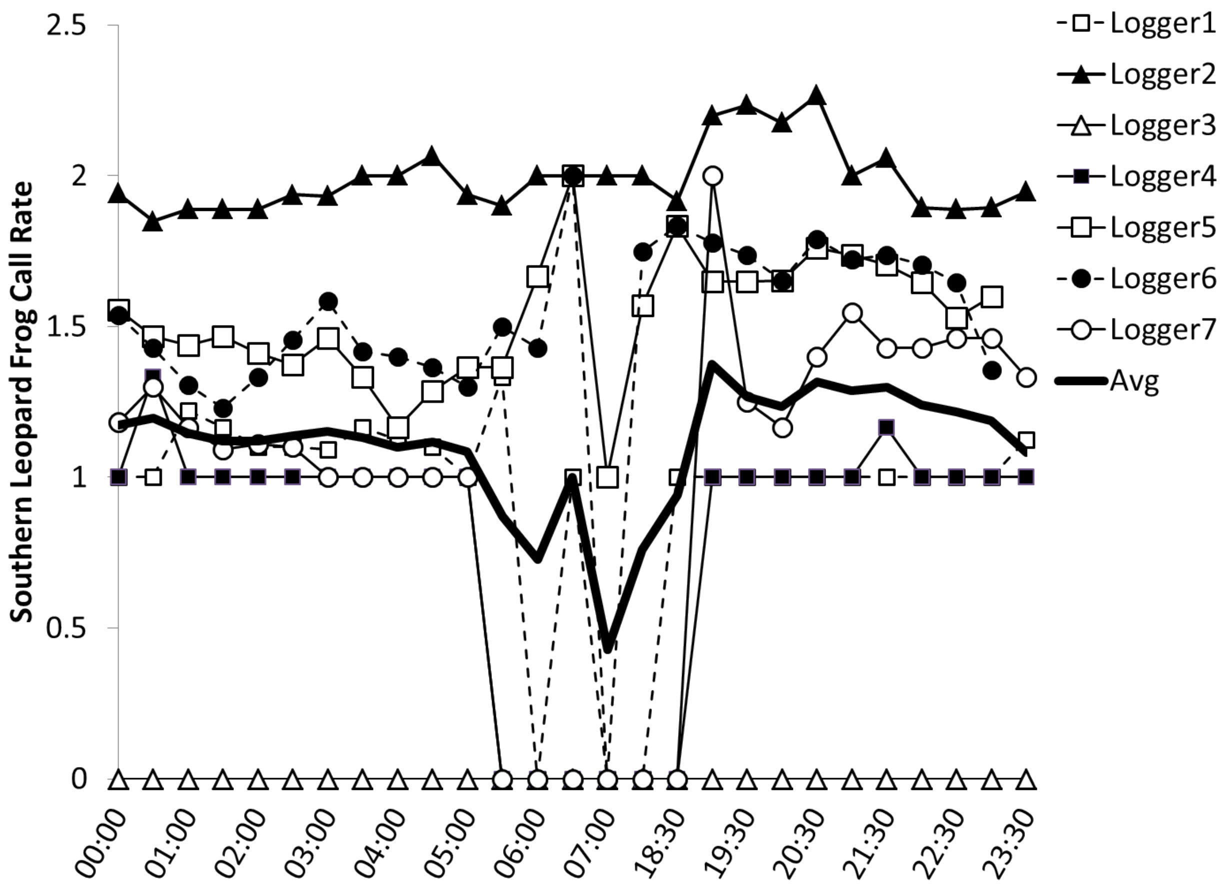

Figure 2.29. Southern leopard frog call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

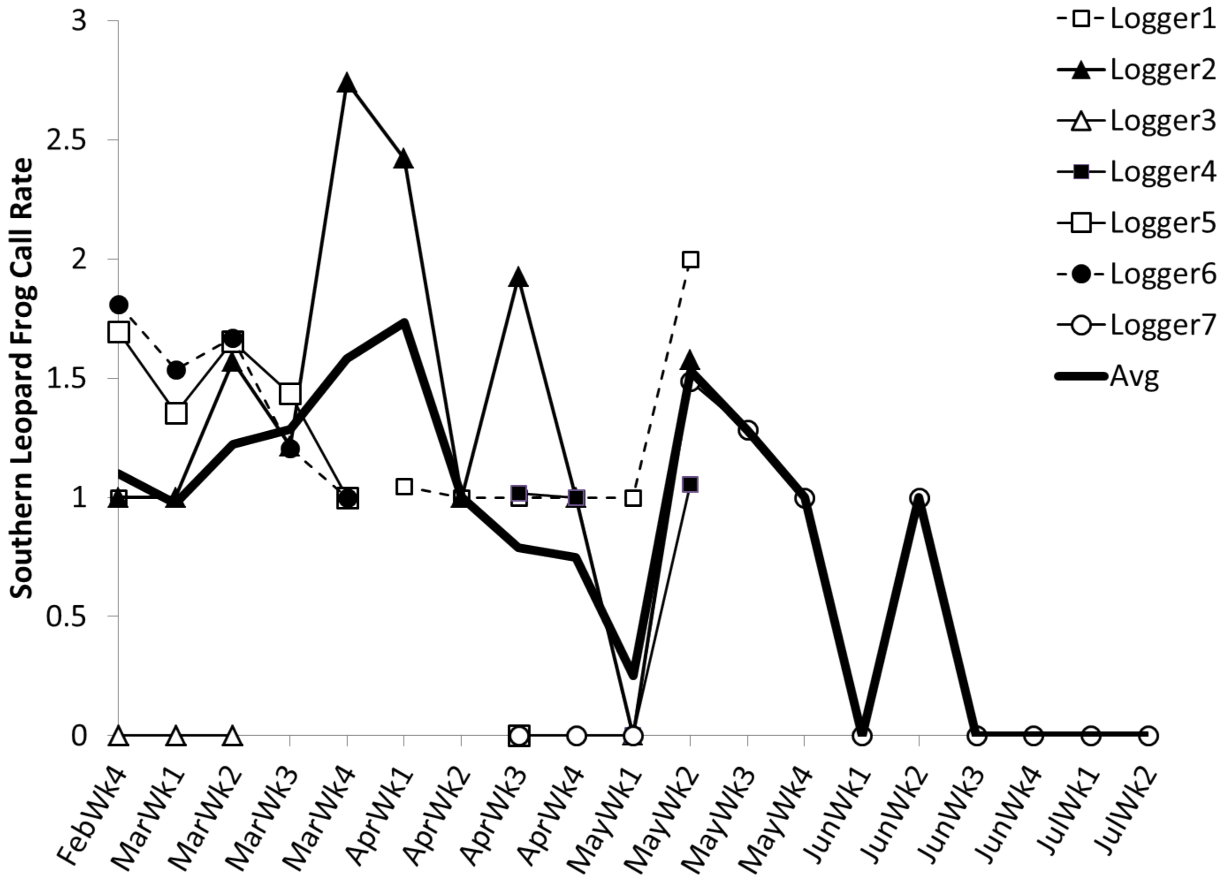

Figure 2.30. Southern leopard frog call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.

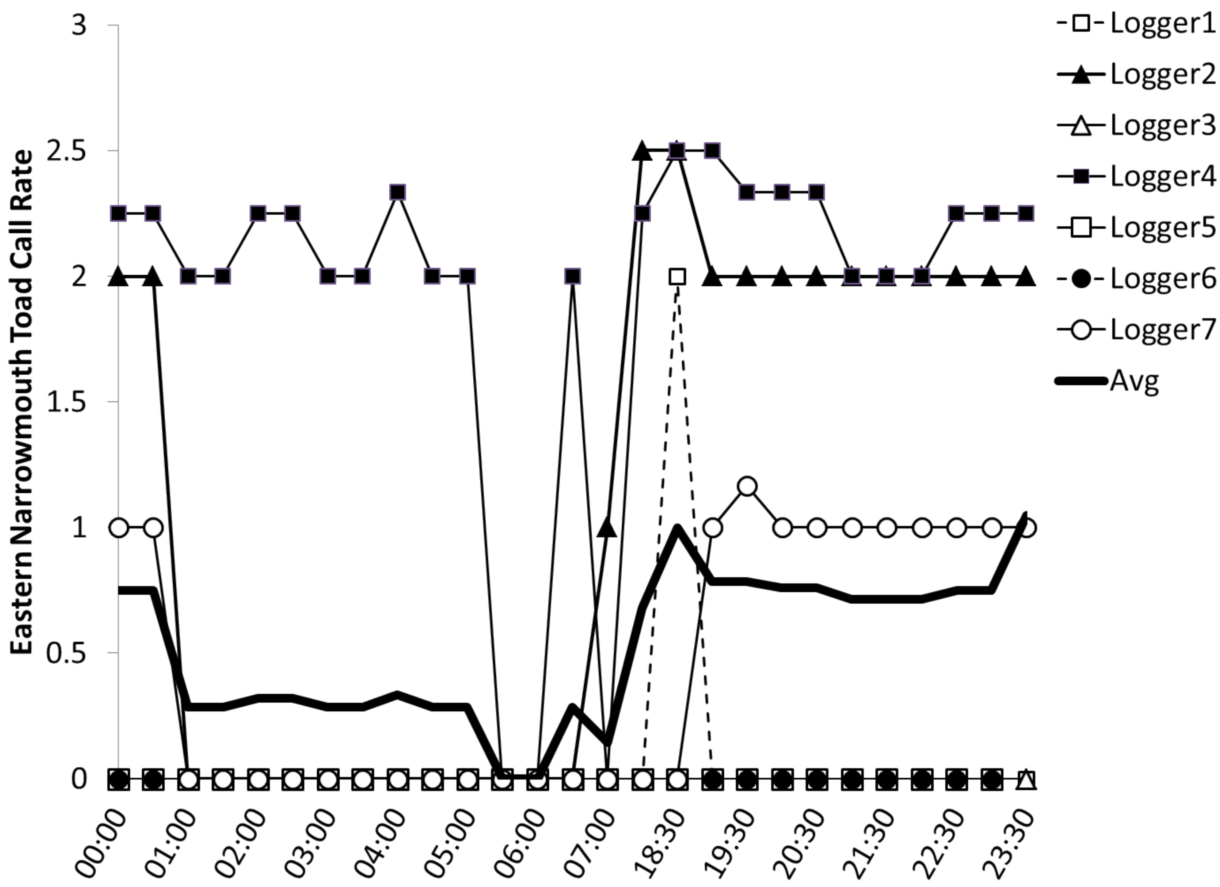

Figure 2.31. Eastern narrowmouth toad call rate by time period across all frog loggers averaged across weeks from Feb – July 2013 Gus Engeling WMA, Anderson County, Texas.

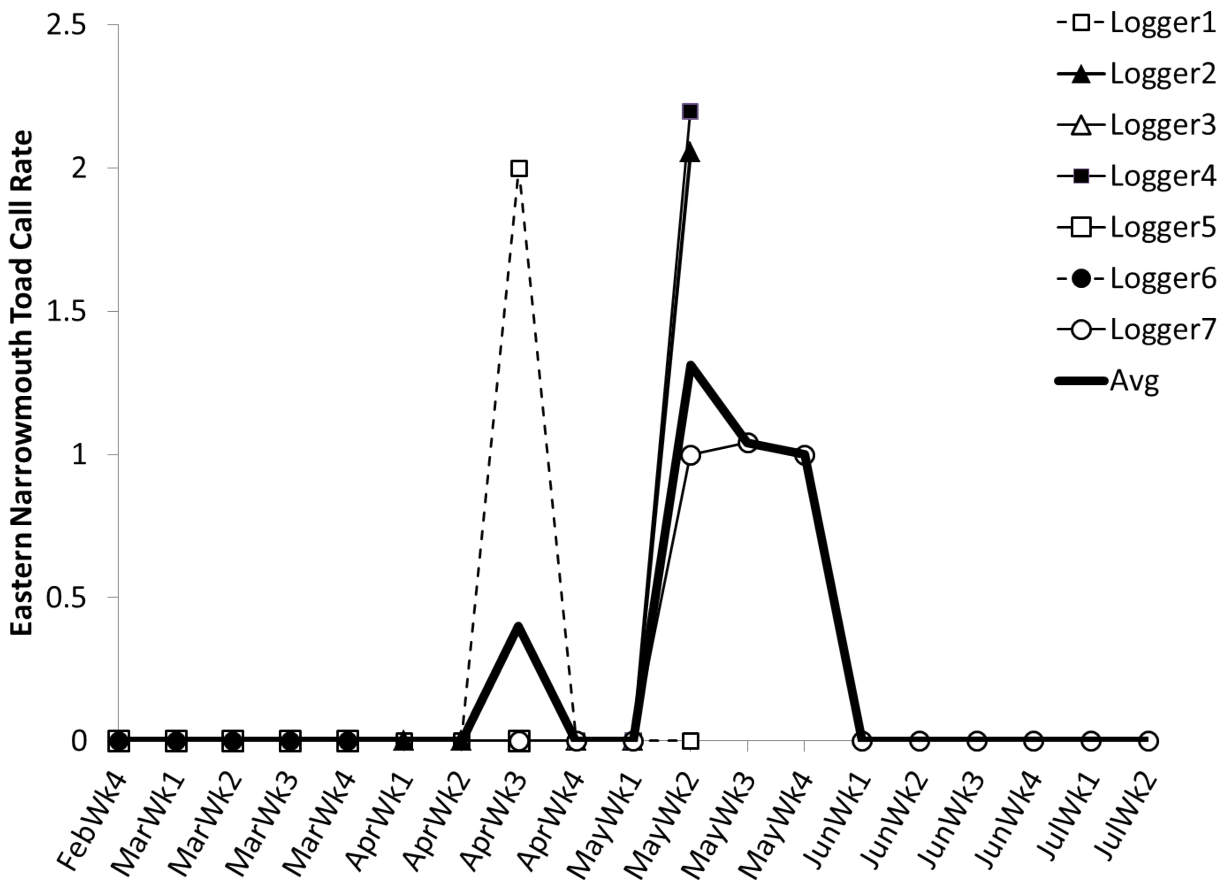

Figure 2.32. Eastern narrowmouth toad call rate averaged across all time periods for each week from the 4th week of February until the 2nd week of July at Gus Engeling WMA, Anderson County, Texas in 2013.