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Efficacy of the Boar-Operated-System to deliver baits to feral swine

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ABSTRACT

Feral swine (*Sus scrofa*) pose a significant disease threat to livestock and humans. Emerging technologies to reduce feral swine disease transmission risks include fertility control, vaccination, and toxicants. However, for these technologies to be appropriate for field application, a feral swine-specific oral delivery system is needed. We used two field trials to generate information related to appropriate field application of the Boar-Operated-System (BOS™), an oral delivery system designed to provide bait access only to feral swine. Our objectives were to determine whether pre-baiting BOS™ units increased bait removal and to evaluate the proportion of feral swine and non-target animals that ingest baits designed to deliver pharmaceuticals through the BOS™. During both trials we used baits housed within 10 BOS™ units. We monitored wildlife visitation, bait removal, and ingestion using motion sensing digital photography and baits containing the bait marker tetracycline hydrochloride (TH). During trial 1 we found three of five pre-baited BOS™ units were used by feral swine only. Additionally, we found the five BOS™ units that were not pre-baited were not used by feral swine or non-target wildlife. During trial 2 we determined bait removal from the BOS™ to be reduced by only 10% for feral swine when activated, whereas bait removal from the BOS™ by all other wildlife was reduced by 100% when activated. We captured 81 feral swine and 23 raccoons and found 90% and 13% to have TH-marked teeth, respectively. With minor modifications, the BOS™ should be considered a valuable tool to be used in feral swine disease management in conjunction with existing technologies.

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1. Introduction

Feral swine (*Sus scrofa*) occur worldwide where they often cause significant damage to agriculture, natural resources, the environment, and property (Campbell and Long, 2009a; Massei et al., in press). Feral swine also pose a significant disease threat to livestock and humans (Witmer et al., 2003; Jay and Wiscomb, 2008). For example, across portions of their range, feral swine have been exposed to pathogens important to the livestock industry and human health (Campbell et al., 2008; Hall et al., 2008) and regularly come into direct contact with domestic livestock at facilities with low biosecurity, where disease transmission is likely (Wyckoff et al., 2009).

Control options available to prevent or reduce the risk feral swine present to livestock production include improved animal husbandry and security, exclusion fencing, and population reduction (Reidy et al., 2008a; Wyckoff et al., 2009). In the United States, feral swine population reduction is often conducted using box or corral traps, snares, or through shooting (i.e., aerial, ground or with dogs; Campbell and Long, 2009a). Developing technologies to reduce feral swine populations or disease transmission risks include fertility control (Massei et al., 2008; Campbell

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et al., 2010), vaccination (Fletcher et al., 1990; Ballesteros et al., 2009), and toxicants (Cowled et al., 2008). However, for any of these emerging technologies to be appropriate for field application, a species-specific oral delivery system is needed (Long et al., 2010).

Prior investigations into oral delivery systems include work on feral swine-specific baits in Australia (Cowled et al., 2006a,b), Spain (Ballesteros et al., 2009), Germany (Kaden et al., 2000; Brauer et al., 2006) and the United States (Campbell et al., 2006; Campbell and Long, 2007, 2009b). These studies suggest that baits can be formulated and exist that feral swine find highly attractive and readily ingest; however, at locations in the United States, other wildlife species also ingest candidate baits at a high rate (Campbell et al., 2006). Consequently, investigations into feral swine-specific feeder systems that contain baits intended to deliver pharmaceuticals have commenced in the United Kingdom (Massei et al., 2010) and the United States (Long et al., 2010).

One feeder system that has consistently delivered bait to feral swine, while preventing bait removal by non-target wildlife, is the Boar-Operated-System (BOS™; Long et al., 2010; Massei et al., 2010). For example, in the United Kingdom, Massei et al. (2010) found feral swine feeding visits to the BOS™ to be reduced by only 22%, whereas feeding visits to the BOS™ by all other wildlife was reduced by 100%. Similarly, the BOS™ was found highly effective at allowing feral swine access to bait and excluding non-target wildlife in trials conducted in the United States (Long et al., 2010). However, additional information into how best to deploy BOS™ units is needed. For example, it is unknown whether pre-baiting BOS™ units prior to activation increases the rate of bait removal by feral swine. More importantly, it is unknown what proportion of feral swine populations ingest baits delivered through the BOS™ and therefore would receive a hypothetical pharmaceutical.

We use two field trials conducted in southern Texas to generate information related to appropriate field application of the BOS™. Our objectives were to determine whether pre-baiting BOS™ units prior to activation increased bait removal during activation and to evaluate the proportion of feral swine and non-target animals that ingest baits designed to transport pharmaceuticals as delivered through the BOS™. We hypothesized that pre-baiting would increase bait removal by feral swine and that BOS™ units would deliver bait specifically to a high proportion of the feral swine population.

2. Materials and methods

2.1. Study areas

Our first trial was conducted on the Laureles Division of the King Ranch in Kleberg County, Texas (27°25′N, 97°35′W) from August to September 2009. Our study area was in the eastern Rio Grande Plains ecoregion (Gould, 1975) and was 1037 km^2. The area, a mixed shrub rangeland dominated by mesquite (*Prosopis glandulosa*) and huisache (*Acacia farnesiana*), was stocked with cattle at a rate of 1 animal unit per 0.1 km^2 (McCoy et al., 2005). Additionally, the area received an average of 75 cm of precipitation per year (National climatic Data Center, http://hurricane.ncdc.noaa.gov/ancsum/ACS), although there was a severe drought during our trial (National Oceanic and Atmospheric Administration, Palmer Hydrological Drought Index – April 2009 to March 2010, http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/phdiimage.html). In addition to livestock, potential non-target wildlife that occurred within the area were white-tailed deer (*Odocoileus virginianus*), collared peccaries (*Pecari tajacu*), raccoons (*Procyon lotor*), 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*), and hispid cotton rats (*Sigmodon hispidus*). Population estimates were not available from this area.

Our second trial took place from January to February 2010 on the Rob and Bessie Welder Wildlife Foundation (WWF) (28°06′N, 97°22′W) in San Patricio County, Texas. The WWF was approximately 31 km^2 and received an average of 79 cm of rainfall annually (National climatic Data Center, http://hurricane.ncdc.noaa.gov/ancsum/ACS). The WWF was bordered to the north by the Aransas River, the west by United States Highway 77, and the south and east by private rangeland. Overstory vegetation consisted of huisache, mesquite, live oak (*Quercus virginiana*), cedar elm (*Ulmus crassifolia*), net-leaved hackberry (*Celtis reticulate*), anaqua (*Ehretia anacua*) and muscadine (*Vitis rotundifolia*). Non-target species on the WWF are similar to those listed for Kleberg County above, with the addition of eastern fox squirrels (*Sciurus niger*). Also, cattle were present throughout the trial. Population density estimates from the WWF were 4.3–7.7 feral swine/km^2 (Reidy, 2007).

2.2. Trial 1

Detailed descriptions of the BOS™ can be found in Massei et al. (2010). In general, BOS™ units are made of three all-metal components, a top cone, base plate, and mast. Baits rest on a perforated base plate that is bolted to the mast at 30 cm above the ground making it stationary. The cone of the BOS™ is larger than the base plate and sits firmly on the base plate when activated. Feral swine and other wildlife may access baits by lifting the cone upward. We secured masts into the ground (∼60 cm) with a 3.6 kg hammer. We lubricated the mast daily using lithium grease to ensure smooth operation of the cone.

We distributed BOS™ units in accordance with feral swine habitat and sign of feral swine activity (i.e., in areas with free-standing water, thick brush, and recent rooting). We used 10 BOS™ units during the trial. The minimum distance between two BOS™ units was 1.2 km. We created a minimum convex polygon (Mohr, 1947) around the BOS™ locations to estimate coverage area using ArcGIS 9.0 (Environmental Systems Research Institute, Redlands, CA). BOS™ units were monitored daily using motion sensing digital photography (Silent Image Professional and Rapidfire Editions, Reconyx, Holmen, WI). Throughout the trial we visited BOS™ units daily between 10:00 and 17:00 h to lubricate masts, download digital images, record notes on bait condition, and re-bait units.

We placed all 10 units out on day 1 and pre-baited 5 units for 14 days in an "open" position to allow all species access to bait. We placed a pin in the mast to allow the cone to remain open 8 cm to enable feral swine and other wildlife to become accustomed to using the BOS™. We pre-baited BOS™ units daily with 1.0 kg whole kernel corn, five polymer fishmeal baits (Bait-Tek Inc., Orange, Texas), and five soured grain based baits (Genesis Laboratories, Wellington, CO). The polymer fishmeal baits were 2 cm × 3 cm × 5 cm, open-ended, and hollow; the soured grain baits were 2.5 cm^3 and solid. We placed baits uniformly on the base plate within the BOS™. Also, during the first five days of pre-baiting, 0.4 kg whole kernel corn was placed on the ground in a 1 m radius from the mast of the BOS™ to encourage wildlife discovery, visitation, and use. The remaining five BOS™ units were left idle during the pre-baiting period.

On day 15, we activated the five BOS™ units that were pre-baited and the five idle BOS™ units. During the 5 days of activation we baited all BOS™ units daily with 1.0 kg whole kernel corn, five polymer fishmeal baits, and five soured grain based baits placed onto the base plate. We recorded the presence or absence of baits, bait condition, and replaced baits, as needed. We monitored BOS™ units daily using motion sensing digital photography. For digital image analysis, we recorded the number of baits removed by species.

2.3. *Trial 2*

We used 10 BOS™ units during this trial. We distributed BOS™ units in accordance with feral swine habitat and sign of feral swine activity (i.e., in areas with free-standing water, thick brush, and recent rooting). The minimum distance between two BOS™ units was 1.1 km. We created a minimum convex polygon (Mohr, 1947) around the BOS™ locations to estimate coverage area using ArcGIS 9.0. We monitored BOS™ units daily using motion sensing digital photography.

We pre-baited BOS™ units daily for 14 days with 1.0 kg whole kernel corn and 15 polymer fishmeal baits that were described in Section 2.2. We place baits uniformly within the BOS™. During the first 5 days of pre-baiting, 0.4 kg whole kernel corn was placed on the ground in a 1 m radius from the mast of the BOS™ to encourage wildlife discovery, visitation, and use. We placed a pin in the mast to allow the cone to remain open 8 cm to enable feral swine and other wildlife to become accustomed to using the BOS™. Throughout the trial we visited BOS™ units daily between 10:00 and 15:00 h to lubricate masts, download digital images, record notes on bait condition, and re-bait units.

After the 14 day pre-baiting period, we activated BOS™ units (i.e., removed pins) for 7 days. During this period we placed 1.0 kg whole kernel corn and 15 polymer fishmeal baits with 250 mg of tetracycline hydrochloride (TH) incorporated into the bait matrix into each BOS™ daily. We used baits containing 250 mg of TH because this is a concentration known to permanently mark teeth of feral swine (Reidy et al., 2008b) and other wildlife (Fletcher et al., 1990) to determine the proportion of feral swine and non-target animal populations that ingested baits. We recorded the presence or absence of baits, bait condition, and replaced baits, as needed. For digital image analysis, we recorded the number of baits removed by species.

From our digital images, we determined that raccoons had removed spilled TH baits. Therefore, in addition to sampling feral swine we also sampled raccoons to determine ingestion rates. We began our trapping effort 8 days after deactivation of BOS™ units, a sufficient duration to mark teeth of feral swine (Reidy et al., 2008b). We pre-baited 14 box-style feral swine traps and one corral trap with 20 kg of whole kernel corn for 8 days. Our feral swine trap density was 0.75 traps/km^2 and the distance to the closest BOS™ ranged from 0.28 to 1.3 km. We concurrently set, without pre-baiting, 15 mesomammal live traps (Model 108, Tomahawk Live Trap, Tomahawk, Wisconsin, USA) for sampling raccoons. We baited mesomammal traps with whole kernel corn. We placed these traps between 50 and 100 m from each BOS™ unit. We set and checked feral swine and mesomammal traps for 17 days. We checked traps daily between 07:00 and 11:00 h to reduce heat exposure. We euthanized captured animals by gunshot to the head (AVMA, 2007). We then determined sex, estimated weight, and removed lower mandible from carcasses for TH analysis. We released non-target animals (e.g., white-tailed deer, collared peccaries) immediately upon discovery. All capture and handling procedures were approved by the Institutional Animal Care and Use Committee at the National Wildlife Research Center (protocol no. QA-1720).

We stored mandibles at −20 °C and later boiled them at >100 °C for 1 h or until we could extract teeth. We extracted incisors from feral swine and canines from raccoons. We cross-sectioned teeth with a diamond Isomet low speed saw (Buehler, Lake Bluff, IL), mounted sections on slides, and examined slides for characteristic TH marking with a compound microscope following Johnston et al. (1987). For analysis, we recorded the number of teeth with TH marking by species.

2.4. *Statistical analyses*

For trial 1 we reported descriptive statistics pertaining to species-specific bait removal. For trial 2 we reported descriptive statistics pertaining to species-specific bait removal and ingestion rates ([no. of marked animals/no. of animals in sample] × 100%). We compared between-sex and between-age ingestion rates of feral swine using the chi-square statistic (Alder and Roessler, 1977). We determined statistical significance at $\alpha = 0.05$.

3. Results

During trial 1 our estimated coverage area was 22.6 km^2, which suggested a BOS™ density of 0.44 units/km^2. We recorded 73,671 digital images. During the pre-baiting period we observed regular visitation and use of the BOS™ units by raccoons, collared peccaries, and feral swine, and occasional visitation by white-tailed deer, southern plains woodrats, eastern cottontail rabbits, nine-banded armadillos (*Dasypus novemcinctus*), coyotes, and numerous avian

Fig. 1. A raccoon (*Procyon lotor*) attempting to gain access to bait housed within a BOS™ in Kleberg County, Texas during trial 1, August–September 2009.

species. When activated, three of five pre-baited BOS™ units were used by feral swine only, whereas non-target species like raccoons were not able to use them (Fig. 1). At each of these three sites, all 10 baits were removed by feral swine each day (i.e., 100% of the baits removed [150 of 250 baits available] went to feral swine). Additionally, the five BOS™ units that were not pre-baited were not used by feral swine or non-target wildlife. From our pre-baiting digital images we found that it took 6 days for feral swine to begin using the BOS™ units. Cattle visited BOS™ units and often loafed next to feeders for long periods (>4 h). However, we did not observe cattle removing baits and BOS™ units were not damaged by cattle.

During trial 2 our estimated coverage area was 18.6 km^2, which indicated a BOS™ density of 0.54 units/km^2. We recorded 423,321 digital images. During pre-baiting we found that feral swine began using one BOS™ unit on the first day that it was deployed (Fig. 2) and regular visitation and use occurred by feral swine, raccoons, and white-tailed deer thereafter. After activation, we found bait removal rates from the BOS™ to be reduced by only 10% for feral swine, whereas bait removal rates from the BOS™ by all other wildlife was reduced by 100%. However, we observed raccoons removing baits that feral swine had spilled out of BOS™ units at two locations. Throughout, we determined that cattle were not interested in the BOS™. In total, 938 TH-marked baits were delivered through the BOS™ and nine of ten units were used daily (Table 1). No baits were removed from one BOS™ after it was activated.

Fig. 2. Feral swine (*Sus scrofa*) gaining access to bait contained within a BOS™ on the Rob and Bessie Welder Wildlife Foundation, Texas during trial 2, January–February 2010.

We captured 81 feral swine and 23 raccoons during our 17-day trapping effort. Mean number of feral swine captured at a trap site was 5.4 (range = 1–14). Sex ratio of captured feral swine was 43 M:38 F and mean weight was 43 kg. We found 73 of 81 (90%) feral swine to have TH-marked teeth. Seventeen feral swine were omitted from statistical analyses because age and sex was not recorded at the time of capture due to severe weather conditions. We found no differences by age ($\chi^2_1 = 0.83$, $P > 0.05$) or sex ($\chi^2_1 = 0.99$, $P > 0.05$) in the proportion of feral swine that were marked (Table 2). Mean number of raccoons captured at a trap site was 3.3 (range = 1–6). Sex ratio of captured raccoons was 11 M:12 F. We found 3 of 23 (13%) raccoons to have TH-marked teeth. An insufficient number of marked raccoons prevented us from performing meaningful statistical analysis. However, there was evidence that a greater proportion of adult raccoons (15%) were marked than juvenile raccoons (0%; Table 2).

4. Discussion

Management to reduce disease exposure and transmission that involves the manipulation of wildlife, rather than the manipulation of the environment or the pathogen, takes on three forms: (1) reducing entire populations, (2) reducing the proportion of infected individuals in the population, and (3) reducing the proportion of susceptible individuals in the population (Wobeser, 2006). A feral swine-specific oral delivery system could be used to accomplish tasks 1 and 3 above. Specifically, orally administered fertility control agents and toxicants might be used to reduce entire feral swine populations and vaccines that induce immunity by the oral route might be used to reduce the proportion of feral swine susceptible in the population. For example, work is underway to develop a combination fertility control vaccine and rabies vaccine for wildlife (Bender et al., 2009). Therefore, the importance of developing new scientific tools for wildlife disease management, such as the BOS™, cannot be overstated (Henke et al., 2008).

During trial 2 we achieved a baiting density of 50.4 baits/km^2, as administered through BOS™ units. Given feral swine population density estimates on the WWF of 4.3–7.7 feral swine/km^2 (from 133 to 239 total animals; Reidy, 2007), we believe most feral swine consumed >1 bait. If the pharmaceutical delivered in the baits were a toxicant, then we expect our bait density to have been lower, as animals would have died and not had the opportunity to ingest multiple baits. Con-

Table 1
Number of tetracycline hydrochloride baits delivered by BOS^TM site and date in 2010 on the Rob and Bessie Welder Wildlife Foundation, Texas.

Site	January 27	January 28	January 29	January 30	January 31	February 1	February 2	Total
1	15	15	15	15	15	15	15	105
2	15	15	15	15	15	15	15	105
3	0	0	0	0	0	0	0	0
4	15	15	15	15	15	15	15	105
5	15	15	15	15	15	15	15	105
6	15	15	15	15	15	15	15	105
7	15	15	15	15	15	15	15	105
8	15	15	15	15	15	15	8	98
9	15	15	15	15	15	15	15	105
10	15	15	15	15	15	15	15	105
Total	135	135	135	135	135	135	128	938

versely, if the pharmaceutical delivered in the baits were a vaccine, we believe that animals would have received multiple doses. Nonetheless, our bait density was intermediate between trials conducted on feral swine in North Queensland, Australia, where baits were delivered aerially at 18 baits/km^2 (Mitchell, 1998), and an island population in Georgia, where baits were delivered by hand at 488 baits/km^2 (Fletcher et al., 1990). The BOS^TM functions to cluster baits, which results in greater bait removal by feral swine than baits distributed in a systematic arrangement (Campbell and Long, 2007). Similar to field studies conducted in the United Kingdom by Massei et al. (2010) we did not observe social dominance within groups of feral swine or monopolization by male feral swine at BOS^TM.

Our bait ingestion rate for feral swine of 90% was high compared to other studies from North Queensland, Australia (63%; Mitchell, 1998), southern Texas (74%; Campbell et al., 2006), and Queensland, Australia (80%; Cowled et al., 2006b), but slightly less than that from an insular Georgia population (95%; Fletcher et al., 1990). It has been estimated that very high (>90%) population reduction rates are needed to rapidly eradicate foot-and-mouth in feral swine in Australia (Pech and Hone, 1988). As deployed in our study, the BOS^TM appears capable of achieving this level of population reduction, assuming an effective toxicant was being used. Our bait ingestion rate for raccoons of 13% was low and almost 7 times less than raccoon ingestion rates from a study from southern Texas that deployed baits on the ground (Campbell et al., 2006). Furthermore, we found no evidence that other non-target wildlife or livestock removed or ingested baits. Depending upon the pharmaceutical being delivered through the BOS^TM and the specific application, a 13% ingestion rate by raccoons may be acceptable. It is possible that small mammals also might feed on spilled baits or fragments. This problem could be addressed by using a larger bait that contains a pharmaceutical in an encapsulated core so that spilled bait fragments from the BOS^TM would not affect non-target small mammals (Cowled et al., 2006a).

The BOS^TM exploits the rooting behavior of feral swine; an animal accesses bait by lifting upward on the cone with its rostrum. This process requires learning either through trial-and-error or through observation of cohorts. We found that it took 6 days for feral swine to begin using BOS^TM units during trial 1 and that during trial 2 some feral swine were able to operate the BOS^TM during the first day. In both trials we observed that feral swine first came to the whole kernel corn distributed on the ground around the mast during pre-baiting and we recommend using a pre-baiting period with the BOS^TM. Site-specific variation may occur in the duration of the pre-baiting period needed to facilitate learning and we recommend monitoring BOS^TM units with motion sensing digital photography to determine when this occurs. This variation may be due to differences in relative density, wariness of feral swine due to sustained hunting pressure, general neophobia, or availability of natural foods in different seasons and study sites. When delivering pharmaceuticals such as contraceptives or vaccines, it is likely that animals that feed from the BOS^TM during a baiting campaign will remember and be the first to feed in successive campaigns. Special consideration related to the learning process of feral swine may be needed if delivering toxicants through the BOS^TM. For example, one of the criteria that should be satisfied by any candi-

Table 2
Tetracycline hydrochloride (TH) results from animals captured during trial 2 (January–February 2010) by sex and age following TH-marked bait delivery through the BOS^TM on the Rob and Bessie Welder Wildlife Foundation, Texas.

Species	Category	No. of marked/no. in sample	% Marked
Feral swine[a,b]	Adult	28/29	97
	Juvenile	32/35	91
	Male	31/33	94
	Female	29/31	94
Raccoon[c]	Adult	3/20	15
	Juvenile	0/3	0
	Male	1/11	9
	Female	2/12	17

[a] Age based on weight of sexual maturity (5–7 months or approximately 30 kg; Sweeney et al., 1979; Mauget and Pepin, 1992; Taylor et al., 1998).
[b] Seventeen feral swine were omitted from analysis because age and sex was not recorded at the time of capture due to severe weather conditions.
[c] Age based on weight of sexual maturity (5.8 kg for males and 4.6 kg for females; Gehrt and Fritzell, 1999).

date toxicant is that it be fast-acting (Cowled et al., 2008). Such fast-acting toxicants may result in negative conditioning to the BOS™ (i.e., carcasses in close proximity to the units may frighten cohorts away or sub-lethal doses might discourage animals from feeding from a BOS™) or no conditioning may occur if other members of cohort have been removed. Additional research is needed to better understand these relationships.

At two BOS™ locations we observed raccoons using an ambush strategy of bait removal. Here, raccoons positioned themselves approximately 1 m from feral swine that were ingesting baits from within the BOS™. Because 15 baits were initially available to feral swine, baits that were not being ingested were occasionally spilled by feral swine onto the ground. In these instances we observed raccoons quickly grasping and removing baits by hand. Our ingestion rate data suggest these were experienced adult animals. We believe that increasing the depth of the base plate (i.e., creating an elevated lip) on the BOS™ may prevent bait spillage by feral swine and removal by non-target animals. In no instances did we observe raccoons accessing bait by lifting upward on the cone.

The efficacy of the BOS™ to deliver baits to feral swine and exclude most non-target species was noteworthy. A possible disadvantage to the units is their initial cost (Long et al., 2010). However, we believe that if used regularly over time that these cost can be recouped because the solid, durable construction of the BOS™. For larger baiting campaigns employing tens or hundreds of BOS™ units, the cost per unit would be reduced because of scaled-up production. An advantage to the BOS™ compared to ground or aerial distribution of baits is that BOS™ units do not require a pre-deployment estimate of feral swine density to calculate a target baiting intensity from (Fleming et al., 2000) because feral swine voluntarily remove baits and a known baiting intensity can be calculated at the end of the campaign.

5. Conclusion

The BOS™ performed best with pre-baiting prior to activation, delivered baits to a high proportion of the feral swine population, and delivered baits to a low proportion of the non-target (i.e., raccoon) population. With minor modifications, the BOS™ should be considered a viable disease management tool to be used with existing technologies in an integrated fashion. Concurrent development of oral fertility control agents, vaccines, and toxicants are needed.

Conflict of interest

The authors declare that they have no conflicts of interest regarding the present study and manuscript.

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