

Assessing whole-sounder removal versus traditional control for reducing invasive wild pig (*Sus scrofa*) populations

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Abstract

BACKGROUND: Trapping is commonly used as the primary management tool in attempts to reduce invasive wild pigs (*Sus scrofa*), but traditional trapping techniques are often ineffective. However, recently developed traps permit the capture of entire social groups (sounders) of wild pigs, and the strategy of whole-sounder removal may achieve more effective control. Our objective was to experimentally compare traditional control (TC; primarily traditional trapping, but including hunting with dogs, and opportunistic shooting) and whole-sounder removal (WSR) strategies by assessing density reduction and removal rate after 1 and 2 years of treatment.

RESULTS: After 1 year of trapping, average wild pig density on WSR units declined 53% and remained stable after the second year, whereas on TC units, pig density did not differ after trapping, although it declined 33% and remained stable after the second year of trapping. The median removal rate (percentage of uniquely marked pigs present at the beginning of each year that were removed) was 42.5% for WSR units and 0.0% for TC units during 2018 and were 29.6% from WSR units and 5.3% from TC units during 2019.

CONCLUSIONS: WSR removal was more effective at reducing wild pig density than TC, but factors such as previous exposure of this population to traditional traps and the lack of barriers to recolonization from surrounding areas may have reduced WSR efficacy. WSR can effectively reduce wild pig density to a greater extent than TC, but managers should recognize the additional time and expense necessary for implementation.

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1 INTRODUCTION

Invasive wild pigs (*Sus scrofa*) are not native to the Western Hemisphere but have been present in parts of North America for centuries.¹ However, as the economic and ecological damage they cause has increased concurrent with their increasing abundance and expanding distribution,^{2–4} wild pigs have become the focus of greater attention for management and control during recent decades.⁵ Their impacts include destructive rooting, habitat degradation, depredation of tree seedlings, crops, and livestock, property damage (e.g. vehicle collisions), competition with and predation on native wildlife, and spread of diseases affecting native wildlife, livestock, and humans. Annual economic impact to agriculture alone in the United States is estimated at \$1.5 billion,⁶ and wild pigs have been implicated in the declines and extinctions of numerous species of flora and fauna and in the spread of noxious weeds.⁷ As a result, the species has been listed by the International Union for Conservation of Nature (IUCN) as ranking among the 100 worst non-native invasive species worldwide⁸ and is considered among the ten most important invasive species in North America.⁹

Throughout much of their introduced range, eradication of invasive wild pigs is unlikely given their extensive distribution, high fecundity, and ability to disperse.^{10,11} Thus, property owners suffering damage from wild pigs are tasked with control, wherein the objective is typically to reduce wild pig density in a localized

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area in order to limit damage. Such control is accomplished by various means, including trapping, aerial gunning, sport hunting (with or without the aid of dogs), and shooting, the latter often with the aid of bait and/or night vision or thermal scopes.¹² Trapping is commonly used in control efforts due to its efficiency and availability to most managers. Most wild pig traps traditionally have been corral or box-type enclosures with a gate that closes when a trigger mechanism in the enclosure is contacted by a wild pig feeding on bait in the trap. Although multiple wild pigs are often caught in such traps, this design frequently captures only a portion of a social group (sounder) because a wild pig often triggers the gate before the entire sounder has entered the trap. In such situations, not only do wild pigs outside the trap when the gate is closed remain on the landscape, they are left to continue reproducing and can become trap-shy and thus more difficult to capture in future efforts.

In response to this difficulty, an approach to trapping known as whole-sounder removal (WSR), more easily enabled by newly available technology, has grown in use among practitioners in recent years. Sounders are matriarchal social groups consisting of one or more sows and one or more generations of their offspring.¹³ The WSR strategy relies on first identifying the composition of target sounders for removal. Cellular cameras can then both send real-time surveillance imagery of wild pig activity in the trap to the trapper and allow the trapper to remotely activate the gate-closure mechanism only when the entire target sounder has entered the trap. In the event that a trap-shy member of the sounder will not enter the trap, it is subsequently removed via shooting, most readily accomplished over bait.

In addition to the advantage of complete removal of sounders when using the WSR approach, aspects of wild pig movement ecology could be leveraged to maximize success of WSR in achieving effective control. For example, wild pig sounders are generally territorial, with the strength of territorial behavior being dependent on resource availability.¹⁴ They typically maintain exclusive home ranges with high site fidelity,^{13,15,16} so immigration into space vacated when a sounder is removed may be low.¹⁷ Thus, the removal of a single sounder, or of several adjacent sounders, from an area should eliminate wild pigs from that area for some extended period, rendering WSR more effective than traditional trapping. However, despite the strong theoretical basis for the WSR strategy, little research has assessed its effectiveness in the field, although two recent studies demonstrated great success with the approach. In Oklahoma, USA using suspended traps that captured whole sounders reduced the estimated wild pig populations on three tracts ranging in size from 10 to 20 km² by 80.7–95.1%,¹⁸ and in Alabama, USA, WSR resulted in complete eradication of the population on a 27 km² tract.¹⁹

Our objective was to experimentally assess the relative efficacy of WSR and a traditional control (TC) strategy (primarily involving traditional-style traps but also including hunting with dogs and opportunistic shooting) in reducing wild pig density on each of ten management units ≥ 20 km² in size, each randomly assigned to either WSR or TC treatments. We also compare effort between WSR and TC treatments in terms of person-hours per wild pig removed, miles driven per wild pig removed, and trap-nights per wild pig removed to aid in estimation of implementation costs.

2 STUDY AREA

We conducted the study on the US Department of Energy's Savannah River Site (SRS) in Aiken and Barnwell counties, South Carolina, USA. The SRS is situated in the Upper Coastal Plain

physiographic province. The landscape is gently rolling, with uplands dominated by loblolly (*Pinus taeda*; 35%), longleaf (*Pinus palustris*; 23%), and slash pine (*Pinus elliotii*; 11%) forests managed on 50–120 years rotations, depending on site-specific objectives. Prescribed fire was used on 3–10 year intervals. Common understory species in pine forests included poison oak (*Toxicodendron pubescens*), blackberry (*Rubus* spp.), sparkleberry (*Vaccinium arboreum*), wax myrtle (*Myrica cerifera*), and saplings of various hardwood trees, particularly sweetgum (*Liquidambar styraciflua*) and oaks (*Quercus* spp.). Bottomland hardwood and cypress (*Taxodium distichum*)-tupelo (*Nyssa aquatic* and *Nyssa sylvatica* var. *biflora*) forests occurred on floodplains of the Savannah River and major tributaries and occupied 23% of the area,²⁰ with understories dominated by switchcane (*Arundinaria tecta*) and swamp palmetto (*Sabal minor*).

At the time of federal acquisition of SRS property in 1951, wild pigs were restricted to the Savannah River swamp and adjacent uplands, having been free ranged there by settlers since colonial times.¹ The SRS has conducted various forms of control since 1956 to reduce wild pig population size, primarily in an effort to limit the number of wild pig–vehicle collisions, but also to limit damage to radiological waste areas and natural resources. Wild pigs were shot opportunistically during public deer hunts, and since 1985, the US Forest Service Savannah River has contracted control to operators who primarily use traditional traps, both corral and box types, and hunting with dogs. Despite these control efforts, wild pig abundance and distribution increased on SRS, and they had occupied the entire SRS by the early to mid-2000s. Annual removals by contract operators during the 5 years prior to our study, 2013–2017, averaged 1348 pigs, with a high of 1434, in addition to an average of 69 harvested annually on deer hunts during this period.

3 METHODS

3.1 Study design

We selected ten management units on SRS and randomly assigned five to the WSR treatment and five to the TC treatment (Fig. 1). Units ranged in size from 20.1 to 35.7 km² and averaged 27.1 km². We obtained pre-treatment density estimates via camera-trap survey (see later) for each area during September 2017. Wild pig trapping treatments then were implemented on all units from 1 October 2017 through 30 September 2019, with post-treatment density estimates obtained after 1 and 2 years (September 2018 and 2019, respectively) of trapping.

3.2 Field methods and data acquisition

We conducted camera-trap surveys to record wild pig detections within each trapping treatment unit over 10-day periods. We systematically deployed 25 cameras (Reconyx Hyperfire 2 Professional White Flash, Holmen, WI, USA) on grids of 636 m $\times$ 636 m cells within all TC and on four WSR units; we deployed 26 cameras on one WSR unit (Fig. 1). We pre-baited each camera site with 11.5 kg of shelled corn 5 days prior to camera deployment and added another 11.5 kg of corn upon deployment (day 1) and day 5 if needed. We programmed cameras to capture a single image per trigger event with a 5-min delay between consecutive triggers. Camera grids and deployment locations within grid cells were consistent throughout the study. From the images, we assigned individual identification to as many wild pigs as possible based on unique natural markings (coat color, spot patterns,

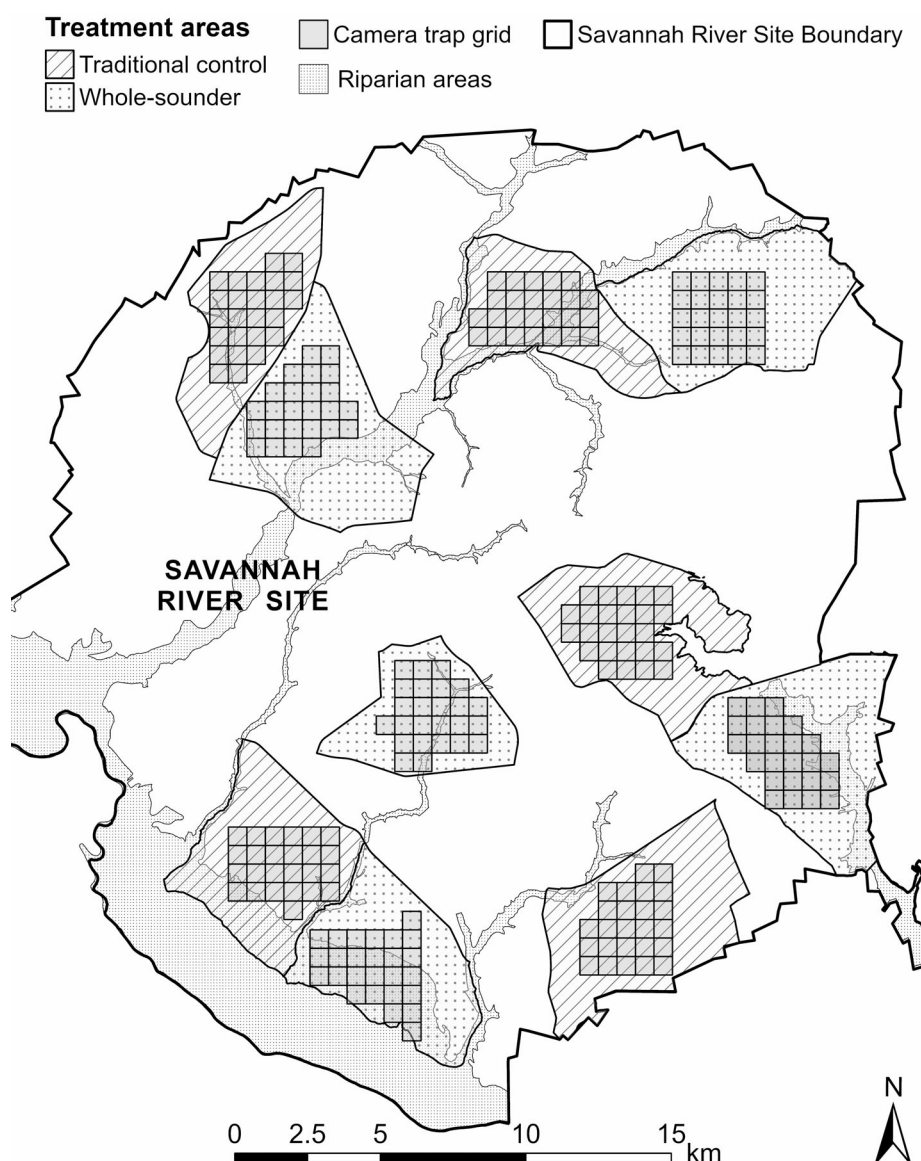


Figure 1. Removal treatment units and associated remote camera grids used to record detections of wild pigs (*Sus scrofa*) during September 2017, 2018, and 2019 on the Savannah River Site, South Carolina, USA.

scars, etc.) or uniquely numbered ear tags on a few wild pigs marked for previous research.

We used spatial capture–recapture models for partially marked populations (hereafter, partially marked SCR)²¹ and data augmentation²² to estimate wild pig density using wild pig detections from camera-trap surveys. We used data augmentation to add all-zero detection histories that represented the number of pigs (M) that could have been present, but were not detected, in the survey area. Choice of M is largely arbitrary, but M must be large enough such that it does not truncate the posterior distribution of N , thus minimizing risk of underestimating the true value of N . However, setting M too large adds unnecessary computational costs.^{19,21} Accordingly, we specified M to three times the number of uniquely marked pigs identified from camera survey images from each trap treatment replicate during 2017, 2018, and 2019 to balance risk of underestimating N and computational time. We defined the state-space as the area of remote camera grids plus a 1-km buffer. We ran three chains for 500 000 iterations with

a burn-in of 100 000 for all units across trap treatments and years in the R statistical environment²³ using the ‘scrPID’ MCMC algorithm from the contributed package ‘scrbook’.²⁴

US Forest Service staff operated traps on WSR units generally following the procedures described by Lewis *et al.*¹⁹: bait sites with shelled corn were spread evenly across the area in locations where wild pig activity was present and after a 7–14-day period during which the size and composition of target sounders were identified, those sounders were removed using traps constructed on a single day and equipped with cellular-enabled cameras (JagerPro M.I.N.E. traps, Fortson, GA, USA; BoarBuster traps, W-W Livestock Systems, Thomas, OK, USA). New bait sites were added and traps were moved throughout the study period as sounders shifted their activity centers and new evidence of wild pig presence was discovered. JagerPro traps were constructed of 3 m long by 1.7 m tall rigid-frame panels and a 2.4 m long gate panel, all connected by 12-gauge wire. Number of panels per trap, including the gate panel, depended on size of the target group and

varied from three (for lone boars) to seven. BoarBuster traps were round steel pens, with a uniform 5.5-m diameter, that were suspended on three poles. When the entire target group entered a JagerPro trap or the space under a BoarBuster trap, an observer remotely activated the gate closure mechanism or drop mechanism, respectively, whereupon wild pigs were euthanized via gunshot to the brain with a 0.22 caliber rifle. If an individual member of a sounder would not enter a trap after 2 weeks of regular visits by the sounder, the portion of the sounder entering the trap was removed as described earlier. Efforts were then made to attract the trap-shy sounder member to a nearby bait site where it was shot from a tree stand, thereby achieving WSR. Taxon-specific guidelines for euthanasia²⁵ and the use of vertebrates in research²⁶ were followed to ensure animals were treated ethically and humanely.

US Forest Service contractors operated traps on TC units. Contractors used box traps and corral traps baited with shelled corn both inside the trap and in the immediate vicinity surrounding the trap in an effort to acclimate wild pigs to feeding in and around the trap.^{27,28} No pre-baiting was conducted. Corral traps were 4–5 panels plus a gate panel containing a root door and were equipped with a root stick or trip wire set at a height of 20–25 cm that closed the root door when contacted by a wild pig foraging for bait in the trap. Contractors also were permitted to hunt with dogs 2 days per week and to shoot opportunistically encountered wild pigs.

Personnel on both WSR and TC units recorded time spent and vehicle mileage during all removal efforts. For each wild pig removed, personnel recorded sex, size class as a coarse approximation of age (piglet: <18 kg; juvenile: 18–45 kg; adult: > 45 kg), date of removal, unit name, removal method (trap, shooting, dog hunting), trap type (including number of panels for corral traps), and number of wild pigs in the group. Each removed wild pig was also photographed for comparison with uniquely marked wild pigs detected on camera surveys to identify marked wild pigs that were removed.

3.3 Data analysis

We used three complementary approaches to compare efficacy of WSR and TC methods. First, we compared estimates of wild pig density before and after trapping between treatments. We used a mixed-effects analysis of variance to compare density across years for each trap treatment. We fit unit-specific estimates of wild pig density (obtained from partially marked SCR models described earlier) as the response variable and a two-way interaction between year and trap treatment as explanatory variables. We fit unit identifier (ID) as a random intercept term to account for repeated sampling of each unit across years. We used non-parametric bootstrapping techniques to evaluate precision of coefficient estimates of the mixed-effects analysis of variance.²⁹ We sampled with replacement to generate 1000 bootstrap samples from the wild pig density estimates and subsequently calculated bootstrapped coefficients and 90% confidence intervals (CIs). As needed for non-parametric bootstrapping techniques, we resampled observations from within individual units of each trap treatment to maintain the grouping structure of the wild pig density estimates.²⁹ We then used *post hoc* contrasts to compare mean differences in pre-trapping (2017) and post-trapping wild pig density (2018 and 2019) between trap treatments. We conducted these analyses in the R statistical environment²³ using the packages 'glmmTMB'³⁰ for mixed-effects analysis of variance and 'emmeans'³¹ for *post hoc* contrasts. Second, we evaluated

removal rates, calculated in two different ways, between trapping treatments. Annual removal rate was the percentage of the initial estimated abundance (in September) that was removed during the ensuing year $[(\text{number removed}/\text{abundance}) \times 100]$, with estimated abundance calculated as SCR-estimated density $\times$ area of each unit. This measure necessarily includes removed wild pigs born or immigrated during the removal year, after initial abundance was estimated. We therefore calculated the percentage of uniquely marked wild pigs detected during camera surveys that were removed the ensuing year (marked-pig removal rate) as an index to the proportion of the initial population removed by each trapping treatment. We assumed that whether a wild pig possesses uniquely identifiable markings does not affect its vulnerability to trapping, that is, the marked wild pigs detected during camera surveys that were removed the ensuing year represent a random sample of the population. Third, we present the number of wild pigs removed per trap night and per person-hour to evaluate removal per unit-effort between trap treatments.

4 RESULTS

In 2017, prior to initiation of our treatments, wild pig density ranged from 1.22 pigs/km² (90% CI = 1.09–1.36 pigs/km²) to 6.88 pigs/km² (90% CI = 5.42–8.34 pigs/km²), and average wild pig density was similar between WSR (3.68 pigs/km², 90% CI = 2.84–4.39 pigs/km²) and TC units (3.41 pigs/km², 90% CI = 2.62–4.34

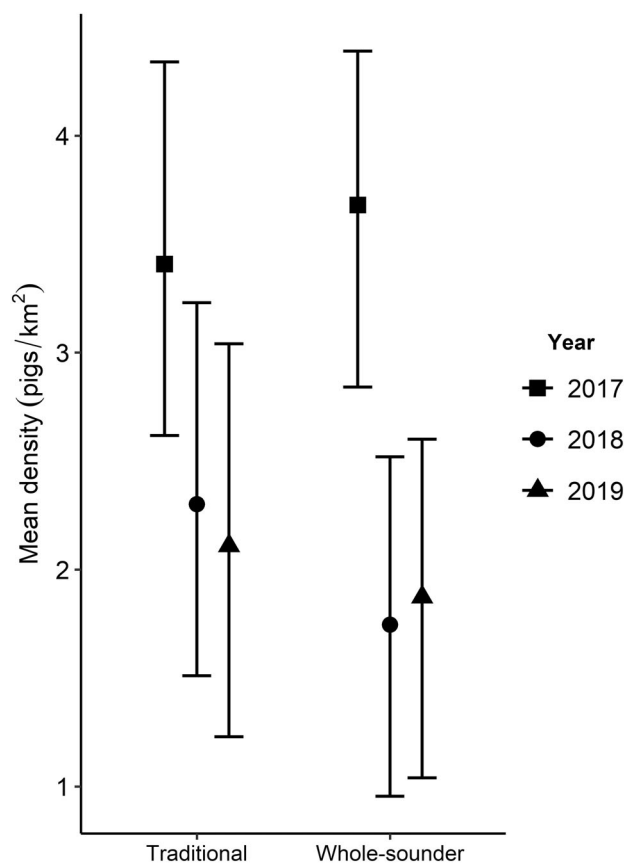


Figure 2. Mean estimated wild pig (*Sus scrofa*) density (pigs/km²) for traditional control ($n = 5$) and whole-sounder removal treatment units ($n = 5$) during September 2017 (pre-treatment), 2018 (after 1 year of treatment), and 2019 (after 2 years of treatment) on the Savannah River Site, South Carolina, USA.

Table 1. Wild pig (*Sus scrofa*) density estimates (pigs/km²) and change in density on whole-sounder removal (Whole-sounder; $n = 5$) and traditional control treatment units (Traditional; $n = 5$) during 2017–2019 on the Savannah River Site, South Carolina, USA

Trap treatment	Area	Year	Number of pigs removed	Density (pigs/km ²) (90% CI) [†]	Change in density (%) [‡]
Whole-sounder	Deerkill	2017		3.61 (3.18–4.05)	
		2018	230	1.62 (1.27–1.97)	–55.1
		2019	83	2.62 (1.85–3.39)	+61.7
	L-Area	2017		3.2 (2.73–3.66)	
		2018	100	1.36 (1.15–1.56)	–57.5
		2019	50	1.47 (1.23–1.72)	+8.1
	Lower Three Runs	2017		1.96 (1.5–2.42)	
		2018	52	0.68 (0.63–0.74)	–65.3
		2019	36	1.62 (1.42–1.81)	+138.2
	Phinizy	2017		3.77 (2.95–4.6)	
		2018	45	2.51 (1.93–3.1)	–33.4
		2019	46	1.74 (1.72–1.82)	–30.7
	Water Gap	2017		5.46 (4.80–6.10)	
		2018	238	2.48 (2.01–2.97)	–54.6
		2019	96	1.77 (1.44–2.11)	–28.6
Traditional	Hog Barn	2017		6.88 (5.42–8.34)	
		2018	155	2.99 (2.35–3.63)	–56.5
		2019	135	1.86 (1.44–2.27)	–37.8
	Par Pond	2017		2.21 (2.01–2.41)	
		2018	36	2.27 (2.19–2.36)	+2.7
		2019	26	2.37 (2.10–2.65)	+4.4
	SATA	2017		2.18 (1.95–2.42)	
		2018	17	0.79 (0.73–0.84)	–63.8
		2019	31	0.34 (0.31–0.38)	–57
	Tennessee Road	2017		4.06 (3.83–4.30)	
		2018	23	2.77 (2.37–3.17)	–31.8
		2019	9	2.74 (2.51–2.98)	–1.1
	Tinker Creek	2017		1.22 (1.09–1.36)	
		2018	9	2.62 (2.3–2.95)	+114.8
		2019	31	3.23 (2.91–3.53)	+23.3

[†] Estimated from spatial-capture–recapture models for partially marked populations based on images from camera-trapping grids within each unit. CI, confidence interval.

[‡] From time $t - 1$ to t .

pigs/km²; Fig. 2). During the removal periods of 2018 and 2019, workers removed 1448 wild pigs across all treatment units, with 976 removed from WSR units (952 by trapping, 24 by shooting) and 472 removed from TC units (360 by trapping, 92 by hunting with dogs, 20 by shooting; Table 1). Removals on WSR units were greater during 2018 than 2019, with 665 of 976 (68%) removed during 2018. In contrast, removals on TC units were comparable between years (240 in 2018 and 232 in 2019). The size of sounders trapped using WSR and of groups trapped by TC trapping methods (excluding captures of lone males and bachelor groups) averaged 4.99 (range = 1–21) and 2.30 (range = 1–8) wild pigs, respectively.

WSR methods reduced wild pig density to a greater extent than TC methods. After 1 year of removal (2018), average wild pig density on WSR units declined 53% (90% CI = 43–66%) to 1.75 pigs/km² (90% CI = 0.96–2.52 pigs/km²; $z = 2.89$; $P = 0.011$) and remained low (relative to 2017) after the second year of removal (i.e. 2017 compared with 2019) with 1.87 pigs/km² (90% CI = 1.04–2.60 pigs/km²; $z = 2.61$; $P = 0.025$; Table 1, Fig. 2). Although wild pig density on TC units declined 33% (90%

CI = 25–42%) after 1 year of removal, the decline to 2.30 pigs/km² (90% CI = 1.51–3.23 pigs/km²) in 2018 and to 2.11 pigs/km² (90% CI = 1.23–3.04 pigs/km²; Table 1, Fig. 2) in 2019 did not differ statistically ($z = 1.62$; $P = 0.236$ and $z = 1.98$; $P = 0.118$ for 2018 and 2019, respectively) from pre-treatment average wild pig density on TC units. Abundance estimates were not biased low by our choice of M ; all estimates were all well below three times the number of marked pigs identified during camera surveys (Table 2).

Median annual removal rates during 2018 were 140.4% (range = 37.9–188.7%) of initial abundance for WSR units and 43.1% (range = 10.4–80.1%) for TC units, and during 2019 median rates were 161.2% (range = 58.0–205.0%) for WSR units and 49.9% (range = 10.4–152.3%) for TC units (Table 2). The number of marked wild pigs detected on camera surveys in WSR units averaged 69.6 (range = 45–89) in 2017 prior to removal, 36.2 (range = 19–37) in 2018 after 1 year of removal, and 30.8 (range = 9–45) in 2019 after 2 years of removal (Table 2). For TC units, the number of marked wild pigs detected on camera surveys units averaged 55.2 (range = 23–87) in 2017, 36.4

Table 2. Wild pig (*Sus scrofa*) removal rates on whole-sounder removal (Whole-sounder; $n = 5$) and traditional control treatment units (Traditional; $n = 5$) during 2017–2019 on the Savannah River Site, South Carolina, USA

Treatment	Area	Year	Abundance [†]	Annual removal rate (%) [‡]	Number of marked pigs [§]	Marked-pig removal rate (%) [¶]
Whole-sounder	Deerkill	2017	118		66	
		2018	52	188.7	34	25.8
		2019	94	171.5	26	41.2
	L-Area	2017	64		60	
		2018	26	156.4	19	43.3
		2019	30	205.0	28	63.2
	Lower Three Runs	2017	57		45	
		2018	22	91.8	9	62.2
		2019	51	161.2	42	11.1
	Phinizy	2017	116		50	
		2018	79	37.9	27	14.0
		2019	55	58.0	39	29.6
	Water Gap	2017	143		80	
		2018	65	140.4	34	42.5
		2019	46	148.6	28	26.5
Traditional	Hog Barn	2017	192		66	
		2018	86	80.1	30	7.6
		2019	49	152.3	33	16.7
	Par Pond	2017	62		41	
		2018	63	58.1	38	0.0
		2019	66	41.2	40	5.3
	SATA	2017	51		34	
		2018	23	43.1	22	0.0
		2019	12	113.0	9	9.1
	Tennessee Road	2017	128		82	
		2018	87	14.9	35	7.3
		2019	86	10.4	45	0.0
	Tinker Creek	2017	29		11	
		2018	62	10.4	30	0.0
		2019	76	49.9	48	3.3

[†] Calculated by multiplying density estimates by the area of each unit.

[‡] Calculated as the percentage of initial population size (abundance in year $t - 1$) that was removed in year t .

[§] Number of marked (uniquely identifiable) pigs detected on camera survey.

[¶] Calculated as the percentage of uniquely marked pigs detected on camera survey in year $t - 1$ that was removed in year t .

(range = 22–54) in 2018, and 36.8 (range = 26–48) in 2019. Across all units, we estimate 62% of the population was uniquely marked, based on the proportion of all photographed removed wild pigs that were uniquely identifiable (639 of 1023). WSR methods removed a greater percentage of marked wild pigs detected during camera surveys than TC methods. During 2018, median marked-pig removal rate was 42.5% (range = 14.0–62.2%) for WSR units and 0.0% (range = 0.0–7.6%) for TC units, and during 2019 the median marked-pig removal rate was 29.6% (range = 11.1–63.2%) for WSR units and 5.3% (range = 0.0–16.7%) for TC units (Table 2).

Workers on WSR units expended more time (1038 h) than those on TC units (540 h), and they spent more time in 2018 (787 h) than in 2019 (251 h; Fig. 3). Workers on WSR units drove a total of 8280 km (6530 km in 2018, 1750 km in 2019), and workers on TC units drove 18 649 km (6768 km in 2018, 11 881 km in 2019). Number of trap nights were comparable between WSR and TC units during 2018 but were more than twice as great on TC units as on WSR units during 2019 (Fig. 3). WSR traps removed 330%

more wild pigs per trap night [1.9 pigs/trap night ($n = 510$) across both years] than traditional traps [0.68 pigs/trap night ($n = 815$); Fig. 4]. In contrast, traditional traps removed 65% more wild pigs per person-hour (1.82 pig/person-hour across both years) than WSR traps (0.69 pig/person-hour across both years; Fig. 4).

5 DISCUSSION

The WSR strategy was more effective at reducing wild pig density than TC, having achieved an average of 53% reduction across our five WSR units compared to only 33% reduction across our five TC units. Average annual cost of the wild pig control contract at SRS, which uses TC, has steadily increased over the past 20 years, averaging \$57 600 during 2017–2021 compared to approximately \$22 000 during the early 1990s. Although this increasing cost is due in part to increasing contract rates and added program emphasis on wild pig control, the trend in cost and emphasis largely reflects an increase in the wild pig population size that occurred despite ongoing control efforts³² (TT Mims,

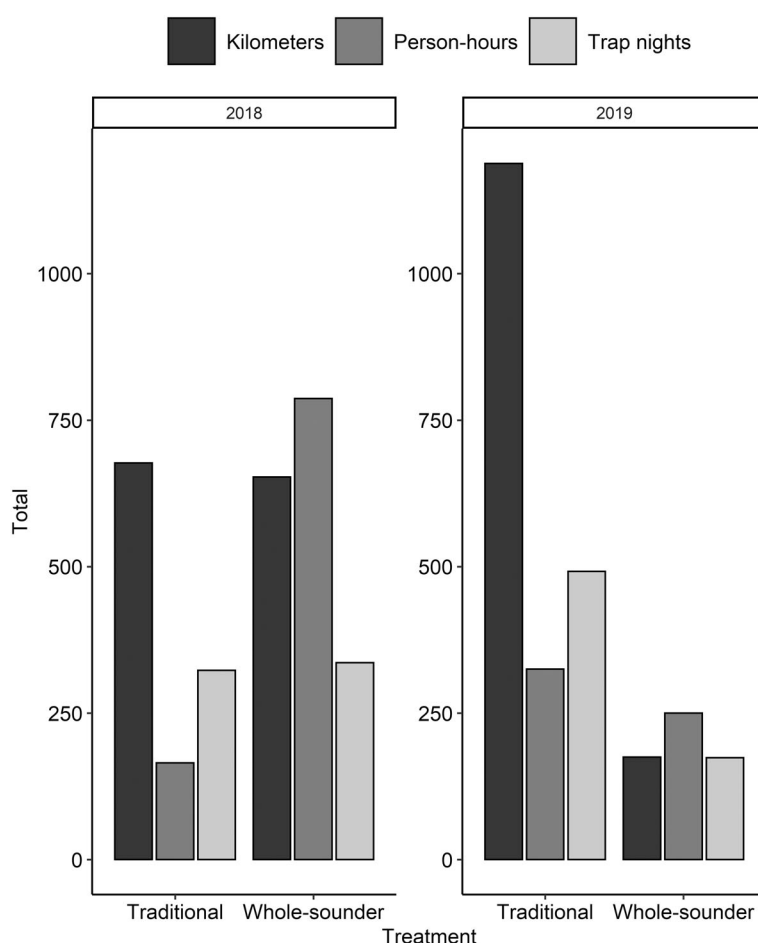


Figure 3. Total number kilometers driven (Kilometers), number of trap nights (Trap nights), and person-hours (Person-hours) worked for wild pig (*Sus scrofa*) traditional control ($n = 5$) and whole-sounder removal treatment units during September 2018 and 2019 on the Savannah River Site, South Carolina, USA.

unpublished). Given the inability of TC to prevent growth of the SRS wild pig population, much less reduce the population size, WSR represents a promising alternative strategy for wild pig control at SRS.

Despite its relative success, WSR did not achieve the level of reduction we hoped for or expected. Other recent research evaluating WSR has reported > 85% reduction after 1 year in Oklahoma, USA,¹⁸ and complete eradication of a semi-open population within 2.5 years in Alabama, USA,¹⁹ albeit number of wild pigs removed in these studies were somewhat smaller than in ours, suggesting that initial population sizes may have been smaller or immigration in our areas was greater. However, lacking physical barriers such as fencing to limit immigration and movement,³³ eradication using WSR may not be an achievable goal when populations exist over large, non-insular areas such as SRS, and instead maintaining low densities to minimize damage³⁴ can be a valid and achievable goal, as our results demonstrate.

Several factors may explain why density reduction on our WSR units was lower than expected. First, wild pigs had been subjected to TC methods at SRS for more than three decades, and most individuals in the population had likely been exposed to corral traps or observed sounder members getting trapped, some almost certainly many times, and thus were not naïve to them. Although the 'smart traps' we used for WSR were designed specifically to

capture whole sounders (leaving no wild pigs that had experienced the trap and thereby preventing development of trap-shyness), these traps remain corral traps in basic design. Therefore, where wild pig populations previously have been exposed to traps, achieving greater population reduction than we observed may be difficult using WSR, despite its advantages. Second, populations in our study units were demographically open, with no physical barriers to immigration from adjacent areas on any side of any unit. Considering wild pigs are widely distributed across SRS at densities ranging 3–20 pigs/km²,¹⁴ pigs may have moved from surrounding areas that were only lightly trapped using TC into newly vacated areas of WSR units¹⁷ where sounders had been removed. Indeed, marked wild pigs detected in camera surveys on two TC units were removed on nearby WSR units during the same year, but no marked wild pigs detected in camera surveys on WSR were removed on TC units. Thus, the entire landscape matrix surrounding our units effectively served as a source for recolonization when sounders in our units were removed. Finally, given the high fecundity of wild pigs³⁵ and the 2 years duration of our study, considerable reproduction by sows not removed within our treatment units likely occurred and could have partially offset reductions achieved in WSR units.

Such reproduction, combined with immigration, explains the high annual removal rates we observed on WSR units, with median removal rates averaging > 150% over the 2 years of

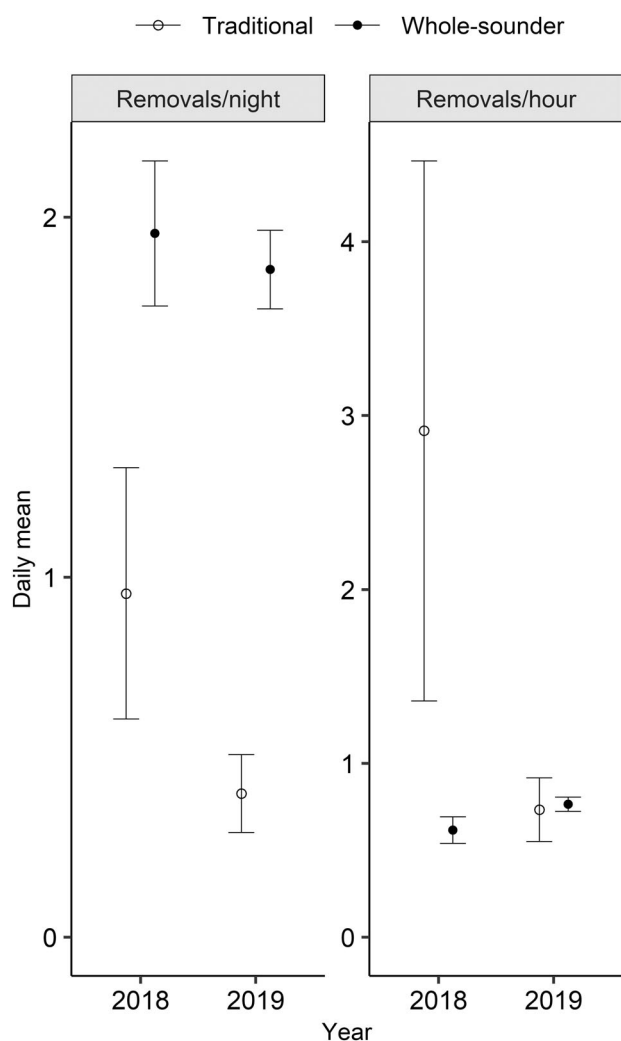


Figure 4. Mean number of wild pigs (*Sus scrofa*) removed per trap night (Removals/night) and per person-hour (Removals/hour) during September 2018 and 2019 for traditional control ($n = 5$) and whole-sounder removal treatment units ($n = 5$) on the Savannah River Site, South Carolina, USA.

study. Although removal of more individuals than were present at the beginning of each year might be expected to reduce the year-end population density by more than 53%, this highlights the problem with using a threshold annual removal rate as a target for successful control, as described recently by Pepin *et al.*³⁶ Density of demographically open populations can fluctuate dramatically over an entire year depending on reproduction and immigration, thereby rendering annual removal rates inappropriate as targets for success. For example, if a large proportion of removed wild pigs were offspring born during the removal year, less reduction in initial population size would be expected despite a high annual removal rate. For this reason, our marked-pig removal rates may be more appropriate for comparison with results of modeling studies. Various modeling studies have reported that 60–80% of a wild pig population must be removed annually to reduce the population.^{37,38} Giles³⁹ determined that 70% would need to be removed within a short period, presumably much less than a year, to ensure the population remained below pre-control levels for 12 months following control. However, Pepin *et al.*^{36,40} demonstrated that rather than targeting a

particular removal rate (e.g. 70%), the removal rate necessary to reduce a population varies primarily with the population's growth rate, but also with factors such as the spatial distribution of removal and its timing relative to reproductive pulses. Under the right combination of the earlier factors, annual removal rates as low as 20% can reduce a population to half of its carrying capacity within 5 years.^{40,41} Thus, it may not be surprising that our annual and marked-pig removal rates of > 140% and > 30%, respectively, on WSR units reduced density by > 50% in only 1 year, despite the broad acceptance of 70% as the annual removal rate needed to reduce populations. Regardless, managers using removal rates should recognize that rates greater or less than 70% may be effective at achieving a particular density reduction, depending on various characteristics of the local population, spatial extent and timing of the control efforts, and how removal rates are calculated.

The lack of additional reduction in WSR areas during the second year of trapping likely was attributable to reduced effort that year. Number of trap nights during the second year on that treatment was approximately half that in the first year, and number of person-hours the second year was considerably less than half (36%) of the first year due to various logistical constraints and staffing shortages. Still, field personnel reported much greater difficulty in locating sounders to target for removal, highlighting the increasing difficulty of further control when populations have been reduced by half, as was achieved with WSR. However, this situation may be informative for many control operations, considering that control operators typically do not estimate density before and after removal efforts (and therefore do not know the actual percent reduction) but instead rely on field evidence, observations, and declining trap success to evaluate when control has been achieved. When a wild pig population occupies an area > 780 km², such as SRS, operators must focus efforts on smaller units of a more manageable size, moving traps from those units to others when success has been obtained, but leaving units already controlled as they work in others. Giles⁴² concluded that unless a population is reduced by $\geq 70\%$, recovery to pre-control levels is likely within 2 years. We saw no indication that recovery was underway during the second year, likely because of ongoing control effort, even if at a reduced level. Additional research is needed to determine the duration of the reduced-density condition in locally reduced areas to inform how often such areas must be revisited for maintenance or follow-up control.¹⁹

Although WSR was more effective than TC at reducing wild pig density, it required considerably greater effort, as well as the added investment in more expensive traps. Personnel spent more than twice the number of hours on WSR areas than on TC areas during the first year of trapping, resulting in a number of removals per person-hour much lower on WSR than TC areas and suggesting greater efficiency of TC, although Gaskamp *et al.*¹⁸ reported greater removals per person-hour using WSR than traditional corral traps. However, removals per trap-night, number of wild pigs per sounder trapped, and total removals were greater for WSR, despite the fact that more trap nights were conducted in TC units. More importantly, WSR ultimately resulted in greater density reduction, the objective of the control program. User-operated traps for WSR can cost from \$4600 to \$8800 each, not including shipping and cellular plan costs. Operators should be aware of the greater commitment of resources necessary to implement a WSR control program. More time must be spent scouting with trail cameras to identify target sounders for removal, to construct and monitor traps, and to replenish bait in traps when only a portion

of a sounder is entering but still consuming the bait. However, WSR did not require daily trips to check traps if no wild pigs were caught and rebaiting was not necessary, because trappers knew from cellular surveillance when wild pigs had been trapped. Conversely, TC operators had to check traps daily but spent less time scouting (and none with trail cameras). Rather, they relied on their long-term knowledge of successful trap sites, as well as information on high-use areas gleaned while afield hunting with dogs. Thus, the choice of trapping strategy involves a tradeoff between cost and return on investment in the form of density reduction.

Contrary to our expectations given the long-term increase in the SRS wild pig population despite the use of TC, this treatment did reduce estimated wild pig density by 33%, albeit indistinguishably from pre-control levels statistically and of less magnitude than the reduction in WSR units. The TC method had not been effective at preventing growth of the SRS wild pig population, much less reducing it, prior to the study. Although TC operators continued to trap other areas of SRS during the study, their efforts were more focused on our TC study units. Nevertheless, TC removed far fewer wild pigs than WSR (472 *versus* 976, respectively), fewer pigs/group, and fewer pigs/trap night, even during the second year of study when WSR effort was reduced. We doubt that success would have been greater on TC units had number of person-hours been greater, given the number of trap nights were in fact greater on TC than WSR units (815 *versus* 510, respectively). Whatever the explanation for the slight reduction in wild pig density on TC areas, WSR proved more effective at reducing density.

6 CONCLUSION

Managers should consider the use of WSR methods as a strategy to reduce wild pig density. However, they must be aware of the additional effort and expense associated with WSR. In addition, if the population targeted for control has previously experienced trapping, density reductions > 50–60% may be difficult to achieve and expectations should be adjusted accordingly. Finally, follow-up control effort on some level will be necessary to maintain the reduced-density condition when using WSR methods. The level of this effort will depend on factors such as actual reduction achieved, proximity to sources of immigration, and resource quality.

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DATA AVAILABILITY STATEMENT

Data are available from Figshare: <https://doi.org/10.6084/m9.figshare.22561447>.

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