CSIRO PUBLISHING

RESEARCH PAPER
https://doi.org/10.1071/WR23063

WILDLIFE RESEARCH

An estimate of the marginal annual economic contribution of wild-pig hunting in Texas

Sophie C. McKee[A,B,*], Keith M. Carlisle[B], John Tomeček[C], Stephanie A. Shwiff[B], Rachael Connally[C], Maureen Frank[C], Mike Bodenchuk[D] and Nicole Didero[A]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
Sophie C. McKee
Department of Economics, Colorado State University, Fort Collins, CO 80523, USA
Email: Sophie.McKee@colostate.edu

Handling Editor:
Thomas Prowse

ABSTRACT

Context. Wild-pig hunting is a culturally significant recreational and commercial activity in Texas, but the overall impacts are contested. Except for one 1980s study, there has been no research to formally quantify any economic benefits of wild-pig hunting in Texas, which is an important component for weighing the costs and benefits of wild-pig presence in the state. **Aims and methods.** To fill that research gap, we surveyed a sample of resident and non-resident 2018–2019 hunting-license holders in Texas about various topics related to their wild-pig hunting activities, including expenditures. **Key results.** On the basis of the 37,317 responses received, we estimated that the marginal annual direct economic benefit of wild-pig hunting to the Texas economy ranges between US$68.5 million and US$188.0 million (2022 dollar values). Given that we were not able to distinguish whether purchases were made in or out of state for expenses provided, we believe this range is an upper estimate. **Conclusion and implications.** Although hunting is an important consideration in the discussion of wild-pig management, this estimate is dwarfed by the estimated total damage costs associated with wild pigs in Texas.

Keywords: cost–benefit analysis, human dimensions, introduced species, invasive species, management strategies, pest management, social behaviour, statistical modelling, wildlife economics.

Introduction

Wild pig (*Sus scrofa*), also known as 'feral swine,' 'wild boar,' and 'feral hog', among other names (Keiter *et al.* 2016), is an invasive species in the USA that was introduced as a food source by early Spanish explorers to North America in the 1500s (Belden and Frankenberger 1977). Its presence and continued proliferation are of considerable economic concern (Shwiff *et al.* 2017, 2020; Didero *et al.* 2023), because they cause extensive damage to US agriculture (Bankovich *et al.* 2016; Carlisle *et al.* 2021; McKee *et al.* 2023, 2024), negatively affect natural resources and the environment (e.g. Barrios-Garcia and Ballari 2012; Engeman *et al.* 2019), and present disease risks to domestic livestock and humans (Brown *et al.* 2021; Orr *et al.* 2022). However, some stakeholder groups find social and economic value in wild pigs. For example, wild pigs provide recreational hunting opportunities and may support subsistence livelihoods (Bevins *et al.* 2014; Boumendjel *et al.* 2016). In addition, in some communities, they are valued as integral aspects of culture and heritage (Maly *et al.* 2007; Pejchar and Mooney 2009; Weeks and Packard 2009; Boumendjel *et al.* 2016). Because wild pigs are associated with benefits as well as significant costs, their management can become contentious (Keuling *et al.* 2016; Carlisle *et al.* 2022), particularly insofar as the role of wild-pig hunting, as either a means of control or spread of wild-pig populations, is implicated.

Wildlife hunting can be a tool to enhance the populations of wild animals, or, alternatively, to control their populations (Braga *et al.* 2010; Heffelfinger 2018; Rosa *et al.* 2018). The relationships between hunting and wild-pig behaviour have been considered and studied around the world, including in Europe (e.g. Keuling *et al.* 2008, 2013), Algeria (Boumendjel *et al.* 2016), Brazil (Rosa *et al.* 2018), and the USA (Burton *et al.* 2013; Todd and Mengak 2018). Furthermore, hunters play an important role in wildlife policy

Received: 6 June 2023
Accepted: 13 March 2024
Published: 15 April 2024

Cite this: McKee SC *et al.* (2024) An estimate of the marginal annual economic contribution of wild-pig hunting in Texas. *Wildlife Research* **51**, WR23063. doi:10.1071/WR23063

decisions regarding the management of wild pigs (Peine and Farmer 1990; Boumendjel *et al.* 2016; Grady *et al.* 2019), and various research has been conducted to understand hunter opinions about wild pigs and wild-pig hunting (e.g. McLean *et al.* 2021; Vaske *et al.* 2021; Jaebker *et al.* 2022). Although wild-pig hunting may seem like an intuitive solution for controlling wild-pig populations, it also plays a unique role in the spread of wild pigs (Tabak *et al.* 2017; McLean *et al.* 2021). For example, previous studies have found that wild-pig hunting in the USA promotes interest to maintain or establish new wild-pig populations for hunting, hindering success in population-reduction efforts (Tabak *et al.* 2017, Hernández *et al.* 2018, Grady *et al.* 2019).

To the authors' knowledge, there is only one published study (Degner *et al.* 1983) concerning the economic aspects of wild-pig hunting in the USA, which was a large survey study in Florida evaluating the recreational and commercial importance of wild pigs to hunters, taxidermists, and trappers. On the basis of reported counts of harvested wild pigs, the researchers concluded that the economic value of recreational wild-pig hunting in 1980 was US$6 million (on the basis of US$58/head hunted). Researchers also reported that the value of trapping was approximately US$700,000 (on the basis of US$26/head trapped) and about US$389,000 in gross income was generated from taxidermy for mounting wild-pig heads. Additionally, landowners collected about US$1.2 million in hunting-lease fees and the sale of feral swine to hunting clubs totaled about US$81,000. Sales of feral swine through commercial livestock auctions were US$16,800 in 1980 for 1620 animals sold. The authors concluded that wild pigs were an important economic aspect of the Florida recreation economy, but not for commercial agriculture in Florida. It is important to note that at the time of the study, wild-pig hunting was still an emerging activity in the state.

Currently, Texas is estimated to have the largest wild pig population in the United States (USA) (Mayer 2014), with wild pigs being present in all counties (APHIS 2023). In addition, Texas has a large population of hunters, and is known for recreational wild-pig hunting (Connally *et al.* 2021*a*). Specifically for Texas, wild-pig hunters have historically been involved in policy decisions concerning wild-pig management (Jaebker *et al.* 2022). For example, after the Texas Agricultural Commissioner issued an emergency rule in 2017 approving use of a wild-pig toxicant (Poché *et al.* 2018), hunters started an online petition in opposition to the toxicant and, together with other groups, lobbied lawmakers to pass legislation restricting or regulating the use of the toxicant (Carlisle *et al.* 2022). This resulted in the Texas House of Representatives passing a bill requiring further scientific research of any wild-pig toxicant intended for use in Texas (Carlisle *et al.* 2022).

Given the debated concerns about the advantages and disadvantages of wild-pig hunting in the USA and the lack of understanding of the potential economic benefits of wild-pig hunting, we sought to estimate the marginal annual economic contribution of direct wild pig hunting-related expenditures in Texas based on a survey of resident and non-resident Texas hunters for the 2018–2019 season. For this analysis, the 'marginal annual economic contribution' is the annual value of wild-pig hunting from hunter activity in Texas that was specifically for wild-pig hunting and/or would not otherwise be occurring if wild pigs were less available or unavailable to hunt in Texas; 'direct wild pig hunting-related expenditures' are payments directly tied to a specific good or service for wild-pig hunting. For this research, we first provide an overview of the methods used for the survey data-collection and -cleaning processes, followed by a detailed explanation of steps taken for data analysis, after which we provide the results. We conclude with a discussion in consideration of how these findings fit in to the context of wild-pig management in the USA.

Methods

Survey methods

The Texas A&M University Institutional Review Board reviewed this study and determined that it met the criteria for exemption (IRB ID: IRB2018-1219M). The data were primarily collected using an online questionnaire hosted on Qualtrics, an online survey software. Copyright © [2019] Qualtrics. Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA. https://www.qualtrics.com. The questionnaire was developed by individuals with subject-matter expertise, and it was pre-tested with 51 individuals. The questionnaire included items related to hunting activities, landownership, attitudes towards wild pigs, wild-pig management practices, and demographics.

The Texas Parks and Wildlife Department (TPWD) provided the sample population, which included all adult holders of a Texas hunting license (in-state and out-of-state) for the 2018–2019 hunting year who had provided an email address to TPWD when they purchased a license (169,619 of 1,106,625 licensed non-youth hunters in Texas). To evaluate coverage error, a randomly selected subset of 2615 licensed hunters in Texas who did not have an email address on record with TPWD was also included for a total sample population size of $n = 172{,}234$. At the time of survey administration, a general hunting license was required to hunt wild pigs in Texas, with an exception for landowners who killed pigs that were causing damage to their property. On the basis of these methods, a large proportion of wild-pig hunters in Texas were likely to be included in the sampling procedure.

Sample members with email addresses were sent an email on 4 June 2019, inviting them to participate in the survey. Five days later, they were emailed a reminder about survey participation. Sample members with no email address were mailed an invitation letter to participate in the survey (online or through a paper survey), and a reminder postcard was sent

to 1000 randomly selected mail group non-respondents 21 days later on 26 June 2019. The survey remained open through to 13 August 2019, after which data were exported from Qualtrics into a relational database created in FileMaker Pro v14.0.6 (Claris InternationalInc., Santa Clara, CA, USA).

Key variables and data cleaning

At the beginning of the survey, respondents were asked whether they hunt in Texas (Item 1 in the questionnaire[1]) and, if they answered yes, they were asked to rank the animals they hunt in Texas, which included wild pigs as an option. Respondents who indicated that they hunted wild pigs were also asked the question 'How much money did you spend on wild pig hunting-related purchases in 2018? Please estimate the costs of the following items to a whole dollar amount' (Item 8 in the questionnaire[2]). Respondents were to write in their estimates of individual expenditures on hunting lease(s) or access fees, tour operator or guide fees, overnight accommodations, transportation, meals, ammunition, bait/attractant, processing/taxidermy, hunting tools/guns and accessories, and 'other' expenditures (an open-ended write-in category). The text descriptions provided for the 'other' expenditures were reviewed for the entire sample in terms of qualifying as an actual direct expense of wild-pig hunting. Therefore, expenditures provided by respondents represented expenses for wild-pig hunting by license-holding individuals.

All individual expenditures were reviewed with particular focus on cleaning and organising the 'other' expenditures category. After this, a numeric variable was created by summing all expenditure categories to represent total direct expenditures on wild-pig hunting for each individual respondent. Additionally, a variable for Texas resident status (non-resident/resident) was created on the basis of the type of the Texas hunting license (in-state or out-of-state) purchased by each respondent for the 2018–2019 season. Texas resident status was coded as a binary variable (one being resident, zero being non-resident).

Data analysis

A non-response bias analysis was conducted for the items specific to our analysis by using an ordered logistic regression (e.g. Fullerton 2009), which is further detailed in Supplementary material B. The estimation of the direct marginal annual benefits of wild-pig hunting in Texas for the 2018–2019 hunting season was derived from the expenditure values reported by respondents who would not otherwise hunt other animals if wild pigs were less available or unavailable to hunt and who identified as primarily or exclusively wild-pig hunters. Answers to Item 14 (I would go hunting for other animals more if wild pigs were less available to hunt), Item 19 (I only purchase my hunting license to hunt wild pigs), and Item 7 (Which statement better describes the majority of your hunting trips?) (Figs 1–3) best identify these respondents. Specifically, two individual subsets of respondents were created on the basis of answers to Item 14 (abbreviated hereafter as 'Hunt other animals') and Item 19 (abbreviated hereafter as 'License only for pigs'), followed by further subsetting within each the two subsets on the basis of Item 7 (abbreviated hereafter as 'Hunting trip category'). If a respondent answered, 'strongly disagree' or 'somewhat disagree' (labelled as Options 1 or 2 in Fig. 1) to Item 14 (Hunt other animals) *and* selected 'I exclusively hunt wild pigs on most of my hunting trips' or 'I primarily hunt wild pigs, but will harvest a native game animal if I see one' to Item 7 (labelled as Option 1 or 2 in Fig. 3) (Hunting-trip category), they were included the subset for Item 14 (Hunt other animals). If a respondent answered, 'strongly agree' or 'somewhat agree' (labelled as Options 4 or 5 in Fig. 2) to Item 19 (License only for pigs) and selected one of the first two options in Item 7 (Hunting-trip category), they were included in the subset for Item 19 (License only for pigs). This approach allowed for a more nuanced consideration of the economic estimate and provided an estimate range.

Economic benefit estimation

The estimation of the marginal annual direct economic contribution (US$) of wild-pig hunting to the economy of Texas (Y_q, where q pertains to the survey Item 14 (Hunt other animals) or Item 19 (License only for pigs)) is represented by Eqn 1, as follows:

$$Y_q = \sum_{i\in\{\mathrm{r,nr}\}} \left[\left(\frac{N_i}{n_i}\right) \times \left(\frac{R_i}{r_i,q}\right) \times S_{i,q} \times x_{i,q} \right] \quad (1)$$

The Resident category i is 'r' for residents and 'nr' for non-residents; N_i is the population of hunting-license holders in Texas (respectively resident and non-resident) for the 2018–2019 season, calculated on the basis of the share of residents (91.7%) and non-residents (8.3%) provided by TPWD; n_i is the size of the corresponding survey sample. Hence, the ratio of N_i to n_i is a scaling ratio linking the information provided by the hunter sample to the whole hunter population in Texas on the basis of no detection of non-response bias. The variable R_i represents the number of respondents in category i who indicated that they hunt wild pigs (selected 'yes' to Item 1) and thus had the opportunity to respond to Questions 7 (Hunting-trip category), 14 (Hunt other animals), and 19 (License only for pigs). The variable $r_{i,q}$ is the number of respondents who answered either Item 14 and Item 7 or Item 19 and Item 7. The ratio of variables R_i and $r_{i,q}$, establishes an assumption that those who did not answer the items of interest are otherwise similar to those who did answer. $S_{i,q}$ is the number of the residents or

[1]Questionnaire available in Supplemental material A.

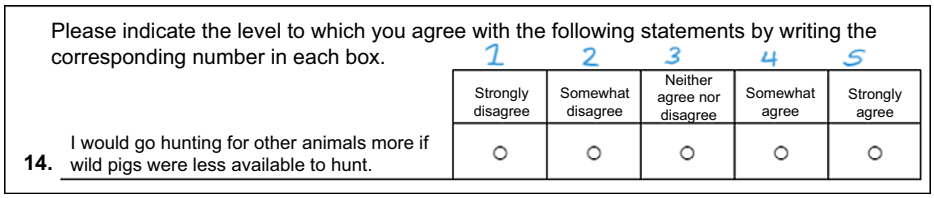

Fig. 1. Questionnaire Item 14 (Hunt other animals).

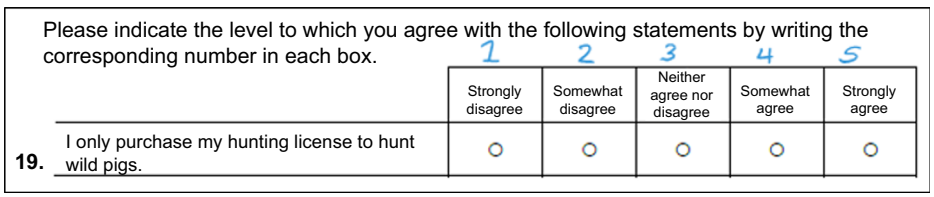

Fig. 2. Questionnaire Item 19 (License only for pigs).

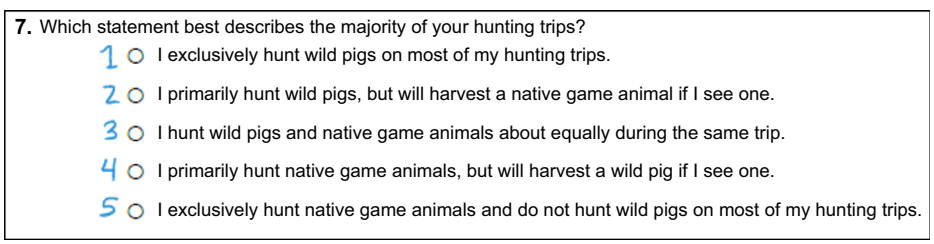

Fig. 3. Questionnaire Item 7 (Hunting-trip category).

non-residents in subsets based on Question q. Last, the variable $x_{i,q}$ is the average total expenditures as reported by respondents in Category i within the subset based on Question q. Dollar values were then updated to reflect the 2022 equivalent of the 2018 values on the basis of annual average inflation (Bureau of Labor Statistics 2023).

Results

The response rate to the survey was 23% (n = 37,317), and a previous analysis of this dataset by Connally *et al.* (2021*a*, 2021*b*) determined that the results could be generalised to the target population of hunting-license holders[2] in Texas. The response rate for the email contact group was 23% and for the conventional mail group 7% (Connally *et al.* 2021*a*). Although the intent was to check for coverage error, the low response rate for the conventional mail group prevented us from doing so. After removing incomplete surveys, we maintained 35,560 responses in our analysis sample.

Most (90%) of respondents left the 'Other' expenditure category for questionnaire Item 8 blank. Of those who entered a response, 1.7% were re-allocated to a previously prompted expenditure category, and 7.5% remained as appropriate 'Other' direct expenditures. The final list of accepted 'Other' direct wild-pig hunting expenditures included hunting-trip package value, expenditures described as 'Miscellaneous,' other equipment understandably not considered to be a part of the 'Hunting tools/guns and accessories' expenditure category (e.g. ATVs, UTVs, fuel, gas), hunting business expenses, helicopter hunting, gifts for others related to hunting, gratuities/tips for hunting guides, hunting-equipment maintenance/repair, time to build/install hunting equipment, expenses for sharing the hunting experience (e.g. teaching youth to hunt), and other fee items (e.g. hunting club fees, rental fees, range fees). Afterwards, five observations were removed on the basis of unreasonable total expenditure values, resulting in a sample size of 35,555. A Texas hunting-license type was anonymously attached to all but 76 responses (<1%), 70 of which were from the paper version of the survey and six of which were from online surveys; these were

[2]Connally *et al.* (2021*a*, 2021*b*) regressed several key items (Items 1, 2, 31, and 73 in Appendix 1) on the number of days to response as an indicator for potential non-response bias. Although responses were different by the number of days to response ($P < 0.05$), effect sizes were small ($r^2 = 0.0003$). They therefore assumed no significant effect of non-response bias and that results could be generalised to the target population (Lindner *et al.* 2001).

excluded from analysis for a final sample size of 35,479, split up between residents and non-residents (n_r = 31,528 and n_{nr} = 3951).

A complete description and results of the non-response bias can be found in Supplementary material B; there was no significant detection of non-response bias.

Average total marginal annual expenditures

Seventy-six per cent of the survey sample (n = 27,063) indicated that they hunt wild pigs in Texas, split up into R_r = 24,711 residents and R_{nr} = 2352 non-residents. Among those who gave answers to both Item 14 (Hunt other animals) and Item 7 (Hunting-trip category), 5.6% (n = 1304) of respondents met the 'Item 14 subset' criterion that they strongly or somewhat disagreed with the statement, 'I would go hunting for other animals more if wild pigs were less available to hunt' and for Item 7 that they 'exclusively' or 'primarily' hunt wild pigs. Among this Item 14 subset, 950 were residents ($S_{r,14}$) and 354 were non-residents ($S_{nr,14}$). The average total expenditures related to wild-pig hunting was similar for residents and non-residents of Texas (Table 1).

Among those who gave answers to both Item 19 (License only for pigs) and Item 7 (Hunting-trip category), 3.9% (n = 921) of respondents met the 'Item 19 subset' criterion that they somewhat or strongly disagree with the Item 19 statement, i.e. 'I only purchase my hunting license to hunt wild pigs', and that they 'exclusively' or 'primarily' hunt wild pigs for Item 7. Among the Item 19 subset, 407 were Texas residents ($S_{r,19}$) and 514 were non-residents ($S_{nr,19}$). Average total wild-pig hunting-related expenditure was similar for residents and non-residents, although the maximum spent by non-residents was over four times higher (Table 2).

Median marginal annual expenditures on individual wild-pig hunting-related items

Pertinent to the total expenditure values are the individual expenditure categories that they comprise. Given the high standard deviations about the expenditure means, the median was a more informative measure of central tendency. Figs 4 and 5 present the median values for individual wild-pig hunting-related expenditures, broken up by Texas resident status, for Item 14 (Hunt other animals) and Item 19 (License only for pigs) respectively. For the Item 14 subset, the non-resident median values were noticeably higher for lease/access fees, overnight accommodations, tour operator/guide fees, and transportation (Fig. 4). The differences between medians for non-resident and resident expenditures on ammunition and meals for either subset was negligible. Very similar trends were seen with the Item 19 subset, with the exception that the non-resident and resident medians for ammunition were the same (Fig. 5). For both subsets, the Texas resident medians for bait/attractant and hunting tools (including guns and accessories) were marginally different between resident groups (residents tending to pay more than non-residents), and both non-residents and residents of Texas often did not indicate paying for 'Other' expenditures or processing/taxidermy.

Table 1. Summary statistics (in 2018 dollar values) for total expenditures for the Item 14 (Hunt other animals) subset (n = 1304).

Resident status	Mean ($\bar{x}$)	s.d.	Median	Min	Max
Resident (n = 950)	US$3042	US$5792	US$1022	US$0	US$58,500
Non-resident (n = 354)	US$2956	US$14,514	US$1390	US$0	US$261,500

Table 2. Summary statistics (in 2018 dollar values) for total expenditures for the Item 19 (License only for pigs) subset (n = 921).

Resident status	Mean ($\bar{x}$)	s.d.	Median	Min	Max
Resident (n = 407)	US$2356	US$4216	US$900	US$0	US$45,350
Non-resident (n = 514)	US$2764	US$12,157	US$1380	US$0	US$261,500

Marginal annual economic benefit estimation

Using the average total value for expenditures from each resident category for each subset and Eqn 1, the estimated marginal annual economic contribution of wild-pig hunting to the Texas economy (Y_q) in 2018 dollars on the basis of Item 14 was US$133.3 million (M) (CI(95%): US$105.3 M; US$161.3 M, n = 1304), and on the basis of Item 19 it was US$73.0 M (CI(95%): US$58.7.0 M; US$112.9 M, n = 921). On the basis of these direct expenditure values and the 2018 and 2022 CPIs, the estimated marginal economic benefit of wild-pig hunting for one hunting season ranged from US$68.5 million to US$188.0 million annually in 2022 US dollar value.

Discussion

Resistance to the control of invasive wild pigs may be founded on the belief that revenue from the hunting of wild pigs is significant and outpaces the level of damage caused by the species, especially in Texas. The results of this study are timely because they have provided an estimated range of the potential revenue generated by wild-pig hunting in Texas, allowing for a direct comparison of some of the benefits of hunting wild pigs with some of the damages they cause.

Considering the study results, non-resident median values were noticeably higher for lease/access fees, overnight accommodations, tour operator/guide fees, and transportation for the Item 14 subset, which is not surprising because non-resident hunters may be more likely to need lodging during their out-of-state hunting trip, spend more on transportation, and may be more likely to use tour operators/guides. Very similar trends were seen for the median comparisons with the Item 19 subset. Non-residents and residents often indicated paying US$0 for 'other' expenditures and

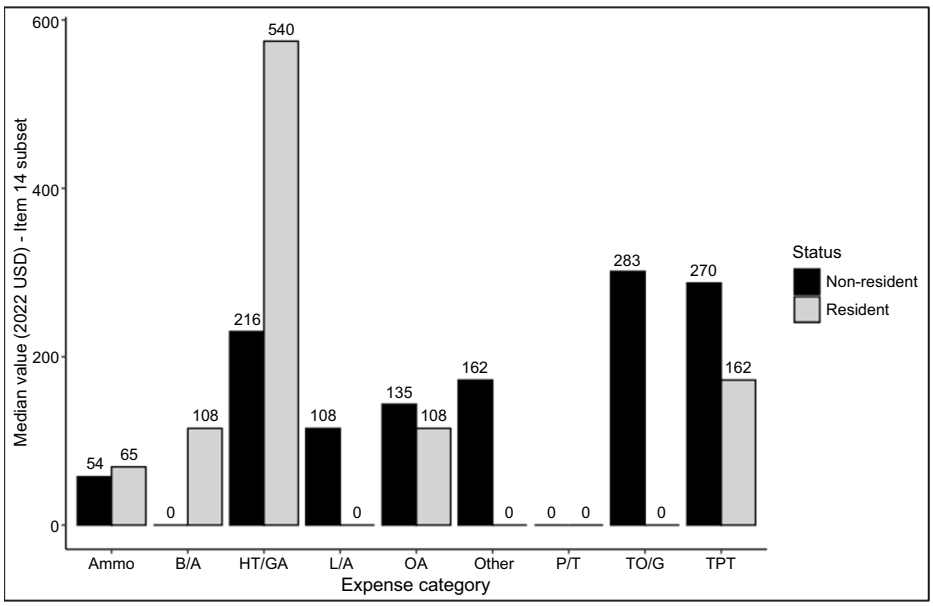

Fig. 4. Median individual wild-pig hunting-related expenditures by resident status of Texas, Item 14 (Hunt other animals) subset. B/A: bait/attractant; HT/GA: hunting tools/guns and accessories; L/A: lease(s)/access; OA: overnight accommodations; P/T: processing/taxidermy; TO/G: tour operator/guide; and TPT: transportation.

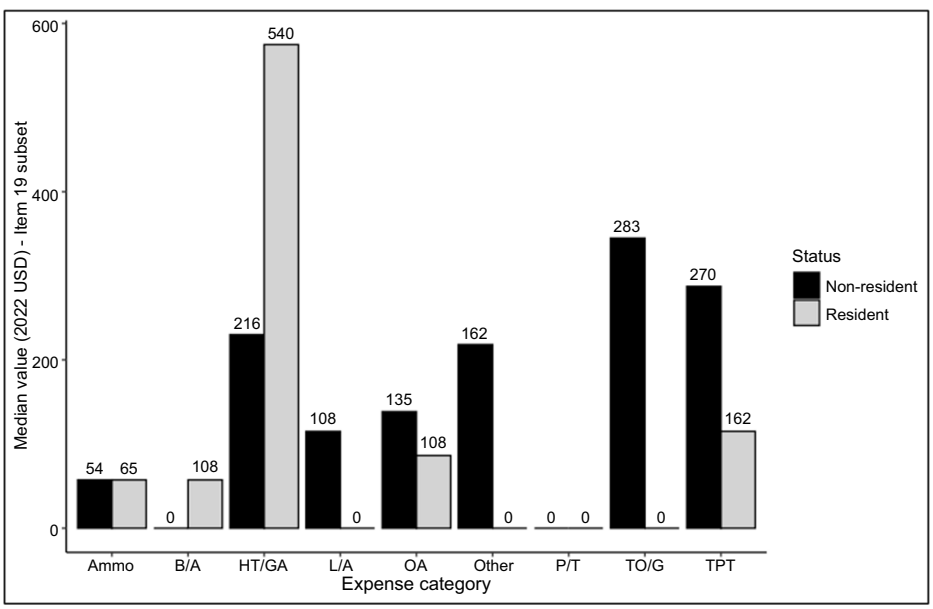

Fig. 5. Median individual wild-pig hunting-related expenditures by resident status of Texas, Item 19 (License only for pigs) subset. B/A: bait/attractant; HT/GA: hunting tools/guns and accessories; L/A: lease(s)/access; OA: overnight accommodations; P/T: processing/taxidermy; TO/G: tour operator/guide; and TPT: transportation.

processing/taxidermy. An explanation for this may be that most respondents felt that they had covered their annual individual expenses with the expense categories provided and processing/taxidermy is not commonly used for wild-pig hunting trophies.

There are limitations of this study that are common to most studies that rely on self-reported estimates of costs. One such limitation is that we cannot confirm that all reported spending on wild-pig hunting-related items by non-residents contributed to the Texas economy. Payment for some items (e.g. airfare for

travel to Texas) may have been made out-of-state and thus not benefited the Texas economy. This could potentially be the case for residents as well, with expenditures on items such as 'gear,' especially given the popularity of online shopping. In addition, we included in our estimates the cost of hunting licenses purchased by respondents who indicated that they purchased a license only to hunt wild pigs. However, there is no longer a requirement that hunters possess a license in Texas to hunt wild pigs, and thus, this benefit would no longer accrue to the state. Hence, our estimates are likely to be an overestimate of the likely benefits to the Texas economy today.

Previous studies have documented the annual value of damage inflicted by wild pigs to the Texas economy as US$204.7 million (2022 dollar value) to producers of corn, (*Zea mays*), soybeans (*Glycine max*), wheat (*Triticum*), rice (*Oryza sativa*), peanuts (*Arachis hypogaea*), and sorghum (*Sorghum bicolor*) (McKee *et al.* 2024); US$135.2 million (2022 dollar value) in production lost of hay, pecans (*Carya illinoinensis*), melons (cantaloupe (*Cucumis melo* L. var. *cantalupensis*), honeydew (*C. melo*), and watermelon (*Citrullus*), sugarcane (*Saccharum officinarum*), sweet potatoes (*Ipomoea batatas*), and cotton (*Gossypium*) (McKee *et al.* 2020); and US$477.2 million (2022 dollar value) in predation, disease and other livestock deaths, as well as veterinary and medical treatment costs, property damage and the rooting of pasture (McKee *et al.* 2023). Further, the body of research that estimates the economic impact of wild pigs to Texas and other regions of the world is still growing. There is still much unknown about the negative economic impacts to infrastructure (i.e. damage to roadways, bridges, buildings), vehicles, natural resources (i.e. wildlife, endangered species, habitats), other agricultural resources, and public health (Didero *et al.* 2023; VerCauteren *et al.* 2024).

Conclusions

Comparing the results of this study with existing estimates suggested that the costs associated with wild-pig presence in Texas are significantly greater than the marginal benefits associated with them as a hunting resource. In another study based on this survey, Connally *et al.* (2021*a*) found that most wild-pig hunting was conducted by hunters who were primarily hunting other big game and were opportunistically harvesting wild pigs. In other words, wild-pig hunting was an 'add-on' activity but not a primary motivation for most hunters who harvested wild pigs in Texas. It should also be noted that interest in wild-pig hunting among a minority of hunters is the most likely driver of human translocation of wild pigs and the further spread of wild-pig populations (Comer and Mayer 2009; Hernández *et al.* 2018; Grady *et al.* 2019). In sum, the research suggests that the hunting of wild pigs is mostly a peripheral activity in Texas that contributes modest benefits to the economy and that may incentivise illegal transport and release of wild pigs in Texas or elsewhere.

Our findings have raised the following important question for Texas resource managers and policymakers: is there a role for wild-pig hunting in the state's overall management strategy for the species? This will depend on a number of considerations, including the extent to which hunter harvest helps control the number of wild pigs in Texas, the extent to which incentives associated with wild-pig hunting lead to the transport and release of wild pigs in Texas, and the extent of the economic benefits compared with the costs associated with wild-pig hunting. Regarding the latter, in this study, we have seen evidence that the economic benefits are greatly outweighed by the costs that wild pigs impose on agricultural producers and others in Texas.

Supplementary material

Supplementary material is available online.

References

APHIS (2023) History of feral swine in the Americas: distribution maps. United States Department of Agriculture, Animal and Plant Health Inspection Service. Available at https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/sa-fs-history [accessed 11 May 2023]

Bankovich B, Boughton E, Boughton R, Avery ML, Wisely SM (2016) Plant community shifts caused by feral swine rooting devalue Florida rangeland. *Agriculture, Ecosystems & Environment* **220**, 45–54. doi:10.1016/j.agee.2015.12.027

Barrios-Garcia MN, Ballari SA (2012) Impact of wild boar (*Sus scrofa*) in its introduced and native range: a review. *Biological Invasions* **14**, 2283–2300. doi:10.1007/s10530-012-0229-6

Belden RC, Frankenberger WG (1977) Management of feral hogs in Florida – past, present, and future. In 'Research and management of wild hog populations'. (Ed. GW Wood) pp. 5–10. (Clemson University: Georgetown, SC, USA)

Bevins SN, Pedersen K, Lutman MW, Gidlewski T, Deliberto TJ (2014) Consequences associated with the recent range expansion of nonnative feral swine. *BioScience* **64**, 291–299. doi:10.1093/biosci/biu015

Boumendjel FZ, Hajji GEM, Valqui J, Bouslama Z (2016) The hunting trends of wild boar (*Sus scrofa*) hunters in northeastern Algeria. *Wildlife Biology in Practice* **12**, 1–13. doi:10.2461/wbp.2016.12.9

Braga C, Alexandre N, Fernández-Llario P, Santos P (2010) Wild boar (*Sus scrofa*) harvesting using the espera hunting method: side effects and management implications. *European Journal of Wildlife Research* **56**(3), 465–469. doi:10.1007/s10344-010-0373-1

Brown VR, Bevins SN (2018) A review of African swine fever and the potential for introduction into the United States and the possibility of subsequent establishment in feral swine and native ticks. *Frontiers in Veterinary Science* **5**, 11. doi:10.3389/fvets.2018.00011

Brown VR, Miller RS, McKee SC, Ernst KH, Didero NM, Maison RM, Shwiff SA (2021) Risks of introduction and economic consequences associated with African swine fever, classical swine fever and foot-and-mouth disease: A review of the literature. *Transboundary and Emerging Diseases* **68**(4), 1910–1965. doi:10.1111/tbed.13919

Bureau of Labor Statistics (2023) Consumer price index, April 2023. US Bureau of Labor Statistics. Available at https://www.bls.gov/cpi/tables/supplemental-files/home.htm [accessed 11 May 2023]

Burton JL, Westervelt JD, Ditchkoff SS (2013) Simulation of wild pig control via hunting and contraceptives. Construction Engineering Research Laboratory.

Carlisle KM, Didero N, McKee S, Elser J, Shwiff SA (2021) Towards a more comprehensive understanding of wild pig (*Sus scrofa*) impacts on agricultural producers: insights from a Texas case study. *Crop Protection* **150**, 105793. doi:10.1016/j.cropro.2021.105793

Carlisle KM, Harper EE, Shwiff SA (2022) An examination of ethical attitudes towards wild pig (*Sus scrofa*) toxicants in the United States. *International Journal of Pest Management* **68**(1), 35–42. doi:10.1080/09670874.2020.1791372

Comer CE, Mayer JJ (2009) Wild pig reproductive biology. In 'Wild pigs: biology, damage, control techniques, and management'. pp. 51–75. Savannah River National Laboratory SRNL-RP-2009-00869.

Connally RL, Frank MG, Briers GE, Silvy NJ, Carlisle KM, Tomeček JM (2021*a*) A profile of wild pig hunters in Texas, USA. *Human–Wildlife Interactions* **15**(1), 8.

Connally RL, Frank MG, Briers GE, Silvy NJ, Carlisle KM, Tomeček JM (2021*b*) Hunter motivations and use of wild pigs in Texas, USA. *Human–Wildlife Interactions* **15**(1), 10.

Degner RL, Rodan LW, Mathis WK, Gibbs EPJ (1983) The recreational and commercial importance of feral swine in Florida: relevance to the possible introduction of African swine fever into the USA. *Preventive Veterinary Medicine* **1**(4), 371–381. doi:10.1016/0167-5877(83)90007-7

Didero NM, Ernst KH, McKee SC, Shwiff SA (2023) A call and suggested criteria for standardizing economic estimates of wild pig damage. *Crop Protection* **165**, 106149.

Engeman RM, Laine E, Allen J, Preston J, Pizzolato W, Williams B, Kreider AS, Teague D (2019) Invasive feral swine damage to globally imperiled steephead ravine habitats and influences from changes in population control effort, climate, and land use. *Biodiversity and Conservation* **28**(5), 1109–1127. doi:10.1007/s10531-019-01713-y

Fullerton AS (2009) A conceptual framework for ordered logistic regression models. *Sociological Methods Research* **38**(2), 306–347. doi:10.1177/004912410934616

Grady MJ, Harper EE, Carlisle KM, Ernst KH, Shwiff SA (2019) Assessing public support for restrictions on transport of invasive wild pigs (*Sus scrofa*) in the United States. *Journal of Environmental Management* **237**, 488–494. doi:10.1016/j.jenvman.2019.02.107

Heffelfinger JR (2018) Inefficiency of evolutionarily relevant selection in ungulate trophy hunting. *The Journal of Wildlife Management* **82**(1), 57–66. doi:10.1002/jwmg.21337

Hernández FA, Parker BM, Pylant CL, Smyser TJ, Piaggio AJ, Lance SL, Milleson MP, Austin JD, Wisely SM (2018) Invasion ecology of wild pigs (*Sus scrofa*) in Florida, USA: the role of humans in the expansion and colonization of an invasive wild ungulate. *Biological Invasions* **20**, 1865–1880. doi:10.1007/s10530-018-1667-6

Jaebker LM, Teel TL, Bright AD, McLean HE, Tomeček JM, Frank MG, Connally RL, Shwiff SA, Carlisle KM (2022) Social identity and acceptability of wild pig (*Sus scrofa*) control actions: a case study of Texas hunters. *Human Dimensions of Wildlife* **27**(6), 507–521. doi:10.1080/10871209.2021.1967525

Keiter DA, Mayer JJ, Beasley JC (2016) What is in a 'common' name? A call for consistent terminology for nonnative *Sus scrofa*. *Wildlife Society Bulletin* **40**(2), 384–387. doi:10.1002/wsb.649

Keuling O, Stier N, Roth M (2008) How does hunting influence activity and spatial usage in wild boar *Sus scrofa* L.? *European Journal of Wildlife Research* **54**(4), 729–737. doi:10.1007/s10344-008-0204-9

Keuling O, Baubet E, Duscher A, Ebert C, Fischer C, Monaco A, Podgórski T, Prevot C, Ronnenberg K, Sodeikat G, Stier N, Thurfjell H (2013) Mortality rates of wild boar *Sus scrofa* L. in central Europe. *European Journal of Wildlife Research* **59**(6), 805–814. doi:10.1007/s10344-013-0733-8

Keuling O, Strauß E, Siebert U (2016) Regulating wild boar populations is 'somebody else's problem'! – human dimension in wild boar management. *Science of The Total Environment* **554–555**, 311–319. doi:10.1016/j.scitotenv.2016.02.159

Lindner JR, Murphy TH, Briers GE (2001) Handling nonresponse in social science research. *Journal of Agricultural Education* **42**, 43–53.

Maly K, Pang BK, Burrows CPM (2007) Pua'a (Pigs) in Hawaii, from Traditional to Modern. East Maui Watershed. Available at https://www.eastmauiwatershed.org/wp-content/uploads/2013/01/Puaa-cultural-fact-sheet-04.03.pdf [accessed 12 December 2010]

Mayer J (2014) Estimation of the number of wild pigs found in the United States. Report STI2014-00292 prepared for the US Department of Energy. Savannah River National Laboratory, Jackson, SC, USA.

McKee S, Anderson A, Carlisle K, Shwiff SA (2020) Economic estimates of invasive wild pig damage to crops in 12 US states. *Crop Protection* **132**, 105105.

McKee S, Miller RS, Psiropoulos J, Shwiff SA (2023) Economic impacts of wild pigs on livestock producers in 13 states. *Human Wildlife Interactions*. (forthcoming)

McKee SC, Mayer JJ, Shwiff SA (2024) Comprehensive economic impacts of wild pigs on producers of six crops in the South-Eastern US and California. *Agriculture* **14**(1), 153.

McLean HE, Teel TL, Bright AD, Jaebker LM, Tomecek JM, Frank MG, Connally RL, Shwiff SA, Carlisle KM (2021) Understanding tolerance for an invasive species: an investigation of hunter acceptance capacity for wild pigs (*Sus scrofa*) in Texas. *Journal of Environmental Management* **285**, 112143. doi:10.1016/j.jenvman.2021.112143

Orr B, Westman ME, Malik R, Purdie A, Craig SB, Norris JM (2022) Leptospirosis is an emerging infectious disease of pig-hunting dogs and humans in north Queensland. *PLoS Neglected Tropical Diseases* **16**(1), e0010100. doi:10.1371/journal.pntd.0010100

Peine JD, Farmer JA (1990) Wild hog management program at Great Smoky Mountains National Park. In 'Proceedings of the Vertebrate Pest Conference, Vol. 14, No. 14'. (University of California: Davis, CA, USA)

Pejchar L, Mooney HA (2009) Invasive species, ecosystem services and human well-being. *Trends in Ecology & Evolution* **24**(9), 497–504. doi:10.1016/j.tree.2009.03.016

Poché RM, Poché D, Franckowiak G, Somers DJ, Briley LN, Tseveenjav B, Polyakova L (2018) Field evaluation of low-dose warfarin baits to control wild pigs (*Sus scrofa*) in North Texas. *PLoS ONE* **13**(11), e0206070. doi:10.1371/journal.pone.0206070

Rosa CAD, Wallau MO, Pedrosa F (2018) Hunting as the main technique used to control wild pigs in Brazil. *Wildlife Society Bulletin* **42**(1), 111–118. doi:10.1002/wsb.851

Shwiff S, Shwiff S, Holderieath J, Haden-Chomphosy W, Anderson A (2017) Economics of invasive species damage and damage management. In 'Ecology and management of terrestrial vertebrate invasive species in the United States'. (Eds J Beasley, J Riley) pp. 35–60. (CRC Press: Boca Raton, FL, USA)

Shwiff S, Pelham A, Shwiff S, Haden-Chomphosy W, Brown VR, Ernst K, Anderson A (2020) Framework for assessing vertebrate invasive species damage: the case of feral swine in the United States. *Biological Invasions* **22**(10), 3101–3117. doi:10.1007/s10530-020-02311-8

Tabak MA, Piaggio AJ, Miller RS, Sweitzer RA, Ernest HB (2017) Anthropogenic factors predict movement of an invasive species. *Ecosphere* **8**(6), e01844. doi:10.1002/ecs2.1844

Todd CT, Mengak MT (2018) The impact of wild pig hunting outfitters on pig populations across the Southeast. Publication WSFNR-18-45. Warnell School of Forestry & Natural Resources, University of Georgia, Athens, GA, USA.

Vaske JJ, Miller CA, McLean HE, Jaebker LM (2021) Beliefs, perceived risks and acceptability of lethal management of wild pigs. *Wildlife Research* **48**(3), 202–208. doi:10.1071/WR19207

VerCauteren KC, Pepin KM, Cook SM, McKee S, Pagels A, Kohen KJ, Messer IA, Glow MP, Snow NP (2024) What is known, unknown, and needed to be known about damage caused by wild pigs. *Biological Invasions*, 1–13. doi:10.1007/s10530-024-03263-z

Weeks P, Packard J (2009) Feral hogs: invasive species or nature's bounty? *Human Organization* **68**(3), 280–292. doi:10.17730/humo.68.3.663wn82g164321u1

Data availability. The data that support this study cannot be publicly shared due to ethical or privacy reasons and may be shared upon reasonable request to the corresponding author if appropriate.

Conflicts of interest. Stephanie Shwiff is an Associate Editor of Wildlife Research but was blinded from the peer-review process for this paper. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or US Government determination or policy.

Declaration of funding. This work was supported by Texas A&M AgriLife Extension Service, College Station, TX, USA, and the National Feral Swine Damage Management Program, Fort Collins, CO, USA.

Acknowledgements. We thank the Texas A&M University System, Texas A&M AgriLife Extension Service, and Texas Wildlife Services for their support with the inception, funding, and delivery of this project. We also thank the United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Feral Swine Damage Management Program, and the National Wildlife Research Center for making this research possible. We specifically thank Mr Michael J. Bodenchuk for his insightful assistance during the formation of this study, and the Texas Parks and Wildlife Department for access to hunter licensee data. Additional support was provided by Colorado State University.

Author affiliations

[A]Department of Economics, Colorado State University, Fort Collins, CO 80523, USA.

[B]National Wildlife Research Center, United States Department of Agriculture, Animal and Plant Health Inspection Service, 4101 LaPorte Avenue, Fort Collins, CO 80521, USA.

[C]Department of Rangeland, Wildlife, and Fisheries Management, Texas A&M University, 495 Horticulture Road, College Station, TX 77843, USA.

[D]United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, PO Box 690170, San Antonio, TX 78269, USA.