2023

Changes in Wild Pig (*Sus scrofa*) Relative Abundance, Crop Damage, and Environmental Impacts in Response to Control Efforts

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U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Wildlife Services

U.S. Government Publication

Research Article

Received: 26 December 2022 Revised: 13 July 2023 Accepted article published: 18 July 2023 Published online in Wiley Online Library: 28 July 2023

(wileyonlinelibrary.com) DOI 10.1002/ps.7671

Changes in wild pig (*Sus scrofa*) relative abundance, crop damage, and environmental impacts in response to control efforts

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Abstract

BACKGROUND: As the population and range of wild pigs (*Sus scrofa*) continue to grow across North America, there has been an increase in environmental and economic damages caused by this invasive species, and control efforts to reduce damages have increased concomitantly. Despite the expanding impacts and costs associated with population control of wild pigs, the extent to which wild pig control reduces populations and diminishes environmental and agricultural damages are rarely quantified. The goal of this study is to quantify changes in wild pig relative abundance and subsequent changes in damages caused by invasive wild pigs in response to control.

RESULTS: Using a combination of wild pig population surveys, agricultural damage assessments, and environmental rooting surveys across 19 mixed forest-agricultural properties in South Carolina, USA, we quantified changes in wild pig relative abundance and associated damages over a 3-year period following implementation of a professional control program. Following implementation of control efforts, both the number of wild pig detections and estimated abundance decreased markedly. Within 24 months relative abundance was reduced by an average of ∼70%, which resulted in a corresponding decline in environmental rooting damage by ∼99%.

CONCLUSION: Our findings suggest that sustained wild pig control efforts can substantially reduce wild pig relative abundance, which in turn resulted in a reduction in environmental rooting damage by wild pigs. Ultimately this study will help fill critical knowledge gaps regarding the efficacy of wild pig control programs and the effort needed to reduce impacts to native ecosystems, livestock, and crops.

Keywords: agricultural damage; corn; environmental damage; management; peanuts; rooting; *Sus scrofa*; wild pigs

1 INTRODUCTION

Invasive species can have profound impacts in areas where they are introduced, disrupting ecosystem function, creating losses and localized extinctions of native species, and negatively impacting human health and economies.[1,2] Wild pigs (*Sus scrofa*), which are native to Eurasia, have been introduced worldwide for food and hunting opportunities, and over the last several decades have become one of the world's most troublesome invasive species.[3,4] Wild pigs are currently experiencing global range expansion due to translocations by humans, natural dispersal, and favorable changes in environmental conditions. Widespread escapes and intentional releases of wild pigs for the purpose of sport hunting continues across numerous countries, which is believed to be the most influential driver of their population expansion today, especially in the United States.[5–9] In addition, expansion in the geographic distribution and abundance of wild pig populations within their native and non-native ranges has been influenced in part by changing human land-use and climatic conditions.[10–13] 13 Expansion of agricultural lands, in particular, can facilitate the expansion of wild pig populations through providing both cover and high-quality forage.[10,14–16]

Wild pigs are omnivorous,[17] have high reproductive rates, and low mortality due to predation, even when young,[18,19] which has hastened wild pig range expansion into new regions and habitats.[20] In natural ecosystems, wild pigs can severely damage native habitats and sensitive ecological communities, especially riparian areas and deciduous forests.[3,7,21] In addition, wild pigs can impact

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a variety of rare, threatened, and endangered species through habitat destruction, predation, and competition for resources.[3] Wild pigs also host numerous parasites and diseases, many of which, like classical swine fever and *Brucella* spp. can be transmitted to other wildlife, humans, and livestock.[7,22–25] These factors make wild pigs not only a successful invasive species, but also a major concern for landowners, managers, and agencies across the globe.

Within North America, wild pigs descended from escaped domestic pigs introduced nearly 500 years ago that sometimes subsequently interbred with introduced Eurasian wild boar.[26] Populations of wild pigs and associated damages remained relatively localized for centuries; however, over the last few decades the number of US states and Canadian provinces reporting wild pigs has nearly doubled.[5,7] Concurrent with this expansion, the ecological, agricultural, and economic impacts of wild pigs have increased markedly as well.[4,7,27,28] Wild pig damage to crops, in particular, is a pervasive issue affecting landowners, wildlife management agencies, and conservation organizations, and is projected to increase further if more effective population control methods are not implemented.[29] Within the United States alone, annual agricultural damage attributed to wild pigs and associated control efforts exceeded \$1.5 billion in 2007, or ~\$2 billion today when adjusted for inflation.[30] Wild pig damage to row crops is particularly extensive, both in their native and introduced range.[31,32] Corn (*Zea mays*) fields are often heavily damaged by wild pigs, but grasses, cereals, and legumes also are routinely impacted.[33,34] A landowner survey conducted in 11 southern US states alone estimated annual damage to corn at over \$61 million and peanuts (*Arachis hypogaea*) at over \$40 million.[35]

Due to the substantive damage caused by wild pigs, efforts are often made to control populations throughout their invasive range, and in many US states recreational hunting is popular and assumed to help control populations. However, there is little evidence supporting the effectiveness of recreational hunting as a long-term management tool for controlling the spread of wild pigs, and in many cases sport hunting may be counterproductive to population control objectives.[36,37] Recreational hunting typically removes ~23% of a population, on average, far below thresholds believed to be needed to reduce populations.[37–39] Recreational hunting also provides financial incentives for keeping wild pigs on the landscape, which is counter to the goal of control efforts.[37] Thus, successful wild pig population control is most effectively achieved through coordinated and adaptive strategies by wildlife professionals.[40,41] As a result, there are widespread and growing efforts by local, state, and federal agencies to supplement recreational hunting of wild pigs through trapping and aerial removal programs.[37]

For example, the US Department of Agriculture (USDA) established a nationally coordinated program in 2014 to mitigate damages from wild pigs to natural ecosystems, residential developments, agriculture, and rangelands.[42] This program has since been supplemented through efforts by other state and federal agencies, particularly the Feral Swine Eradication and Control Pilot Program (FSCP). The FSCP was established by the USDA's 2018 Farm Bill to provide additional resources to control populations and restore lands impacted by wild pigs. Collectively, these efforts have removed vast numbers of wild pigs across the United States to date, successfully eliminating populations from ten states where they were not yet well established. However, despite the extensive removal of pigs throughout the United States and other areas of their invasive range, and high costs associated with these efforts, there has been little effort to quantify the benefits of wild pig removal to agricultural or environmental resources. Similarly, due to limited resources for monitoring, removal efforts of invasive species typically report the number of individuals removed and rarely quantify changes in population size, which although difficult to quantify, is needed to assess the efficacy of control programs.

Therefore, our objective in this research was to quantify changes in wild pig relative abundance and associated damages to agricultural and environmental resources in conjunction with wild pig removal efforts conducted under the FSCP, which involves extensive removal of wild pigs by professional agencies throughout several US states. We predicted that professional control efforts would substantially decrease local wild pig populations resulting in a corresponding decrease in both agricultural and environmental damage. These data fill critical gaps in our knowledge of the efficacy of wild pig control programs, information needed to inform and adapt management plans to reduce the impacts and spread of this highly invasive species.

2 MATERIALS AND METHODS

2.1 Study area

We conducted wild pig population, crop, and rooting surveys in conjunction with wild pig removal efforts conducted across 19 privately owned agricultural (POA) properties throughout Newberry, Hampton, and Jasper Counties, South Carolina, USA. Properties were mixed agricultural lands that ranged from ~50 ha to over ~9400 ha in size, though their average size was ~1000 ha. Newberry County is in the lower Piedmont of northcentral South Carolina and bordered by the Broad and Saluda Rivers. The Piedmont region is the most inland region of the three counties surveyed and includes features such as rolling hills with stream-cut valleys and few level floodplains. Newberry County is overwhelmingly rural, with farmland and pasture comprising approximately 53% of the total area and much of the remaining landscape composed of forested upland pine and mixed hardwoods.[43] Hampton and Jasper are bordering counties located in south-western South Carolina in the Southern Coastal Plain, bordered on the west by the Savannah River. Jasper County extends south to the Atlantic Coast. The Coastal Plains region features distinctive attributes such as large floodplains, river swamps, and longleaf pine (*Pinus palustris*) savannahs. Both counties are also chiefly rural, with farmland accounting for roughly 30% of the landscape and forested areas consisting of mostly upland pine and bottomland hardwoods making up the majority of the remainder of the land area.[43] Upland pine is composed mainly of widely spaced pines with a varying shrub layer and groundcover of grasses and herbs. The canopy is dominated by loblolly pine (*Pinus taeda*) and longleaf pine, and there is a fragmented subcanopy layer of smaller pines and various hardwoods. Bottomland hardwood forests are deciduous forested wetlands made up of different species able to survive in seasonally or permanently flooded areas along bodies of water. The main canopy species include a mixture of Gum (*Nyssa* sp.), Oak (*Quercus* sp.), and Bald Cypress (*Taxodium distichum*), while the understory is composed of either dense shrubs with sparse ground cover, or open with few shrubs and a groundcover of ferns, herbs, and grasses. Throughout the state of South Carolina, wild pigs have been present since the 1500s, when the Spanish released domestic pigs onto the landscape.[4] Their populations remained small, and their ranges were mainly limited to wetland and river basins. However, over the last few decades wild pig populations have increased substantially in size and distribution across South Carolina and they are now found in all counties

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throughout the state.[26] Most properties included in this study have been managed for wild pigs in some capacity by landowners via hunting, shooting, and/or trapping, although these management activities have been limited in scope prior to this study.

2.2 Wild pig abundance assessments

To estimate relative abundance of wild pigs on properties targeted for wild pig population control, we set baited remote camera traps (Reconyx HP2W; Reconyx, Holmen, WI, USA) throughout each property. Camera surveys were implemented immediately prior to initiation of control efforts and repeated every 6 months from January 2020 through July 2022. We used ArcGIS Pro to generate random points across each property to establish camera locations, with a density of one camera per 25 ha, and a minimum spacing of ~500 m. Cameras were set to trigger on motion and programed to take three pictures, 1 s apart, with a 1-min quiet period between sets of pictures when triggered. Cameras were baited with 22.7 kg of whole corn approximately 5 m away from the camera and left in the field for 2 weeks; cameras were re-visited on day seven and rebaited with 11.3 kg of corn as necessary.[26,44] All images not containing wild pigs were removed before importing images into the Colorado Parks and Wildlife Photo Warehouse Database for detection analysis.[45] The total number of wild pig detections for each camera on each property was quantified for each session. A detection event was classified as any time a wild pig entered the frame. If a wild pig left the frame for < 30 min before re-entering the frame, it was still considered a single detection event. Any gaps in wild pig visits exceeding > 30 min were considered new detection events. Cameras were pooled for each property during each session to quantify overall detections per property, per session to achieve a relative abundance index (RAI). Due to timing of property entry within the FSCP, the number of total surveys per property ranged from two to five, and while all properties were surveyed pre-control efforts, the number of post-control surveys differed. Therefore, we organized camera survey results into sessions (pre-control and 6, 12, 18, and 24 months post-initiation of control) to facilitate standardization.

2.3 Wild pig removal

Removal of wild pigs from properties was done by professional trappers with the US Department of Agriculture – Animal and Plant Health Inspection Service – Wildlife Services (USDA-APHIS-WS). Upon conclusion of pre-removal wild pig abundance surveys, traps were set in areas frequented by wild pigs. Trap styles used by the USDA included corral traps, drop traps, and net traps baited with whole corn. All captured pigs were euthanized by USDA. While trapping was the main method of wild pig removal, ground and night shooting events also took place where applicable. Aerial gunning by helicopter was also used on one property that had large enough open areas. Initial control efforts on each property targeted large groups of wild pigs and were sustained until targeted pigs were captured, after which properties were monitored by remote cameras (see earlier) or anecdotally through landowners and trapping was reinitiated or maintained accordingly. USDA documented all removals, including property, date, time, age class (e.g., juvenile or adult) of removed animals, trap type, and sex.

2.4 Agricultural damage surveys

Agricultural damage assessments were conducted for 18 of the properties involved in this study using in-person and telephone surveys. Landowners signed up through the removal program were contacted prior to control efforts to gather pre-control crop damage data, and again roughly 1 and 2 years later to reassess crop damage after control efforts were implemented. Trained surveyors used a standardized questionnaire for each property. The questionnaire included total crop area for any crop types present on the property, total crop damage due to wild pigs, total area replanted, total crop conversions due to wild pig damage, and total monetary and time losses due to wild pig damage. We used landowner responses from these surveys to estimate crop damage caused by wild pigs (in hectares) for the year prior to initiation of wild pig control as well as during 1- and 2-years post-removal.[46] These surveys are an estimate of crop damage based on the landowners' estimation and as such may come with inherent reporting bias.[47] While not empirical estimates of measured damage of individual landowners, landowner surveys are commonly used as an index of crop damage to show trends in damage over time across multiple properties.[46] Crop damage surveys were conducted with Institutional Review Board (Project: 00002907) approval through the University of Georgia.

2.5 Environmental damage surveys

Wild pigs cause extensive environmental damage through rooting, where they overturn soil using their snout in search of food. To quantify changes in environmental rooting damages attributed to wild pigs, we conducted systematic rooting damage surveys on 18 of the 19 properties. Within each property, we established ten randomly placed transects spaced a minimum of ~50 m apart. Transects each had a width of 10 m, and the length of transects was determined such that 1% of the total natural area (total property area – crop area and developed area) of each property would be surveyed across the ten transects. Randomization of transects was performed by using ArcGIS Pro to establish ten random points within each property, which were used as starting points for each transect, and then a random number generator was used to establish an azimuth for each of the ten transects. Transects were walked by trained observers who recorded the presence, intensity (depth in centimeters), and area (in square meters) of the transect impacted by rooting. Transects were georeferenced with a global positioning system (GPS) and surveyed once prior to control efforts, and again both 1 and 2 years later, following the implementation of wild pig control. Due to the timing of sign-up, one property was only surveyed prior to control efforts, but was not surveyed again before the end of the study, and thus was excluded from our environmental damage analysis. A standardized aging structure was used to classify damage into one of three age groups: (1) damage approximately 0–1 months old characterized by rooting damage where plants had been destroyed and regrowth had not happened yet, and no or little debris had fallen into the damage area, (2) damage approximately 1–6 months old, which included damage where new plant regeneration was present in the damaged area but there was no or little debris covering the damage, and (3) approximately 6+ months old damage, which included rooting that had plant regeneration and was mostly covered with debris. Any damage located within the 10-m wide transect and classified into age groups (1) or (2) was used in our analysis.

2.6 Statistical analysis

We estimated relative wild pig abundance for each property using a RAI of detections per camera day. Camera days were calculated for each property by multiplying the number of cameras by the number of days each camera was deployed. The number of detections for each site was then divided by the total camera days. This was conducted for each session to provide an average RAI for each property during each session (pre-control, 6, 12, 18, 24 months). Normality of RAI estimates was tested using a Shapiro–Wilk test. Due to the non-normality of the data, we transformed the data using a square-root transformation. After the data were transformed and scaled, we ran a linear mixed effects model to test for differences in RAI values among treatment periods. We included property as a random effect in the model.

We compiled agricultural damage from 2019 to 2021, and environmental damage from 2020 to 2023, and tested these datasets for normality using a Shapiro–Wilk test. Due to the non-normality of the data, we used a log-transformation and added 1 because there were several zeros included in the data. After the data were transformed and scaled, we ran separate mixed effects models to test for differences in crop and environmental damage values among treatment periods. We included property as a random effect in both models. All statistical analyses were performed in R version 1.3.1073, and the significance level was determined by $P < 0.05$.[48]

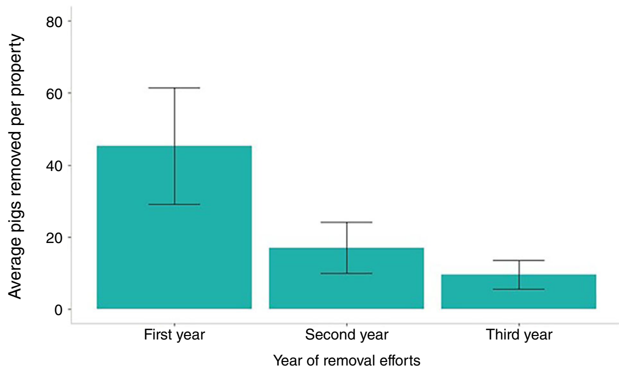

Figure 1. Average number of wild pigs (*Sus scrofa*) removed per property, with standard error bars for 19 properties in the first, second and third year of removal efforts in South Carolina, USA. Removal effort was consistent over the 3 years of the study.

3 RESULTS

Wild pig removal by the USDA-APHIS-WS during the program ranged from 0 to 295 individuals per property. USDA removed a total of 860 wild pigs from 19 properties during the first year of removal efforts [$\bar{x} = 45.26 \pm 16.18$ standard error (SE)], 290 wild pigs from 17 properties during the second year of removal efforts ($\bar{x} = 17.06 \pm 7.01$ SE), and 125 wild pigs removed from 13 properties in the third year of removal efforts ($\bar{x} = 9.62 \pm 3.97$ SE) (Fig. 1). Of the wild pigs removed in 2020, ~22% were adult males, ~26% were adult females, ~26% were juvenile males, and ~26% were juvenile females. The wild pigs removed in 2021 consisted of ~25% adult males, ~28% adult females, ~21% juvenile males, and ~26% juvenile females. Of the wild pigs removed in 2022, ~13% were adult males, ~24% were adult females, ~29% were juvenile males, and ~33% were juvenile females.

Over the 3-year study, 920 cameras were deployed to survey the 19 properties, resulting in 12 880 total camera nights. Due to the timing of landowner participation, all properties were surveyed at least twice, once before control efforts and once ~6 months later. Eleven properties were surveyed through 24 months post-initiation of management. The remaining eight properties were surveyed anywhere from 6 months post-initiation to 18 months post-initiation. These differences in duration resulted from the timing of when properties were signed up, and the cessation of certain properties

Table 1. Property area, number of wild pigs (*Sus scrofa*) removed, pre-control, 12, and 24 months post-control wild pig relative abundance index (RAI) for 19 properties in South Carolina, USA

Property identifier	Area (ha)	Wild pigs removed 2020	Wild pigs removed 2021	Wild pigs removed 2022	Pre-control RAI	12-month control RAI	24-month control RAI
MK1	327.90	52	39	18	0.41	0.00	0.01
SW1	85.20	0	0	N/A	0.00	0.00	N/A
SW2	356.90	0	0	N/A	0.00	0.00	N/A
S1	338.40	0	0	0	0.00	0.00	N/A
Y2	216.40	14	0	0	0.00	0.00	N/A
Y1	611.10	39	32	38	0.58	0.53	0.64
LSP1	232.40	6	10	20	0.16	0.28	4.09[a]
TB1	50.30	31	N/A	N/A	3.14	N/A	N/A
WC1	573.80	46	0	0	0.74	0.29	0.01
B1	50.50	15	6	5	0.93	0.54	0.14
ISE1	314.80	14	2	0	0.67	0.38	0.05
W1	46.70	6	0	0	2.07	0.46	0.00
BO1	258.60	0	0	3	0.01	0.00	0.06
BO2	349.80	4	14	1	0.49	0.04	0.54
CL1	3921.00	193	62	37	1.28	0.17	0.39
H&B1	584.90	0	19	1	0.08	0.36	0.13
D1	175.20	N/A	16	0	1.33	0.00	N/A
OK	9484.00	N/A	189	106	0.84	1.18	N/A
MS1	781.00	N/A	N/A	236	0.08	N/A	N/A

Note: N/A, not available.
[a] Property excluded from RAI analysis.

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being involved with the program. One property was considered an extreme outlier at the 24-month mark and was removed from analysis for that time period. This property had a limited amount of suitable habitat that we were able to survey (~75 ha) despite the total property size being much larger (~232 ha). This resulted in a limited number of cameras used for the survey ($n = 3$), which greatly inflated the estimated RAI due to a large number of images ($n = 139$) recorded for a single group of pigs, substantially increasing the average RAI across all properties. This property's RAI is included and noted with a superscript letter in Table 1. Excluding this property, RAI values showed significant decreases from pretreatment to 12 months post-control ($\beta = -0.68 \pm 0.28$ SE, $P = 0.02$), pretreatment to 18 months post-control ($\beta = -0.96 \pm 0.28$ SE, $P = 0.001$), and pretreatment to 24 months post-control ($\beta = -0.81 \pm 0.33$ SE, $P = 0.02$). All other sampling period comparisons were found to be insignificant ($P > 0.05$). Throughout the 24 months of the study, we observed the overall average RAI decrease ~70% from 0.67 (±0.18 SE) in the pretreatment period, to 0.20 (±0.05 SE) after 24 months of management efforts (Fig. 2).

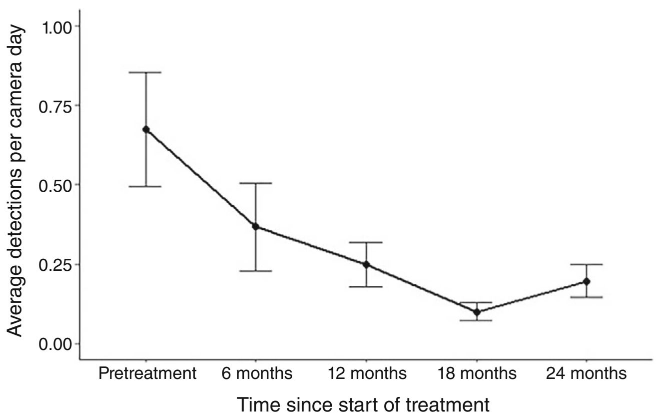

Figure 2. Average detections per camera day with standard errors from a relative abundance index for wild pigs (*Sus scrofa*) on 19 properties in South Carolina, USA, 2020–2022, with an extreme outlier removed for the 24-month period.

All property owners were surveyed, and crop damage was estimated based on their responses before control efforts began and again both 1 and 2 years later. One property was excluded from analyses because it did not include any agricultural land. All other property owners reported agricultural damage associated with wild pigs (Fig. 3). The range of damage reported by landowners varied greatly between our two survey periods. During pre-control surveys reported damage from wild pigs ranged from 0 to 20.23 ha, while after 2 years of control reported damage ranged from 0 to 13.76 ha (Table 2). Overall, average agricultural damage estimated from landowner surveys decreased following implementation of control from 4.96 ha (±1.62 SE) to 3.22 ha (±1.09 SE) per property, however no pairwise comparisons

Figure 3. Environmental and agricultural damage caused by wild pigs (*Sus scrofa*) from privately owned agricultural (POA) properties in South Carolina, USA.

between sampling periods were found to be significant ($P > 0.05$) (Fig. 4).

Environmental rooting damage was found on all but two properties prior to control, whereas no environmental damage was found on ten of the 18 properties after control. We observed significant decreases in environmental damage between pretreatment and 12 months post-control ($\beta = -1.17 \pm 0.25$, $P < 0.001$) and from pretreatment to 24 months post-control ($\beta = -1.49 \pm 0.28$, $P < 0.001$). The difference in damage between 12 and 24 months post-control was not found to be significant ($P > 0.05$). Environmental rooting damage ranged from 0 to 1160.50 m^2 before control efforts to 0–6.48 m^2 2 years after control (Table 2). Prior to control, we recorded an average of 268.51 m^2 (±89.06 SE) of rooting damage per property across our damage transects. However, 2 years into removal efforts environmental damage was reduced by 99%, averaging 0.90 m^2 (±0.60 SE) per property across our damage transects (Fig. 5).

4 DISCUSSION

Despite extensive control programs to reduce populations of wild pigs across much of their invasive range, efforts are rarely undertaken to quantify the efficacy of removal programs at mitigating impacts. Here we present results of a study quantifying changes in the relative abundance of wild pigs following the implementation of a continuous control program, and the impact of changes in wild pig relative abundance on the extent of agricultural and environmental damage across private mixed agricultural and forested lands. Our results revealed control efforts were successful in reducing the relative abundance of wild pigs on private agricultural lands on average by ~70% within 12–24 months following the implementation of trapping. These RAI reductions were found to directly influence the extent of damages caused by wild pigs, as environmental rooting damage decreased by 99% within 2 years of the implementation of population control measures. These findings are consistent with a previous study that found that intensive trapping efforts can mitigate damage to rangelands by wild pigs and suggest wild pig control efforts that implement extensive and adaptive trapping approaches can be an effective management tool for reducing populations and ultimately reducing damage associated with wild pigs.[49]

Wild pigs are ecological generalists with high reproductive capabilities and low mortality, which allows them to not only expand into new habitats but also increase populations quickly in response to management or population introductions.[19,28,50] As a result, it is difficult for managers to control populations of

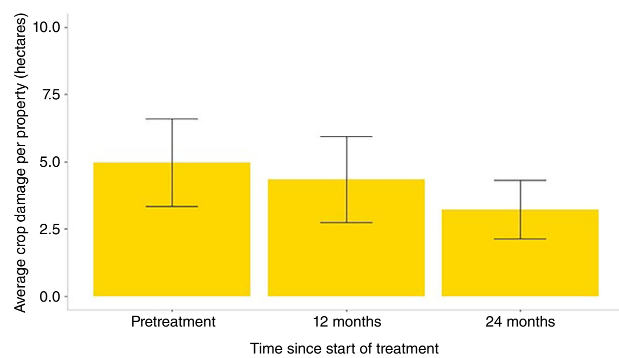

Figure 4. Average landowner reported crop damage estimates per property caused by wild pigs (*Sus scrofa*) across 18 privately owned agricultural (POA) properties in South Carolina, USA during pre-removal, 12 months post-initiation of removal, and 24 months post-initiation of removal.

Table 2. Property area, pre-control, 12 and 24 months post-control agricultural damage attributed to wild pigs, pre-control, 12 and 24 months post-control environmental damage by wild pigs for 19 properties in South Carolina, USA

Property identifier	Area (ha)	Pre-control Agricultural damage (ha)	12 months Agricultural damage (ha)	24 months Agricultural damage (ha)	Pre-control environmental damage (m^2)	12 months environmental damage (m^2)	24 months environmental damage (m^2)
MK1	327.90	0.00	0.00	0.81	192.00	0.00	0.00
SW1	85.20	3.64	8.09	2.02	18.00	0.00	N/A
SW2	356.90	1.01	0.00	2.02	376.00	0.00	N/A
S1	338.40	20.23	0.00	1.62	1.00	0.00	N/A
Y2	216.40	9.79	N/A	0.00	52.00	0.00	N/A
Y1	611.10	15.38	N/A	13.76	1160.00	277.00	1.70
LSP1	232.40	0.00	4.86	8.50	860.00	3.00	0.00
TB1	50.30	1.61	N/A	N/A	922.00	N/A	N/A
WC1	573.80	5.26	2.02	1.62	560.00	4.00	0.00
B1	50.50	1.42	0.81	0.61	0.00	0.00	0.00
ISE1	314.80	0.00	3.64	2.02	100.00	0.00	0.00
W1	46.70	1.62	2.02	0.00	0.25	6.00	0.00
BO1	258.60	0.00	11.33	N/A	9.50	6.00	1.77
BO2	349.80	3.24	0.00	4.05	73.00	0.00	6.48
CL1	3921.00	14.97	0.00	8.09	573.00	6.00	0.00
H&B1	584.90	1.21	1.62	0.00	0.50	20.00	0.00
D1	175.20	N/A	8.09	N/A	26.00	0.00	N/A
OK	9484.00	N/A	22.66	N/A	N/A	N/A	N/A
MS1	781.00	N/A	N/A	N/A	4.01	0.00	N/A

Note: N/A, not available.

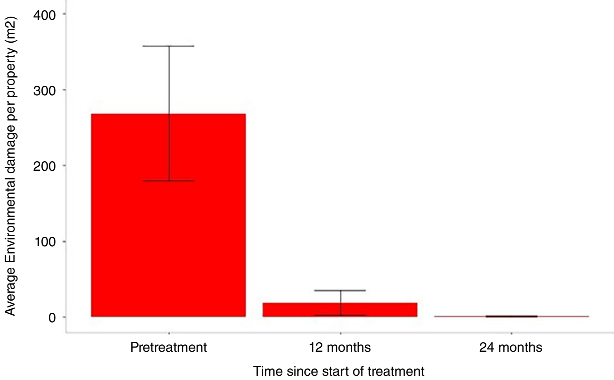

Figure 5. Average environmental rooting damage per property caused by wild pigs (*Sus scrofa*) across 17 privately owned agricultural (POA) properties in South Carolina, USA during pre-removal, 12 months post-initiation of removal, and 24 months post-initiation of removal.

wild pigs once they have become established within a landscape. Indeed, populations of wild pigs have continued to increase throughout much of their invasive range over the last few decades, despite removal through recreational hunting and control programs implemented by agencies.[38] While recreational hunting is generally one of the most popular population management methods for wildlife, hunting alone has been demonstrated to be insufficient for controlling wild pig populations, and alternative or supplementary approaches such as intensive trapping are needed to achieve management goals.[37] Trapping can be particularly effective for removing animals that form social groups like wild pigs and there is increased recognition that employing trapping strategies that systematically remove entire social groups may be most effective for controlling wild pig populations.[51,52] Through continuous effort, control programs implemented in our study targeting social groups were able to reduce relative abundance by ~70%, on average, with significant decreases in relative abundance within as little as 12 months. This falls into the documented range needed to achieve negative growth rates in wild pig populations and suggests sustained adaptive trapping programs can be effective in controlling populations over relatively short timeframes. However, further studies are needed to determine the long-term efficacy and costs associated with sustained wild pig control programs. We observed a slight (non-significant) increase in RAI of wild pigs between 18- and 24-months following implementation of control efforts. This slight increase seen in the RAI is likely due to either recolonization events from neighboring properties, or changes in the movement patterns of wild pigs on these properties causing an increase in detections. If recolonization is taking place, this highlights the importance of collaboration and cooperation among landowners and agencies to achieve long-term population control. Due to removal efforts remaining constant throughout our study, coupled with the slight increase seen in RAI after 18 months post-management, these findings also likely suggest wild pig populations in these areas have hit the lowest population level achievable given the intensity of population control being performed, and additional resources, management techniques, and cooperation from neighboring landowners are needed to further reduce populations. In addition to trapping, aerial shooting is becoming an increasingly effective and cost-efficient means of removing wild pigs, and other methods of population control such as toxicants are under development.[53] Thus, although our results demonstrate trapping alone targeting entire social groups substantially reduced local populations, future studies should evaluate the extent to which integration of other management approaches such as aerial shooting can accelerate population reduction and minimize costs.

Agricultural damage such as direct consumption, trampling, and rooting caused by wild pigs is a widespread problem for producers and managers. Wild pigs have highly variable diets and are known to cause damage to a variety of crops, including grasses, cereals, vegetables and fruits, orchards, cotton, and soybeans.[3,17,29] Within 11 states in the southern United States alone, annual damage to corn, peanuts, soybeans (*Glycine max*), wheat (*Triticum* spp.), rice (*Oryza* spp.), and sorghum (*Sorghum* spp.) from wild pigs has been estimated at over \$190 million.[35] Similarly, within their native range wild boar cause extensive damage to agriculture; in Poland, \$13.4 million in compensation for wild boar damages was provided to farmers in 2010.[54] Following the implementation of control efforts in our study, landowner-reported agricultural damage associated with wild pigs did slightly decrease on average, however no pairwise comparisons were found to be significant. Further reductions in crop damage could be achieved through focused removal efforts immediately prior to peak periods of crop depredation by wild pigs. For example, Boyce *et al*. found wild pigs commonly consumed crops such as corn and peanuts soon after planting, with further damage to corn during later stages of development.[55] These links are important for landowners and managers in deciding when it is best to implement control efforts to save on limited resources.

Wild pigs also are known to cause extensive environmental damage with their rooting and wallowing behavior, yet few studies have characterized impacts of wild pig rooting to native ecosystems. Wetlands are known to be heavily selected for by wild pigs due to their ample food, cover, and water resources.[56] However, wetlands are sensitive ecosystems, often containing threatened and endangered species that can be disrupted by rooting and wallowing.[57,58] In our study, rooting damage by wild pigs was found across almost all study sites, with as much as 1160.5 m^2 of rooting damage recorded within a single property, despite our surveys covering only 1% of the natural land area. Further, rooting damage was concentrated mainly around resources such as wetlands and crops, highlighting the potential impacts of wild pigs to wetland habitats. We observed a substantial decrease (99%) in wild pig rooting damage after the implementation of control efforts, and this decrease was shown to be significant in as little as 12 months. In fact, ten properties had no damage found on our transects after 1 year. Given that our surveys were limited to 1% of the natural area of each site (total area – developed and crop area), it is likely these sites still sustained some rooting damage by wild pigs after initiation of control efforts. Nonetheless, these results suggest changes in damage caused by wild pigs is closely linked to changes in population size, and thus benefits achieved through removal programs can be estimated through establishment of population monitoring programs.

Collectively, our results demonstrate extensive trapping programs can be highly successful in not only removing large portions of wild pigs off the landscape at a local level, but also in reducing environmental damage. Thus, investments in wild pig control programs can be effective in reducing economic and environmental impacts of wild pigs and should be associated with monitoring programs to inform adaptive approaches to maximize the efficacy of management investments. Although our study focused only on properties where population control programs were implemented, there are likely additional benefits to the surrounding landscape. Within fragmented agricultural landscapes wild pig home ranges often extend across multiple property boundaries. Therefore, for many of our study sites wild pigs that incorporated adjacent properties within their home range boundaries were likely to have been removed. As a result, in landscapes with fragmented ownership control efforts implemented on one property may have broader impacts through reducing damage on adjacent properties as well.[49] Thus, while individual landowners may not have the resources to continually support intensive removal efforts, groups of landowners may be able to cooperate to reduce damage from wild pigs across more extensive areas. However, without widespread participation from private landowners, areas that can be used by wild pigs as safe havens will continue to limit the efficacy of control programs. This study only monitored properties for ~24 months, so more long-term studies are needed to determine the long-term efficacy of wild pig control programs, particularly after direct control by state and federal agencies ceases and further control is left up to local landowners. More research also should be undertaken to quantify the benefits of wild pig removal efforts to surrounding landowners. In addition, research into the efficiency and cost of varied management approaches would help further tailor population control efforts that are constrained by limited resources.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Natural Resources Conservation Service through the FSCP, as well as the US Department of Energy Office of Environmental Management under Award Number DE-EM0005228. The authors thank H. Bontrager, A. Neal, G. Detweiler, and T. Aliferis for assisting with the collection of data. The authors also thank N. Myers and L. Buxton for providing assistance with this work, as well as the USDA-APHIS-WS employees who carried out wild pig control efforts. The authors also thank M. Kohl and anonymous reviewers for their useful feedback on drafts of this manuscript.

CONFLICT OF INTEREST STATEMENT

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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