Commentary

A critical look at wild pig elimination: myths and facts

Kim M. Pepin, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, 4101 Laporte Ave., Fort Collins, CO 80521, USA *kim.m.pepin@usda.gov*

Travis L. Guerrant, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, Columbia, MO 65202, USA

Jeremiah L. Psiropoulos, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Feral Swine Damage Management Program, 4101 Laporte Ave., Fort Collins, CO 80521, USA

Jeanine T. Neskey, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Feral Swine Damage Management Program, 4101 Laporte Ave., Fort Collins, CO 80521, USA

John M. Tomeček, Department of Rangeland, Wildlife, and Fisheries Sciences, Texas A&M University, MS 2138, College Station, TX 77843, USA

Michael J. Bodenchuk, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, Cooperative Wildlife Services Program – Texas, P.O. Box 690170, San Antonio, TX 78269, USA

Janean L. Romines, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Feral Swine Damage Management Program, 4101 Laporte Ave., Fort Collins, CO 80521, USA

Abstract: Wild pigs (*Sus scrofa*) are abundant and widely distributed in the United States. They damage crops and pastures, predate livestock and sensitive species, impact ecosystem functions, and damage personal property. To address these issues, some states in the United States are seeking complete elimination. A frequently asked question by stakeholders is: "What portion of the population needs to be removed annually to reach elimination?" The number 70% is widely touted as the answer. There is little scientific evidence to support that this percent annual removal would be needed to achieve elimination, yet 70% has now become a standard measure of management success, and in some cases the rationale for support or lack thereof for operational management programs. For example, some stakeholders believe that if a wild pig elimination program does not remove 70% of the population annually across the state, then it is not being effective. These strong and widespread anecdotal beliefs may actually impede management progress. Herein, we describe the likely origin of the 70% parameter and the science to support why this metric measuring success of an elimination program is inaccurate.

Key words: feral swine, invasive species, management bias, management policies, population elimination, population growth rate, science-based management, *Sus scrofa*, wild hogs, wild pigs

In the United States, wild pigs (*Sus scrofa*) are an invasive species that cause an enormous amount of damage to agriculture, natural resources, and private property annually (Bevins et al. 2014). To mitigate this damage, the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS) program has been working with federal, state, territorial, and local agencies, tribes, conservation and commodity organizations, and private individuals for a few decades to mitigate local wild pig damage. Earlier management actions were successful at the local level, but the size and range of the wild pig population and associated damage increased despite local efforts in several areas.

To address a growing national problem, in 2014, APHIS began a national program, the Feral Swine Damage Management Program (USDA-APHIS 2020). In some U.S. regions and states, the main objective of the program was elimination of wild pig populations. For those managing state programs to eliminate wild pig populations, a fundamental question is "What proportion of the population must be removed annually to eliminate a population?" One answer widely cited in informal conversations is 70%. However, experienced wildlife managers and population ecologists know that the true answer is "it depends." Herein we discuss origins of the 70% number, the management challenges it poses, and why planning and evaluation of elimination programs should not be based on a universal parameter such as a percentage of annual take.

Methods

To evaluate the origins of the 70% number, we searched the Web of Science topic query on June 3, 2022, using the following search terms: "(wild or feral) and (swine or pig or hog or boar) and (elimination or eradication)." This returned 459 results. We then constrained the search results to relevant scientific categories, focusing on ecological and environmental sciences (specifically we selected the following Web of Science categories: Ecology, Biodiversity Conservation, Zoology, Multidisciplinary Sciences, Environmental Sciences, Biology, Evolutionary Biology, Ornithology, Agronomy, Environmental Studies, Agriculture Multidisciplinary, Economics, Forestry, Regional Urban Planning, Agricultural Economics Policy, Horticulture, Mathematical Computational Biology, Mathematical Interdisciplinary Applications, Reproductive Biology, and Urban Studies). This reduced the search results to 145. From this list, we identified publications that described in the abstract the effects of removal rates on wild pig populations in areas where elimination or maximum control is the objective (inclusion criterion). We identified 5 articles with these criteria. In addition to searching Web of Science, we searched the references in the Web of Science papers that met our inclusion criteria and references in 4 comprehensive book chapters on wild pig elimination (Mayer 2009; Hone 2012*a*, *b*; Snow et al. 2020) to locate older articles and those from the gray literature. From all sources, we selected 15 publications for inclusion (Table 1). Our objective was to provide examples of studies of different removals rates across a variety of ecological contexts, not to be comprehensive.

Results and discussion

Origin of the 70% "rule"

The 70% removal number was originally reported by Giles (1976) as the annual removal rate needed to reduce a wild pig population over 12 months. The conclusion was based on wild pig population growth rates in the state of New South Wales in Australia, which were estimated to be 57–70% annually (specifically, intrinsic growth rate r = 0.57–0.70) across 2 study sites, and on the effects of control efforts on abundance in the region (Giles 1980). In his dissertation, Giles (1980) concluded that "an effective control program would need to reduce a wild pig population by at least 70% within a short period of time to keep it below pre-control level for more than 12 months. Even with this reduction, the program would have to be repeated at intervals of about two years to be of more than short-term benefit. Although a reduction of 70% in a large pig population is technically feasible on agricultural and grazing lands, it is very difficult and expensive" (229).

In later work, Giles (1999) examined the population response to a 1-time 70% removal rate and demonstrated how the response differs dramatically depending on the underlying population growth rates. Giles (1999) concludes "it can be seen that a population reduction of the order of 70% or below, is likely to result in recovery to pre-control levels within a couple of years if r is about 0.6 [i.e., intrinsic growth rate of 60% annually] or above" (42). Similarly, Hone and Robards (1980) used a population model to examine the 70% number on the same growth rate (r = 0.60 annually) and emphasized the importance of considering multiple factors when making recommendations about removal rates for management—especially the local population growth rate, the frequency at which management is applied, and whether the removal rate occurs on the original population size or current population size.

Building on this work, other authors have reported varying effects of removal rates near 70% depending on ecological contexts and effects of other removal rates (Mayer 2009, Snow et al. 2020; Table 1). Thus, the scientific evidence evaluating the 70% "rule" highlights a simple fact in population ecology: to cause a population decline, you must remove more individuals than are produced (Fryxell et al. 2014), meaning

Table 1. Selected studies of the effects of different removal rates on wild pig (*Sus scofa*) populations. N_0 = initial population size.

Author(s)	Year	Location	Objective[a]	r[b]	Range of removal rates examined[c]	Outcome of removal	Source
Hone and Robards	1980	New South Wales, Australia	1	0.60	70%	Years to elimination = 9	Mayer chapter
					70% twice per year	Years to elimination = 3.8	
Klinger et al.	2011	California, USA	1	NA	70%	Years to elimination = 10 (all N_0)	Snow chapter
Dexter and McLeod	2015	New South Wales, Australia	1	0.79	50% removal rate over 90% of the area	Years to elimination = 14.5	Web of Science search
					90% removal rate over 90% of the area	Years to elimination = 7.7	
					50% removal rate over 50% of the area	Years to elimination = 27.5	
					90% removal rate over 50% of the area	Years to elimination = 10	
Dzieciolowski et al.	1992	Northern part of South Island, New Zealand	2	0.90	70% once ever	Years for population to recover to original size = 2.5	Mayer chapter
					80% once ever	Years for population to recover to original size = 2.9	
					90% once ever	Years for population to recover to original size = 3.8	
					95% once ever	Years for population to recover to original size = 4.6	
Giles	1999	New South Wales, Australia	2	0.92	70% once ever (N_0 = 100)	Abundance after 2 years = 189 (population growth 189%)	Mayer chapter
				0.80	70% once ever (N_0 = 100)	Abundance after 2 years = 150 (population growth 150%)	

Table continued on next page...

Table continued from previous page...

				0.66	70% once ever (N_0 = 100)	Abundance after 2 years = 113 (population growth 113%)	
				0.41	70% once ever (N_0 = 100)	Abundance after 2 years = 68 (population decline 32%)	
				0.19	70% once ever (N_0 = 100)	Abundance after 2 years = 44 (population decline 56%)	
				-0.23	70% once ever (N_0 = 100)	Abundance after 2 years = 19 (population decline 81%)	
McMahon et al.	2010	Northern Territory, Australia	2	0.34	17% in first year, 9% in subsequent years	Population declined by 25% after5 years	Snow chapter
					50% in first year, 35% in subsequent years	Population declined by 75% after 10 years	
					50% in first year, 42% in subsequent years	Population declined by 75% in priority areas and 50% park-wide in 10 years	
Klinger et al.	2011	California, USA	2	NA	50% (N_0 = 800)	Population remained at N_0 after 10 years	Snow chapter
					50% (N_0 = 2,400)	Population declined by 66% after 10 years	
					50% (N_0 = 5,000)	Population declined by 84% after 10 years	
					30% (N_0 = 800)	Population increased by 250% after 10 years	
					30% (N_0 = 2,400)	Population declined by 29% after 10 years	
					30% (N_0 = 5,000)	Population declined by 64% after 10 years	

Table continued on next page...

Table continued from previous page...

Timmons et al.	2012	Texas, USA	2	0.25	15%	Population growth rate declined by 21% (from 28% to 22%)	Pepin et al. (2017*b*)
					28%	Population growth rate declined by 43% (from 28% to 16%)	
					41%	Population growth rate declined by 57% (from 28% to 12%)	
					66%	Population growth rate declined by 100% (from 28% to 0)	
Salinas et al.	2015	Tennessee, USA	2	NA	40%	Population declined over 6 years	Snow chapter
Pepin et al.	2017*b*	South Carolina, USA	2	0.26	40%	90% population declined in 4.4–5.8 years depending on spatial removal strategy	Web of Science search
					50%	90% population declined in 2.5–3.8 years depending on spatial removal strategy	
					70%	90% population declined in 1.9 years for all spatial removal strategies	
Pepin et al.	2017*a*	Texas, USA	2	0.26	38%	> 95% population reduction within 4 years	Web of Science search
				0.58	50%	> 95% population reduction within 4 years	
				0.89	60%	> 95% population reduction within 4 years	

Table continued on next page...

Table continued from previous page...

				0.26	20%	50% population reduction within 4 years	
				0.58	30%	50% population reduction within 4 years	
				0.89	35%	50% population reduction within 4 years	
Anderson and Stone	1993	Hawaii, USA	3	NA	66% in first 3 months, followed by 40–50% in subsequent 3-month intervals	88% reduction after 1 year, elimination in 2 years	Snow chapter
					20% in first 3 months, 39% next 3 months, 40–60% in subsequent 3-month intervals	54% reduction after the first year, elimination in 2 years	
McCann and Garcelon	2008	California, USA	3	NA	71.5% in the first 3 months with continued intense removal	Elimination in 1.3 years	Web of Science search
Barrett and Stone	1993	Hawaii, USA	4	NA	Removal of 30–40% twice per year	Maintain population at 50% of equilibrium density	Mayer chapter
Hess et al.	2006	Hawaii, USA	4	NA	71%	Reduce population by half in each successive year	Mayer chapter
					>41–43%	Necessary to cause population decline	
Salinas et al.	2015	Tennessee, USA	4	NA	19.60%	Population growth rate declined by 24% over 6 years	Snow chapter
Davis et al.	2022	Missouri, USA	4	0.16	18% monthly	95% chance of population decline	Web of Science search

[a] Methods/objective of the study: simulation modeling to determine time to elimination (1), simulation modeling to examine effects of removal rates on population abundance or growth rates (2), empirical measure of time to elimination (3), empirical measure of effects of removal rates on abundance or population growth rates (4).
[b] Intrinsic rate of increase per animal. Note: r is related to net population growth rate through other factors such as population density (Figures 1B and 1C) and can fluctuate in nature due to environmental conditions (Choquenot 1998).
[c] Percent of population removed annually unless time period is specified.

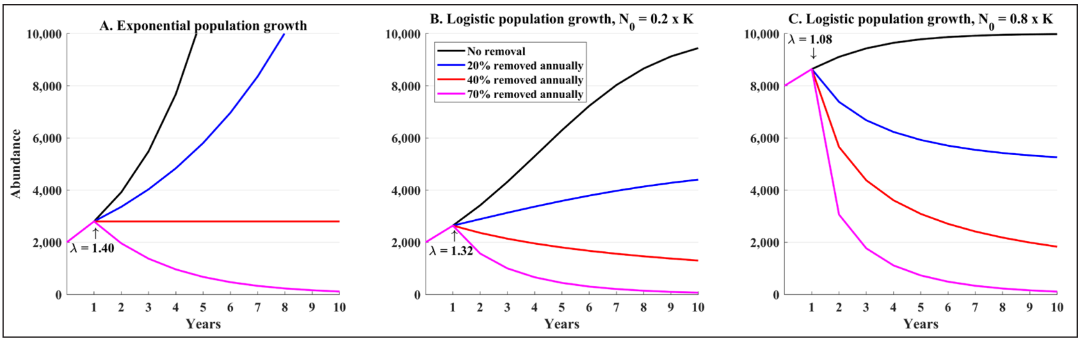


Figure 1. Population growth trajectory under exponential (A) or density-dependent (B, C) wild pig (*Sus scrofa*) population growth models assuming an intrinsic rate of increase (r) of 0.4. Annual growth is shown under 3 different removal rates (see legend) starting after 1 year of growth. The density-dependent model assumes a carrying capacity (K) of 10,000. Under the exponential growth model (A), the population grows beyond K within 5 years (black line), but slower growth occurs for the model with density-dependent growth even though each model uses the same r. This is because in the density-dependent models, density modifies the net population growth rate (λ) such that λ is much lower when the abundance is closer to carrying capacity (C), and lower removal rates can cause a population decline because density is working synergistically with removal to reduce abundance. For similar reasons, we also see that lower removal rates initially cause high rates of population decline when N_0 is closer to K (compare blue lines in B and C). When the removal rate matches the population growth rate (red line in A), the population maintains a constant abundance.

that the effect of a 70% annual removal rate is highly dependent on the underlying population growth rate. However, anecdotally, we have noticed that the 70% removal rate is widely quoted as a rule for effective wild pig management in public media outlets and by word of mouth, often in contexts where population growth rate is unknown.

Note that the net population growth rate (N_t/N_0, often denoted as λ and referred to as the net population growth rate or finite rate of increase) can be different from the intrinsic or maximum population growth rate (r or r_m, often referred to as the per individual [maximum] instantaneous rate of increase). This is because r is a parameter in a population growth model, whereas λ is the predicted outcome (net population growth rate) from all parameters in the model. In the simplest model of population growth ($e^{r(t+1-t)}$); Figure 1A), r equals λ across different initial population sizes (N_0) and wild pig densities, and thus r and λ are sometimes used interchangeably when referring to population growth rate. These are the models that were assumed in Giles (1976) and Giles (1980). However, when density-dependent growth is assumed, λ changes for the same r based on population density and N_0 (Figures 1B and 1C). The relationship between r and λ can be even less intuitive when more realistic ecology, such as age-specific r, environmentally dependent r, or spatial processes are added into the population growth model (Choquenot 1998; McMahon et al. 2010; Pepin et al. 2017*a*, *b*). These realistic ecological processes can work synergistically with removal rates to cause population decline at removal rates different from r (McMahon et al. 2010; Pepin et al. 2017*a*, *b*). Similarly, the effects of a particular management removal rate on λ can be different depending on how removals are conducted in time and space (Hone and Robards 1980; McMahon et al. 2010; Pepin et al. 2017*a*, *b*), and how the analysis is conducted (Table 1). Thus, while some of the mixed findings (Table 1) are due to local population differences in r, other discrepancies, especially among the simulation-based studies, are due to differences in the model structures used to evaluate removal rates and their underlying ecological assumptions.

Management challenges

Managing wildlife or invasive species is challenging because wildlife ecology is complex (Fryxell et al. 2014). Management is further complicated by diverse stakeholder knowledge, perceptions, and opinions about wildlife (Messmer et al. 1997). Concomitantly, to be effective, managers must cultivate partnerships with other managers, landowners, and stakeholders rather than use a single metric to manage populations.

In the case of the 70% metric, some stakeholders have become such strong proponents that they may not support efforts that do not meet this number (T. Guerrant, Wildlife Services, personal communication). In other cases, opponents to wild pig elimination weaponize the 70% metric to argue that a management strategy is not working and therefore should not be supported. When stakeholders do not agree on how to proceed, actions to mitigate wild pig impacts can be delayed. Control delays magnify the challenge of elimination because of the extreme reproductive potential of wild pigs. While managers hash out the "how to," the population is continuing to expand. In some areas, this can allow development of a hunting culture that argues against elimination or plays a role in spreading wild pigs to new areas (Bevins et al. 2014).

The downstream issues that can arise from all these challenges are that managers may respond by not estimating local wild pig densities locally to avoid determination of removal rates. However, density estimates are important as they can help prioritize allocation of limited resources to different areas in a way that optimizes both local management objectives and widespread elimination (Pepin et al. 2020, Davis et al. 2022). Population density estimates are also important for assessing disease risks, planning national disease surveillance, planning response to potential disease introductions (e.g., African swine fever), and estimating time to elimination in local areas (Pepin et al. 2017*a*, *b*).

Why one removal rate is wrong

Ultimately, the removal rate needed to cause a population decline depends on *l* in the local population during the time frame the removal rate is applied and how removal is conducted in space and time. In the absence of management, annual population growth rate values are the net difference of gain and loss rates in a population from all non-management processes (λ; Figure 1; [births + immigration] – [mortality + emigration]). Thus, to determine the removal rate that will cause a population decline, one needs to know the net population growth rate, which can be estimated by monitoring abundance over time. For example, if a population consists of 100 individuals on January 1 and has 125 individuals on December 31, then the annual population growth rate is (N_1/N_0 = 125/100 = 1.25) or 25% higher than the initial abundance. This population would decline if >25% of the initial population size is removed annually, assuming that population growth from natural sources remains constant.

Population growth rates in nature are rarely constant; they may vary within a single year or across years (Hone and Robards 1980, Choquenot 1998, Snow et al. 2020). Environmental conditions such as shifts in food abundance may alter birth rates or survivorship (Choquenot 1998, Snow et al. 2020). Many populations are thought to follow a pattern of density-dependent population growth where the growth rate of a nascent population with few females is lower than the growth rate of the same population once well-established ("Allee effect"; Kramer et al. 2009). For similar reasons, population dynamics may change in response to culling. For a population at or near carrying capacity (an upper limit defined by the environment's ability to support further population growth), growth rates approach 0 (Figures 1B and 1C) and thus the culling of some percentage of pigs may increase birth rates or survival while decreasing λ (Choquenot 1998). This increase in birth rates or survival may alter the percentage of pigs that need to be culled in subsequent events (Pepin et al. 2017*b*). Removal rates above the current input level will lead to declines in the population. In practice, this may occur at levels as low as 20% (Snow et al. 2020), though managers need to remain adaptable to current rates of net population growth to continue to drive populations downward. That is why using one number to guide population management is not necessarily effective or efficient and can be misleading.

Other strategies used by managers can amplify effects of removal rates providing "more bang for the buck." In many situations where elimination is the goal, it is infeasible to control the full management unit simultaneously due to financial or logistical constraints. Instead, a better strategy can be to focus control on areas that have the highest population growth rates from all sources until local elimination occurs, and then move sequentially to other areas (Pepin et al. 2017*b*, 2020). In this case, removal rates over the entire area might appear low on average, but elimination is more likely because resources are used in a way that eliminates local populations that could otherwise be the source of new populations or contribute to population growth in other local populations through immigration.

A second strategy for efficient use of control resources has to do with timing (Hone and Robards 1980). If the most intense removal efforts are targeted during times of the year before the most litters are born, then higher rates of population decline can occur than if the same removal rates are applied during times of the year after most litters are born (Pepin et al. 2017b). This strategy, referred to as "additive mortality," acts to pull the grass out at the roots rather than simply mowing it (compensatory mortality; Burnham and Anderson 1984, Bartmann et al. 1992). The fact that the same removal rate can play out differently depending on how it is applied to the populations further illustrates why a single removal rate number is a misleading evaluation of program success.

Finally, in geographically expanding populations, control acts to limit not only the growth rate within the local population where control occurs but also the expansion rate across the landscape (Pepin et al. 2019). However, the concept of "removal rates" only applies to the effects of control within a local population, emphasizing the limitations of the removal rate concept. When elimination is the ultimate objective, it is important not to lose sight of the value the control program might have on expansion rates in evaluating overall benefits and planning or refining elimination strategies. Ultimately, if the culling rates that are used lead to progress toward elimination, then those culling rates are beneficial. Using one number to decide whether a management program is successful gets in the way of realizing its benefits and achieving the management objectives.

Recommendations

Effective management should not be planned or evaluated based on a single removal rate. The scientific evidence demonstrates that multiple factors determine the effectiveness of a given removal rate, yet the 70% metric continues to be propagated in fact sheets and other outreach sources in the absence of information about local ecological context or management objectives. A better approach for outreach materials would be to describe the factors that determine effective management and how they can be manipulated to optimize management in a given population, management, or environmental context.

Acknowledgments

This work was funded by the National Feral Swine Damage Management Program of the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, and by the Texas A&M AgriLife Extension Service. Comments provided by T. Messmer, J. Mayer, J. Giles, and 2 anonymous reviewers improved our paper. We thank J. Mayer for suggesting a first draft of Table 1.

Literature cited

Anderson, S. J., and C. P. Stone. 1993. Snaring to control feral pigs *Sus scrofa* in a remote Hawaiian rain Forest. Biological Conservation 63:195–201.

Barrett, R. H., and C. P. Stone. 1993. Hunting as a control method for wild pigs in Hawaii Volcanoes National Park: a report for resource management. Research Division, Hawaii Volcanoes National Park, Hawaii, USA.

Bartmann, R. M., G. C. White, and L. H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121:1–39.

Bevins, S. N., K. Pedersen, M. W. Lutman, T. Gidlewski, and T. J. Deliberto. 2014. Consequences associated with the recent range expansion of nonnative feral swine. BioScience 64:291–299.

Burnham, K. P., and D. R. Anderson. 1984. Tests of compensatory vs. additive hypotheses of mortality in mallards. Ecology 65:105–112.

Choquenot, D. 1998. Testing the relative influence of intrinsic and extrinsic variation in food availability on feral pig populations in Australia's rangelands. Journal of Animal Ecology 67:887–907.

Davis, A. J., R. Farrar, B. Jump, P. Hall, T. Guerrant, and K. M. Pepin. 2022. An efficient method of evaluating multiple concurrent management actions on invasive populations. Ecological Applications 32(6): e2623.

Dexter, N., and S. R. McLeod. 2015. Modeling ecological traps for the control of feral pigs. Ecology and Evolution 5:2036–2047.

Dzieciolowski, R. M., C. M. H. Clarke, and C. M. Frampton. 1992. Reproductive characteristics of feral pigs in New Zealand. Acta Theriologica 37:259–270.

Fryxell, J. M., A. R. E. Sinclair, and G. Caughley. 2014. Wildlife ecology, conservation, and management. Third edition. Wiley Blackwell, Oxford, United Kingdom.

Giles, J. R. 1976. Feral pigs and agriculture. Pages 125–128 *in* Agriculture, forestry and wildlife: conflict or coexistence? Proceedings of a workshop held at the University of New England, Armidale, New South Wales, Australia.

Giles, J. R. 1980. The ecology of feral pigs in western New South Wales. Dissertation, Sydney University, Sydney, Australia.

Giles, J. R. 1999. The dynamics of feral pig populations in Australia: implications for management. Pages 39–42 *in* C. N. Johnson, editor. Feral pigs: pest status and prospects for control. Proceedings of a feral pig workshop held at James Cook University, Cairns. Research report no. 13, Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns, Australia.

Hess, S. C., J. J. Jeffrey, D. L. Ball, and L. Babich. 2006. Efficacy of feral pig removals at Hakalau Forest National Wildlife Refuge. Transactions of the Western Section of the Wildlife Society 42:53–67.

Hone, J., 2012*a*. Feral pig population management. Pages 72–96 *in* Applied population and community ecology: the case of feral pigs in Australia. Conservation Science and Practice Series no. 11, Wiley-Blackwell, West Sussex, United Kingdom.

Hone, J., 2012*b*. Population ecology of feral pigs. Pages 30–53 *in* Applied population and community ecology: the case of feral pigs in Australia. Conservation Science and Practice Series no. 11, Wiley-Blackwell, West Sussex, United Kingdom.

Hone, J., and G. E. Robards. 1980. Feral pigs: ecology and control. Wool Technology and Sheep Breeding 28:7–11.

Klinger, R., J. Conti, J. K. Gibson, S. M. Ostoja, and E. Aumack. 2011. What does it take to eradicate a feral pig population? Pages 78–86 *in* C. R. Veitch, M. N. Clout, and D. R. Towns, editors. Island invasives: eradication and management. International Union for Conservation of Nature, Auckland, New Zealand.

Kramer, A. M., B. Dennis, A. M. Liebhold, and J. M. Drake. 2009. The evidence for Allee effects. Population Ecology 51:341–354.

Mayer, J. J. 2009. Wild pig population biology. Pages 157–191 *in* J. J. Mayer and I. L. Brisbin, Jr., editors. Wild pigs: biology, damage, control techniques and management. Technical report SRNL-RP-2009-00869, Savannah River Site, Aiken, South Carolina, USA.

McCann, B. E., and D. K. Garcelon. 2008. Eradication of feral pigs from Pinnacles National Monument. Journal of Wildlife Management 72:1287–1295.

McMahon, C. R., B. W. Brook, N. Collier, and C. J. A. Bradshaw. 2010. Spatially explicit spreadsheet modelling for optimising the efficiency of reducing invasive animal density. Methods in Ecology and Evolution 1:53–68.

Messmer, T. A., L. Cornicelli, D. J. Decker, and D. G. Hewitt. 1997. Stakeholder acceptance of urban deer management techniques. Wildlife Society Bulletin 25:360–366.

Pepin, K. M., A. J. Davis, F. L. Cunningham, K. C. VerCauteren, and D. C. Eckery. 2017*a*. Potential effects of incorporating fertility control into typical culling regimes in wild pig populations. PLOS ONE 12(8): e0183441.

Pepin, K. M., A. J. Davis, and K. C. VerCauteren. 2017*b*. Efficiency of different spatial and temporal strategies for reducing vertebrate pest populations. Ecological Modelling 365:106–118.

Pepin, K. M., T. J. Smyser, A. J. Davis, R. S. Miller, S. McKee, K. C. VerCauteren, W. Kendall, and C. Slootmaker. 2020. Optimal spatial prioritization of control resources for elimination of invasive species under demographic uncertainty. Ecological Applications 30(6): e02126.

Pepin, K. M., D. W. Wolfson, R. S. Miller, M. A. Tabak, N. P. Snow, K. C. VerCauteren, and A. J. Davis. 2019. Accounting for heterogeneous invasion rates reveals management impacts on the spatial expansion of an invasive species. Ecosphere 10(3): e02657.

Salinas, R. A., W. H. Stiver, J. L. Corn, S. Lenhart, C. Collins, M. Madden, K. C. VerCauteren, B. S. Schmit, E. Kasari, A. Odoi, G. Hickling, and H. McCallum. 2015. An individual-based model for feral hogs in Great Smoky Mountains National Park. Natural Resource Modeling 28:18–36.

Snow, N. S., R. S. Miller, J. C. Beasley, and K. M. Pepin. 2020. Wild pig population dynamics. Pages 57–82 *in* K. C. VerCauteren, J. C. Beasley, S. S. Ditchkoff, J. J. Mayer, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in

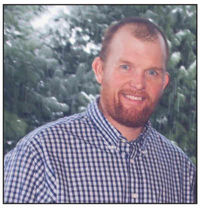
North America: ecology, impacts and management. CRC Press, Boca Raton, Florida, USA.

Timmons, J. B., B. Higginbotham, R. Lopez, J. C. Cathey, J. Mellish, J. Griffin, A. Sumrall, and K. Skow. 2012. Feral hog population growth, density and harvest in Texas. Report no. SP-472. Texas AgriLife Extension Service, Texas A&M University, College Station, Texas, USA.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS). 2020. APHIS National Feral Swine Damage Management Program. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Washington, D.C., USA, <https://www.aphis.usda.gov/aphis/resources/pests-diseases/feral-swine/feral-swine-program>. Accessed May 17, 2022.

Associate Editor: Jessica Tegt

Kim M. Pepin is a quantitative ecologist at the National Wildlife Research Center (U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services). She develops analytical tools for assisting the evaluation and implementation of wildlife damage and disease management programs.

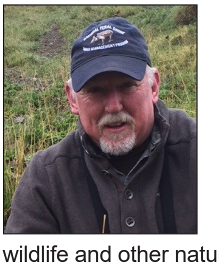


Travis L. Guerrant is the state director for the Missouri/Iowa U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services program and serves as an incident commander for the Missouri Feral Hog Elimination Partnership. He graduated from the University of Missouri-Columbia with a bachelor's degree in fisheries and wildlife in 2001 and is a Certified Wildlife Biologist through The Wildlife Society. In his current position, he oversees the delivery of integrated wildlife damage management assistance to cooperators across Missouri and Iowa.

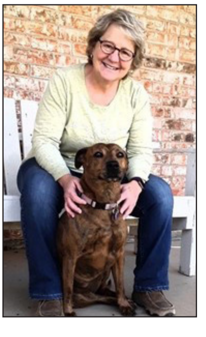
Jeremiah L. Psiropoulos is a wildlife biologist with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Feral Swine Damage Management Program. He earned B.S. degrees in fisheries and wildlife sciences from Oregon State University and environmental studies from the University of Oregon. His professional interests include invasive species management and bird, mammal, and fish ecology.

Jeanine T. Neskey is a biologist and extension specialist with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), National Feral Swine Damage Management Program. She earned her B.S. degree in animal sciences from the University of Vermont and her M.S. degree in agricultural extension from Colorado State University. Early in her career, she worked to support small-scale market farmers in Northern Colorado through technical training and education. Currently, with APHIS Wildlife Services, she has worked for the past 7 years to create impactful outreach products and advance communication and education surrounding invasive feral swine and wildlife damage management issues.

John M. Tomeček is an associate professor and extension wildlife specialist with the Texas A&M AgriLife Extension Service. He specializes in research and education on a variety of issues, especially wildlife damage and disease concerns, particularly with canines. He has worked extensively on the culture and habits of wildlife resources users, helping to tailor management solutions that are not only scientifically sound, but socially accepted.



Michael J. Bodenchuk is the state director for the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services and the Cooperative Texas Wildlife Services Program. The program serves the citizens of Texas by providing predator and feral hog management, wildlife disease surveillance and management, and bird and beaver damage management. The program also protects wildlife and other natural resources, provides urban wildlife damage assistance, and protects the public by minimizing wildlife at airports. His professional interests include feral hog management, predation management, and predator ecology. He lives near Hondo, Texas, with his wife, Debby.



Janean L. Romines (retired) worked as a wildlife biologist with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (WS) National Feral Swine Damage Management Program. Before then, she served 31 years in several WS roles including wildlife disease biologist, staff wildlife biologist at WS headquarters, and liaison for the WS National Training Academy at Mississippi State University. Her retired life is full of camping, hiking, cycling, and enjoying family and friends.