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SPECIES-SPECIFIC VISITATION AND REMOVAL OF BAITS FOR DELIVERY OF PHARMACEUTICALS TO FERAL SWINE

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ABSTRACT: Within the domestic swine industry there is growing trepidation about the role feral swine (*Sus scrofa*) play in the maintenance and transmission of important swine diseases. Innovative disease management tools for feral swine are needed. We used field trials conducted in southern Texas from February to March 2006 to compare species-specific visitation and removal rates of fish-flavored and vegetable-flavored baits with and without commercially available raccoon (*Procyon lotor*) repellent (trial 1) and removal rates of baits deployed in a systematic and cluster arrangement (trial 2). During trial 1, 1) cumulative bait removal rates after four nights ranged from 93% to 98%; 2) bait removal rates by feral swine, raccoons, and collared peccaries (*Pecari tajacu*) did not differ by treatment; and 3) coyotes (*Canis latrans*) removed more fish-flavored baits without raccoon repellent and white-tailed deer removed more vegetable-flavored baits without raccoon repellent than expected. During trial 2, feral swine removed fish-flavored baits distributed in a cluster arrangement (eight baits within 5 m^2) at a rate greater than expected. Our observed bait removal rates illustrate bait attractiveness to feral swine. However, the diverse assemblage of omnivores in the United States compared with Australia where the baits were manufactured adds complexity to the development of a feral swine-specific baiting system for pharmaceutical delivery.

Key words: Baits, feral swine, oral delivery system, pig, *Sus scrofa*, vaccine, wild hog.

INTRODUCTION

Burgeoning feral swine (*Sus scrofa*) populations are increasingly coming into conflict with natural resource managers, agriculture producers, and ecologists in the United States and abroad. Within the livestock industry there is growing trepidation about the role feral swine play in the maintenance and transmission of diseases agents important to domestic swine, such as pseudorabies virus (PRV) and *Brucella suis* (Witmer et al., 2003). Pseudorabies virus in feral swine has received added attention given the successful eradication of the disease from domestic swine in the United States in late 2004. This attention is justified given that feral swine have been found positive for antibodies to PRV throughout much of their transcontinental distribution (Müller et al., 2000) and this virus has been found to persist in feral swine populations for >20 yr (Corn et al., 2004).

Knowledge is growing pertaining to interaction events (and possible transmission) between PRV-positive feral swine and domestic swine. For example, in southern Texas, Wyckoff et al. (2005) found that 38% of feral swine had antibodies against PRV and 50% of global positioning system (GPS)-collared feral swine regularly interacted with domestic swine; this number was based on estimated GPS locations within 100 m of domestic swine facilities. Thus, in portions of their range, feral swine represent a serious disease threat to the domestic swine industry, and innovative disease management tools are needed.

One such tool that has received increased interest is the use of baits as delivery vehicles for pharmaceuticals, such as oral vaccines, to feral swine (Fletcher et al., 1990). The foundational basis for this technology stems from >35 yr developing and implementing oral vaccination programs in Europe (Schneider et al., 1988), New Zealand (Barlow, 1991), and the United States (Baer et al., 1971) in other mammalian species.

Noteworthy advances have been made in developing species-specific baits to deliver toxicants to feral swine in herbivore-rich Australia (Lapidge et al., 2006). In the United States, investigations involving feral swine oral delivery systems (or baits) have been limited to three studies; two of these studies were conducted on Ossabaw Island, Georgia (Fletcher et al., 1990; Kavanaugh and Linhart, 2000), and one study was conducted in southern Texas (Campbell et al., 2006). These studies found high removal, high consumption rates, or both of baits made up of or flavored with fish or corn products by feral swine and nontarget animals, such as raccoons (*Procyon lotor*). However, no studies have reported modifications aimed at reducing bait removal by nontarget animals. These modifications could include the addition of chemical repellents or distribution of baits in a cluster arrangement rather than systematically to increase likelihood of feral swine removal.

Herein, we used two field trials to compare species-specific visitation and removal rates of fish-flavored and vegetable-flavored baits with and without commercially available raccoon repellent (trial 1) and species-specific removal rates of fish-flavored and vegetable-flavored baits deployed in a systematic and cluster arrangement (trial 2). Given our previous work with fish-flavored baits (Campbell et al., 2006), we hypothesized that vegetable-flavored baits would be more specific to feral swine. Additionally, we hypothesized that baits with raccoon repellent would have reduced nontarget removal rates and that baits distributed in a cluster distribution would have increased feral swine removal rates.

MATERIALS AND METHODS

Study area

Our field trials were conducted on the Laureles Division of the King Ranch in Kleberg County, Texas (27°25′N, 97°35′W) from February to March 2006. Our 103,691-ha study area was in the eastern Rio Grande Plains ecoregion (Gould, 1975). The area had a mixed shrub rangeland dominated by mesquite (*Prosopis glandulosa*) and huisache (*Acacia farnesiana*), and it was stocked with domestic cattle at a rate of one animal unit per 10 ha. Additionally, the area received an average of 74.7 cm of precipitation per year, with mean monthly high temperatures from February to March of 22.5 C (National Climatic Data Center, http://hurricane.ncdc.noaa.gov/ancsum/ACS). In addition to livestock, potential nontarget wildlife that occurred within the area were collared peccaries (*Pecari tajacu*), raccoons, striped skunks (*Mephitis mephitis*), opossums (*Didelphis virginiana*), badgers (*Taxidea taxus*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), eastern cottontail rabbits (*Sylvilagus floridanus*), black-tailed jack rabbits (*Lepus californicus*), southern plains woodrats (*Neotoma micropus*), hispid cotton rats (*Sigmodon hispidus*), and white-tailed deer (*Odocoileus virginianus*).

Experimental baits

During both trials, we used PIGOUT® Feral Pig Bait (Animal Control Technologies Australia P/L, Somerton, Victoria, Australia). Baits were grain-based, with either fish flavoring or vegetable flavoring added to the proprietary mixture. Our baits were moist, and they were cylindrical.

Trial 1

Our initial trial used baits that were 9 × 5 cm and weighed approximately 250 g. We used four treatments during this trial. Treatment A consisted of PIGOUT fish-flavored baits, treatment B consisted of PIGOUT vegetable-flavored baits, treatment C consisted of PIGOUT fish-flavored baits plus raccoon repellent (Get Away®, Woodstream, Lititz, Pennsylvania, USA), and treatment D consisted of PIGOUT vegetable-flavored baits plus raccoon repellent. Our raccoon repellent was allyl isothiocyanate- and capsaicinoid-based, and it was applied to the surface of baits upon deployment at a rate of 3 ml per bait following the label.

From 7 February to 13 March 2006, we hand-placed 80 baits from each of the four treatments (i.e., 320 baits) between 8:00 AM and 11:00 AM. We used roads as transects, placing baits at 200-m intervals. We randomly assigned treatment placement order (bait D, A, C, and B), and we maintained this order throughout the trial. Identical baits were 800 m apart throughout the trial. We distributed baits throughout the study area between 5 and 30 m from road edges. For each bait, we randomly assigned roadside orientation (right or left side) by flipping a coin. We monitored baits with automated camera systems (Deer Cam-200, Non-typical, Park Falls, Wisconsin, USA) for four or less nights. Our camera systems used a 35-mm auto focus camera (Trip 505, Olympus America, Denver, Colorado, USA) with automated film advance and flash. We operated systems at their highest sensitivity setting, and we programmed cameras to maintain a 30-sec delay. We set camera systems 3–5 m from baits, and we used vegetation or artificial structures, such as fence posts, as supports.

We revisited baits and checked camera systems daily from 8:00 AM to 11:00 AM, recording the presence or absence of bait, bait condition, and number of photographs captured. If a bait was trampled, it was replaced with a bait from the same treatment. If a bait was moved outside the view of the camera, then we returned the bait to its original position. If a bait was removed, then we removed the camera system. Once baits from all four associated treatments were removed or four or more nights had passed, we moved camera systems to their next position on the transect. The number of baits deployed on a given night was limited by the number of camera systems available ($n=40$).

We determined species-specific visitation and removal rates of baits through examination of photographs. We defined visitation as the total number of individuals within 3 m of baits before and including bait removal. When possible, unique physical characteristics, such as body size, pelage color, and antler pattern, were used to identify individuals. We recorded photographic data into one of five removal categories: 1) definitely removed by species (photographs in which the bait is in the mouth of an animal or a series a photographs $\leq$5 min apart in which only the species of record was observed and the bait was removed); 2) likely removed by species (a series of photographs $\leq$30 min apart in which only the species of record was observed and the bait was removed); 3) possibly removed by species (a series of photographs $>$30 min apart in which only the species of record was observed and the bait was removed); 4) removed by unknown species; and 5) not removed. We considered baits in the definitely and likely categories as removed.

Trial 2

Our second trial used baits that were 4.5 × 5 cm and weighed approximately 125 g. We used four treatments during this trial. Treatment A consisted of a series of eight PIGOUT fish-flavored baits distributed systematically at 200-m intervals following the methods of trial 1. Treatment B consisted of a series of eight PIGOUT fish-flavored baits distributed in a cluster encompassing 5 m^2. Treatment C consisted of a series of eight PIGOUT vegetable-flavored baits distributed systematically at 200-m intervals following the methods of trial 1. Treatment D consisted of a series of eight PIGOUT vegetable-flavored baits distributed in a cluster encompassing 5 m^2.

From 14 March to 31 March 2006, we hand-placed eight replicates of baits from each of the four treatments (256 total baits) between 800 AM and 11:00 AM. We monitored baits with automated camera systems (as described for trial 1) for three or less nights. We used methods described in trial 1 to assess treatments A and C, in which each bait was monitored with an individual camera system. However, we used only four camera systems to monitor replicates in treatments B and D due to the proximity of the eight baits (within 5 m^2).

As in trial 1, we revisited baits and checked camera systems daily from 8:00 AM to 11:00 AM, recording the presence or absence of bait, bait condition, and number of photographs captured. Additionally, bait replacement, movement, and removal procedures from trial 1 were followed. Furthermore, we used methods described in trial 1 to determine species-specific visitation and removal rates, and we considered baits in the definitely and likely categories as removed.

Statistical analyses

For trial 1 data, we reported descriptive statistics pertaining to species-specific visitation and removal. Removal rates (standardized for visitation, following Kavanaugh and Linhart, 2000) were compared among the four treatments in species with $\geq$30 cumulative visits by using the chi-square statistic with Yates correction (Alder and Roessler, 1977). For trial 2, we considered the number of baits removed by feral swine versus the total removed for each replicate as the response variable. We compared the four treatments by using the chi-square statistic with Yates correction (Alder and Roessler, 1977). For all tests, we considered statistical significance at $\alpha=0.05$.

RESULTS

Trial 1

We found cumulative bait removal rates (based on presence or absence) for treat-

TABLE 1. Confirmed visits (before and including removal) and bait removal of PIGOUT baits monitored with motion-sensing photography and distributed from 6 February to 13 March 2006 during trial 1 on the Laureles Division of the King Ranch, Texas.

Species	Treatment[a]			
	A (n=80)	B (n=80)	C (n=80)	D (n=80)
Feral swine	27/67 (40)[b]	25/66 (38)	26/77 (34)	28/75 (37)
Raccoon	12/24 (50)	12/20 (60)	15/32 (47)	10/14 (71)
Cattle	7/52 (13)	10/55 (18)	7/66 (11)	16/47 (34)
Collared peccary	4/39 (10)	6/35 (17)	6/32 (19)	4/24 (17)
Coyote	3/8 (38)	1/8 (13)	1/10 (10)	0/4 (0)
White-tailed deer	0/15 (0)	2/19 (11)	0/17 (0)	1/22 (5)
Eastern cottontail rabbit	0/0 (0)	1/8 (13)	0/2 (0)	2/7 (29)
Rodent	1/6 (17)	0/8 (0)	1/2 (50)	0/1 (0)
Striped skunk	0/0 (0)	0/0 (0)	1/1 (100)	0/0 (0)

[a] A = fish-flavored baits; B = vegetable-flavored baits; C = fish-flavored baits plus raccoon repellent; D = vegetable-flavored baits plus raccoon repellent.

[b] Baits removed/visit (%).

ments A, B, C, and D after four nights were 93, 98, 98, and 98%, respectively. We generated 3,441 photographs of sites where baits were deployed, which allowed us to determine species-specific visitation and removal rates of 229 of 320 baits. Overall (four treatments combined), we found bait removal rates of 46% by feral swine, 21% by raccoons, 17% by cattle, 9% by collared peccaries, 2% by coyotes, and 5% by other nontarget animals. Additionally, we observed bobcat, Rio Grande turkey (*Meleagris gallopavo intermedia*), greater roadrunner (*Geococcyx californianus*), nine-banded armadillo (*Dasypus novemcinctus*), and eastern meadowlark (*Sturnella magna*) visiting baits.

Feral swine bait removal rates ranged from 34% for treatment C to 40% for treatment A, and they did not differ among treatments (χ^2_3=0.42, P>0.05) (Table 1). Raccoon bait removal rates ranged from 47% for treatment C to 71% for treatment D, and they did not differ among treatments (χ^2_3=5.87, P>0.05). Cattle removal rates differed among treatments (χ^2_3=15.68, P<0.005), with baits in treatment D being removed at a greater rate (34%) than expected. Collared peccary bait removal rates ranged from 10% for treatment A to 19% for treatment C, and they did not differ among treatments (χ^2_3=2.04, P>0.05). Coyote removal rates differed among treatments (χ^2_3=47.9, P<0.005), with baits in treatment A being removed at a greater rate (38%) than expected. White-tailed deer removal rates differed among treatments (χ^2_3=16.08, P<0.005), with baits in treatment B being removed at a greater rate (11%) than expected.

Trial 2

We generated 2,402 photographs of sites where baits were deployed, which allowed us to determine species-specific removal rates of 198 of 256 baits. Overall (four treatments combined), we found bait removal rates of 31% by feral swine (61 baits), 29% by cattle (58 baits), 27% by raccoons (53 baits), 5% by collared peccaries (10 baits), 4% by white-tailed deer (8 baits), 2% by coyotes (four baits), and 2% eastern cottontail rabbits (four baits). Feral swine bait removal rates for treatments A, B, C, and D were 33, 54, 21, and 8%, respectively. These removal rates differed among treatments (χ^2_3=39.76, P<0.005), with baits in treatment B being removed at a rate greater than expected and baits in treatment D being removed at a rate less than expected.

DISCUSSION

Our observed cumulative bait removal rates indicated that PIGOUT fish-flavored and vegetable-flavored baits are desired by animals residing in southern Texas. These findings concur with Lapidge et al. (2005) who found cumulative bait removal rates approximating 98–100% in Australia. Animals readily consume PIGOUT fish-flavored and vegetable-flavored baits across their multicontinental distributions. However, unlike Lapidge et al. (2005) who found cattle to remove <1% of PIGOUT baits in Australia, we found overall (all four treatments combined) cattle removal rates of 17% during trial 1 and 29% during trial 2. We attribute this disparity to the severe climatic conditions occurring in southern Texas during our trials. For example, the Palmer Drought Index (Palmer, 1968) from February to March 2006 indicated severe drought conditions (National Climatic Data Center, http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/pdiimage.html) in southern Texas. We think that although cattle will remove PIGOUT baits under severe climatic conditions, baits are not their preferred forage. Additional research conducted during periods of average or moist climatic conditions would increase our understanding into the removal of PIGOUT baits by cattle.

Our first objective was to determine whether the deployment of vegetable-flavored baits versus fish-flavored baits produces removal rates more specific to feral swine. Contrary to our hypothesis, we did not find differences in feral swine removal rates among the four treatments during trial 1. Additionally, during trial 2, which used baits half the size of baits in trial 1, we found fish-flavored baits (44% removal by feral swine when combining treatments A and B) to generally be more specific to feral swine than vegetable-flavored baits (15% removal by feral swine when combining treatments C and D). We attribute the apparent difference in feral swine removal of vegetable-flavored baits between trials 1 and 2 to the size of the baits. We think that the smaller baits used during trial 2 promoted removal by nontarget animals that were less likely to remove the larger baits used during trial 1 and that many of these nontarget animals were more likely to remove vegetable-flavored baits. For example, during trial 1, vegetable-flavored baits distributed systematically (treatment B) had a removal rate of 56% by nontarget animals and during trial 2 vegetable-flavored baits distributed systematically (treatment C) had a removal rate of 79% by nontarget animals.

Our second objective was to determine whether commercially available raccoon repellent reduces nontarget removal rates of baits intended for feral swine. Overall, we found limited evidence in support of our hypothesis that baits with raccoon repellent would have reduced nontarget removal rates. Trial 1 data indicated that feral swine, raccoons, and collared peccaries were not affected in their removal of baits by additions of raccoon repellent. However, coyotes removed more fish-flavored baits without raccoon repellent than expected, and white-tailed deer removed more vegetable-flavored baits without raccoon repellent than expected. In the United States, raccoons are the primary nontarget animal that remove baits intended to deliver pharmaceuticals to feral swine (Fletcher et al., 1990; Campbell et al., 2006). In the current study, we found the addition of allyl isothiocyanate- and capsaicinoid-based raccoon repellent to baits did not reduce bait removal rates by raccoons, further illustrating the attractiveness of PIGOUT baits and demonstrating the complexity of designing a feral swine-specific oral delivery system in United States with its diverse assemblage of omnivores.

Our third objective was to determine whether baits distributed in a cluster (eight baits within 5 m^2), rather than systematically (at 200-m intervals), increases feral swine removal rates. In agreement with our hypothesis, trial 2 data indicate that feral swine removal rates for fish-flavored baits distributed in a cluster were greater than expected. Moreover, treatment B was the only treatment in which all eight baits within a replicate were removed by feral swine; this removal occurred in 25% of the replicates. However, feral swine removal rates for vegetable-flavored baits distributed in a cluster were less than expected. As with our first objective, this may be attributable to the affinity of nontarget animals to the smaller vegetable-flavored baits.

Based on our findings, we suggest that future experimental work aimed at developing a feral swine-specific oral delivery system in the United States concentrate on large baits (9 × 5 cm) distributed in a cluster arrangement. The large-scale distribution of baits in such a manner would likely necessitate ground-based deployment based on habitat characteristics or known feral swine activity centers, such as wallows, and consideration should be given to the cost effectiveness of such a strategy. Additional repellents against nontarget animals, such as putrescent whole egg solids or naphthalene-based products, also should be evaluated. The use of generic grain-based baits with an overcoat of species-specific attractant also has been suggested as a plausible means of orally delivering pharmaceuticals to feral swine (Kavanaugh and Linhart, 2000). This approach would require such attractants to be identified, and it highlights an additional area of needed research.

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