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Movements of Feral Hogs in Response to Warfarin Bait Consumption

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ABSTRACT: The distribution of feral hogs throughout North American has increased dramatically since their introduction. The use of toxicants has proven to be an effective tool in controlling feral hog numbers in several countries. Using data from 13 GPS hogs, we compared movements and space use of control and treated hogs between pre-baiting and baiting phases of 3 feral hog toxicant field tests. Generalized linear mixed models were used to explain prospective changes in movements. In addition, we evaluated the distance of toxicant-killed feral hog carcasses from bait stations, roads and cultivated crop plots. The mean distances traveled by treatment hogs between the pre-baiting and baiting periods was reduced by 43.9%, 32.1%, and 48.8% for daily, diurnal, and nocturnal periods, respectively. Daily and nocturnal movements exhibited a significant decrease between pre-baiting and baiting phases by feral hogs as a result of bait consumption. Mean space use size between the pre-baiting and baiting periods for treatment hogs was reduced by 37.5% and 30.0% for 95% MCP and 50% MCP, respectively but was not a result of bait consumption. Toxicant-killed feral hog carcass distance from bait stations, cultivated crops, and roads averaged (± SE) 919.4 ± 68.1 m, 908.9 ± 72.1 m, and 120.7 ± 34.9 m, respectively. These carcasses were never recovered from crop plots or near roads and were typically found in natural land cover types. The toxicant warfarin reduced movements of feral hogs, which in turn can reduce their damage to crop and reduce the spread of disease.

KEY WORDS: carcass, feral hogs, GPS, movement, *Sus scrofa*, toxicant, warfarin, wild pigs, wildlife damage management

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INTRODUCTION

The feral hog (*Sus scrofa*) distribution in the United States continues to expand as a result of translocation by humans and high reproductive rates (Gaston et al. 2008, Bevins et al. 2014). Feral hogs in the U.S. cause approximately $1.5 billion in economic losses annually due to spread of disease, cultivated crop damage, and control efforts (Pimentel 2007), but estimates could be as high as $2.5 billion (Frey 2017). In addition, feral hogs damage natural habitat and agricultural areas by rooting and consuming native vegetation and agricultural crops, and transmit disease to livestock and wildlife (Seward et al. 2004). Feral hogs are known to prey on wild and domestic fauna including small rodents (Loggins et al. 2002), amphibians and reptiles (Jolly et al. 2010), and lambs (Pavlov and Hone 1982).

Control techniques used for reducing feral hogs, and associated disease transmission risk, include fencing (Hone and Atkinson 1983), trapping (Peine and Farmer 1990), shooting (Coblentz and Baber 1987), and fertility control with the use of ovotoxins (Sanders et al. 2011) and immunocontraception (Killian et al. 2006). These methods are costly and labor intensive; however, the use of feral hog toxicants is considered a cost-efficient and efficacious option (Coblentz and Baber 1987, Lapidge et al. 2009).

Testing of toxicants to control feral hogs includes sodium fluoroacetate (compound 1080; Hone and Kleba 1984, Twigg et al. 2005), warfarin (Hone and Kleba 1984, McIlroy et al. 1989, Saunders et al. 1990), and sodium nitrite (Snow et al. 2017). The advantages associated with feral hog toxicants are the potential to manage swine populations on a larger scale, reduce numbers over a short time period, and target trap-shy individuals (Massei et al. 2011). In particular, anticoagulants such as warfarin have an antidote (vitamin K1) as an added safety (Hone and Kleba 1984).

Currently, one toxicant is registered by the U.S. Environmental Protection Agency to control feral hog numbers in the United States. This toxicant's active ingredient is warfarin (Kaput®; Scimetrics Ltd. Corp., Wellington, CO), and is formulated at a low dose of 0.005% warfarin, which is one-fifth dose in most over-the-counter rat and mouse warfarin baits (Erikson and Urban 2004). Warfarin bait is an effective control method in reducing feral hog numbers, being highly toxic to pigs (McIlroy et al. 1989, O'Brien and Lukins 1990, Saunders et al. 1990). Warfarin bait has a latency period of 4 or more days (Hone and Mulligan 1982), therefore bait-shyness is less likely and does not produce symptoms to deter from feeding before a lethal dose is consumed (Godfrey and Lyman 1980).

The effects of warfarin bait on feral hog activity include lameness, lethargy, and inappetence (Choquenot et al. 1996, O'Brien and Lukins 1990) which can influence movement and activity of individual hogs. Reduced feral hog movement after warfarin bait consumption can minimize human-feral hog conflict and has the potential of hindering diseases spread between swine, wildlife and livestock. Currently, there is no information on feral hog movement in response to toxic bait consumption in the United States.

The objective of the study was to assess movements of GPS collared feral hogs that expired from warfarin consumption and compare hog movements before and after bait presentation. The influence of sex, temperature, group (control and treatment) and phase (pre-baiting and baiting) on movements were evaluated. We predicted that movements of treatment hogs during the baiting phase would be less when compared to movements during the pre-baiting phase, and there would be no change in the movement of control hogs between the two phases. A secondary objective of the project was to survey carcasses

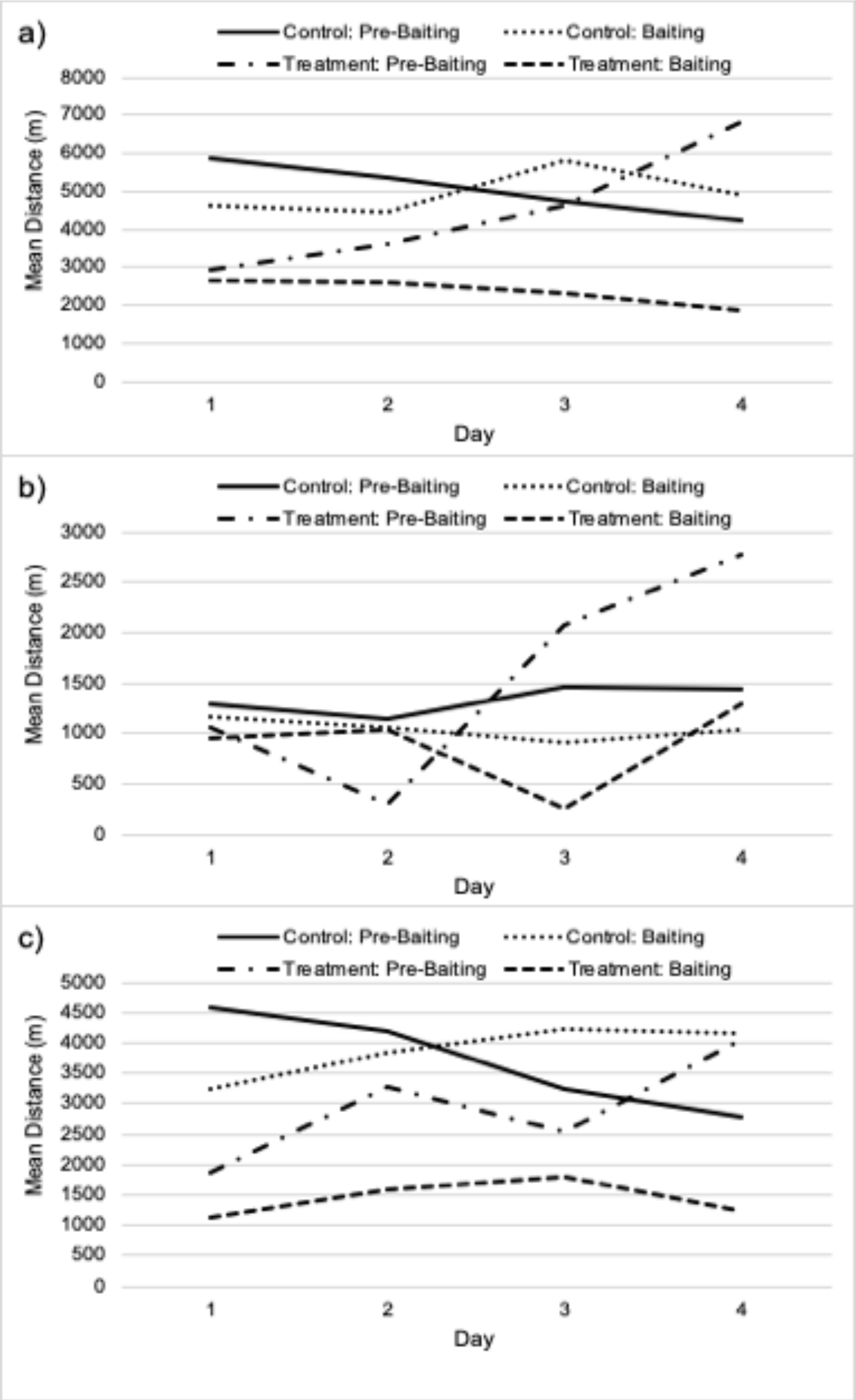

Figure 1. Changes in mean values of a) daily distance traveled, b) diurnal distance traveled, and c) nocturnal distance traveled for 4-day pre-baiting and baiting phases for treatment and control feral hogs (*Sus scrofa*) in northern Texas.

of warfarin baited hogs recovered during field studies. Hog carcass distances from bait stations, cultivated crop plots, and roads were surveyed.

METHODS

Analyses were conducted *post hoc* following three feral hog toxicant field studies (Poché et al. 2018) completed in the spring of 2015, 2016, and 2017 in the Texas panhandle. Field tests were conducted in two separate locations, approximately 45 km apart, and were comprised of the same habitat types and terrain. The 2015 and 2017 studies were located near Quitaque and Turkey, TX, along the Los Lingos and Quitaque Creeks in Briscoe, Floyd, and Motley Counties (34°17'28" N latitude, -100°59'26" W longitude). The 2016 study was located near Lakeview, TX, along the Prairie Dog Fork of the Red River in Briscoe and Hall Counties (34°36'25" N latitude, -100°41'18" W longitude).

Trapping, Handling, and Collaring

Feral hogs were trapped using box traps (1 × 1.2 × 2.4 m; Voorhies Outdoor Products, LLC, Clifton, TX) baited with fermented corn and hog attractants. Traps were placed in shaded areas and were examined 1-2 times per day. Hogs estimated to weigh ≥55 kg, and in good physical condition, were fitted with GPS Collars (Lotek Wireless, Inc., Newfoundland, ON, Canada; North Star Science and Technology, LLC., King George, VA). Hogs were chemically immobilized with a mixture of Telazol® and xylazine (100 mg/ml; Bimeda, Inc., Oakbrook Terrace, IL) applied intramuscularly at a dosage of approximately 1.0 cc/18 kg of body mass. Hogs were fitted with a fabricated harness to ensure the GPS collar would not fall off the individual, and were safely released at the trap site when fully alert after chemical immobilization. These studies were performed under Good Laboratory Practice Guidelines (40 CFR 160). Animal capture and handling procedures were approved by the Institutional Animal Care and Use Committee of Genesis Laboratories, Inc. in accordance with the Animal Welfare Regulations (USDA 2013), and the American Society of Mammalogists (Sikes et al. 2011).

Baiting

Baits applied during this project (Kaput® Feral Hog Bait) were manufactured by Scimetrics, Ltd. Corp. (Wellington, CO). Two bait formulations were presented to hogs: bait containing either 0.005% or 0.01% warfarin (hereafter known as bait). A blue dye was incorporated into warfarin baits to color the subcutaneous fat of any hogs succumbing to the bait, subsequently deterring potential human consumption. Hogs were also fed commercial corn and a formulated cracked corn mix containing no warfarin or dye (hereafter known as placebo).

Feral hog movements were compared between two study phases: *pre-baiting phase* (having both treatment and control plots provided with exclusively placebo) and *baiting phase* (where bait was provided to feeders within treatment plots and placebo presented in feeders within control plots). Feeders were checked and refilled with bait or placebo *ad libitum* for all phases. Human activity was minimized to better condition hogs to the feed provided. Feeders were secured in an upright position with studded t-posts, restricted to natural hog habitat (e.g., river bottom areas, wooded areas, areas of thick vegetation), and positioned in areas protected from inclement weather. Feeders were placed alone, or in groups of 3 adjacent to one another in a single location, hereafter known as bait stations.

Analyses

Data were obtained every 3 h for collared hogs. For each animal, 2D fixes (those locations taken by fewer than four satellites) were removed from the analyses because of greater amounts of associated error (Rempel and Rodgers 1997). Fixes with dilution of precision (DOP) values ≥10 were also excluded from analyses. Spatial data were evaluated using ArcGIS 10.3 geographical information system (GIS) software (Environmental Systems Research Institute, Redlands, CA) and analyzed in the UTM 14N Projected Coordinate System.

Movements were calculated by summing the linear distance between consecutive fixes using the "point-distance" function in the geospatial modelling environment (GME; Beyer 2015). Movement was estimated for daily, diurnal, and nocturnal time periods. Diurnal and nocturnal periods lasted 12 hours. Due to differences in fix collection times between hogs, beginning-end times of diurnal and nocturnal periods varied slightly between individuals, approximately ± 30 minutes. Diurnal and nocturnal periods were 0600-1800 h and 1800-0600 h, respectively. A full daily period (24 h) encompassed all movements from the beginning of a diurnal period through the end of the following nocturnal period.

Hogs were categorized into two groups: *treatment hogs* (hogs that expired as a direct result of bait consumption) and *control hogs* (hogs never exposed to the bait and only to placebo). We examined the activity of feral hogs that died from bait consumption by comparing movement between phases (pre-baiting and baiting). Because of the latency in the effects of warfarin, we found that movements during the first 4 days of bait exposure were statistically similar to pre-baiting movements. To account for this, we compared the distances moved by treatment and control hogs for the last 4 consecutive days of the pre-treatment phase with the last 4 consecutive days of each individual hog before the animal expired. Movement data for days 6-10 (after bait presentation) for control hogs were used for comparison with treatment hogs since that is when treatment hogs would show possible effects of bait consumption. One control hog was killed by a hunter within the first week of the baiting phase. For this individual, the last 4 days alive were analyzed for baiting phase movements.

The rate of movement throughout a 24-h period was evaluated for control and treatment hogs during the pre-baiting and baiting phase to examine for possible changes in circadian activity. Movement rate was determined from distances between sequential fixes by dividing the total distance moved per consecutive fix by the number of hours between each fix. These velocities were analyzed for each diel hourly period. As a conservative measure of activity,

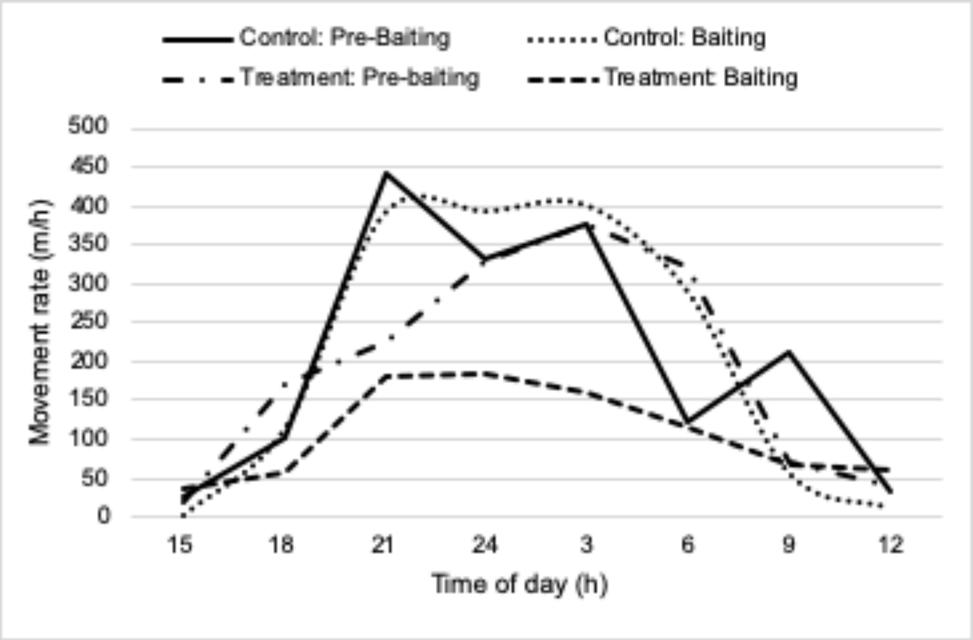

Figure 2. Mean movement rate throughout 24-hour periods during 4-day pre-baiting and baiting phases for treatment and control of feral hogs (*Sus scrofa*) in northern Texas

the rate of movement between missing fixes (>3 h) were not analyzed.

Minimum convex polygons (MCP; Mohr 1947) were used to determine feral hog space use. The 95% MCP and 50% MCP (core area) were calculated for each feral hog using Home Range Tools 2.0 for ArcGIS (Rodgers et al. 2015) for the 4-day periods within the pre-baiting and baiting phase to evaluate differences. Temperatures collected by Lotek GPS collars were used to evaluate if temperature influenced home range size for each individual hog. Two North Star Technology collars were not designed to collect ambient temperatures, therefore temperature from the nearest town of Turkey, TX was obtained from National Oceanic and Atmospheric Administration and averaged for those periods. (http://w2.weather.gov/climate/xmacis.php?wfo=lub)

Distances of all feral hogs found dead from bait consumption were calculated to the nearest bait station, cultivated crop plots, and road. Feral hog carcass locations were recorded on handheld GPS at the time of recovery. If the condition of carcasses allowed, dead hogs were sexed and categorized by size as juvenile (~ <45 kg) or adult (~ > 45 kg; similar to Gaston et al. 2008). Distances of each hog carcass to the nearest bait station were calculated using the "pointdistance" function in the GME. Cultivated crop plots were digitized using ArcGIS over aerial images, and road vector data was obtained from the Texas Department of Transportation (Texas Department of Transportation 2015). Southwest Tablelands vector data obtained from the Texas Parks and Wildlife Department (Texas Parks and Wildlife, 2017) were used to determine vegetation types feral hog carcasses were recovered from.

Descriptive statistics of distance, space use size, and all carcass data were calculated using SigmaPlot 12.0 (Systat Software, San Jose, CA). Since sample sizes of treatment and control groups were small, we pooled year and sex within groups for movement and space use comparisons between pre-baiting and baiting phases. A *post hoc* Tukey multiple comparison test was conducted to evaluate interactions between groups (control and treatment) and phase (pre-baiting and baiting) for distances using R version 3.4.3 software (R Development Core Team 2017). Generalized linear mixed models (GLMM) were used to analyze relationships between dependent variables (daily distances, diurnal distances, and nocturnal distances, 95% MCP, and 50% MCP) and explanatory variables (sex, temperature, group, and phase), using individual hogs as random factors. GLMM distance and 50% MCP data were log-transformed [log(*n*)] to reduce skewness. Akaike information criterion (AIC) with a second-order correction for sample size (AIC_c) ranked models dependent on fit (Burnham and Anderson 2002). Modeling was conducted using the lme4 package (Bates et al. 2017) in R version 3.4.3 software.

RESULTS

Activity was examined for 7 (6F, 1M) treatment hogs and 6 (4F, 2M) control hogs. Locations of 77 feral hog carcasses (*n* = 28 in 2015, *n* = 6 in 2016, *n* = 43 in 2017; 21 M, 37 F, 19 Unk.; 36 Juv., 39 Adult, 2 Unk.) as a result of warfarin consumption were recovered.

The mean distance traveled between pre-baiting and baiting phases by treatment hogs were reduced by 43.9%, 32.1%, and 48.8% for daily, diurnal, and nocturnal periods, respectively (Table 1). Distances moved by control hogs between pre-baiting and baiting phases were reduced 1.8% and 21.7% for daily and diurnal periods, respectively; however, nocturnal distances increased by 4.5%.

Table 1. Mean space use and daily, diurnal, and nocturnal distances for 4-day pre-baiting and baiting phases of treatment and control groups of feral hogs (*Sus scrofa*) in northern Texas.

		Pre-Baiting Phase					Baiting Phase				
		Movements (m)			Space Use (km^2)		Movements (m)			Space Use (km^2)	
Group		Daily	Diurnal	Nocturnal	95% MCP	50 % MCP	Daily	Diurnal	Nocturnal	95% MCP	50 % MCP
Treat-ment	Mean (± SE)	4,630.7 ± 454.0	1,348.4 ± 275.5	3,282.3 ± 353.3	4.68 ± 0.9	0.97 ± 0.4	2,598.3 ± 459.8	916.0 ± 231.4	1,679.4 ± 348.5	2.92 ± 1.52	0.68 ± 0.48
	Range	582.3 - 8,915.8	17.9 - 4,049.4	351.6 - 7,144.5	0.40 - 7.1	0.01- 0.92	25.0 - 8,831.3	12.4 - 4,708.9	6.8 - 6,857.0	0.00 - 11.56	0.00 - 3.50
Con-trol	Mean (± SE)	5,031.8 ± 429.4	1,333.0 ± 231.5	3,698.9 ± 500.4	3.23 ± 0.67	0.52 ± 0.18	4,942.9 ± 503.9	1,044.0 ± 212.9	3,863.6 ± 498.3	4.24 ± 0.71	0.91 ± 0.56
	Range	880.1 - 9,329.6	13.2 - 3,209.7	30.0 - 9,316.4	1.46 - 6.25	0.06 - 1.13	702.0 - 8,353.8	29.3 - 3,268.0	16.5 - 8,158.0	2.80- 6.94	0.06- 1.13

The best-fit model discerning daily and diurnal distances included group, phase, temperature, sex, and the interaction between group and phase (Tables 2 and 3). The best-fit model discerning nocturnal distances included group, phase, temperature, and the interaction between group and phase (Tables 2 and 3). Daily distances exhibited a significant interaction between the effects of group and phase ($F_{5,\ 687} = 32.57$, $p < 0.001$), where distances of treatment hogs during the baiting phase were significantly smaller than during their pre-baiting phase ($p < 0.001$), and pre-baiting and baiting phase of control hogs ($p < 0.001$; Figure 1a). Diurnal distances exhibited a significant interaction between the effects of group and phase ($F_{5,\ 340} = 6.98$, $p < 0.001$), but no significant differences were determined (Figure 1b). Nocturnal distances also exhibited a significant interaction between group and phase ($F_{4,\ 347} = 15.21$, $p < 0.001$), where distances of treatment hogs during the baiting phase were significantly smaller than pre-baiting phase ($p < 0.01$), and pre-baiting and baiting phase of control hogs ($p < 0.001$, Figure 1c). For daily, diurnal, and nocturnal distances there were no significant differences between movements of treatment hogs during the pre-baiting phase with control hogs during pre-baiting and baiting phase.

Circadian hog movements were similar in pattern between control and treatment hogs with noticeable reduction in nocturnal movement rate for treatment hogs during the baiting phase (Figure 2). Activity was not uniform throughout the 24-h period for control animals during the pre-baiting (Kruskal-Wallis H = 58.60, $p < 0.001$) and baiting (Kruskal-Wallis H = 82.58, $p < 0.001$) phases with movement rates being higher during nocturnal hours (Figure 2). Similarly, treatment hog activity was not uniform throughout the 24-h period during the pre-baiting phase (Kruskal-Wallis H = 62.32, $p < 0.001$) and baiting phase (Kruskal-Wallis H = 20.10, $p = 0.005$) with movement rates being slightly higher during nocturnal hours.

Mean space use size by treatment hogs between the pre-baiting and baiting phases were reduced by 37.5% and 30.0% for 95% MCP and 50% MCP, respectively (Table 1). The mean space use size between pre-baiting and baiting phases by control hogs increased 31.3% and 75.0% for 95% MCP and 50% MCP, respectively (Table 1). There was no significant interaction between groups and phase for 95% MCP ($F_{3,22} = 0.62$, $p = 0.61$) and 50% MCP sizes ($F_{3,22}$ 1.41, $p = 0.266$) (Table 3).

No significant differences in distances of carcasses from nearest bait stations were detected when comparing years (Kruskal-Wallis H = 2.02, $p = 0.364$). The distance of carcasses from the nearest bait station ranged from 17.4 m - 3,595.2 m averaging (± SE) 919.4 ± 68.1 m. There was no significant difference in carcass distance to feeding stations between male and female hogs (Mann-Whitney U = 314, $p = 0.231$), while distances of adult feral hog carcasses were significantly larger than juveniles (Mann-Whitney U = 452, $p = 0.008$).

No significant differences were found from distances of hog carcasses to cultivated crop plots between years (Kruskal-Wallis H = 1.90, $p = 0.387$). Pooled feral hogs' average carcass distances from the nearest cultivated crop plot ranged from 13.6 m - 3,379.3 m averaging (± SE) 908.9 ± 72.1 m. There was no difference in carcass distance to cultivated crops between male and female hogs (Mann-Whitney U = 352, $p = 0.56$) or age (Mann-Whitney U = 619, $p = 0.38$). Hog carcasses were not recovered from agricultural fields, but were typically found in various land cover types, such as shrubland (e.g. floodplain, riparian, mesquite), herbaceous vegetation, mixedgrass prairie, and grassland. Feral hog carcasses were significantly farther from roads in the Lakeview area than near Quitaque, TX (Kruskal-Wallis H = 16.639, $p < 0.001$) because there were fewer roads in the area. Pooled feral hog carcass distance to roads ranged from 182.1-1,684.7 m averaging (± SE) 120.7 ± 34.9 m. There was no difference in hog carcass locations to roads as a function of known age (Mann-Whitney U = 555, P$p = 0.12$) or sex (Mann-Whitney U = 299, p =0.15).

DISCUSSION

This study showed a reduction in movements of GPS collared feral hogs after the consumption of warfarin bait. The movements by hogs when naïve to the bait (control and pre-baiting treatment hogs) were significantly higher than treatment hogs during the baiting phase, primarily during daily and nocturnal periods. No significant

Table 2. Mixed linear models for variables explaining space use and daily, diurnal, and nocturnal period distances for 4-day pre-baiting and baiting phases for treatment and control feral hogs (*Sus scrofa*) in northern Texas. Models were ranked dependent on the AIC_c value and in descending order (the most parsimonious model on top of each list).

Response Variable		Model Variables	*k*	AIC_c	ΔAIC_c	ω_i
Move-ment	Daily	Group + Phase + Temperature + Sex + Group × Phase	8	1,902.98	0.00	0.79
		Group + Phase + Temperature + Group × Phase	7	1,905.66	2.68	0.21
		Group + Phase + Group × Phase	6	2,413.83	510.85	0.00
		Group + Phase + Sex + Group × Phase	7	2,415.45	512.47	0.00
	Diurnal	Group + Phase + Temperature + Sex + Group × Phase	8	934.34	0.00	0.65
		Group + Phase + Temperature + Group × Phase	7	935.56	1.22	0.35
		Group + Phase + Group × Phase	6	1,153.47	219.14	0.00
		Group + Phase + Sex + Group × Phase	7	1,154.48	220.14	0.00
	Nocturnal	Group + Phase + Temperature + Group × Phase	7	903.27	0.00	0.65
		Group + Phase + Temperature + Sex + Group × Phase	8	904.49	1.22	0.35
		Group + Phase + Group × Phase	6	1,106.04	202.77	0.00
		Group + Phase + Sex + Group × Phase	7	1,108.11	204.84	0.00
Space Use	95%MCP	Group + Phase + Group × Phase	6	135.35	0.00	0.48
		Group + Phase + Sex + Group × Phase	7	135.89	0.54	0.37
		Group + Phase + Temperature + Sex + Group × Phase	8	138.99	3.64	0.08
		Group + Phase + Temperature + Group × Phase	7	139.15	3.80	0.07
	50%MCP	Group + Phase + Group × Phase	6	95.59	0.00	0.53
		Group + Phase + Sex + Group × Phase	7	96.52	0.93	0.33
		Group + Phase + Temperature + Group × Phase	7	99.22	3.63	0.09
		Group + Phase + Temperature + Sex + Group × Phase	8	99.98	4.39	0.06

differences in movements were discerned diurnally of feral hogs, as prior research has demonstrated diurnal periods are when hogs can be found least active (Saunders and Kay 1991, Singer et al. 1981, Caley 1997, Campbell and Long 2010). In Namadgi National Park, Australia, the movement rates of warfarin baited feral hogs fitted with very-high-frequency transmitters decreased during darkness periods and increased during daylight during their last 2 days alive, but overall mobility was not altered before death (McIlroy et al. 1989).

For these studies, it was impossible to determine the exact time until death for hogs who ingested warfarin bait.

One GPS collared hog died on day 5 after bait presentation, and when collected the next day showed signs of warfarin toxicosis (e.g., blue dye in subcutaneous fat, internal hemorrhaging). It was assumed the hog consumed a lethal dose in an acute exposure to bait. On average our GPS collared hogs perished from bait consumption 8.9 days after bait consumption, similar to other field research evaluating warfarin baits; however, these past studies used higher bait concentrations of 0.13% and 0.09% warfarin (McIlroy et al. 1989, Saunders et al. 1990).

Bait acceptance and hog movements need to be taken into consideration during baiting programs, ensuring hogs are well conditioned to consume feeder contents enough that a lethal amount is ingested before possibly emigrating to new areas. For example, Hone and Kleba (1984) demonstrated that male feral hogs can be tolerant of large doses of warfarin. Our findings demonstrated the only GPS collared treatment male exhibited the highest daily movements averaging 5.4 km during the 4-day baiting phase evaluation, and space use size increased when comparing pre-baiting phase to baiting phase. In addition, of all 77 hog carcasses discovered, the carcass of this male was collected the farthest from any bait stations, nearly 3.6 km away. Earlier research demonstrated this pattern of male hogs having larger space use sizes and traveling longer distances than females (Caley 1997, Adkins and Harveson 2007, Hartley et al. 2014, Franckowiak and

Table 3. Parameters and their statistics included in the most parsimonious model for space use and daily, diurnal, and nocturnal period distances for 4-day pre-baiting and baiting phases for treatment and control feral hogs (*Sus scrofa*) in northern Texas. All explanatory variables were factors and estimates for each factor levels are presented in relation to: group (control), phase (pre-baiting), and sex (female).

Response Variable		Parameter	Estimate	SE	*t*-value	*P*-value
Movement	Daily	Intercept	3.068	0.129	23.732	<0.001*
		Group (Treatment)	0.282	0.105	2.682	0.007*
		Phase (Treatment)	0.200	0.108	1.849	0.065
		Temperature	-0.065	0.006	-11.794	<0.001*
		Sex (Male)	0.345	0.087	3.982	<0.001*
		Group (Treatment) x Phase (Treatment)	-0.664	0.147	-4.527	<0.001*
	Diurnal	Intercept	2.177	0.191	11.410	<0.001*
		Group (Treatment)	0.307	0.145	2.114	0.035*
		Phase (Treatment)	0.002	0.148	0.014	0.989
		Temperature	-0.037	0.007	-5.011	<0.001*
		Sex (Male)	0.311	0.118	2.645	0.009*
		Group (Treatment) x Phase (Treatment)	-0.424	0.203	-2.093	0.037*
	Nocturnal	Intercept	3.250	0.188	17.245	<0.001*
		Group (Treatment)	0.114	0.138	0.828	0.409
		Phase (Treatment)	0.299	0.148	2.024	0.044
		Temperature	-0.053	0.009	-5.609	<0.001*
		Group (Treatment) x Phase (Treatment)	-0.828	0.196	-4.224	<0.001*
Space Use	95% MCP	Intercept	3.233	1.111	2.911	0.008*
		Group (Treatment)	1.446	1.514	0.955	0.350
		Phase (Treatment)	1.010	1.571	0.643	0.527
		Group (Treatment) x Phase (Treatment)	-2.762	2.141	-1.290	0.210
	50% MCP	Intercept	-0.494	0.492	-1.004	0.326
		Group (Treatment)	0.010	0.671	0.016	0.988
		Phase (Treatment)	0.172	0.696	0.246	0.808
		Group (Treatment) x Phase (Treatment)	-1.212	0.949	-1.277	0.215

Poché 2018). Additional research should evaluate if warfarin consumption affects age and sex differently in the field under actual use conditions.

In our study, the range of feral hog carcass distances to the nearest bait stations were slightly larger in northern Texas when compared to warfarin-baited areas in Namadgi National Park, Australia and New South Wales, Australia that ranged 0 - 2060 m and 20 - 1100 m, respectively (McIlroy et al. 1989, Saunders et al. 1990). Investigating the efficacy of compound 1080, Twigg et al. (2005) reported 61 carcasses within 20 - 610 m of active bait stations, averaging 232 m. The difference in carcass distance between 1080 and warfarin is possibly because compound 1080 kills hogs in 3 - 80 hours (McIlroy 1983) compared to 5 - 10 days with warfarin (Hone and Kleba 1984). Differences in carcass distance to warfarin-baited areas between our research and the past studies may be a result of differences in warfarin concentration, formulation, and its latency time. Hog behavior may also play a role in carcass distances to feeders, such as modifying space and habitat use. During feeder conditioning, hogs may begin utilizing cover closer to baiting areas or begin routinely traveling farther from cover to consume feeder contents. It could be that hogs in northern Texas were better conditioned to eating from feeders, that held more feed and were re-filled continuously, than what was tested in Australia with warfarin bait piles on the ground; therefore, traveling longer distances between preferred areas of cover and our baiting stations.

It is recognized that the current study investigating the movements of feral hogs impacted by warfarin bait consumption had some caveats including small sample size, frequency of hog feeding, if it was acute or chronic feeding, and the amount of warfarin bait consumed. Ideally, more GPS collared hog movements would be evaluated between pre-baiting and baiting phases with a shorter duration between fixes, and higher sample size of each sex, weight, and age classes. Unfortunately, the continuous trapping and radio-tagging of hogs for baiting programs could potentially drive hogs away from areas where bait stations were present. It was not uncommon for some collared hogs to leave the baited study plots and were sometimes shot by hunters.

CONCLUSIONS

Our assessments of differences in hog movement before and after bait consumption suggested that warfarin bait was efficient at minimizing distances traveled by hogs. The reduced movement by feral hogs after warfarin bait consumption could minimize problems associated with feral hog presence such as crop damage, predation on native species, and spread of disease between swine, wildlife, and livestock. We recommend that this management method be considered a viable tool in reducing human-feral hog conflicts and disease transmission risk.

Feral hog carcass locations suggest bait stations should be placed in or near natural habitat types where hogs are known to seek cover, but not in such close proximity to humans. Multiple feeders should be placed throughout the landscape, ideally 0.25 - 0.50 km apart. As hogs move throughout their home range they will learn the locations of these bait stations and may feed from multiple stations each night. Placing corn or other attractants inside feeders for approximately 2 - 4 weeks will condition hogs until entire sounders feed regularly, ensuring hogs consume a lethal dose when bait is presented. The continued increase in feral hog numbers in the United States requires control other than traditional methods of trapping and hunting. The use of an EPA-approved feral hog toxicant is prudent to minimizing growing environmental problems created by this invasive species.

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