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Evaluation of movement behaviors to inform toxic baiting strategies for invasive wild pigs (*Sus scrofa*)

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Abstract

BACKGROUND: Invasive wild pigs damage agriculture, property, and natural ecosystems. To curtail damage, an effective and humane toxic bait containing microencapsulated sodium nitrite is under development. Strategies for delivering the toxic bait are needed to establish adequate spacing of bait sites, and for simultaneously accustoming wild pigs to the novel bait and wild pig-specific bait stations designed to exclude non-target species.

RESULTS: We monitored movements of 32 Global Positioning System (GPS)-collared wild pigs relative to 41 bait sites containing placebo bait. Among the bait sites, we compared three experimental baiting strategies (and a control) to evaluate which strategy led to the most wild pigs accessing the placebo bait inside bait stations. We found that bait sites should be spaced 0.5–1 km apart to maximize opportunities for all wild pigs to find and utilize the bait sites. Baiting strategies that allowed ≥ 15 days for accustoming wild pigs to bait stations were most effective and resulted in nearly 90% of wild pigs accessing the placebo bait inside the bait stations. Bait stations excluded all non-target animals, except one instance with a raccoon (*Procyon lotor*).

CONCLUSION: These results demonstrate the potential for toxic bait to be an effective tool for reducing populations of wild pigs with minimal risks to non-target species, if optimized delivery procedures are followed.

Supporting information may be found in the online version of this article.

Keywords: bait station; invasive wild pig; sodium nitrite; *Sus scrofa*; toxicant

1 INTRODUCTION

Non-native domestic pigs (*Sus scrofa*) were brought to multiple continents around the world as a food source during explorations centuries ago.[1,2] Outside their native range, sufficient numbers of pigs escaped or were released and established breeding populations of invasive wild pigs ('wild pigs' from this point forward). On all continents except Antarctica,[3] wild pig populations are a source of zoonotic disease, livestock disease, natural resource damage, and damage to agricultural and private resources.[1–3] Further, wild pig populations have increased in many regions including, but not limited to, Europe, Japan and Australia, as well as in 38 of 50 states in the USA.[1] Wild pigs are very adaptable and are expected to expand their range unless met with an aggressive and coordinated approach to suppress their population growth,[4] emphasizing the need for more efficient control strategies.[1]

One such control strategy includes the development and use of toxic bait to reduce local populations. Recently developed bait containing microencapsulated sodium nitrite is delivered orally and demonstrated potential to reduce population growth in research evaluations[5–7] in which 95% lethality was documented.[7] The bait incorporates the active ingredient sodium nitrite into a bait matrix that is designed to appeal to wild pigs and induce methemoglobinemia resulting in a relatively quick (60–180 min) and humane death.[7] Sodium nitrite is a United States Department of Agriculture approved food additive used in preserving meat.[8]

Use of the landscape by wild pigs is primarily driven by the location and availability of food and water.[9–12] However, previous research has shown that wild pigs will adjust their space-use to utilize transitory anthropogenic food sources, such as bait or crops.[10–13] Some wild pigs shift their home ranges to include these types of resources or constrict their movements around such resources demonstrating the importance of thoughtful spatial strategies when deploying bait stations to maximize bait delivery.[9,14]

Accustoming wildlife to consuming novel food items is an important and challenging step for effectively delivering pharmaceuticals to wildlife populations and may require extensive

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prebaiting.[15–18] Prebaiting is used to congregate target animals at a baiting site, accustom the animals to eating a novel bait, ascertain presence and risk for non-target animals,[16] and finally to deliver a pharmaceutical if all prerequisites are met. Monitoring bait sites during prebaiting also allows for the delivery of prescribed amounts of the pharmaceuticals. Previous research has demonstrated the importance of prebaiting for wild pigs to locate bait sites, establish routine visitation, and allow wild pigs to become accustomed to the bait;[5,6,19,20] however, no evaluations of strategies that maximize the efficacy of prebaiting have been reported.

Considerable research has been conducted towards the development of wild pig-specific bait stations with the goal of minimizing access by non-target species without inhibiting access and feeding by the target species.[19–24] Our prototype bait station designed to dispense toxic bait requires wild pigs to exceed 13 kg of magnetic resistance to open a lid and access the bait. Only 80% of free-ranging wild pigs reliably accessed this device in a recent field test however,[24] thus more effective strategies for accustoming wild pigs to bait stations are needed.

Our objectives were to: (1) examine movement behaviors of wild pigs relative to baiting sites to determine how sex and space-use influenced visitation; (2) evaluate different baiting strategies for accustoming wild pigs to a novel bait in a bait station; (3) determine the proportion of wild pigs that gained access to bait in a bait station; and (4) evaluate risk of access to bait by the most ubiquitous non-target species, white-tailed deer (*Odocoileus virginianus*) and raccoons (*Procyon lotor*). We used placebo bait (i.e., non-toxic) in this study, but made inferences to the last 2 days of baiting which simulated deployment of a toxic bait. The prototype bait station we tested was a refined version of two back-to-back troughs, 1.1 m in length, with overhanging lids, and constructed from marine-grade high density polyethylene (HDPE) plastic (Fig. S1).[24]

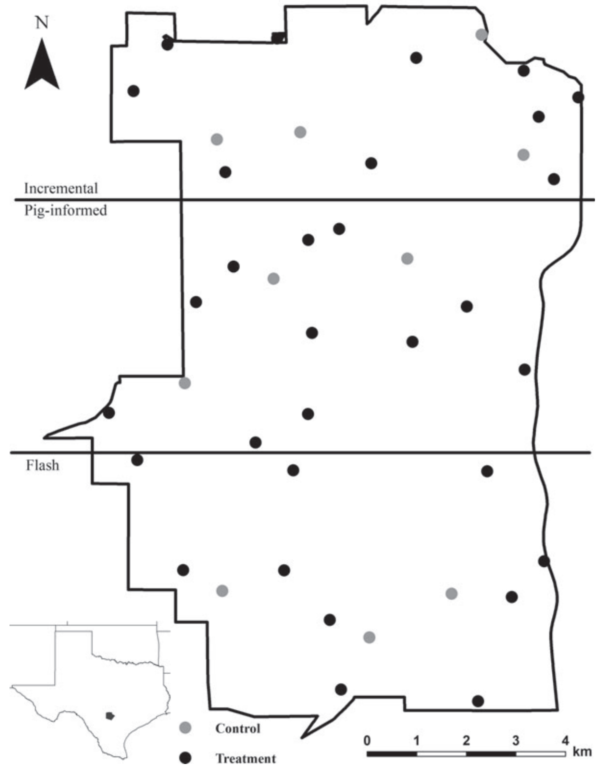

Figure 1. Study area layout. Distribution of bait sites across the study area on Camp Bullis, San Antonio, TX, USA during a field trial in July 2016 designed to determine the best deployment strategy for training invasive wild pigs (*Sus scrofa*) to access a bait station and maximize feeding by multiple individuals simultaneously. There were 10 replicates of each treatment strategy including incremental, pig-informed, flash and control. All progressed through a series of training stages from 11.3 kg of corn on the ground on day 1 to 20 kg of placebo bait from a magnetically locked bait station on the final day (control did not include the bait station).

2 MATERIALS AND METHODS

2.1 Study area

We conducted this study on Joint Base San Antonio, Camp Bullis (112.9 km^2), TX, USA (Fig. 1). Camp Bullis consisted of rolling hills with rocky soils and limestone outcroppings straddling the Edwards Plateau and Blackland Prairie ecoregions of Texas,[25,26] with vegetation characterized by a matrix of oak (*Quercus* spp.) and juniper (*Juniperus* spp.) woodland, and grassland.[27–29] Average temperatures during the study varied from 22 to 30.7 °C and average daily precipitation ranged from 0 to 8.13 mm (January to July 2016; National Climatic Data Center). Camp Bullis was a partially high-fenced military property where management activities for wild pigs during this study were limited to opportunistic hunting and trapping. Population density estimates for wild pigs ranged from 1.4 to 4.7 adult wild pigs per km^2 throughout Camp Bullis during August 2017 (Nathan Snow, USDA APHIS WS NWRC, unpublished data).

2.2 Monitoring wild pigs

During 15 January to 20 June 2016, we used corral traps and box traps baited with whole kernel corn to capture and attach Global Positioning System (GPS) satellite transmitting collars (VERTEX PLUS-2 Collar, VECTRONIC Aerospace GmbH, Berlin, Germany) equipped with ultra-high frequency (UHF) proximity sensors on adult wild pigs (i.e., ≥ 45 kg). We located traps within the study area to generate an even distribution of collared wild pigs. Specifically, we attached GPS collars to one or two wild pigs per family group, and up to four wild pigs per trapping location. We immediately released wild pigs that were captured but not collared. To attach GPS collars to wild pigs, we chemically immobilized them using a mixture of 3.3 mg kg^{-1} Telazol® and 1.5 mg kg^{-1} xylazine delivered via intramuscular injection.[30] We also applied ear tags (Allflex A Cattle Tags, Allflex USA Inc., Dallas, TX, USA) with unique IDs. After handling was complete, we reversed the xylazine with 0.2 mg kg^{-1} of yohimbine hydrochloride delivered via intramuscular injection.[30]

We programmed GPS collars to collect and store locations every 15 min and had every sixth location transmitted to us via Iridium satellite for real-time monitoring. We programmed drop-off mechanisms to automatically release the collars on 15 August 2016, after which we collected the collars and retrieved full location data sets. Using $n = 2840$ fixes truthed with a Trimble GEOXH 2008 (Trimble Navigation, Sunnyvale, CA, USA), we assessed locational error of GPS collars to be up to ± 5.0 m (SE = 0.16) throughout the study area. We also assessed the error rate of the UHF proximity sensors placed at ground level using five test collars at three locations for 4 h each (i.e., totaling $n = 720$ potential proximity events) and found 100% detection within 25 m. Capture and handling procedures were reviewed and approved by the Texas A&M University-Kingsville's Institutional Animal Care and Use Committee (2015-08-20) and the National Wildlife Research Center (USDA-APHIS-WS-NWRC, QA-2263).

2.3 Comparison of baiting strategies

Using the Spatially Balanced Points tool in ArcGIS (version 10.2, ESRI Redlands, CA, USA), we generated 61 spatially balanced baiting sites in areas that represented habitat types preferred by wild pigs across Camp Bullis. Specifically, we used the 2006 National Land Cover Database to identify areas with trees, shrubs, and grass-dominated land cover as potential baiting areas. We excluded land cover that represented open water, developed, and barren areas, as well as areas around sensitive features including karsts, caves, and restricted cultural sites. We specified that all points be separated by > 500 m using the Spatially Balanced Points tool to ensure independence among bait sites.

We divided Camp Bullis into northern, central and southern treatment areas, and randomly assigned all sites within each treatment area to one of three baiting strategies (described below; Fig. 1). On 6 July 2016, we began prebaiting all the sites for 1–6 days to ascertain whether pigs were present. Throughout the prebaiting period, we reduced our 61 sites to 41 sites with most consistent and highest amount of visitation by wild pigs, and discontinued baiting the rest. Each treatment area contained 10–11 bait sites designated as incremental, pig-informed, or flash baiting strategy treatments and three or four randomly assigned bait sites within each treatment area to serve as controls for comparison (Fig. 1).

Each baiting strategy involved a unique three- to six-stage approach to accustoming wild pigs to readily consume an experimental placebo bait matrix (Animal Control Technologies Australia, Victoria, Australia) from a wild pig-specific bait station (Fig. S2). The placebo bait used for prebaiting contained no sodium nitrite, whereas the toxic bait contained microencapsulated sodium nitrite. The control, incremental, and pig-informed strategies all proceeded through the same six stages with regard to the quantities of whole-kernel corn and placebo bait delivered. Control sites did not receive a bait station and bait was delivered directly onto the ground. The flash strategy involved an abbreviated approach designed to evaluate if the middle transitional stages (2–5) were necessary for training wild pigs to open lids of bait stations. Immediately following stage 1 (i.e., on day 7 of the trial), we initiated stage 2 by deploying bait stations at treatment sites and only provided bait from within bait stations at each of the treatment sites from that point forward.

For stage 2 at sites assigned to the incremental and pig-informed strategies, we propped open the lids of bait stations at 25.4 cm to provide an unobstructed view of the bait yet requiring wild pigs to contact the lids while accessing bait (Fig. S2). For stage 3 at the same sites, we lowered the lids of bait stations to 5.1 cm, providing a limited view of bait and requiring wild pigs to lift and allow lids to rest on their heads while accessing and consuming bait. For stage 4, we completely closed the lids, requiring wild pigs to open and support the lids to consume bait. Additionally, from stage 4 onwards, we applied 16 g of peanut butter to the underside of bait station lids to entice wild pigs to explore under the lid during the following stages. At the initiation of stage 5, we installed magnets paired with steel strike plates into the junction of lids and bait station frames requiring wild pigs to exceed ~ 13.6 kg of resistance to access and consume bait from inside the bait stations.[31] All strategies eventually ended with stage 6, two simulated toxic days with 20 kg of placebo bait.

The incremental and pig-informed strategies progressed through the same six stages in which wild pigs were trained to accept the weight of the lids of bait station on their heads and later to open the lids of bait stations. These strategies varied in requirements met prior to advancing to the next stage. With the incremental strategy, we required 5 days at each training stage before advancing to the next stage, regardless of the level of progress demonstrated by wild pigs, thus was longest approach demanding increased time and labor for applicators. Conversely, the pig-informed strategy represented a dynamic approach based on the behaviors of wild pigs at each stage of training at each bait station. This strategy required daily decision-making by the applicators based on behaviors of wild pigs observed in the camera imagery. After two successive days of access and consumption of bait by wild pigs, we proceeded to the next stage. The flash strategy proceeded immediately from stage 1 of prebaiting to the introduction of the bait station with closed and magnetized lids. We then required 2 days of consistent access before proceeding from stage 1 directly into stage 6 for the last 2 days.

We monitored each bait site using remote cameras (Reconyx PC900; RECONYX, Inc., Holmen, WI, USA) by capturing single images at time-lapse intervals of 5 min. The cameras were mounted on T-posts or trees 5 m from the bait, facing north, 1.5 m above the ground, and at an angle of 70° to provide consistent field of view at each site (i.e., ~ 12 m long × 8 m wide). We also installed UHF emitting stationary ID loggers (VECTRONIC Aerospace GmbH) 15 cm above ground level and within 5 m of bait stations to document visitations by collared wild pigs when they approached within ~ 25 m of a site. The GPS collars logged these encounters as proximity events and recorded the date and time of each visitation.

To estimate the true proportion of wild pigs accessing bait stations, we deployed a second camera (Reconyx PC900) programmed to record motion-activated images at all incremental baiting strategy sites during the final 2 days. We chose this strategy because it had the longest training period and thus provided the most opportunity for wild pigs to learn to open bait stations and access bait. These cameras were set to record bursts of 99 images per motion event detected, 1 s apart with no delay between motion-activated events. As such, these cameras collected near-video imagery of wild pigs interacting with the bait stations.

2.4 Data analysis

2.4.1 *Movement data analysis*

We estimated pre-trial home ranges for each collared wild pig using locational data collected during 14–29 June 2016. We also estimated home ranges for the duration of treatments for the trial during 5–30 July 2016, which excluded the 6-day prebaiting period. Finally, we estimated home ranges post trial during 5–15 August 2016, which allowed for a 6-day recovery period after baiting. To estimate home ranges, we used a movement-based kernel density estimator (MKDE) to estimate 95% utilization distribution (UD) contours in the adehabitatHR package[32] in Program R (v3.3.3; R Foundation for Statistical Computing, Vienna, Austria). The MKDE approach uses biased random bridges, movement trajectories, and accounts for serial autocorrelation of relocations.[33,34] We parameterized the MKDE analysis to use an upper time limit of 1 h between fixes and considered fixes ≤ 12 m apart (i.e., two or more times the GPS error) to be inactive. We calculated the centroids of the home ranges using the sp package in program R.[35] We used the centroids of the pre-trial home ranges to represent an average location for each wild pig prior to the deployment of bait stations.

We examined how the distance from pre-trial centroids of home range to the bait sites influenced the frequency of visitation to bait sites for male and female collared wild pigs. Specifically, we used Poisson generalized linear models with log links to examine how the distances influenced the number of days it took for wild pigs to first visit a bait site. Actual visits to bait stations at bait sites were confirmed by the UHF proximity records. We then examined how these distances influenced repeated visitation by collared wild pigs. Specifically, we used binomial generalized linear models with logit links to examine how the distances influenced the probability of continued visits after an initial visit occurred at each bait site.

For the final analysis using movement data, we compared how the three treatment strategies and control influenced visitation to the bait sites during the final stage of baiting. Specifically, we used a binomial generalized linear model with a logit link to examine how the treatments influenced the probability that the collared wild pigs visited during one of the simulated toxic days. In this model, we also included covariates to account for sex of the collared wild pigs and distance from the centroid of home ranges to the visited bait stations. For all models we examined the 95% confidence intervals (CI) surrounding the regression coefficients (β) for lack of overlap on zero to provide statistical and biological evidence of influences.

2.4.2 *Time-lapse imagery analysis*

We evaluated visitation events to the bait stations observed in the time-lapse imagery using the Colorado Parks and Wildlife Photo Warehouse database[36] and aggregated the data into distinct visitations for each species. A visitation was considered as any consecutive images documenting presence at the bait separated by 30-min inactive periods without that species present. For each visitation, we identified the maximum number of each species present by identifying the image(s) with the greatest number of each species. We also identified the maximum number of each species observed accessing the bait during each visitation by identifying the image(s) with the greatest number of each species consuming bait. We considered accessing bait as any animal with its head inside the bait station, or directly above the bait on the ground at control sites.

For an objective measure to compare among baiting strategies, we calculated an index of the number of animals that accessed bait during each visitation (i.e., maximum observed accessing bait/maximum observed present). This index rate presented an unbiased method for comparing among treatments, although conservatively underestimated the true proportion of animals that accessed bait stations. We focused our analysis on wild pigs, white-tailed deer, and raccoons because these were the primary species that visited bait stations.[6] We plotted the indices for each species to examine how well the bait stations allowed access by wild pigs and deterred non-target species from accessing the bait.

We compared how the baiting strategies influenced the index rate that wild pigs accessed bait. Specifically, we used Poisson generalized linear mixed-effect models with REML, log links, a response variable of the maximum number of wild pigs accessing bait during visitations, and an offset of the maximum number of wild pigs present during visitations to normalize the response variable by number of wild pigs participating in a visitation. We considered the pig-informed strategy as the reference treatment for which we compared all other treatments. We also considered the day of treatment as a random effect to account for pseudo-replication that occurred by measuring the index each day and every bait site.

Table 1. Summary of home range sizes (95% utilization distribution contours from movement-based kernel density estimators) and *t*-test results for invasive wild pigs (*Sus scrofa*) during 15 days pre-trial, 25 days during trial, and 10 days post trial, June–August 2016 on Camp Bullis near San Antonio, TX, USA. Experimental field trial was conducted to develop strategies for deploying bait stations on the landscape

	Females		Males		
	Mean (km^2)	SE	Mean (km^2)	SE	Female versus male comparison
Pre-trial	1.46	0.29	1.57	0.19	$t_{21.8} = -0.33$, $P = 0.742$
During	1.44	0.23	2.50	0.42	$t_{26.5} = -2.21$, $P = 0.036$
Post trial	1.43	0.31	1.64	0.24	$t_{22.7} = -0.53$, $P = 0.599$

2.4.3 *Near-video imagery analysis*

We combined the motion-activated images into image sequence movies using (VEGAS Movie Studio Platinum 14.0, Magix Computer Products, Reno, NV, USA). From these movies, we identified the actual number of wild pigs that were present during each visitation and the actual number of those animals that gained access to the bait stations. We used this information to make inferences about the true proportion of wild pigs that gained access during the days of simulated toxic baiting.

3 RESULTS

Overall, we captured and collared 38 wild pigs, of these five lost their collars and one collar failed prior to the study. Our complete sample of collared wild pigs included 13 females and 19 males. The flash, incremental, and control baiting strategies all included $n = 10$ baiting sites, and the pig-informed strategy had $n = 11$ (Fig. 1). The average number of days from prebaiting initiation through simulated toxic days was 11.7 (SE = 1.7) for the flash strategy, 15.7 (SE = 0.5) for the pig-informed, 28.5 (SE = 0.8) for the incremental, and 29.3 (SE = 0.7) for the control sites.

3.1 Movement analysis results

The mean size of 95% UD contours for female wild pigs stayed constant throughout the pre-trial, during, and post-trial periods (Table 1; Fig. S3). The size for males became temporarily larger during the trial, but not during pre- or post trial. All wild pigs with GPS collars visited one or more active baiting sites, except for two females that were not recorded visiting any sites. Overall, 8 of 13 (62%) females and 16 of 19 (84%) males visited multiple bait sites, with averages of 1.7 (range = 0–4) for females and 2.8 (range = 1–5) for males. None of the collared wild pigs visited any bait sites that were ≥ 4 km from their pre-trial home range centroid. Therefore, we excluded combinations of bait sites that were ≥ 4 km from those centroids for each collared wild pig in further analyses.

The number of days it took for females to visit bait sites increased with distance from pre-trial home range centroids ($\beta = 1.20$, 95% CI = 0.77–1.63), and similarly for males ($\beta = 0.28$, 95% CI = 0.17–0.39). However, females were more likely to visit bait sites within 1 km, and less likely to visit sites that were farther away when compared with males (Fig. 2). The sooner that wild pigs found the bait sites, the more likely they were to have continued daily visitation for females ($\beta = 0.35$, 95% CI = 0.26–0.47) and males ($\beta = 0.07$, 95% CI = 0.04–0.10). If females found a bait site

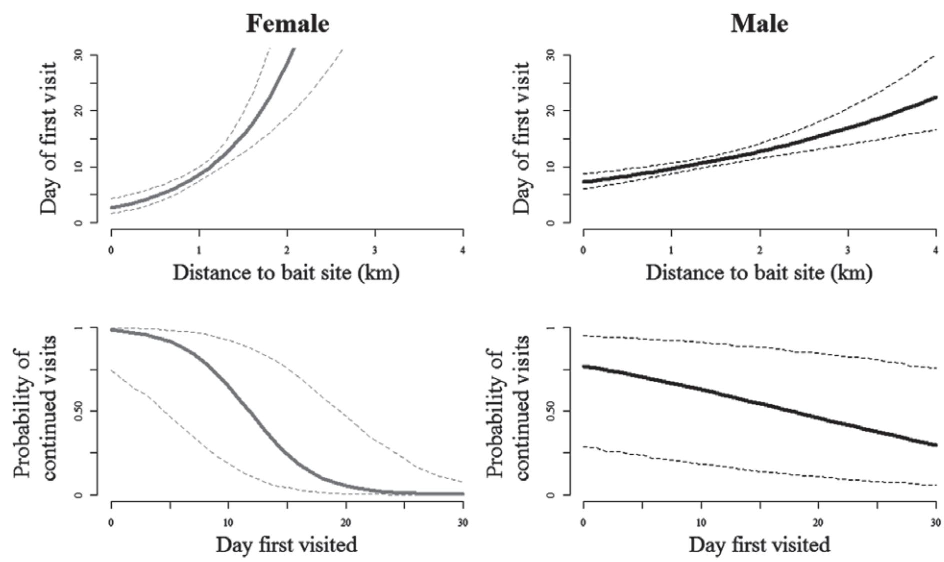

Figure 2. Variation in bait station visitation by sex. Movement of female and male wild pigs (*Sus scrofa*) in relation to all bait stations in July 2016, on Camp Bullis, San Antonio, TX, USA. We examined how the distance from pre-trial centroids of home range to the bait sites varied based on the day of first visitation by wild pigs. We used Poisson generalized linear models with log links to examine how the distances influenced the number of days it took for wild pigs to first visit a bait site. We found no differences in movements among baiting strategy treatments, thus all treatments were combined in this figure.

within 5 days, they had ≥ 90% probability of continued nightly visitation to that site, but males were more variable (Fig. 2). Of the wild pigs that visited bait sites at least once, 7 of 11 (64%) females and 13 of 19 (68%) males visited during the last 2 days.

For the last 2 days simulating deployment of toxic bait, we found that collared wild pigs were just as likely to visit the control sites as any of the other sites with bait stations using the flash strategy ($\beta = -0.45$, 95% CI = −1.99 to 0.98), the incremental strategy ($\beta = -0.35$, 95% CI = −1.68 to 0.93), or the pig-informed strategy ($\beta = -0.20$, 95% CI = −1.67 to 1.12). We also found there were no differences in the probability of visitation by females and males ($\beta = 0.48$, 95% CI = −0.57 to 1.69) during simulated toxic baiting days. Additionally, as would be expected, we found that the probability of visitation was highest for bait sites that were closest to the centroids of pre-trial home ranges ($\beta = -2.15$, 95% CI = −3.16 to −1.40).

3.2 Time-lapse imagery results

We recorded an average of 18 feeding visitations by wild pigs per day for the sites using the flash baiting strategy, 37 per day for pig-informed, 47 per day for incremental, and 44 per day for the control sites. The flash strategy resulted in fewer wild pigs accessing the bait compared with the pig-informed strategy ($\beta = -0.38$, 95% CI = −0.51 to −0.25; Fig. 3). The incremental and pig-informed sites had similar numbers of wild pigs accessing ($\beta = -0.04$, 95% CI = −0.12 to 0.02). The control sites had more wild pigs accessing bait than all other treatment strategies ($\beta = 0.60$, 95% CI = 0.53–0.67) but did not include a bait station.

3.3 Near-video imagery results

Overall, we collected near-video images at 10 incremental sites for 2 days each. We excluded 9 of the 20 days due to partial sampling from camera errors. We recorded an average of 19.7 (SE = 1.47) individual wild pigs at a bait site per day, and an average of 88.61% (SE = 3.88) of those individuals gained access to the bait stations during the simulated days of toxic baiting.

4 DISCUSSION

The movement behaviors of wild pigs in this study provide valuable insight into the efficient delivery of a toxic bait across landscapes for potentially reducing populations of free-ranging wild pigs. Primarily, we observed notable differences between the movement behaviors of female and male wild pigs relative to the bait sites, which allowed us to refine baiting strategies. Similar to other studies of wild pig movements throughout the USA,[37,38] space-use by females was more restricted than males, suggesting that spacing of bait sites should focus on exposing the high site-fidelity females to the bait, and subsequently roving males will also be exposed. To this end, we found that females quickly located bait sites within 1 km from the centroid of their home ranges, and consequently had a high probability of continued visitation to those sites (Fig. 2) leading us to conclude that bait sites should not be spaced farther than 0.5–1 km apart. If females did not find a bait site within the pre-baiting period (i.e., 6 days), the probability of continued visitation to a bait site was less likely.

Population control of wild pigs becomes more efficient as more reproductive females are removed from the landscape.[39–42] Therefore, optimizing baiting strategies to remove females as described herein is desired. However, the increased movements of males, presumably to our bait treatments, indicates that males will also be susceptible to removal. Males likely increased their movements in response to the dispersed food resources from our baiting, or because they followed multiple females that were using distinct bait sites.[43] Males also visited more bait sites than females but showed higher variation in continued visitation to any particular bait site. Regardless of this higher variation, similar proportions of males and females visited the bait sites during the days of simulated toxic bait. Therefore, baiting strategies should primarily focus on maintaining bait sites with reliable visitation by females, which will in turn be sufficient to expose males. Also, males tend to be less risk averse (e.g., will enter traps or consume baits more readily) than females,[39,44] supporting the prioritization of females with

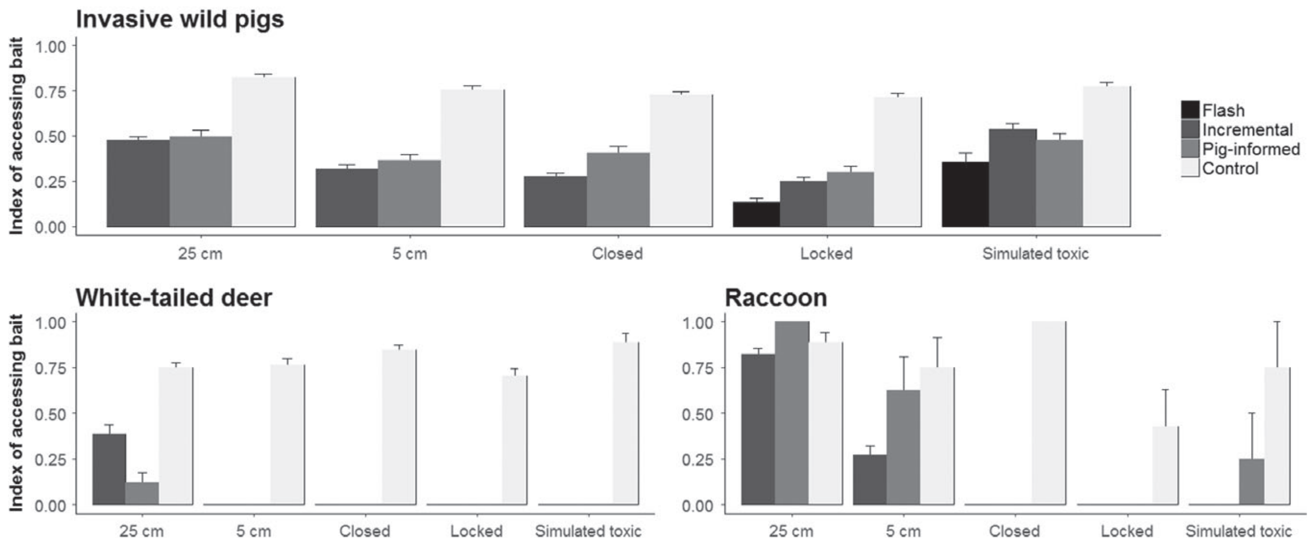

Figure 3. Comparison of access to bait stations by species. Index of access to bait stations by wild pigs (*Sus scrofa*), white-tailed deer (*Odocoileus virginianus*), and raccoon (*Procyon lotor*) in July 2016, at Camp Bullis, San Antonio, TX, USA. We compared four different treatments including three training strategies (flash, incremental, and pig-informed) and a control. An index of the number of animals that accessed bait during each visitation (i.e., maximum observed accessing bait/maximum observed present) was used as an unbiased method for comparing among treatments, although conservatively underestimated the true proportion of animals that accessed bait stations. Indices were calculated from data extracted from time-lapse imagery collected every 5 min throughout the study. The *x*-axes represent the stage of the treatment including the status of the doors (25 cm, 5 cm, closed, and locked) as well as the final stage (simulated toxic) in which only placebo bait was provided within the bait stations for 2 days.

a toxic bait as the most efficacious strategy for ensuring all wild pigs are exposed and susceptible to the bait.

Our findings support the importance of prebaiting by patiently accustoming wild pigs to novel baits and bait stations to maximize visitation and access. Prebaiting is an essential component of baiting regimes for wild pigs with a minimum recommendation of free feeding for 6 days to maximize potential for encountering bait and bait acceptance.[14] The strategies that resulted in the greatest proportion of wild pigs accessing the placebo bait during the simulated toxic days required 15–28 days, similar to that demonstrated in other baiting programs.[16–19,22] Specifically, from previous research with wild pigs, 7–14 days were needed to accustom wild pigs to accept bait delivered from bait stations locked open to facilitate acclimation.[19,22] Further, an additional 4–14 days were needed to insure wild pigs could gain access to bait once bait stations were closed to exclude non-target species.[19,22]

The flash strategy, with the least amount of time for acclimation, achieved the lowest percentage of wild pigs that gained access to the bait station and should not be used operationally. The longer strategies resulted in nearly 90% of wild pigs accessing the bait stations, which when combined with a predicted lethality of 95%[7] exceeds the estimated 52–70% population reduction needed to overcome the reproductive potential of wild pigs and keep their populations from increasing.[7,45–47]

No non-target animals, except a single raccoon during a single visitation, were observed accessing the bait stations during the simulated days of toxic baiting, suggesting minimal risk of direct non-target hazards. Surprisingly, partially closing the lids of bait stations (i.e., 5 cm during stage 4) seemed to exclude all white-tailed deer and most raccoons. The one notable raccoon was repeatedly deterred from accessing the bait station until the last day of the study. During the last day, the raccoon gained access shortly after wild pigs accessed the same bait station. Therefore, it is unclear whether the raccoon gained access because it learned to overcome the magnetic resistance, or perhaps the wild pigs dropped some debris on the magnets, causing the magnets to malfunction. Based on previous results[31] suggesting that raccoons are incapable of breaking 13 kg of magnetic resistance, we suspect the latter.

5 CONCLUSION

Placing one bait station every 0.5–1.0 km is effective for exposing all wild pigs to toxic bait. If female wild pigs fail to visit a bait site during the initial 1–6 days of prebaiting, we recommend relocating the site to another location because continued visitation by wild pigs will be reduced. Delivering toxic bait to wild pigs from a novel bait station may take 15–28 days but following the pig-informed strategy herein should allow ~ 90% of animals access to the bait in the minimum number of days. Risks to non-target species are minimal but should be evaluated throughout the accustoming process to ensure that they have not learned to gain access. Based on our results, we surmise that using the pig-informed baiting strategy with an endpoint of delivering toxic bait has potential to effectively reduce populations of non-native invasive wild pigs.

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SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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