MONITORING WILD PIGS (SUS SCROFA) IN THE RED HILLS REGION OF NORTHERN FLORIDA AND SOUTHERN GEORIGA: IMPACTS ON NATIVE WILDLIFE AND NATURAL RESOURCES

by

KELSEY R. HOSKINS

(Under the Direction of Michael T. Mengak)

ABSTRACT

Wild pigs (*Sus scrofa*) are a nuisance species for private landowners and to native wildlife and natural resources. In accordance with the National Feral Swine Damage Management Program, USDA APHIS Wildlife Services managed a pig reduction program across the region. We assessed responses of natural resources to pig removal using a trail camera and line transect survey. Responses of white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallopavo*) were analyzed using linear regression and activity analyses. We quantified pig damage and target species habitat use with linear regression and chi-squared tests. Pig removal resulted in less pig observations and damage across our study sites. Deer and turkey activities were altered where pigs were not managed for. However, we found no relationship between pig removal and deer and turkey observations. Deer and turkey preferred habitats that pigs avoided. Results suggest deer and turkey avoid pigs temporally and spatially.

INDEX WORDS: camera trap, competition, feral swine, line transect, Red Hills, *Sus scrofa*, wildlife damage, wild pig, wild pig trapping,

MONITORING WILD PIGS (SUS SCROFA) IN THE RED HILLS REGION OF NORTHERN FLORIDA AND SOUTHERN GEORIGA: IMPACTS ON NATIVE WILDLIFE AND NATURAL RESOURCES

by

KELSEY R. HOSKINS

BS, Eastern Kentucky University, 2019

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2023

MONITORING WILD PIGS (SUS SCROFA) IN THE RED HILLS REGION OF NORTHERN FLORIDA AND SOUTHERN GEORIGA: IMPACTS ON NATIVE WILDLIFE AND NATURAL RESOURCES

by

KELSEY R. HOSKINS

Major Professor: Michael T. Mengak

Committee: Kim Sash

L. Mike Conner

Jeffrey Hepinstall-Cymerman

Electronic Version Approved:

Ron Walcott

Vice Provost for Graduate Education and Dean of the Graduate School

The University of Georgia

August 2023

ACKNOWLEDGEMENTS

I would first like to acknowledge Dr. Michael Mengak of the University of Georgia and Kim Sash of Tall Timbers Research Station for bringing me onto this project back in 2020. I had no idea what I was doing at the time, but thanks to their guidance, constant support, and flexibility, I gained new skills and grew as a biologist. I would also like to thank the staff at Tall Timbers for housing me while I traveled around the Red Hills for my field work. Thank you to all participating landowners for allowing my team and I to come out and collect data. A special thanks to the team themselves, all my interns and technicians, who in my opinion had the biggest role to play in all this – Mackenzie Hallmark, Alexa Murray, Evan Williams, Garrett Wong, and Katy Pabody. To my lab mates and many friends – McKayla Susen, Faith Kruis, Justine Smith, Kyle Madgziuk, and Deanna Riente, your confidence boosts, check-ins, and unwavering support are things I will never forget. To my sister and nieces – Julia Venema, Annabella Venema, and Audrey Venema, thank you for reminding me that giving up wasn't an option. To my parents – Joyce and Danny Hoskins, who never questioned letting their daughter spend her childhood outside. My passion for the outdoors is now a part of my career, thanks to a lifetime of hunting, fishing, and camping.

Lastly, I would like to thank my loving fiancé – Christopher Terrazas, for everything.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Since their introduction into North America during the 15th century, coinciding with European settlement, pigs have steadily survived and expanded into many regions, especially the Southeastern United States (Mengak 2016*b*, Mayer 2018, VerCauteren et al. 2020). Although multiple expeditions included domestic livestock and occurred throughout the 1500s, Hernando de Soto's expedition is credited as the first introduction and eventual establishment of pigs in the wild in the Southeastern U.S. Even so, due to human-induced movements, wild pigs have expanded into all major geographic regions of the continental USA in recent decades (VerCauteren et al. 2020). This issue, in conjunction with their generalist diets and impressive reproductive habits, has helped establish populations in over 30 United States (Mayer and Brisbin 2008, Corn and Jordan 2017, USDA APHIS | History of Feral Swine in the Americas).

Across their distribution, a wild pig's diet consists of 90% plant material (Ballari and Barrios-García 2014). As vegetation quality and availability fluctuate seasonally, wild pig diets can exhibit a deficiency in protein and energy (Baber and Coblentz 1987). To make up for the lack of protein in hardwood mast, wild pigs can turn to consuming animal matter which can vary between 0.3% - 30% of their diets (Mayer and Brisbin 2009, Ballari and Barrios-García 2014, McClure et al. 2018). Wild pigs have been documented killing and eating white-tailed deer fawns (*Odocoileus virginianus*), pursuing herpetofauna, and opportunistically depredating nests of eastern wild turkeys (*Meleagris gallopavo*), northern bobwhite (*Colinus virginianus*), and other ground-nesting birds (Rollins and Carroll 2001, Schaefer 2004, Wilcox and Van Vuren 2009, Jolley et al. 2010). Wild pig diets also overlap with white-tailed deer, wild turkeys, and black bears (*Urus americanus*) (Wood and Barrett 1979, Yarrow 1987, Taylor and Hellgren 1997). Although overlapping diets between native and invasive species are inevitable, wild pigs may create negative conflicts and displace native species (Wood and Lynn 1977, Tolleson et al. 1995, Taylor and Hellgren 1997). Bodenchuk (2008) documented wild pigs consuming 3-5% of their body mass daily. This amount of food consumed is only amplified by larger sounders, which can induce exploitative competition and allow pigs to find and consume resources faster than other competitors (Pianka 1983).

Using sensitive spade-like snouts, pigs will root in large areas to find food and explore the areas they occupy (Gray et al. 2020). Wild pig movements across a landscape depend on food abundance and landcover types (Morelle et al. 2015, Boyce et al. 2020). If left unmanaged, wild pig populations can spread and disturb the soil for prolonged periods of time leading to altered landscapes and reduced plant biomass (Sweitzer and Van Vuren 2002). However, in the Southeast, agriculture and forest resources are most affected by wild pig damage (Mayer et al.

2020). Wild pigs can directly impact longleaf pine (*Pinus palustris*) by rooting or chewing the lateral roots and rubbing or tusking the tree bark (Conley et al. 1972, Lucas 1977). This behavior can significantly damage young longleaf pine trees. Wild pigs have been observed not consuming longleaf pine seedlings entirely but chewing on them for their sap then spitting them out (Wood and Roark 1980). This type of foraging has the potential to cause regeneration failure and delay restoration efforts (Fern et al. 2020). Reestablishing longleaf pine forests and native ground cover systems has become an important component of forest management in the southeast (Staller 2015, Alavalapati et al. 2007). Longleaf pine provides economic utilization through timber harvest, supports native wildlife species, including threatened and endangered species like the red-cockaded woodpecker (*Leuconotopicus borealis*), and represents the state of southeastern landscapes pre-settlement (McIntyre et al. 2018).

Depending on the forage and soil type, pigs can root up to a meter beneath the soil surface in search of food (Mayer and Brisbin 2009). While rooting, pigs may indirectly create wallows (Gray et al. 2020). Wallowing occurs when pigs find or create a depression in the ground, usually along streams or areas with standing water, and cover themselves in mud (Belden and Pelton 1976, Gray et al. 2020). This behavior is common during the warmer seasons for thermoregulation and insect relief (Crouch 1983, Bracke 2011). Wallows are typically found in riparian wetlands, swamps, or cooler and shaded areas (Stegeman 1938). Wallows can increase negative interactions between native wildlife, domestic livestock, and humans by contaminating water sources, creating mosquito habitat, and spreading pathogens (Eckert et al. 2019, Lewis et al. 2020). Research has shown an increase in fecal coliform bacteria in waterways where wild pigs had been active (Kaller and Kelso 2003, Bolds et al. 2021). Other studies have documented water quality improvement during pig removal efforts and found a 50-75% reduction in *E. coli* and fecal coliform concentrations (Bolds et al. 2022).

Wild pigs serve as reservoirs capable of carrying at least 30 types of diseases and over 50 types of parasites (Miller et al. 2017, Corn and Yabsley 2020). Wild pigs can expose livestock to detrimental diseases like pseudorabies and swine brucellosis (Wood and Barrett 1979, Meng et al. 2009, Corn and Yabsley 2020, Yang et al. 2021). These diseases spread through direct contact with wild pigs, their urine, feces, saliva, blood, and water systems contaminated from wallowing (Eckert et al. 2019). The pseudorabies infection is common in adult wild pigs yet when infected, they are rarely harmed. However, domestic and wild piglets less than four weeks old can experience fever, tremors, and death (Hahn et al. 1997, Stallknecht and Little 2009). Adult domestic pigs can experience respiratory infections, fever, and aborted fetuses (Stallknecht and Little 2009). Swine brucellosis, caused by the bacteria *Brucella suis*, can cause abortions, still-born piglets, and infertility in wild and domestic pigs (West et al. 2009, Corn and Yabsley 2020). Classical swine fever, also called hog cholera, was once common within the United States domestic swine industry until its eradication in 1978 (Nettles et al. 1989). This viral disease causes lethargy, fever, and vomiting, with infected animals dying 20 days after exposure (West et al. 2009). Even though it has been eradicated, hog cholera is still monitored to prevent any transmission to domestic swine, as it could be determinantal if re-introduced. African swine fever has not been recorded in the United States and is not a threat to human health (USDA APHIS | African Swine Fever (ASF)). However, the disease is highly contagious in wild and domestic pigs and has been documented in Europe, Asia, and Africa (Ata et al. 2022). The introduction of ASF to the United States would severely impact our domestic swine industry due to the mortality and morbidity of the disease (Brown and Bevins 2018).

Wild pigs are nonselective when damaging crops, pastures, fields, or suburban landscapes (e.g., golf courses, lawns, cemeteries). Large commercial growers, small-scale crop producers, and local communities face the same chance of being disturbed by wild pigs if they are in the area (Strickland et al. 2020, Poudyal et al. 2017). Wild pigs may cost landowners at least $1.5 billion annually in crop loss and control efforts, based on a damage estimate of $300 per pig (Pimental 2007, Strickland et al. 2020). Most commercially grown crops (e. g., peanuts, cotton, corn) are subject to wild pig damage during growth or harvest, though the level of damage can vary depending on location (Strickland et al. 2020). Previous research focusing on different states in the Southeast have produced varying estimates of damages (Anderson et al. 2016, Mengak 2016*a, b*, Poudyal et al. 2017).

Managing pigs has become a challenge for researchers and private landowners alike. McCann and Garcelon (2008) observed successful eradication when managers and the National

Park Service removed all pigs from Pinnacles National Monument in California, USA. Fencing the affected area and applying techniques like hunting, trapping, transect surveys, and Judas techniques resulted in 200 pigs being eradicated from the park. Parkes et al. (2010) saw similar results when five zones of the 25,000-ha Santa Cruz Island, California, USA were fenced for pig eradication. The five zones were treated with trapping, aerial shooting from a helicopter, hunting, and Judas techniques. During one year of removal treatment, a total of 5,036 pigs were removed from the island.

While these examples show successful eradication, their study sites were able to be fenced off and targeted directly. A major control problem with wild pigs in the contiguous United States is their ability to move around and opportunistically survive in different habitats. Although various types of management strategies have been developed, intensive management remains time consuming and expensive (Campbell and Long 2009, Delgado-Acevedo et al. 2013). A considerable amount of research has focused on either pig population dynamics, monitoring methods, management challenges and strategies, or the effects of pig removal on pig populations (Bieber and Ruf 2005, Campbell and Long 2009, Delgado-Acevedo et al. 2013, Engeman et al. 2013, Keiter and Beasley 2017, Lewis et al. 2019, Bolds et al. 2022). While these studies provide valuable information, few have focused on large extent study sites for a prolonged period.

The Red Hills region of northern Florida and southern Georgia lies between Tallahassee, FL and Thomasville, GA., and is largely dominated by privately-owned land parcels which support over 100 threatened and endangered species (Masters et al. 2007). Wild pigs have increased in this area over the last few decades (personal comm.) and now pose a threat to native ground cover, agricultural crops, and watersheds, as well as game species like white-tailed deer, eastern wild turkeys, and northern bobwhite.

With the increasing population of wild pigs in the USA, researchers, farmers, and the public are concerned for the future of crop production and forest development. As this destructive species has advanced, the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) have taken steps toward monitoring, researching, and developing strategies for future management of wild pigs. In 2014, the USDA's Animal and Plant Health Inspection Service (APHIS) received Congressional appropriations for the creation of a collaborative, nation-wide damage management program for wild pigs. This program is housed within USDA APHIS Wildlife Services at the National Wildlife Research Center (NWRC) in Ft. Collins, CO. In 2018, the Feral Swine Eradication and Control Pilot Program (FSCP) was created and authorized by Congress in the 2018 Farm Bill in response to the threatening impacts wild pigs have on agriculture, native ecosystems, and human and animal health (USDA APHIS | Farm Bill Projects). The FSCP initiated 20 pilot projects in ten states to manage and reduce wild pigs and their damaging effects (USDA NRCS | Feral Swine Eradication and Control Pilot Program).

Our study was one of the 20 pilot projects across 10 states in the initial round of funding (USDA APHIS | APHIS National Feral Swine Damage Management Program). During this pilot study, our goal was to improve habitat for native wildlife by evaluating and refining wild pig management control methods. Our objectives included: 1) Quantifying current native wildlife occurrence and subsequent recovery following intensive wild pig removal, 2) Assessing the efficacy of wild pig removal efforts and evaluating available habitat use. This thesis is presented in three chapters. Chapter One contains an introduction and literature review of the wild pig problem. Chapters Two and Three are formatted in manuscript form in preparation for submission for publication. Chapter Two covers my research on monitoring the impacts of wild pig removal on native wildlife and is formatted as a manuscript following the guidelines for *Wildlife Society Bulletin*. Chapter Three covers my research on the impacts of wild pig removal on damage to native wildlife habitat and is formatted as a manuscript following the guidelines for *Human-Wildlife Interactions.*

Literature Cited

Anderson, A., C. Slootmaker, E. Harper, J. Holderieath, and S. A. Shwiff. 2016. Economic estimates of feral swine damage and control in 11 states. Crop Protection 89:89–94.

Alavalapati, J. R., G. A. Stainback, and J. R. Matta. 2007. Longleaf Pine Restoration. Pages 403–412 *in* S. Jose, E. J. Jokela, D. L. Miller, editors. The Longleaf Pine Ecosystem. Springer Series on Environmental Management. Spring, New York, New York, USA.

Ata, E. B., Z. Li, C. Shi, G. Yang, W. Yang, C. Wang. 2022. African swine fever virus: A raised global upsurge and a continuous threaten to pig husbandry. Microbial Pathogenesis 167:1–13.

Baber, D. W. and B. E. Coblentz. 1987. Diet, nutrition, and conception in feral pigs on Santa Catalina Island. Journal of Wildlife Management 51:306–317.

Ballari, S. A. and M. N. Barrios-García. 2014. A review of wild boar *Sus scrofa* diet and factors affecting food selection in native and introduced ranges. Mammal Review 44:124–134.

Belden, R. and M. Pelton. 1976. Wallows of the European wild hog in the mountains of east Tennessee. Journal of Tennessee Academy of Science 51:91–93.

Bieber, C. and T. Ruf. 2005. Population dynamics in wild boar *Sus scrofa*: ecology, elasticity of growth rate and implications for the management of pulsed resource consumers. Journal of Applied Ecology 24:1203–1213.

Bodenchuk, M. J. 2008. Feral hog management: Tying performance measures to resources protected. Pages 1-4 *in* S. M. Vantassel, editor. 2008. National Conference on Feral Hogs. University of Nebraska, Lincoln, Nebraska, USA.

Bolds, S. A., B. G. Lockaby, S. S. Ditchkoff, M. D. Smith, and K. C. VerCauteren. 2021. Impacts of a large invasive mammal on water quality in riparian ecosystems. Journal of Environmental Quality 50: 441-53.

Bolds, S. A., B. G. Lockaby, L. Kalin, S. S. Ditchkoff, M. D. Smith, and K. C. VerCauteren. 2022. Wild pig removal reduces pathogenic bacteria in low-order streams. Biological Invasions:1–11.

Boyce, C. M., K. C. VerCauteren, and J. C. Beasley. 2020. Timing and extent of crop damage by wild pigs (*Sus Scrofa* Linnaeus) to corn and peanut Fields. Crop Protection 133:105131–105138.

Bracke, M. B. M. 2011. Review of wallowing in pigs: Description of the behavior and its motivational basis. Applied Animal Behaviour Science 132:1–13.

Brown, V. R. and S. N. Bevins. 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 5:1–18.

Campbell, T. A. and D. B. Long. 2009. Feral swine damage and damage management in forested ecosystems. Forest Ecology and Management 257:2319–2326.

Conley, R. H., V. G. Henry, and G. H. Matschke. 1972. Final report for the European Hog Research Project W-34. Tennessee Game and Fish Commission, Nashville, Tennessee, USA.

Corn, J. L. and T. R. Jordan. 2017. Development of The National Feral Swine Map, 1982–2016. Wildlife Society Bulletin 41:758–763.

Corn, J. L. and M. J. Yabsley. 2020. Diseases and parasites that impact wild pigs and species they contact. Pages 83–126 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Crouch, L. C. 1983. Movements of and habitat utilization by feral hogs at the Savannah River Plant, South Carolina. M. S. Thesis, Clemson University, Clemson, South Carolina, USA.

Delgado-Acevedo, J., R. W. DeYoung, and T. A. Campbell. 2013. Effects of local-scale removals on feral swine populations in southern Texas. International Journal of Pest Management 59:122–127.

Eckert, K. D., D. A. Keiter, and J. C. Beasley. 2019. Animal visitation to wild pig (*Sus scrofa*) wallows and implications for disease transmission. Journal of Wildlife Diseases 55:488–493.

Engeman, R. M., G. Massei, M. Sage, and M. N. Gentle. 2013. Monitoring wild pig populations: A review of methods. Environmental Science and Pollution Research 20:8077–8091.

Fern, M. P., J. B. Armstrong, R. J. Barlow, and J. S. Kush. 2020. Ecological factors influencing wild pig damage to planted pine and hardwood seedlings. Human–Wildlife Interactions 14:228–238.

Gray, S. M., G. J. Roloff, R. A. Montgomery, J. C. Beasley, and K. M. Pepin. 2020. Wild pig spatial ecology and behavior. Pages 33-56 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Hahn, E. C., G. R. Page, P. S. Hahn, K. D. Gillis, C. Romero, J. A. Annelli, and E. P. J. Gibbs. 1997. Mechanisms of transmission of Aujeszky's disease virus origination from feral swine in the USA. Veterinary Microbiology 55:123–130.

Jolley, D. B., S. S. Ditchkoff, B. D. Sparklin, L. B. Hanson, M. S. Mitchell, and J. B. Grand. 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy 91:519–524.

Kaller, M. D. and W. E. Kelso. 2003. Effects of feral swine on water quality in a coastal bottomland stream. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 57:291–298.

Keiter, D. A. and J. C. Beasley. 2017. Hog heaven? Challenges of managing introduced wild pigs in natural areas. Natural Areas Journal 37:6–16.

Lewis, J. S., J. L. Corn, J. J. Mayer, T. R. Jordan, M. L. Farnsworth, C. L. Burdett, K. C. VerCauteren, S. J. Sweeney, and R. S. Miller. 2019. Historical, current, and potential population size estimates of invasive wild pigs (*Sus scrofa*) in the United States. Biological Invasions 21:2373–2384.

Lewis, J. S., K. C. VerCauteren, R. M. Denkhaus, and J. J. Mayer. 2020. Wild pig populations at the urban gradient. Pages 439-463 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Lucas, E. G. 1977. Feral hogs: Problems and control on national forest lands. Pages 17-21 *in* G. W. Wood, editor. Research and management of wild hog populations. Belle Baruch Forest Science Institute of Clemson University, Georgetown, South Carolina, USA.

Masters, R. E., K. Robertson, W. E. Palmer, J. Cox, K. McGorty, L. Green, and C. Ambrose. 2007. Red hills forest stewardship guide. Tall Timbers Research Station and Land Conservancy Miscellaneous Publication, 12, Tallahassee, Florida, USA.

Mayer, J. J. and I. L. Brisbin Jr. 2008. Wild Pigs in the United States: Their history, comparative morphology, and current status. University of Georgia Press, Athens, Georgia, USA.

Mayer, J. J, and I. L. Brisbin Jr., editors. 2009. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, SRNL-RP-2009-00869, Aiken, South Carolina, USA.

Mayer, J. J. 2018. Introduced wild pigs in North America: History, problems and management. Pages 229–312 *in* M. Melletti and E. Meijaard, editors. Ecology, evolution and management of wild pigs and peccaries: Implications for conservation. Cambridge University Press, New York, New York, USA.

Mayer J. J., J. C. Beasley, R. K. Boughton, and S. S. Ditchkoff. 2020. Wild pigs in Southeastern North America. Pages 369-402 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Meng, X. J., D. S. Lindsay, and N. Sriranganathan. 2009. Wild boars as sources for infections diseased in livestock and humans. Biological Sciences 364:2697–2707.

McCann, B. E. and D. K. Garcelon. 2008. Eradication of feral pigs from Pinnacles National Monument. Journal of Wildlife Management 76:1287–1295.

McIntyre, R. K., J. M. Guldin, T. Ettel, C. Ware, and K. Jones. 2018. Restoration of longleaf pine in the southern United States: A status report. Pages 297–302 *in* Proceedings of the

19th biennial Southern Silvicultural Research Conference, 14 March – 16 March 2017, Blacksburg, Virginia, USA.

McClure, M. L., C. L. Burdett, M. L. Farnsworth, S. J. Sweeney, and R. S. Miller. 2018. A globally-distributed alien invasive species poses risks to United States imperiled species. Scientific Reports 8:5331–5339.

Mengak, M. T. 2016*a*. 2015 Georgia Wild Pig Survey Final Report. Outreach Publication WMS-16-23. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, Georgia, USA.

Mengak, M. T. 2016*b*. Landowner opinions regarding wild pigs in Georgia, USA. Proceedings of the Vertebrate Pest Conference 27: 162–169.

Miller, R. S., S. J. Sweeney, C. Slootmaker, D. A. Grear, P. A. Di Salvo, D. Kiser, and S. A. Shwiff. 2017. Cross-species transmission potential between wild pigs, livestock, poultry, wildlife, and humans: Implications for disease risk management in North America. Scientific Reports 7:7821–7835.

Morelle, K., T. Podgorski, C. Prevot, O. Keuling, F. Lehaire, and P. Lejeune. 2015. Towards understanding wild boar *Sus scrofa* movement: a synthetic movement ecology approach. Mammal Review 45:15–29.

Natural Resources Conservation Service [NRCS] 2022. Feral Swine Eradication and Control Pilot Program. <www.nrcs.usda.gov >. Accessed 14 June 2022.

Nettles, V.F., J. L. Corn, G. A. Erickson, and D. A. Jessup. 1989. A survey of wild swine in the United States for evidence of hog cholera. Journal of Wildlife Diseases 25:61–65.

Parkes, J. P., D. S. L. Ramsey, N. Macdonald, K. Walker, S. McKnight, B. S. Cohen, and S. A. Morrison. 2010. Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. Biological Conservation 143: 634–641.

Pianka, E. R. 1983. Evolutionary Ecology. Third Edition. Harper and Row, New York, New York, USA.

Pimental, D. 2007. Environmental and economic costs of vertebrate species invasions into the United States. USDA National Wildlife Research Symposia:1–8.

Poudyal, N. C., C. Caplenor, O. Joshi, C. Maldonado, L. I. Muller, and C. Yoest. 2017. Characterizing the economic value and impacts of wild pig damage on a rural economy. Human Dimensions of Wildlife 22:538–549.

Rollins, D. and J. P. Caroll. 2001. Impacts of predation on northern bobwhite and scaled quail. Wildlife Society Bulletin 29:39–51.

Schaefer, J. 2004. Video monitoring of shrub-nests reveals nest predators. Bird Study 51:170–177.

Staller, E. 2015. Reestablishing longleaf pine. Tall Timbers eNews 8(4).

Stallknecht, D. E. and S. E. Little. 2009. Diseases and parasites of wild pigs. Pages 235–245 in Mayer, J. J., and I. L. Brisbin, Jr, editors. Wild pigs: Biology, damage, control techniques and management. SRNL-RP-2009-00869. Savannah River National Laboratory, Aiken, South Carolina, USA.

Stegeman, L. C. 1938. The European wild boar in the Cherokee National Forest, Tennessee. Journal of Mammalogy 19:279–290.

Strickland, B. K., M. D. Smith, and A. L. Smith. 2020. Wild pig damage to resources. Pages 143-174 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Sweitzer, R. A., and D. H. Van Vuren. 2002. Rooting and foraging effects of wild pigs on tree regeneration and acorn survival in California's oak woodland ecosystems. USDA Forest Service General Technician Report: 219–231.

Taylor, R. B. and E. C. Hellgren. 1997. Diet of feral hogs in Western South Texas Plains. The Southwestern Naturalist 42: 33–39.

Tolleson, D. R., W. E. Pinchak, D. Rollins, and L. J. Hunt. 1995. Feral hogs in the rolling plains of Texas: Perspectives, problems, and potential. Great Plains Wildlife Damage Control Conference 12:124–128.

United States Department of Agriculture [USDA]. 2022. African Swine Fever (ASF). < https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/swine-disease-information/african-swine-fever/seminar>. Accessed 06 June 23.

United States Department of Agriculture [USDA]. 2020. APHIS National Feral Swine Damage Management Program. <https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/feral-swine-program>. Accessed 12 July 22.

United States Department of Agriculture [USDA]. 2020. Farm Bill Projects. <https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/fb-projects>. Accessed 12 July 22.

United States Department of Agriculture [USDA]. 2022. History of Feral Swine in the Americas. <https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/sa-fs-history>. Accessed 12 July 22.

VerCauteren, K. C., J. J. Mayer, J. C. Beasley, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland. 2020. Introduction. Pages 1-5 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

West, B. C., A. L. Cooper, and J. B. Armstrong. 2009. Managing wild pigs: A technical guide. Human-Wildlife Interactions Monograph 1:1–55.

Wilcox, J. T. and D. H. Van Vuren. 2009. Wild pigs as predators in oak woodlands of California. Journal of Mammalogy 90:114–118.

Wood, G. W. and R. H. Barrett. 1979. Status of wild pigs in the United States. Wildlife Society Bulletin 36:237–246.

Wood, G. W. and T. E. Lynn. 1977. Wild hogs in southern forests. Southern Journal of Applied Forestry 1:12–17.

Wood, G. W. and D. N. Roark. 1980. Food habits of feral hogs in coastal South Carolina. Journal of Wildlife Management 44:506–511.

Yang, A., P. Schlichting, B. Wight, W. M. Anderson, S. M. Chinn, M. Q. Wilber, R. S. Miller, J. C. Beasley, R. K. Boughton, K. C. VerCauteren, G. Wittenmyer, and K. M. Pepin. 2020. Effects of social structure and management on risk of disease establishment in wild pigs. Journal of Animal Ecology 90:820–833.

Yarrow, G. K. 1987. The potential for interspecific resource competition between white-tailed deer and the feral hogs in the post oak savannah region of Texas. Dissertation, Stephen F. Austin University, Nacogdoches, Texas, USA.

CHAPTER TWO:

MONITORING IMPACTS OF WILD PIG REMOVAL ON NATIVE WILDLIFE[1]

[1]Hoskins, K. R., K. Sash, L. M. Conner, and M. T. Mengak. To be submitted to *Wildlife Society Bulletin*

ABSTRACT

Wild pigs (*Sus scrofa*) are a threat to native wildlife species like eastern wild turkeys (*Meleagris gallopavo)* and white-tailed deer (*Odocoileus virginianus*). Pigs may compete with and displace deer and turkey. In conjunction with removal efforts from USDA APHIS Wildlife Services, we deployed 151 cameras across nine private properties during October 2020 - July 2022 to assess the effect of pig reduction in the Red Hills region of northern Florida and southwest Georgia. Our objectives were to quantify current deer and turkey occurrence and recovery following intensive pig removal. Linear regression analyses found a significant reduction in pig observations as more were removed. However, pig removal did not impact turkey and deer observations. Using an activity analysis, we found pig presence altering deer and turkey activities where pigs were not managed for. Our results suggest that consistent intensive reduction methods will reduce pig populations, ultimately reinforcing deer and turkey populations.

INDEX WORDS: camera trap, damage, linear regression, overlap, pig trapping, Red Hills, Sus scrofa, Wildlife Services, wild pig,

Introduction

The United States Department of Agriculture (USDA) defines an invasive species as, "a species whose introduction causes or is likely to cause economic harm, environmental harm, or harm to human health" (Executive Order 1999). Environmental harm may include competing with native species for food and cover, spreading disease, predation, or altering soil and water quality (Keiter and Beasley 2017, Brooks et al. 2020). Invasive species are usually generalists, able to alter their behavior and needs as they enter a new environment (Ruland and Jeschke 2020). This behavior can potentially enhance environmental harm to numerous habitats and native species. For example, Pearson et al. (2015) found that invasive red-eared sliders (*Trachemys scripta elegans*) negatively competed with native red-belled turtles (*Pseudemys rubriventris*) when food resources were limited in a mesocosm feeding experiment. Dorcas et al. (2011) reported an 87.5% - 99.3% decline in mammals like raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), and bobcats (*Lynx rufus*) in the Everglades National Park due to Burmese python (*Python bivittatus*) predation. They found these mammals to be most abundant in areas outside the python's range. Allen et al. (2004) stated that red imported fire ants (*Solenopsis invicta*) negatively impact reptiles and amphibians, ground-nesting birds, and small mammals during hatching/birthing periods, when juveniles are vulnerable and exposed.

Wild pigs (*Sus scrofa*), hereafter ”pigs,” are an invasive species of mammal that were intentionally introduced to North America in the 1500s by Spanish explorers (Mayer 2018, VerCauteren et al. 2020). Now having spread widely across the United States, pigs directly impact natural resources, private property, and native wildlife populations (VerCauteren et al. 2020, USDA APHIS| Feral Swine Destroy Property). In their native and introduced ranges, pigs are omnivorous generalists with plant matter making up 85-90% of their diets (Rabolli 1983, Schely and Roper 2003, Sweeney et al. 2003, Ballari and Barrios-Garica 2014). This includes seasonally available hard and soft mast, which tend to be consumed in large quantities (Graves 1984, Elston and Hewitt 2010, Barrios-Garcia and Ballari 2012). Southeastern wildlife species like white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallopavo*) share similar diets with wild pigs (Wood and Barrett 1979, Yarrow 1987, Elston and Hewitt 2010). Dietary overlap may lead to competition and interspecific aggression, especially during years of low-mast production (Wood and Barrett 1979, Grether et al. 2017, McDonough et al. 2022). Previous studies have documented this behavior, along with pigs excluding white-tailed deer from pulse food resources, like bait piles and acorns (Taylor and Hellgren 1997, Elston and Hewitt 2010, Keever 2014). Other game species potentially displaced by wild pig presence include gray squirrels (*Sciurus carolinensis*), fox squirrels (*Sciurus niger*), raccoons and northern bobwhite (*Colinus virginianus*) (Tolleson et al. 1993, Cooper and Sieckenius 2016, McDonough et al. 2022, Dykstra et al. 2023).

In addition to vegetation and mast, pigs also consume animal matter. Animal matter includes both vertebrate and invertebrate species, typically done while rooting (Baubet et al. 2003). Multiple studies have documented pigs consuming ground-nesting birds, their eggs, and their chicks (Tolleson et al. 1993, Rollins and Carroll 2001, Cooper and Sieckenius 2016). Pigs also consume herpetofauna, small and large mammals, freshwater mussels, and sea turtle nests (Wilcox and Van Vuren 2009, Jolley et al. 2010, Engeman et al. 2019, van Ee, et al. 2020). Using camera-monitored nests, Sanders et al. (2020) observed pigs depredating almost 30% of their simulated eastern wild turkey nests in South Texas. Over 50% of American alligator (*Alligator mississippiensis*) farmers reported nest loss due to wild pigs in Louisiana (Elsey et al. 2012). Ditchkoff and Mayer (2009) found that out of 40 pig diet studies, 86% listed vertebrates as consumed by wild pigs. However, while volume of animal consumption was low (5-8%), the frequency of occurrence within pig stomachs was often high (80-90%) (Diong 1982, Herrero et al. 2004, Giménez-Anaya et al. 2008, Ditchkoff and Mayer 2009). The rate and frequency at which pigs consume animal matter is seasonally dependent, because wild pigs both intentionally prey on animals and opportunistically scavenge (Scott 1973, Taylor and Hellgren 1997, Loggins et al. 2002, West et al. 2009, Ballari and Barrios-Garcia 2014, McDonough 2022). In summary, wild pigs compete with, and in some cases, consume native wildlife. Negative interactions like these will only persist in the absence of strategic reduction methods.

The goal of the Feral Swine Eradication and Control Pilot Program (FSCP) was to mitigate the effects of the wild pigs in our study area through a combination of whole sounder removal via corral-style trapping, aerial gunning, and night shooting individual pigs provided by the USDA Wildlife Services (West et al. 2009, Williams et al. 2011, Davis et al. 2018, Lewis 2021). Our objective was to determine if the presence of wild pigs affects the presence of white-tailed deer or eastern wild turkey, i.e., displacement.

Study Area

The Red Hills region of northern Florida and southern Georgia, USA is a biodiversity hotspot and supports a variety of land uses like recreational hunting, forestry, and agriculture (Noss et al. 2015, Elkins et al. 2019). Located within the Southeastern Coastal Plain, the Red Hills is situated between the Ochlockonee and Aucilla Rivers and covers 176,442 ha. The Ochlockonee River's tributaries include Telogia Creek and Sopchoppy River while the Aucilla River's tributaries include Little Aucilla River and Wacissa River. Major water bodies in the Red Hills include two sinkhole lakes. Lake Miccosukee is a 2,554-ha sinkhole lake in northern Jefferson County, Florida. Lake Iamonia is a 2,330-ha sinkhole lake in northern Leon County, Florida. Both lakes routinely fluctuate in water levels due to drought and drain into numerous sinkholes.

Our study was based at Tall Timbers Research Station (TTRS) in Tallahassee, FL, but occurred across nine privately owned properties within the Red Hills, including Tall Timbers.

The private properties fell within Leon and Jefferson Counties, FL and Thomas County, GA, and covered 19,829 ha (Figure 2.1). Elevation ranged from 61 m to 85 m. Mean annual precipitation ranged from 2,422 mm to 2,485 mm during our study period (NOAA | Climate at a Glance). Mean monthly temperatures ranged between 9.6° C - 27.8° C in Thomas County, GA, and 10.5° C – 28.1° C in Leon and Jefferson County, FL (NOAA | Climate at a Glance).

The Red Hills region was divided into two sections – focal areas and landowner participation areas. Focal areas were parcels of privately-owned land that had a recent influx of pigs. Landowner participation areas, hereafter "study sites", were properties within the focal areas where our work occurred. The focal areas were determined through USDA APHIS Wildlife Services project leaders based on the size of the area, the pig density, and trapping efforts needed to meet our objectives (USDA APHIS | Farm Bill Projects). Each study site was managed similarly for northern bobwhite (*Colinus virginianus*) hunting in a pine-dominated (*Pinus sp.)* ecosystem. The properties were managed using single-tree selection silvicultural practices and frequent prescribed fire (Masters et al. 2007). All properties were on a one to three-year prescribed burn rotation which currently supports a regionally expansive population of northern bobwhite and one of the largest populations of gopher tortoises (*Gopherus polyphemus)* on private lands (Masters et al. 2007). Forest canopy consisted of longleaf pine (*Pinus palustris*), loblolly pine (*P. taeda*) and shortleaf pine (*P. echinata*), with scattered live oaks (*Quercus virginiana*). Forest groundcover included *Lespedeza spp*., golden rod (*Solidago spp*.), dogfennel

(*Eupatorium spp.*), blackberry (*Rubus spp*.), American beautyberry (*Callicarpa americana*), and wiregrass (*Aristida stricta*). Small (0.20 – 4 ha) agricultural fields are spread across the properties with primary crops being cotton (*Gossypium spp*.) and peanuts (*Arachis spp.*). Common bottomland trees and plants included cypress (*Taxodium spp.*), tupelo (*Nyssa spp.*), red maple (*Acer rubrum*), American sweetgum (*Liquidambar styraciflua*), sparkleberry (*Vaccinium arboreum*), wax myrtle (*Myrica cerifera*), and holly (*Ilex spp*.) (Sash 2007).

Methods

Camera Deployment

Using ArcMap 10.8 (ESRI, Redlands, CA, USA), we created a grid system of 100-acre blocks containing a single randomly generated point. Random points were used to determine the approximate location of 151-Moultrie M50 cameras (Pradco Outdoor Brands, Birmingham, Alabama, USA) across our study sites. Cameras were placed facing north and 1m above ground on trees 5m south of the nearest trail. Cameras were operational for about 21 months (October 2020 to July 2022). Cameras were motion activated at low sensitivity and set to take 3 successive images after a 1-minute delay. We chose settings to avoid excess images of wind-blown vegetation and to capture large groups of pigs (sounders). For each image captured, data was recorded on time, date, and temperature. Camera locations were physically marked with flagging tape and digitally with a GPS location. We checked cameras on a monthly schedule with 1-3 study sites visited per week (Table 2.1). During each camera check we performed camera maintenance, cleared intruding vegetation, collected used SD cards, and recorded the number of new images taken.

Image Management

We removed images that did not include wild pigs or other native wildlife species, e.g., people, vegetation, vehicles, or domestic animals. Remaining images were imported into Camelot Project for identifying and analyzing camera data (Camelot Project). For our project, we defined independent detections as observations at least thirty-minutes apart, unless an individual had uniquely identifying marks and could be differentiated from the previous individual (Herzog and Bateman 2021). For every animal documented, we used Camelot to record the species, number of individuals seen, age, and sex of individuals if possible. Wild pigs were aged (juvenile or adult) based on size and sex was determined if anatomical identifiers were evident in the image. If the sex could not be determined, the sex was recorded as undetermined for that individual.

Our target species list included wild pig, white-tailed deer, and eastern wild turkey. However, we also recorded northern bobwhite, eastern fox squirrels (*Sciurus niger*), raccoons (*Procyon lotor*), gray foxes (*Urocyon cinereoargenteus*), Virginia opossums (*Didelphis virginiana*), armadillos (*Dasypus novemcinctus*), coyotes (*Canis latrans*) and bobcats (*Lynx rufus*).

Data Analysis

We processed images collected between 01 January 2021 and 30 June 2022 because, during this time, every camera was deployed for the same amount of time. We divided up our data into three categories: before removal (the time before any pig removal occurred), during removal (the time during active removal) and after removal (the time after the last pig was removed and no more were taken).These categories were not evenly represented because wild pig removal started and stopped at various times at each site during our study (Table 2.2). We examined the change in deer, pig, and turkey activity patterns during these categorized times using a kernel density estimator from the "overlap" package in Program R (Meredith and Ridout 2021, Meredith and Ridout 2022, R Core Team 2023). We used the number of pig, deer, and turkey observations before and after pig removal as an index of density for the overlap plots. Overlap estimates are defined as the proportion of shared activity throughout a 24-hour period. For example, higher overlap estimates indicate that two species exhibit similar activity patterns. Following recommendations from Meredith and Ridout (2021), we converted all time stamps to radian time and used the coefficient of overlap estimator $\Delta 4$ since sample size for each category was > 75 observations. We obtained confidence intervals from 5,000 bootstrap iterations to determine if the overlap was significant for each category. All data were collected from study sites where Wildlife Services had access to remove pigs. However, one study site allowed us to monitor wild pigs and pig damage but did not participate in removal work from Wildlife Services. We treated this as our control site (tract name withheld due to privacy concerns). We compared pig, deer, and turkey activity from the control to Tall Timbers, where pig removal occurred a full year before we deployed cameras. We did this to determine if deer and turkey activity patterns differed on study sites where no pigs had been removed by Wildlife Services and where almost all had been removed by Wildlife Services.

Wildlife Services provided pig removal data documenting the number of individuals removed from each site per month. Using those data as our independent variables, we performed a linear regression analysis and modeled the relationship between pig removal and pig, deer, and turkey observations. Dependent variables included mean monthly species observations (number of monthly animals/image), the number of images collected per month, and the number of individuals within those images per month.

Results

Between 01 January 2021 and 30 June 2022, we recorded 45,681 images of our target species. Of these images, 37,201 were of deer containing 42,318 individuals counted, 4,917 were of turkey containing 8,800 individuals counted, and 3,563 were of wild pigs containing 6,638 individuals counted. Wildlife Services removed between 3 to over 300 pigs from various study sites with a total of 1,035 pigs taken during our study period.

The effects of pig removal on pig, deer, and turkey observations

Wild pig removal had a significant impact on the monthly number of images with pigs (Figure 2.2; $P \leq 0.001$) and individual pigs counted within those images (Figure 2.3; $P \leq 0.05$) .

These two variables decreased over time, suggesting pig removal efforts were successful in reducing the number of pigs (Table 2.3 and Table 2.4). However, pig removal did not have an impact on the average number of pigs per image (Figure 2.4; $P \geq 0.05$). This means that while saw a reduction in individual pigs and image of pigs, we still saw an average of about 1.87 pigs per image. We did not observe any impact of pig removal on the monthly number of deer images, individual deer counted per month, or mean number of monthly deer observations (Figures 2.5-2.7; $P \geq 0.05$). Eastern wild turkeys were also unaffected by pig removal efforts. There was no impact on the monthly number of turkey images, individual turkeys counted per month, or mean number of monthly turkey observations (Figures 2.8-2.10; $P \geq 0.05$).

The effect of pig removal on pig, deer, and turkey activity

We analyzed pig, deer, and turkey activity patterns before pig removal occurred (Figure 2.11) and compared them to pig, deer, and turkey activity patterns during and after pig removal occurred (Figure 2.12 and Figure 2.13). Overlap estimates of pig activity before and during removal were 0.91 (95% confidence interval [CI]: 0.89-0.95). There was less of an overlap before and after removal with an estimate of 0.81 (95% CI: 0.68-0.87). Deer displayed crepuscular activity before, during, and after pig removal. Overlap estimates of deer activity before and during pig removal were 0.90 (95% CI: 0.89-0.91). Overlap estimates of deer activity before and after pig removal were 0.87 (95% CI: 0.85-0.88). Turkeys were steadily active in the morning and peaked in the afternoon before removal but became equally active in the morning during removal. Overlap estimates of turkey activity before and during removal were 0.86 (95% CI: 0.82-0.89). Turkey activity before and after pig removal remained diurnal with peaks in the morning and afternoon. These patterns had an overlap estimate of 0.91 (95% CI: 0.88-0.95).

Comparing control site to Tall Timbers

We found a difference in turkey activity between Tall Timbers and the control site (Figure 2.14). Turkey activity on Tall Timbers displayed two dominant peaks, suggesting crepuscular patterns while our control showed a continuous peak during the day, suggesting diurnal activity. These patterns had an overlap estimate of 0.81 (CI: 0.73-0.87). There was less difference in deer activity with the overlap estimate being 0.85 (CI: 0.82-0.86) between Tall Timbers and the control (Figure 2.15). We compared pig, deer, and turkey activity on the control (Figure 2.16). We found an inverted relationship between turkeys and pigs with an overlap estimate of 0.20 (CI: 0.08-0.22). Deer remained crepuscular on the control site but were less active in the morning than in the evening. The overlap estimate for pigs and deer on the control was 0.73 (CI: 0.66-0.77). Similarly, on Tall Timbers deer were crepuscular. However, the few observations of wild pigs fluctuated throughout the morning and spiked around midnight. The overlap estimate for pigs and deer on Tall Timbers was 0.68 (CI:0.49-0.80).

Discussion

The effects of pig removal on pig, deer, and turkey observations

Like Lewis (2021), who observed fewer pigs after removing 96 from her Alabama study area over 2.5 years, we report successful removal from an open population of wild pigs in an area that had not used combined reduction methods before. During our study we recorded 664 pig observations before removal and 55 after removal. Removal occurred at different times on each study site. Wildlife Services continued to remove pigs from some sites even after we stopped monitoring with cameras. The time frame for removal varied depending on which study site allowed us to come and monitor first. We did not observe a positive or negative correlation between pig removal and deer and turkey observations. Trendlines for both species were negative while pigs were being removed. The negative trendlines could be due to the timing of our study period. We analyzed images for 17 months starting in January of 2021, after removal began on a few sites. Stickles et al. (2015) found increased deer activity during early December in South Georgia when they created a deer breeding activity map for the state based on deer-vehicle collision data. Similarly, Boughton et al. (2020) documented female deer in North Florida having larger home range sizes in October. Our data aligns with these findings as most of our deer observations occurred during the fall period with fewer observations outside of rut, (Stickles et al. 2015). We observed two peaks in turkey observations during March-May 2021 and 2022. Most of our turkey observations occurred during these two spring periods with fewer observations at the beginning and end of our study period. Previous studies that focused on turkey movements and dispersal found breeding periods to increase movement of males and females (Godwin et al. 1994, Badyaev 1995, Badyaev et al. 1996, Chamberlain et al. 2018).

The effect of pig removal on pig, deer, and turkey activity

Wild turkey activity patterns were different in areas where pigs had not been removed compared to where they had been removed. Turkey activity on the control peaked in the middle of the day while turkey activity everywhere else peaked in the morning and afternoon. Since Wildlife Services did not remove pigs from the control, turkeys may have shifted their activity patterns to limit competition with pigs for resources and space (Wood and Barrett 1979). Walters and Osborne (2021) suggested that even though turkeys and wild pigs occupied the same sites, pig presence reduced turkey detectability and temporarily displaced turkeys from baited camera stations. Wild pigs were primarily nocturnal with little day-time activity on all our study sites (Clontz et al. 2021, Dykstra et al. 2023). More nocturnal activity could have been due to high temperatures during the day and potential hunting pressure from the landowner (Johann et al. 2020). Although we did not identify spatial displacement of turkeys, we did observe a temporal displacement based on the comparison of activity patterns between the control and the other study sites. Our results suggest that turkeys did shift their activity patterns to being fully active during the day to avoid pigs. This behavior could progress and eventually lead to displacement from the control if reduction methods are not implemented in the future.

On study sites where pigs were removed, turkeys displayed their natural diurnal activity. Morning and afternoon peaks could have been influenced by high temperatures in our study area. Nelson et al. (2022) found that thermal refuge was important to female turkeys when selecting for brood habitat. We saw turkeys being more active in the morning and evening when temperatures were lower, suggesting they reduced activity or sought thermal refuge during the day. Lewis (2021) also observed turkeys being more active following sunrise and prior to sunset in Alabama when monitoring the impact of pig removal on deer and turkey.

Before pig removal, deer were more active in the evening and after pig removal, they were more active the morning. Deer did stay active at night after removal but became gradually less active instead of halting all nighttime activity. Our results align with Garabedian et al. (2022) who documented deer and pig activity in South Carolina. They found high overlap in diel activity patterns and co-occurrence at 30-59% of their cameras. However, their results suggested deer made fine-scale behavioral adjustments to avoid pigs, suggesting competition even in areas where pig density was low. While we saw little change in deer activity before and after pig removal, the potential for competition or other negative interactions remain possible.

Management Implications

Our study suggests that white-tailed deer and eastern wild turkeys may have adjusted their activity patterns to reduce interactions with wild pigs. Although we did not detect spatial displacement or reduced deer and turkey observations, a temporal shift in activity could increase environmental stress and reduce access to valuable resources. In areas that are managed for game hunting, wild pig presence could negatively impact hunting success due to modified activity patterns. Wild pig removal can allow deer and turkey to revert to their natural and more predictable activity patterns. Land managers should consistently monitor areas vulnerable to wild pig invasion and continue removing pigs year-round using primarily whole-sounder trapping and night shooting when necessary.

Literature Cited

Allen, C. R., D. M., Epperson, and A. S. Garmestani. 2004. Red imported fire ant impacts on wildlife: A decade of research. The American Midland Naturalist 152:88–103.

Animal and Plant Health Inspection Service (APHIS). 2020. Feral Swine Destroy Property. < https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/feral-swine-damage/feral-swine-destroy-property>. Accessed February 24, 2022.

Animal and Plant Health Inspection Service (APHIS). 2022. History of Feral Swine in the Americas. < https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/sa-fs-history>. Accessed January 16, 2023.

Badyaev, A. V. 1995. Nesting habitat and nesting success of eastern wild turkeys in the Arkansas Ozark highlands. Condor 97:221–232.

Badyaev, A. V., W. J. Etges, and T. E. Martin. 1996. Age-biased spring dispersal in male wild turkeys. Auk 113:240–242.

Ballari, S. A., and M. N. Barrios-Garcia. 2014. A review of wild boar Sus scrofa diet and factors affecting food selection in native and introduced ranges. Mammal Review 44:124–134.

Barrios-Garcia, and M. N., S. A. Ballari. 2012. Impact of wild boar (Sus scrofa) in its introduced and native range: a review. Biological Invasions 14:2283–2300.

Baubet, E., Y. Ropert-Coudert, and S. Brandt. 2003. Seasonal and annual variations in earthworm consumption by wild boar (*Sus scrofa* scrofa L.). Wildlife Research 30:179–186.

Boughton, R. K., B. Wight, S. Wisely, K. Hood, and M. B. Main. 2020. White-tailed deer of Florida. IFAS Extension, University of Florida WEC133:1–12.

Brooks, J. P., R. K. Smith, C. A. Aldridge, B. Chaney, A. Omer, J. Dentinger, G. M. Street, and B. H. Baker. 2020. A preliminary investigation of wild pig (*Sus scrofa*) impacts in water quality. Journal of Environmental Quality 49:27–37.

Camelot Project. 2020. < https://camelotproject.org/>. Accessed 22 June 2022.

Chamberlain, M. J., P. H. Wightman, B. S. Cohen, and B. A. Collier. 2018. Gobbling activity of eastern wild turkeys relative to male movements and female nesting phenology in South Carolina. Wildlife Society Bulletin 42:632–642.

Clontz, L. M., K. M. Pepin, K. C. VerCauteren, and J. C. Beasley. 2021. Scientific Reports 11:1–14.

Cooper, S. M., and S. S. Sieckenius. 2016. Habitat selection of wild pigs and northern bobwhites in shrub-dominated rangeland. Southeastern Naturalist 15:382–393.

Davis, A. J., B. Leland, M. Bodenchuk, K. C. VerCauteren, and K. Pepin. 2018. Costs and effectiveness of damage management of an overabundant species (*Sus scrofa*) using aerial gunning. Wildlife Research 45:696–705.

Diong, C. H. 1982. Population biology and management of the feralpig (Sus scrofa L.) in Kipahulu Valley, Maui. Dissertation, University of Hawaii, Honolulu, Hawaii, USA.

Ditchkoff, S. S. and J. J. Mayer. 2009. Wild pig food habits. Pages 105-143 *in* Mayer, J. J., and I. L. Brisbin Jr., editors. 2009. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, SRNL-RP-2009-00869, Aiken, South Carolina, USA.

Dorcas, M. E., J. D. Wilson, R. N. Reed, R. W. Snow, M. R. Rochford, M. A. Miller, W. E. Meshaka Jr., P. T. Andreadis, F. J. Mazzotti, C. M. Romagosa, and K. M. Hart. 2011. Severe mammal declines coincide with proliferation of invasive Burmese pythons in Everglades National Park. Proceedings of the National Academy of Sciences 109:2418–2422.

Dykstra, A. M., C. Baruzzi, K. VerCauteren, B. Strickland, M. Lashley. 2023. Biological invasions disrupt activity patterns of native wildlife: An example from wild pigs. Food Webs 34:e00270.

Engeman, R. M., R. W. Byrd, J. Dozier, M. A. McAlister, J. O. Edens, E. M. Kierepka, T. J. Smyer, and N. Myers. 2019. Feral swine harming insular sea turtle reproduction: The origin, impacts, behavior and elimination of an invasive species. Acta Oecologica 99:1–8.

Elkins, D., S. C. Sweat, B. R. Kuhajda, A. L. George, K. S. Hill, and S. J. Wenger. 2019. Illuminating hotspots of imperiled aquatic biodiversity in the southeastern US. Global Ecology and Conservation 19: e00654.

Elsey, R. M., E. C. Mouton, and N. Kinler. 2012. Effects of feral swine (*Sus scrofa*) on alligator (*Alligator mississippienis*) nests in Louisiana. Southeastern Naturalist 11:205–218.

Elston, J. J., and D. G. Hewitt. 2010. Intake of mast by wildlife in Texas and the potential for competition with wild boars. The Southwestern Naturalist 55:57–66.

Executive Order 13112 – Invasive Species. FederalRegisters.gov. Federal Register: Feb 3, 1999 (Volume 64, Number 25).

Garabedian, J. E., K. J. Cox, M. Vukovich, and J. C. Kilgo. 2022. Co-occurrence of native white-tailed deer and inavasive wild pigs: Evidence for competition? Ecosphere 14: 1–15.

Gimenez-Anaya, A., J. Herrero, C. Rosell, S. Couto, and A. Garcia-Serano. 2008. Food habits of wild boars (*Sus scrofa*) in a Mediterranean coastal wetland. Wetlands 28:197–203.

Godwin, K. D., G. A. Hurst, and R. L. Kelly. 1994. Movements of wild turkey gobblers in central Mississippi. Pages 117 *in* Proceedings of the Southeastern Association of Fish and Wildlife Agencies 48:117–127.

Graves, H. B. 1984. Behavior and ecology of wild and feral swine (Sus scrofa). Journal of Animal Science 58:482–492.

Grether, G. F., K. S. Pieman, J. A. Tobias, B. W. Robinson. 2017. Causes and consequences of behavioral interference between species. Trends in Ecology and Evolution 32:760–772.

Herrero, J., S. Couto, C. Rosell, and P. Arias. 2004. Preliminary data on the diet of wild boar living in a Mediterranean costal wetland. Galemys 16:115–123.

Herzog, C. J., and H. L. Bateman. 2021. Using trail cameras to document meso and large mammal use of native and nonnative riparian forest types in southeastern Arizona. Western North American Naturalist 81:71–86.

Johann, F., M. Handschuh, P. Linderoth, C. F. Formann, and J. Arnold. 2020. Adaptation of wild boar (Sus scrofa) activity in human-dominated landscape. BMC Ecology 20:1–14.

Jolley, D. B., S. S. Ditchkoff, B. D. Sparklin, L. B. Hanson, M. S. Mitchell, and J. B. Grand. 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy 91:519–524.

Keever, A. C. 2014. Use of N-mixture models for estimating white-tailed deer populations and impacts of predator removal and interspecific competition. Thesis, Auburn University, Auburn, Alabama, USA.

Keiter, D. A., and J. C. Beasley. 2017. Hog heaven? Challenges of managing introduced wild pigs in natural areas. Natural Areas Journal 37:6–16.

Lewis, A. A. 2021. Pigs by the Sounder: Wild pigs, whole sounder removal, and their effects on deer and turkey. Thesis, Auburn University, Auburn, Alabama, USA.

Loggins, R. E., J. T. Wilcox, D. H. V. Vuren, and R. A. Sweitzer. 2002. Seasonal diet of wild pigs in oak woodlands of the central coast region of California. California Fish and Game 88:28–34.

Masters, R. E., K. Robertson, W. E. Palmer, J. Cox, K. McGorty, L. Green, and C. Ambrose. 2007. Red hills forest stewardship guide. Tall Timbers Research Station and Land Conservancy Miscellaneous Publication, 12, Tallahassee, Florida, USA.

Mayer, J. J. 2018. Introduced wild pigs in North America: History, problems and management. Pages 229–312 *in* M. Melletti and E. Meijaard, editors. Ecology, evolution and management of wild pigs and peccaries: Implications for conservation. Cambridge University Press, New York, New York, USA.

Meredith, M. S. and M. Ridout. 2022. Package ‘overlap’ R package version 0.3.4. https://cran.r-project.org/web/packages/overlap/overlap.pdf

Meredith, M. S., and M. Ridout 2021. Overview of the overlap package. https://cran.r-project.org/web/packages/overlap/vignettes/overlap.pdf

McDonough, M. T., S. S. Ditchkoff, M. D. Smith, K. C. VerCauteren. 2022. A review of the impacts of invasive wild pigs on native vertebrates. Mammalian Biology 102:279–290.

National Climate Data Center. 2022. Climate at a glance. <http://www.ncdc.noaa.gov>. Accessed 22 March 2022.

Nelson, S. D., A. C. Keever, P. H. Wightman, N. W. Bakner, C. M. Argabright, M. E. Bryne, B. A. Collier, M. J. Chamberlain, and B. S. Cohen. 2022. Fine-scale resource selection and behavioral tradeoffs of eastern wild turkey broods. Journal of Wildlife Management: e22222.

Noss, R. F., W. J. Platt, B. A. Sorrie, A. S. Weakley, D. B. Means, J. Costanza, and R. K. Peet. 2015. How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. Biodiversity Viewpoint 21:236–244.

Pearson, S. H., H. W. Avery, and J. R. Spotila. 2015. Juvenile invasive red-eared slider turtles negatively impact the growth of native turtles: Implications for global freshwater turtle populations. Biological Conservation 186:115–121.

R Core Team. 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rabolli, C.V. 1983. Nutritional evaluation of the feral hog diet on Hobcaw Barony. Thesis, Clemson University, Clemson, South Carolina, USA.

Rollins, D., and J. P. Carroll. 2001. Impacts of predation on northern bobwhite and scaled quail. Wildlife Society Bulletin 29:39–51.

Ruland, F., and J. M. Jeschke. 2020. How biological invasions affect animal behavior: A global, cross-taxonomic analysis. Journal of Animal Ecology 89:2531–2541.

Sanders, H. N., D. G. Hewitt, H. L. Perotto-Baldivieso, K. C. VerCauteren, and N. P. Snow. 2020. Invasive wild pigs as primary nest predators for wild turkeys. Scientific Reports 10:2625–2634.

Sash, K. J. Snake ecology of the red hills region of south Georgia and north Florida. Thesis, University of Georgia, Athens, Georgia, USA.

Schley, L, and T. J. Roper. 2003. Diet of wild boar Sus scrofa in Western Europe, with particular reference to consumption of agricultural crops. Mammal Review 33:43–56.

Scott, C. D. 1973. Seasonal food habits of European wild hogs (Sus scrofa) in the Great Smoky Mountains National Park. Thesis, University of Tennessee, Knoxville, Tennessee, USA.

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osbourne, and C. H. Killmaster. 2015. Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. Journal of the southeastern association of fish and wildlife agencies 2:202–207.

Sweeney, J. R., J. M. Sweeney, and S. W. Sweeney. 2003. Feral hog. Pages 1164–1179 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America. Johns Hopkins University Press, Baltimore, Maryland, USA.

Taylor, R. B., and E. C. Hellgren. 1997. Diet of feral hogs in western south Texas plans. The Southwestern Naturalist 42: 33–39.

Tolleson, D., D. Rollins, W. Pinchak, M. Ivy, and A. Hierman. 1993. Impact of feral hogs on ground-nesting gamebirds. Pp. 76–83 *In* C.W. Hanselka and J.F. Cadenhead, editors. Feral Swine: A Compendium for Resource Managers. Texas Agricultural Extension Service, Kerrville, Texas, USA.

United States Department of Agriculture [USDA]. 2020. Farm Bill Projects. <https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/fb-projects>. Accessed 12 July 22.

van Ee, B. C., Z. L. Nickerson, and C. L. Atkinson. 2020. Picky pigs prefer pigtoes: Evidence for species-selective feral pigs predation on freshwater mussels. Freshwater Mollusk Conservation Society 23:92–98.

VerCauteren, K. C., J. J. Mayer, J. C. Beasley, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland. 2020. Introduction. Pages 1-5 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Walters C. M., and D. C. Osborne. 2021. Occurrence patterns of wild turkeys altered by wild pigs. Wildlife Society Bulletin 46:1–15.

Williams, B. L., R. W. Holtfreter. S. S. Ditchkoff, and J. B. Grand. 2011. Trap style influences wild pig behavior and trapping success. Journal of Wildlife Management 75:432–436.

West, B. C., A. L. Cooper, and J. B. Armstrong. 2009. Managing wild pigs: A technical guide. Human-Wildlife Interactions Monograph 1:1–55.

Wilcox, J. T., and D. H. Van Vuren. 2009. Wild pigs as predators in oak woodlands of California. Journal of Mammalogy 90:114–118.

Wood, G. W., and R. H. Barrett. 1979. Status of wild pigs in the United States. Wildlife Society Bulletin 36:237–246.

Yarrow, G. K. 1987. The potential for interspecific resource competition between white-tailed deer and the feral hogs in the post oak savannah region of Texas. Dissertation, Stephen F. Austin University, Nacogdoches, Texas, USA.

Table 2.1. Description of study sites with their respective acreage (ha), number of cameras deployed, and time of deployment from October 2020 to July 2022 on 9 properties across 3 counties in the Red Hills region of North Florida and South Georgia, USA.

Property Name	Size (ha)	No. of cameras	Time of Deployment
Elsoma	1, 551	11	15 Oct 20 – 15 Jul 22
Livingston Place	3, 703	23	09 Oct 20 – 11 Jul 22
Longpine	2, 421	16	02 Dec 20 – 07 Jul 22
Mays Pond	2, 290	28	23 Oct 20 – 21 Jul 22
Millpond-Sedgwick	1, 695	12	28 Oct 20 – 27 Jul 22
Norias	2, 456	17	17 Nov 20 – 18 Jul 22
Meander	2, 267	14	19 Nov 20 – 20 Jul 22
Tall Timbers Research Station	1, 607	12	02 Oct 20 – 29 Jun 22
Woodfield Springs	1, 799	18	14 Dec 20 – 13 Jul 22

Table 2.2. Description of wild pig removal categories for each of our study sites in North Florida and Southwestern Georgia. We ran cameras from October 2020 – July 2022, but we only analyzed data between January 2021-June 2022.

Study site	Removal started	Last pig removed	Camera deployment	Before Removal[a]	During Removal[b]	After Removal[c]
Elsoma	Jul 2020	June 2022	15 Oct 20 - 15 Jul 22	N/A[d]	Jan 2021 - Jun 2022	N/A
Livingston Place	Apr 2021	June 2022	09 Oct 20 - 11 Jul 22	Jan 2021 - Apr 2021	Apr 2021 - Jun 2022	N/A
Longpine	May 2020	June 2022	02 Dec 20 - 07 Jul 22	N/A	Jan 2021 - Jun 2022	N/A
Mays Pond	Apr 2021	June 2022	23 Oct 20 - 21 Jul 22	Jan 2021 - Mar 2021	Mar 2021 - Jun 2022	N/A
Norias	Sep 2020	Nov 2021	17 Nov 20 - 18 Jul 22	N/A	Jan 2021 - Jun 2022	Nov 2021 - Jun 2022
Meander	Feb 2022	Mar 2022	19 Nov 20 - 20 Jul 22	Jan 2021-Jan 2022	Feb 2022 - Jun 2022	N/A
Tall Timbers	Nov 2019	Apr 2021	02 Oct 20 - 29 Jun 22	N/A	Jan 2021 - April 2021	Apr 2021 - Jun 2022
Woodfield Springs	Nov 2020	May 2021	14 Dec 20 - 13 Jul 22	N/A	Nov 2020 - May 2021	May 2021 - Jun 2022

[a] Before removal = the time before WS started trapping pigs on a study site.
[b] During removal = the time between when the first pig was removed through when the last pig was removed.
[c] After removal = the time after the last pig was removed through when we stopped surveying (June 2022).
[d] N/A = we did not have data for this category.

Table 2.3. Number of images per month with pigs present between January 2021–June 2022. Green blocks represent the month pig removal began or that a study site was already removing pigs when we started monitoring. Red blocks indicate when the last pig was removed from that site or that removal was still occurring when we finished monitoring.

Month	Tall Timbers	Elsoma	Norias	Longpine	Mays Pond	Woodfield Springs	Livingston Place	Meander	Millpond
Jan-21	5	32	10	218	79	6	4	21	18
Feb-21	5	19	12	246	53	7	13	27	35
Mar-21	10	36	20	119	73	7	15	11	5
Apr-21	1	35	5	60	21	3	24	27	5
May-21	0	41	1	116	16	4	11	40	1
Jun-21	0	26	0	129	23	3	45	20	3
Jul-21	0	30	5	87	23	5	27	33	2
Aug-21	2	43	5	81	13	7	5	5	4
Sep-21	2	31	5	50	12	4	12	6	2
Oct-21	0	35	5	43	14	4	2	76	2
Nov-21	1	55	4	28	11	5	6	13	3
Dec-21	0	12	2	48	3	1	18	17	33
Jan-22	0	58	1	39	2	7	35	21	6
Feb-22	0	48	0	26	13	2	9	11	5
Mar-22	0	50	5	33	20	3	22	5	13
Apr-22	0	35	2	49	20	0	17	2	14
May-22	0	34	6	78	5	2	3	8	19
Jun-22	0	12	3	72	10	7	7	3	13
Total	26	632	91	1522	411	77	275	346	183

Table 2.4. Individual pigs counted each month from images collected with trail cameras between January 2021-June 2022. Green blocks represent the month pig removal began or study site was already removing pigs when we started monitoring. Red blocks indicate when the last pig was removed from that site or that removal was still occurring when we completed monitoring. There were still pigs seen even after they stopped getting removed

Month	Tall Timbers	Elsoma	Norias	Longpine	Mays Pond	Woodfield Springs	Livingston Place	Meander	Millpond
Jan-21	6	61	12	521	136	12	13	40	40
Feb-21	6	20	14	722	85	9	20	31	113
Mar-21	11	66	31	214	149	9	18	14	6
Apr-21	1	60	7	73	36	4	37	53	11
May-21	0	56	1	209	22	5	11	85	1
Jun-21	0	32	0	238	27	3	66	38	7
Jul-21	0	41	5	128	37	5	36	48	2
Aug-21	2	60	5	163	14	8	5	5	8
Sep-21	2	49	7	83	13	5	12	10	3
Oct-21	0	67	10	73	19	4	2	88	4
Nov-21	1	78	8	51	13	6	9	27	12
Dec-21	0	18	2	108	7	1	31	37	78
Jan-22	0	109	1	81	2	9	76	34	17
Feb-22	0	91	0	32	21	2	9	20	17
Mar-22	0	100	12	115	42	3	23	7	21
Apr-22	0	57	2	123	52	0	19	4	24
May-22	0	59	6	176	8	2	3	12	42
Jun-22	0	15	3	151	21	7	7	3	26
Total	29	1039	126	3261	704	94	397	556	432

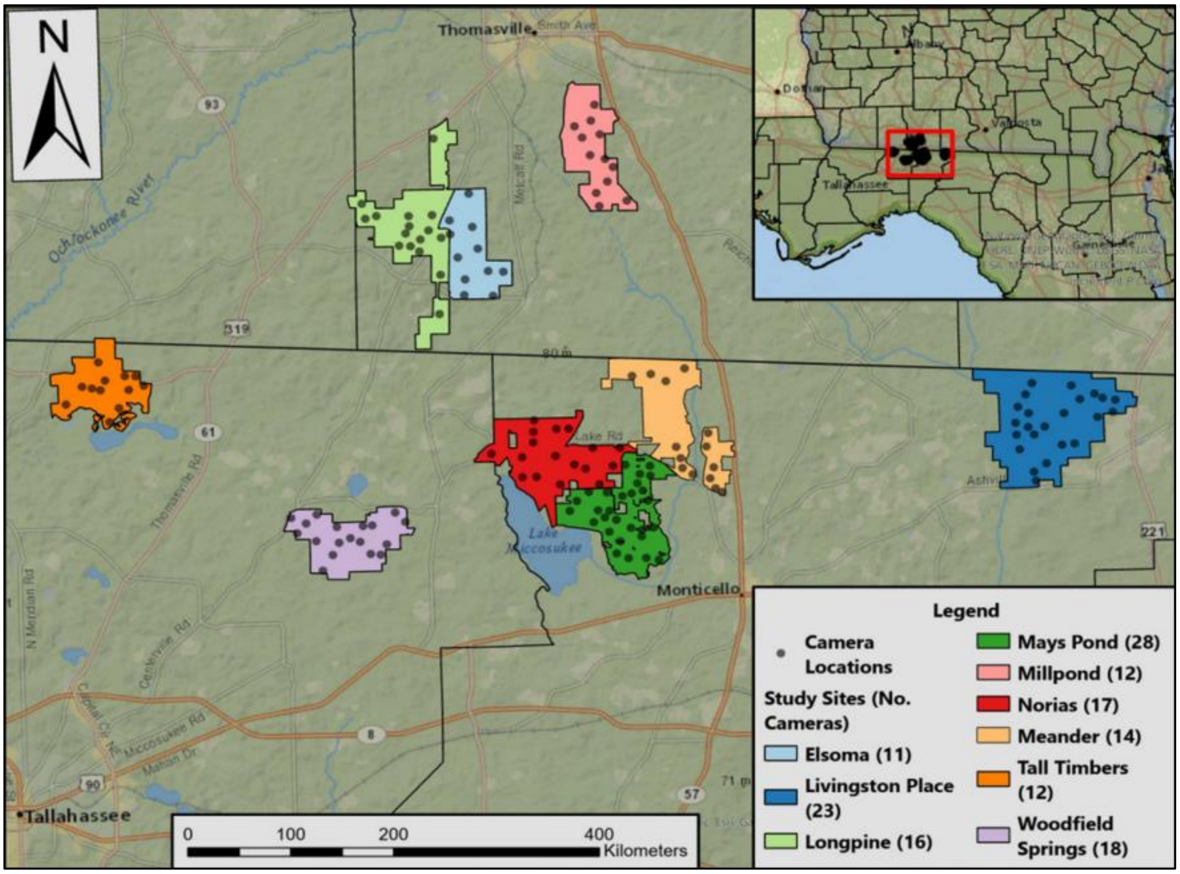


Figure 2.1 A map of the Red Hills region and our nine privately owned study sites within Thomas County, Georgia and Leon and Jefferson County Florida, USA.

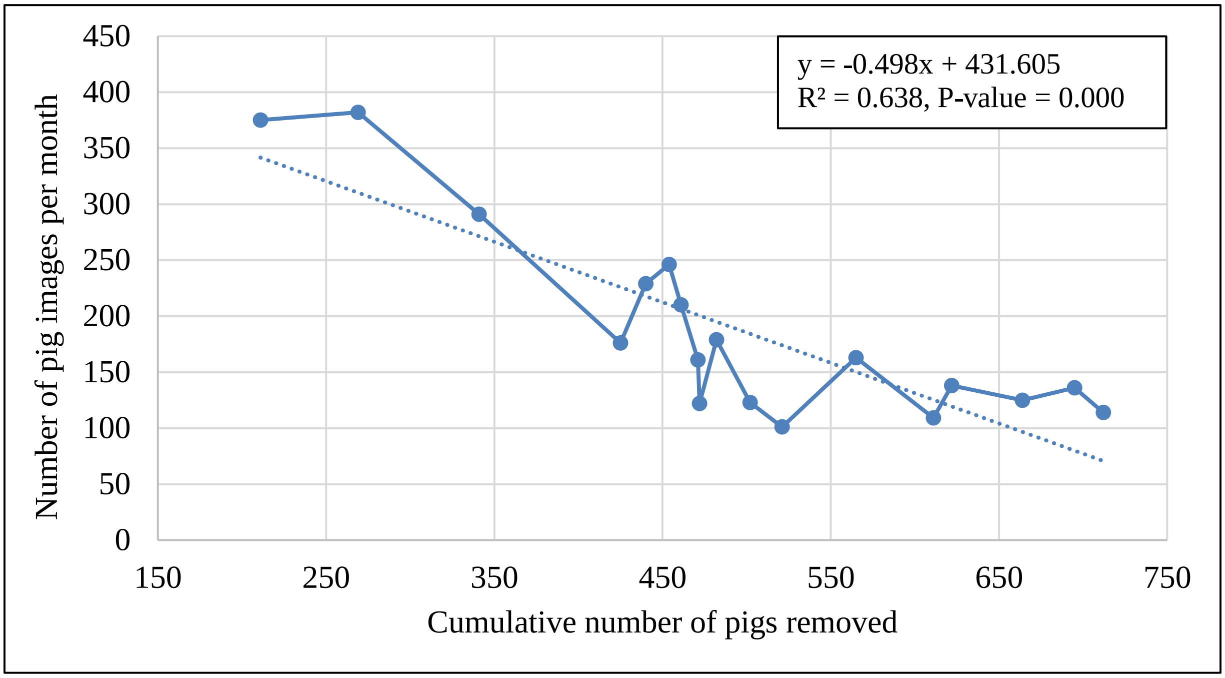


Figure 2.2. Number of images per month containing pigs plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of monthly pig images.

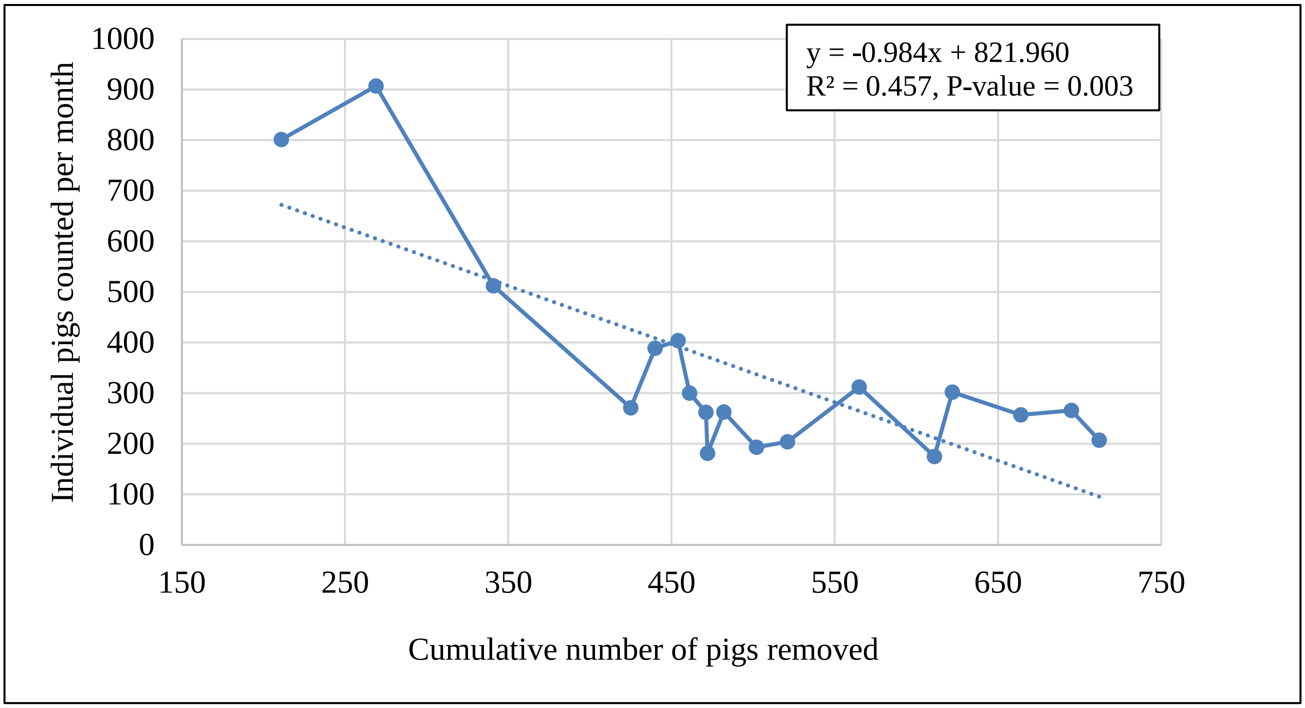


Figure 2.3. Number of individual pigs counted per month plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of pigs counted per month.

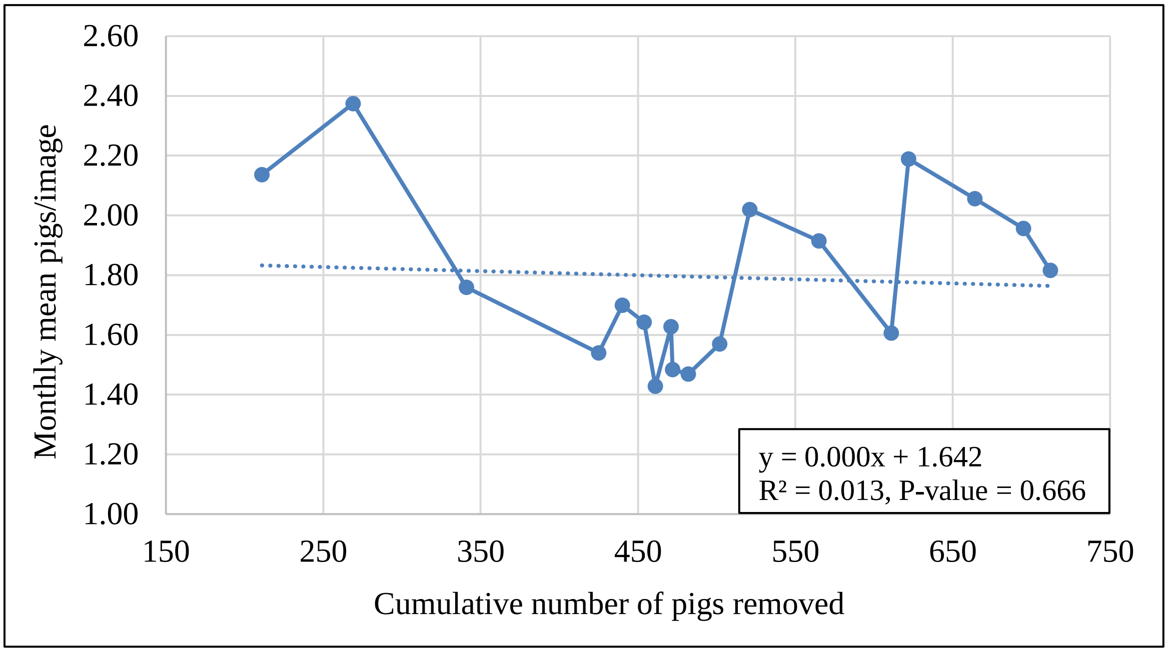


Figure 2.4. Mean number of pigs per image plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the mean number of pigs per image.

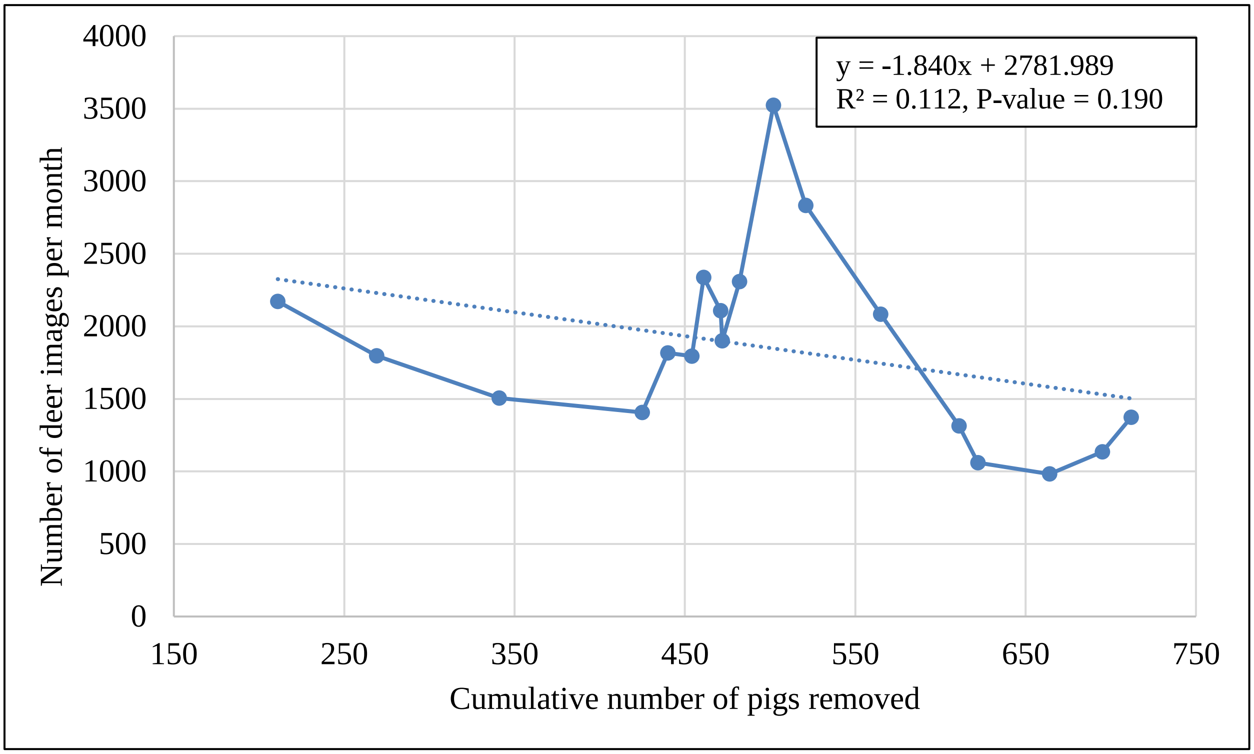


Figure 2.5. Number of monthly white-tailed deer images plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of monthly deer images.

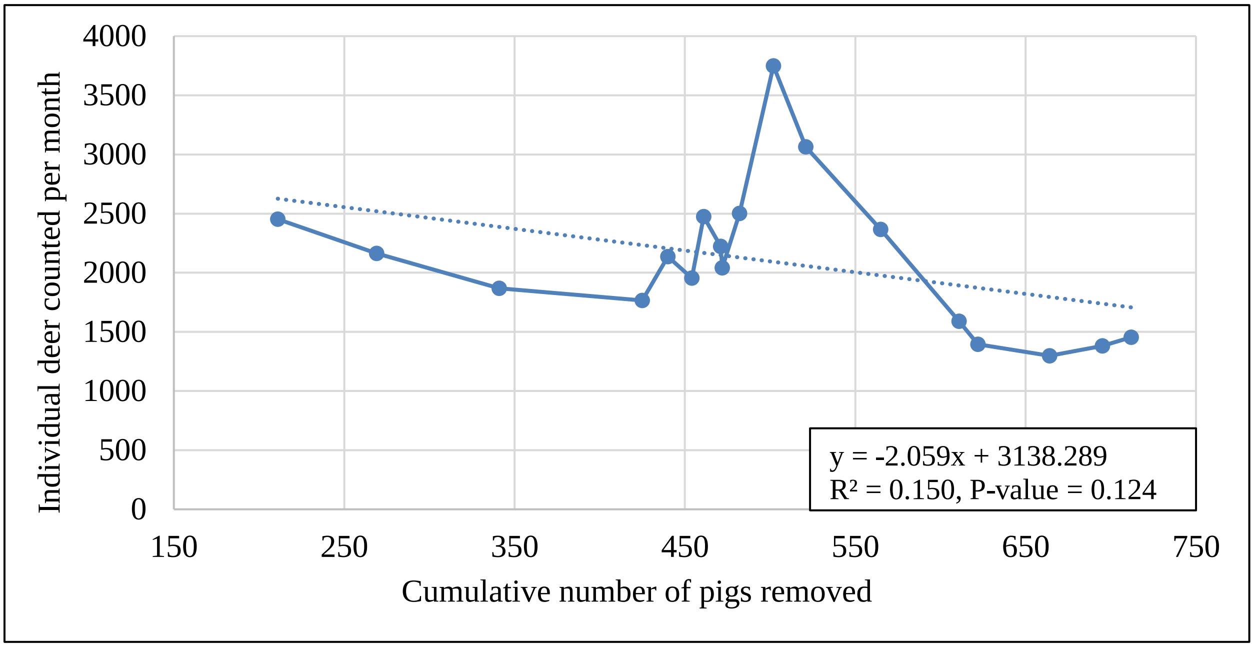


Figure 2.6. Number of individual white-tailed deer counted per month plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of deer counted per month.

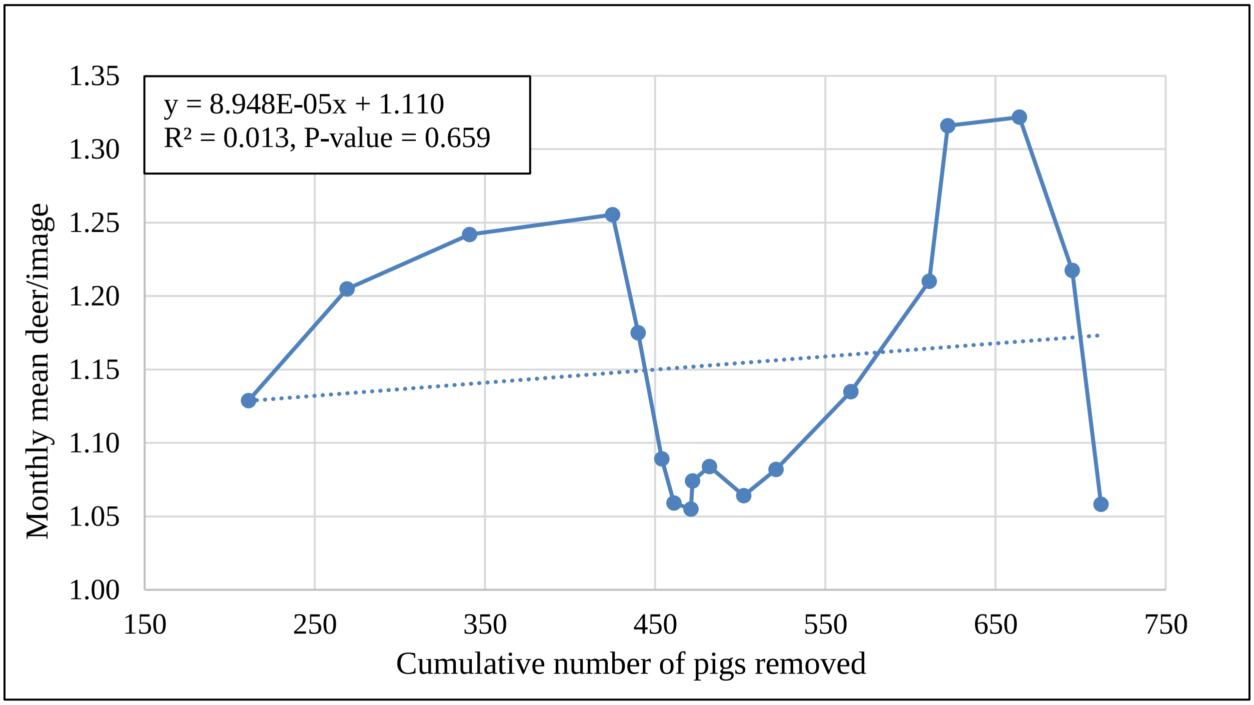


Figure 2.7. Mean number of white-tailed deer per image per month plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the monthly mean number of deer per image.

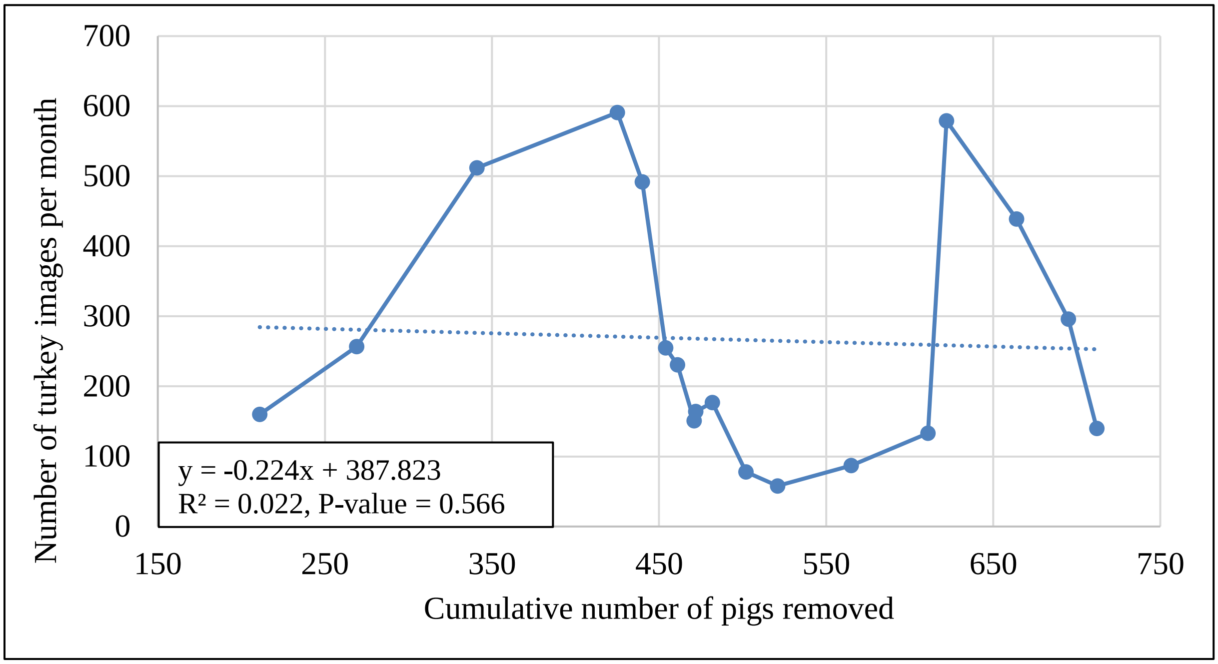


Figure 2.8. Number of monthly eastern wild turkey images plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of monthly turkey images.

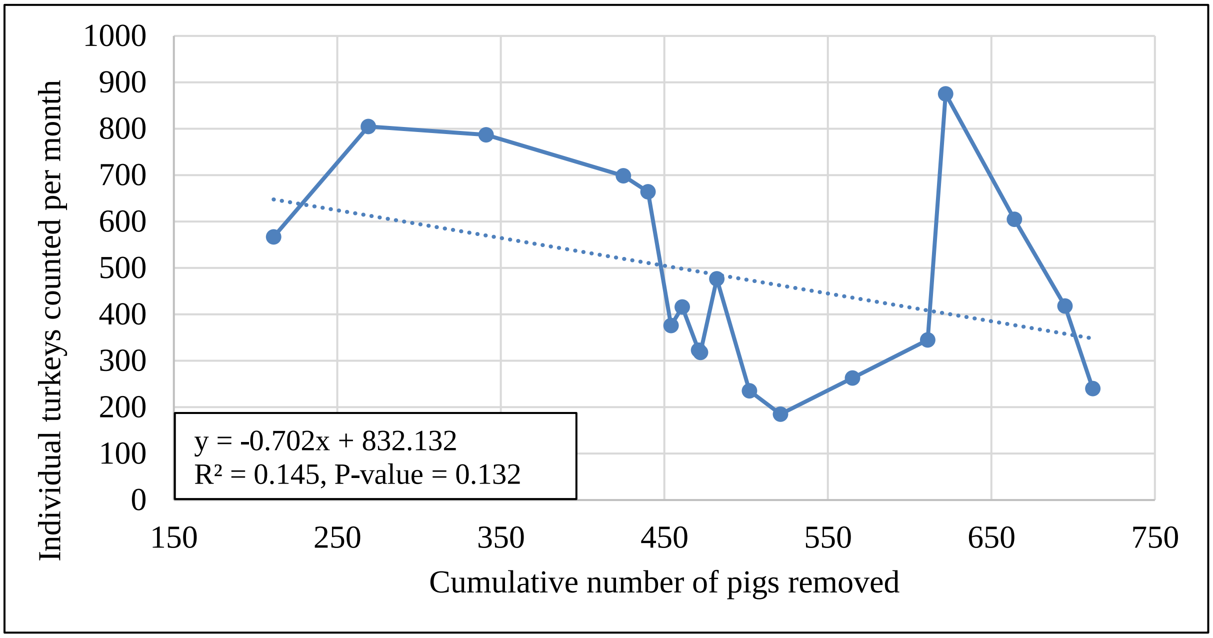


Figure 2.9. Number of individual eastern wild turkeys counted per month plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the number of turkeys counted per month.

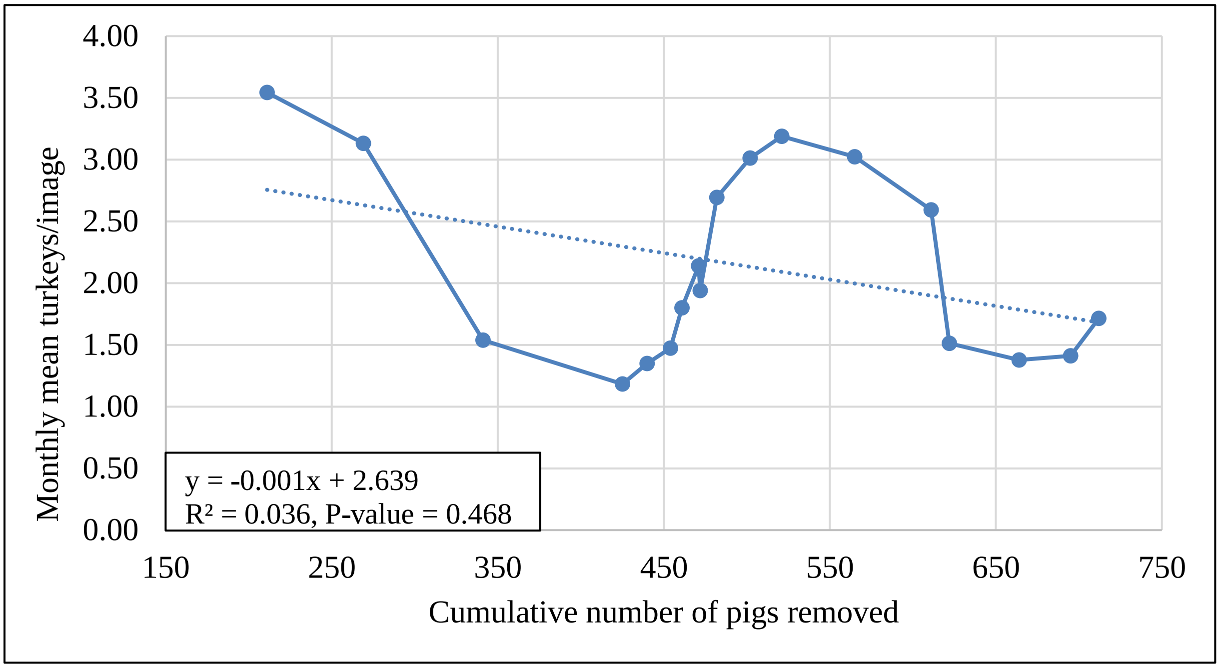


Figure 2.10. Mean number of eastern wild turkeys per image per month plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022. The dotted line represents the fitted linear relationship between the number of pigs removed and the monthly mean number of turkeys per image.

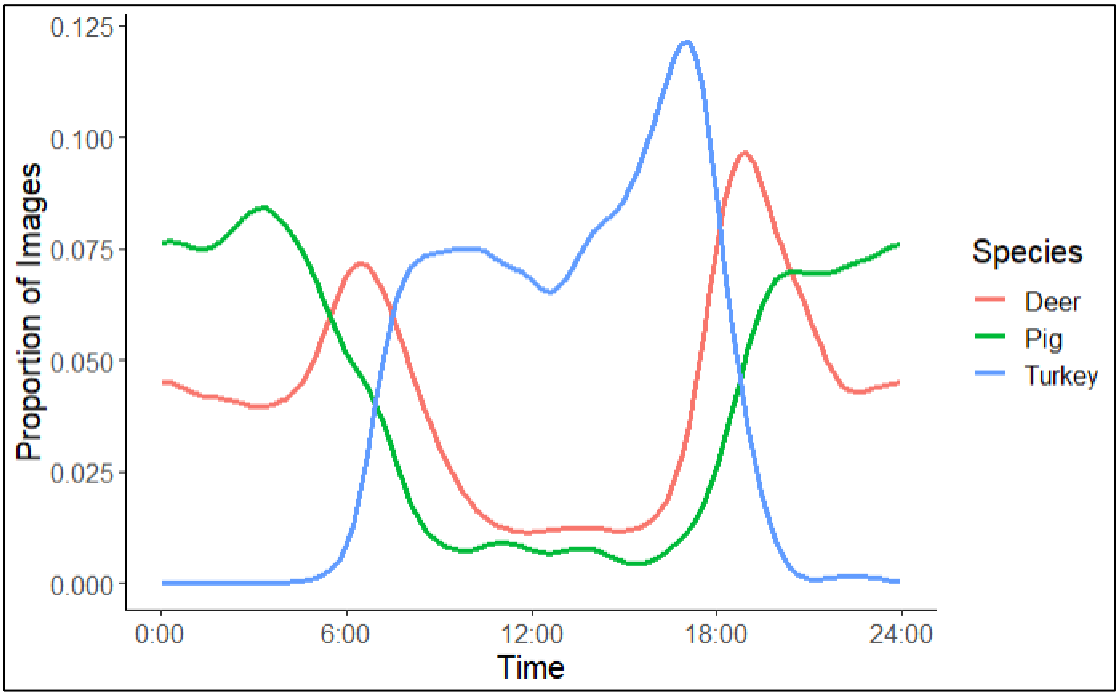
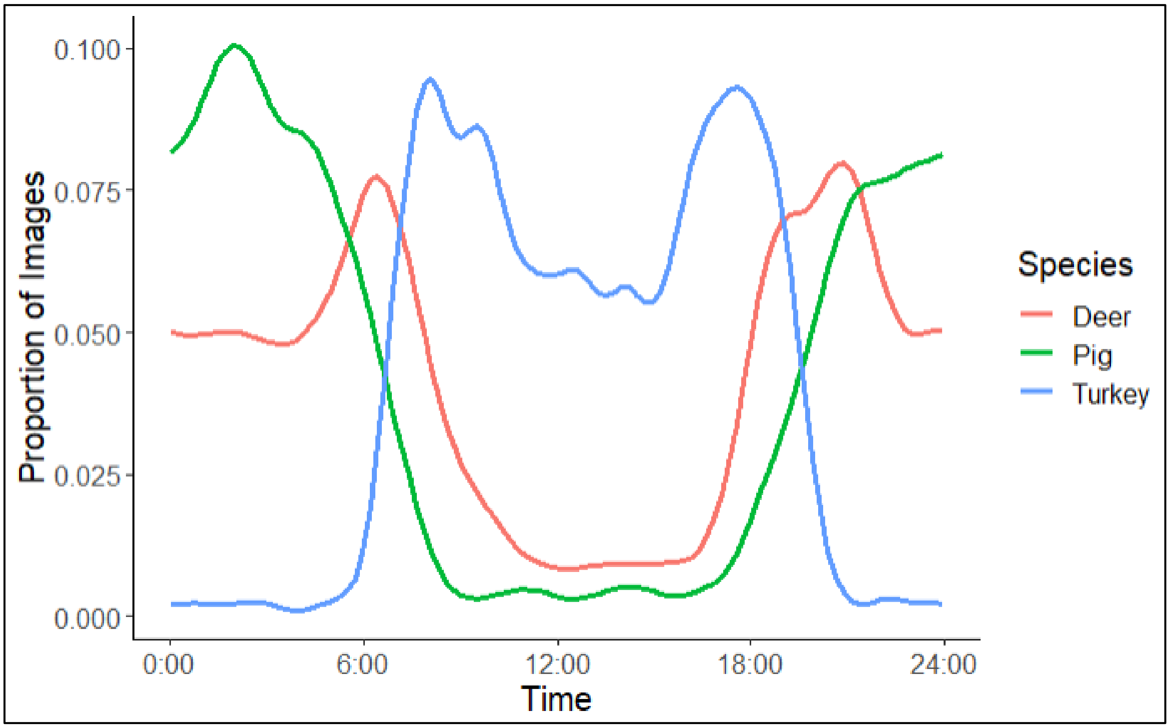


Figure 2.11. Activity patterns of wild pigs, white-tailed deer, and eastern wild turkeys before pig removal occurred on our study sites in North Florida and South Georgia, USA, during January 2021-June 2022.



2.12. Activity patterns of wild pigs, white-tailed deer, and eastern wild turkeys during pig removal on our study sites in North Florida and South Georgia, USA, during January 2021-June 2022.

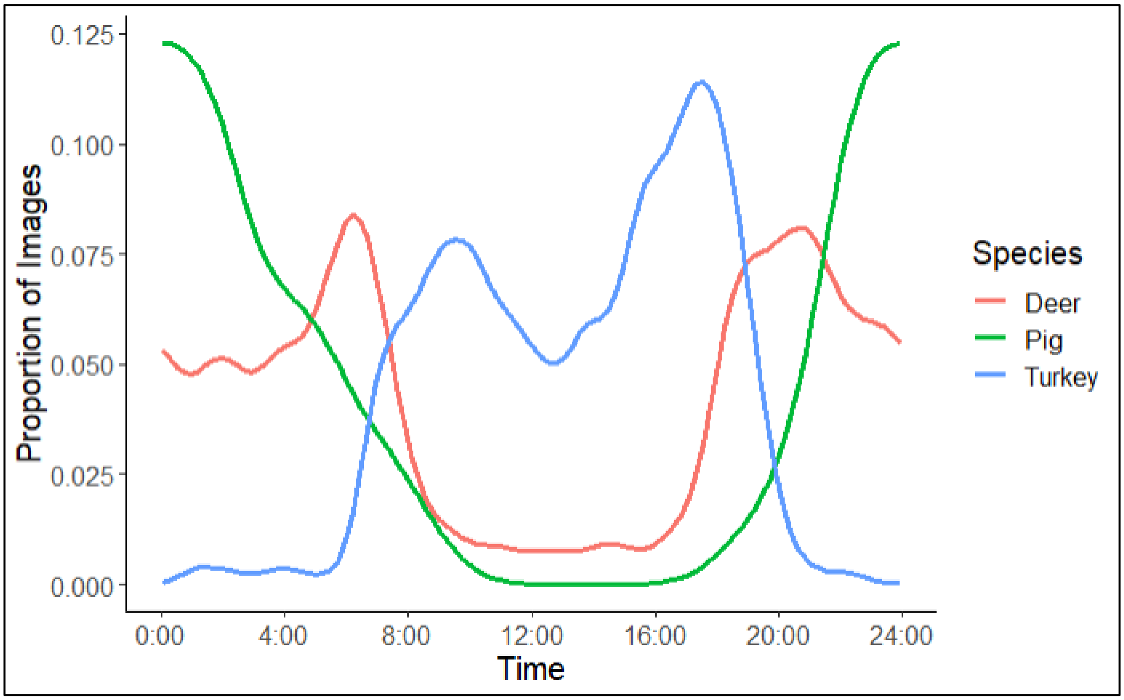


Figure 2.13. Activity patterns of wild pigs, white-tailed deer, and eastern wild turkeys after pig removal occurred on our study sites in North Florida and South Georgia, USA, during January 2021-June 2022.

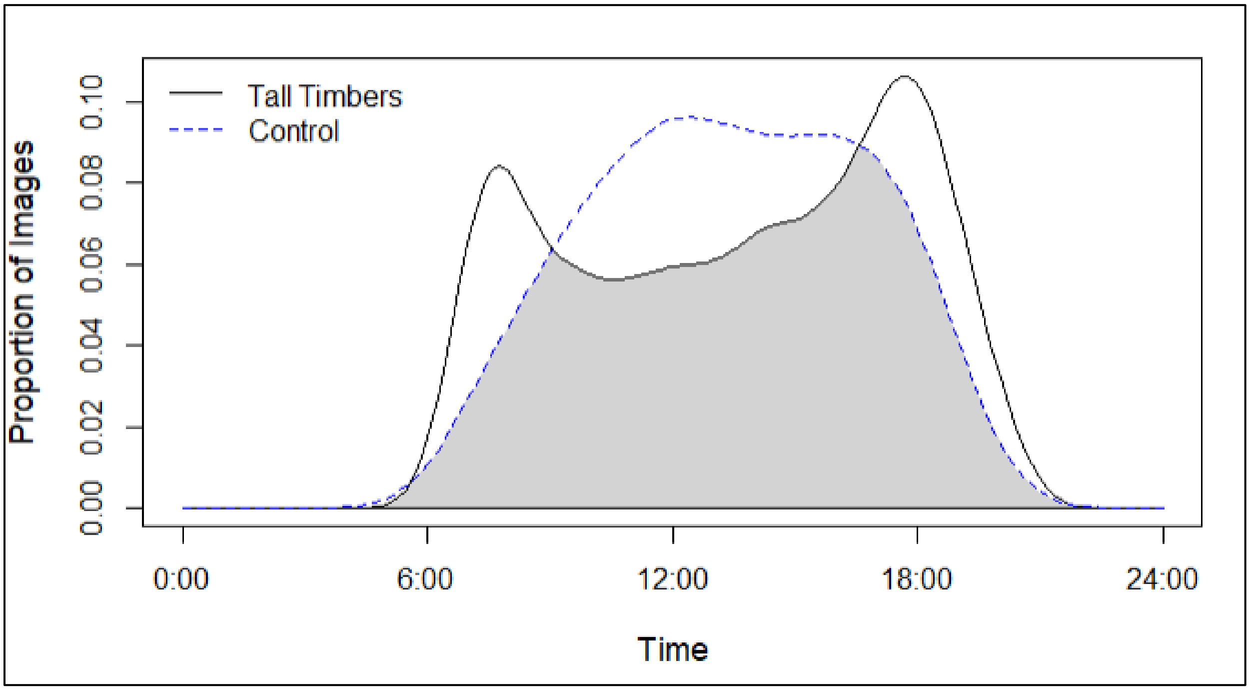


Figure 2.14. Activity patterns of eastern wild turkeys on Tall Timbers and the control. Tall Timbers had removed pigs for one year before we started monitoring. The control site did not have any pigs removed by Wildlife Services during January 2021-June 2022. The gray area indicates overlap between the two sites. Both sites were in North Florida and South Georgia, USA.

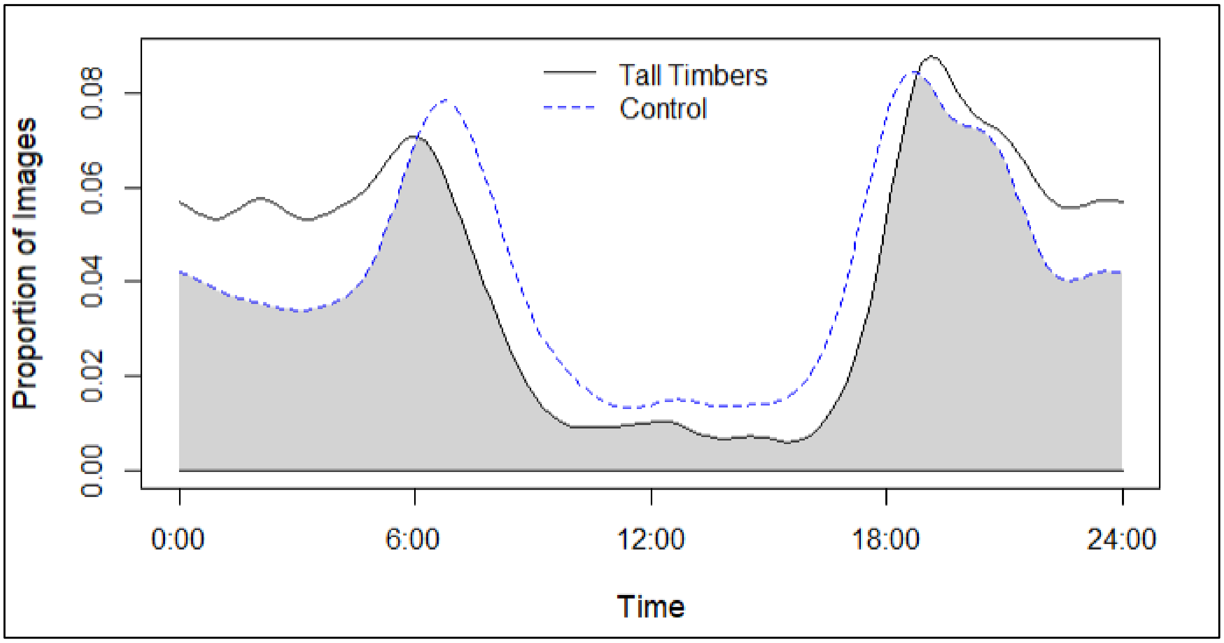


Figure 2.15. Activity patterns of white-tailed deer on Tall Timbers and the control. Tall Timbers began removing pigs one year prior to the start of our monitoring. The gray area indicates overlap between the two sites. The control site did not have any pigs removed by Wildlife Services during January 2021-June 2022.

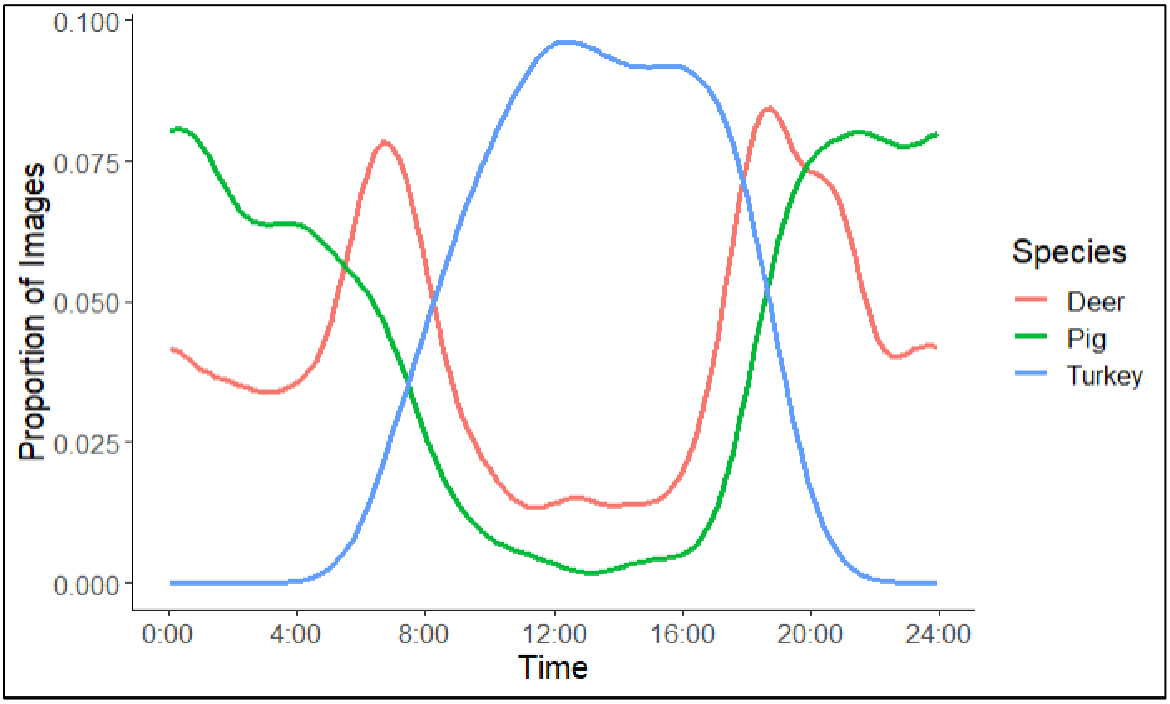


Figure 2.16. Activity patterns of wild pigs, white-tailed deer, and eastern wild turkeys on the control site, where no pigs had been removed by Wildlife Services during January 2021-June 2022 in North Florida and South Georgia, USA.

CHAPTER 3

ASSESSING EFFECTS OF WILD PIG REMOVAL ON DAMAGE TO NATIVE HABITAT*

---

*Hoskins, K. R., K. Sash, L. M. Conner, and M. T. Mengak. To be submitted to *Human-Wildlife Interactions*

ABSTRACT

Invasive wild pigs (*Sus scrofa*) are responsible for damaging multiple ecosystems across the globe. Wild pig damage can be the best indicator of their presence. Coordinating with removal efforts provided by USDA Wildlife Services, we surveyed 604 150m-line transects across nine private properties during October 2020 - July 2022 to assess the effects of pig reduction in the Red Hills region of northern Florida and southern Georgia on habitat features. We documented pig presence through observation of tracks, scat, rubs, wallows, rooting, and live individuals. We assessed the efficacy of wild pig removal efforts and evaluated available habitat use by pigs, deer, and turkey. We found a reduction in most damage types, excluding rubs correlating with pig removal. Pigs used agricultural and upland pine areas more than expected. Results found that consistent pig removal reduced damaging effects of pigs on a landscape.
INDEX WORDS: chi-squared test, damage, linear regression, line transect, pig trapping, Red Hills, *Sus scrofa*, wild pig, Wildlife Services

Introduction

Invasive wild pigs (*Sus scrofa*), hereafter "pigs," have caused a wide range of damage across North America and the Southeast is no exception (Bevins et al. 2014). Their body shape and foraging behavior allow them to modify native habitat composition and alter resources that are available to native species (Boughton and Boughton 2014, Keiter and Beasley 2017). Pig behaviors, such as rooting, wallowing, and tree rubbing, are examples of destructive activities. Pigs modify habitats by rooting, or upturning topsoil and leaf litter, to find food. This behavior may cause the most damage across various habitat types (Dickson 2001). Studies have shown that rooting alters soil chemistry and structure, accelerate erosion, and delay plant succession (Bratton 1975, Mungall 2001, Singer et al. 1982, Seward et al. 2004). Some studies have found rooting promotes plant growth in bulbs and rhizomes (Palacio et al. 2013). Arrington et al. (1993) found that rooting increased diversity and species richness in marshy wetland environments while decreasing broadleaf plant cover. While the effects of rooting on plant communities vary, native southeastern ecosystems are not adapted for this type of disturbance (Baber and Coblentz 1987).

Mayer et al. (2020) note that the two most significant areas impacted by pigs include agricultural and forestry/timber resources. Rooting damages landscapes, but pigs can also cause damage by trampling and consuming crops (Whitehouse 1999, West et al. 2009). Multiple studies found corn, soybeans, hay, cotton, and peanuts to be impacted by wild pigs, with results varying by state (Tanger et al. 2015, Anderson et al. 2016, Mengak 2016). While rooting can heavily impact resources, it may also act as the best indicator for wild pig presence (Mayer and Brisbin 2009).

Recognizing different types of pig sign and damage can be the first step towards managing for them (Campbell and Long 2009). Pig tracks can be difficult to identify. This is due to their resemblance to white-tailed deer (*Odocoileus virginianus*) tracks (Stevens 1996). Pig scat is also difficult to identify. This is because it can resemble that of a domestic dog, varying in size and shape (Stevens 1996). Wallows, tree rubs and mud left on trees are some of the more obvious types of pig damage that can be easier to note.

Wallows are shallow depressions in the ground, either naturally occurring or created from rooting (Gray et al. 2020). These depressions are typically found in low-lying, wet areas (Belden and Pelton 1976). Pigs lack sweat glands, so they will often use these depressions during warm months to thermoregulate (Stevens 1996, Eckert et al. 2019). However, pigs will also use wallows year-round (Stegeman 1938). Frequently used wallows have the potential to spread disease to native wildlife and contaminate riparian wetlands (Stevens 1996, Campbell and Long 2009, Eckert et al. 2019).

Rubs are a form of self-grooming in which a pig rubs its body on a sturdy structure like small trees, fence posts, fallen trees, and wooden poles (Stegeman 1938, Stevens 1996). Rubs are usually associated with wallows. The mud from the wallows immobilize ectoparasites and rubbing helps remove them (Mayer and Brisbin 2009). Rubs can impact timber by damaging trees. Stegeman (1938) observed tree mortality between 3-20 cm in diameter due to severe rubbing from pigs. Fern et al. (2020) also mentions that harsh rubbing can lead to tree girdling, or bark removal, of trees.

While pig removal is an accomplishment, an assessment of reduction in sign and damage over time should be performed to evaluate the effectiveness of removal efforts (Campbell and

Long 2009, Gaskamp et al. 2018). If an area is affected by pigs and management efforts are not implemented, then an increase in rooting, wallowing, rubs, and population will follow.

Our goal was to document any trends in pig sign and damage in response to reductions in the number of wild pigs across our study sites through a collaborative effort of corral-style trapping, aerial gunning, and night shooting (West et al. 2009, Williams et al. 2011, Davis et al. 2018, Lewis 2021). During these removal efforts, our study focused on measuring any changes in wild pig sign and damage through monthly field surveys then correlating the amount of sign with observations from game cameras.

Study Area

The Red Hills region of northern Florida and southern Georgia, USA is a biodiversity hotspot and supports a variety of land uses like recreational hunting, forestry, and agriculture (Noss et al. 2015, Elkins et al. 2019). Located within the Southeastern Coastal Plain, the Red Hills is situated between the Ochlockonee and Aucilla Rivers and covers 176,442 ha. The Ochlockonee River's tributaries include Telogia Creek and Sopchoppy River while the Aucilla River's tributaries include Little Aucilla River and Wacissa River. Major water bodies in the Red Hills include two sinkhole lakes. Lake Miccosukee is a 2,554-ha sinkhole lake in northern Jefferson County, Florida. Lake Iamonia is a 2,330-ha sinkhole lake in northern Leon County, Florida. Both lakes routinely fluctuate in water levels due to drought and drain into numerous sinkholes.

Our study was based at Tall Timbers Research Station (TTRS) in Tallahassee, FL, but occurred across nine privately owned properties within the Red Hills, including Tall Timbers. The private properties fell within Leon and Jefferson Counties, FL and Thomas County, GA, and covered 19,829 ha (Figure 2.1). Elevation ranged from 61 m to 85 m. Mean annual precipitation ranged from 2,422 mm to 2,485 mm during our study period (NOAA | Climate at a Glance). Mean monthly temperatures ranged between 9.6° C - 27.8° C in Thomas County, GA, and 10.5° C – 28.1° C in Leon and Jefferson County, FL (NOAA | Climate at a Glance).

The Red Hills region was divided into two sections – focal areas and landowner participation areas. Focal areas were parcels of privately-owned land that had a recent influx of pigs. Landowner participation areas, hereafter "study sites", were properties within the focal areas where our work occurred. The focal areas were determined through USDA APHIS Wildlife Services project leaders based on the size of the area, the pig density, and trapping efforts needed to meet our objectives (USDA APHIS | Farm Bill Projects). Each study site was managed similarly for northern bobwhite (*Colinus virginianus*) hunting in a pine-dominated (*Pinus sp.)* ecosystem. The properties were managed using single-tree selection silvicultural practices and frequent prescribed fire (Masters et al. 2007). All properties were on a one to three-year prescribed burn rotation which currently supports a regionally expansive population of northern bobwhite and one of the largest populations of gopher tortoises (*Gopherus polyphemus)* on private lands (Masters et al. 2007). Forest canopy consisted of longleaf pine (*Pinus palustris*), loblolly pine (*P. taeda*) and shortleaf pine (*P. echinata*), with scattered live oaks (*Quercus virginiana*). Forest groundcover included *Lespedeza spp*., golden rod (*Solidago spp*.), dogfennel (*Eupatorium spp.*), blackberry (*Rubus spp*.), American beautyberry (*Callicarpa americana*), and wiregrass (*Aristida stricta*). Small (0.20 – 4 ha) agricultural fields are spread across the properties with primary crops being cotton (*Gossypium spp*.) and peanuts (*Arachis spp.*). Common bottomland trees and plants included cypress (*Taxodium spp.*), tupelo (*Nyssa spp.*), red maple (*Acer rubrum*), American sweetgum (*Liquidambar styraciflua*), sparkleberry (*Vaccinium arboreum*), wax myrtle (*Myrica cerifera*), and holly (*Ilex spp.*) (Sash 2007).

Methods

Camera Deployment

Using ArcMap 10.8 (ESRI, Redlands, CA, USA), we created randomly generated points across a grid system of 100-acre blocks. Random points were used to determine the approximate location of 151-Moultrie M50 cameras (Pradco Outdoor Brands, Birmingham, Alabama, USA) across our study sites. Cameras were operational for about 21 months (October 2020 to July 2022). Camera locations were physically marked with flagging tape and georeferenced with a GPS location. We checked cameras on a monthly schedule with 1-3 study sites visited per week (Table 2.1). During each camera check we performed camera maintenance, cleared intruding vegetation, collected used SD cards, and recorded the number of new images taken.

Line Transect Sampling

For every camera deployed, we used ArcMap 10.8 to create four-line transects that extended outwards from the camera's location. Each transect ran 150 m in one cardinal direction (Figure 3.1) Transects were surveyed by a single observer who walked transects during monthly camera checks to identify and record any indication of pig presence. Observers surveyed the same transects every month to avoid double-counting old sign or damage. The observer would scan the transect for tracks, rooting, wallows, rubs, or scat and record it with ArcGIS Survey123 (ESRI, Redlands, CA, USA). If sign or damage was found, we recorded the following information into Survey123 – type of sign, latitude and longitude, approximate size (m^2) of any rooting, signs of other wildlife, a photograph of the sign, and the study site name.

Using a Red Hills region landcover layer provided by Tall Timbers Research Station (TTRS), we identified the habitat type in which each camera was deployed. Some landcover values did not accurately represent the habitats surrounding each camera. To alleviate this issue, we constructed 50m buffers around each camera location and classified its landcover as the dominant cover within that 50m buffer. Reclassified types included fields/pastures/ag (hereafter, agricultural areas), wetlands, planted pine, upland hardwoods, and upland pines. If no evidence of pigs or damage was seen, then no data were recorded. Data collected through Survey123 was stored digitally on the Survey123 website (ArcGIS | Survey123) and downloaded and backed up monthly.

Data analysis

We analyzed records collected between 01 January 2021 and 30 June 2022 because during this time, line transects were equally sampled. We divided our data into two categories: *Sign* and *Damage*. Sign included tracks and scat while damage included rooting, rubs, and wallows. We calculated how many sign and damage records were recorded per month. USDA Wildlife Services provided pig removal data showing the number of individuals removed from each study site per month. We used linear regression analysis and modeled the relationship between pig removal and sign and damage observations.

Following methods in Neu et al. (1974), we used the proportion of cameras and the proportion of images observed in each habitat category to find the expected number of animal images within each habitat category. We calculated 95% confidence intervals for the proportion of images observed. We hypothesize that pigs, deer and turkey utilized each habitat in proportion to its occurrence. We compared the use of each habitat to what was available. We did this to determine if pigs, deer, and turkey overused or under used habitat types in proportion to their availability. We also wanted to know if deer and turkey were avoiding habitats that pigs utilized more.

Results

We collected 936 observations from our transects. Of these, 649 were of rooting, 405 were of tracks, 57 were of rubs, 41 were of scat, and 28 were of wallows. There were 690 total records of sign and 490 of damage. The total exceeds 936 because some records included multiple observations (e.g., one record may have included rooting, scat, and tracks). Wildlife Services removed between 3 to over 300 pigs from various study sites with a total of 1,035 pigs taken during our study period.

Pig sign and damage relative to removal

Pig removal efforts had a significant impact on wild pig sign and wild pig damage observations ($P \leq 0.05$) (Figure 3.2 and Figure 3.2). Individually, pig removal reduced observations of pig tracks, pig scat, and pig wallows ($P \leq 0.05$). There was a reduction in pig rubs, but it was not significant ($P \geq 0.05$). This indicates that pig removal efforts were successful in reducing damage across our study sites.

Wild pig, deer, and turkey habitat use vs. availability

We collected 88,736 images. Of those images, 551 had timestamp errors and were discarded. We removed images taken between October 2020 – December 2020 and any images of non-target species from the remaining 88,185 images. Between 01 January 2021 and 30 June 2022, we recorded 45,681 images. Of these images, 37,201 were of white-tailed deer, 4,917 were of eastern wild turkey, and 3,563 were of wild pigs.

Our results suggest that wild pigs are using habitat significantly different from what was available ($X^2 = 752.54$; 4 df, $p < 0.0001$). We found a higher proportion of pig images in agricultural areas ($0.068 \leq p_1 \leq 0.086$) and areas with upland pine ($0.630 \leq p_5 \leq 0.662$). Comparatively, we found pigs avoiding wetlands ($0.003 \leq p_2 \leq 0.007$), planted pine ($0.038 \leq p_3 \leq 0.051$) and upland hardwood areas ($0.216 \leq p_4 \leq 0.244$) in proportion to availability (Table 3.1). White-tailed deer did not use available habitat as expected ($X^2 = 217.12$; 4 df, $p < 0.0001$). We found white-tailed deer avoiding agricultural areas ($0.021 \leq p_1 \leq 0.024$) and areas with planted pine ($0.138 \leq p_3 \leq 0.145$). However, deer preferred wetlands ($0.033 \leq p_2 \leq 0.036$), upland hardwoods ($0.268 \leq p_4 \leq 0.277$), and upland pines ($0.525 \leq p_5 \leq 0.535$) in proportion to availability (Table 3.2). Eastern wild turkeys also did not utilize habitat as much as expected ($X^2 = 442.31$; 4 df, $p < 0.0001$). Turkeys preferred upland hardwoods more than any other habitat category ($0.354 \leq p_4 \leq 0.381$). We found turkeys avoiding agricultural areas ($0.002 \leq p_1 \leq 0.005$), wetlands ($0.012 \leq p_2 \leq 0.019$), planted pine ($0.111 \leq p_3 \leq 0.130$) and upland pine ($0.480 \leq p_5 \leq 0.508$) (Table 3.3).

Discussion

Pig sign and damage relative to removal

Our results suggest that intensive pig removal can reduce the effects of wild pigs on a landscape. In time, a reduction in damage could potentially improve water quality, native plant recovery, and reduce disease spread (Cole et al. 2012, Keiter and Beasley 2017, Bolds et al. 2022). Apart from rubs, we found all observations of sign and damage significantly reduced. Landowners of our study sites also saw a reduction in pig sign and damage, supporting our results (Multiple landowners, personal comm.).

Wild pig, deer, and turkey habitat use vs. availability

We wild pigs using agricultural areas more than what was available. This was not surprising, as many studies have found wild pigs utilizing agricultural fields on a detrimental level (Mungall 2001, Seward et al. 2004, Snow et al. 2017, McKee et al. 2020). We also found a higher proportion of pig images in upland pine habitats. Wild pig home ranges can vary in size and stretch across multiple habitat types (Kay et al. 2017). Clontz et al. (2021) found male and female pigs selecting for upland pine habitat when studying the connection between behavioral state and resource selection.

We found pigs avoiding wetlands, contrary to other studies that found pigs frequently selecting for this habitat (Baber and Colblentz 1987, Choquenot and Ruscoe 2003, Keiter and Beasley 2017). This may have been because we had so few cameras in the wetland habitat, which was a reclassified combination of forested wetlands and open water. This could have also been because of active trapping pressure. We did not know where Wildlife Services set their traps. However, visual evidence and personal communication told us that many traps were placed near or along the edge of wetlands. Gaston et al. (2008) found that more pressure applied near wetlands pushed pigs in their study into pine forests because of the lack of human presence. This may also be the case in our study area.

White-tailed deer preferred wetlands, upland hardwoods, and upland pine. These results are similar to Hanberry (2021) who found an increase in deer density within deciduous mixed forests and woody wetlands when observing the relationship between regional deer densities and land classes. Hanberry (2021) also found deer densities decreased with agricultural developments, which aligns with our finding of deer slightly avoiding agricultural areas.

Wild turkeys heavily avoided agricultural areas in comparison to pigs and deer. However, they preferred upland hardwoods, an area where less pig images were observed. Previous literature has found deer and turkeys adjusting their space use in response to pig presence (Yarrow and Kroll 1989, Seward et al. 2004, Lewis 2021, Walters and Osbourne 2021).

Knowing which habitat pigs utilize will allow managers to better understand where to bait, trap, and remove pigs from their property. Pig habitat use can vary regionally, creating the need for local studies that account for variability. Deer and turkey did not use all habitat types equally given what was available. This could be due to overlapping habitat use between pigs, deer, and turkey potentially causing displacement and competition for resources. It is important to know where these areas are to prioritize reduction methods like whole sounder removal and limit these negative interactions.

Management Implications

Our study suggests that removing wild pigs from an area will reduce the amount of pig sign and damage seen on a landscape, as we expected. Reduction in damage is the highest priority because costs associated with damage to resources can also be greatly reduced with removal. Particularly in our study area, crops, roads, fishing ponds, and wildlife plantings are most affected by pig damage. Our results found which habitats pigs used the most, given what was available in our study area. These areas of high value should be monitored and managed consistently if managers wish to reduce potential losses. Although pig sign is not as damaging, identifying tracks and scat in the field can assist managers in monitoring wild pig presence. For example, a reduction in pig sign could indicate a reduction in abundance. This could allow deer and turkey to use all habitat types without having to avoid wild pigs.

Literature Cited

Anderson, A., C. Slootmaker, E. Harper, J. Holderieath, and S. A. Shwiff. 2016. Economic estimates of feral swine damage and control in 11 states. Crop Protection 89:89–94.

Arrington, D. A., L. A. Toth, and J. W. Koebel Jr. 1999. Effects of rooting by feral hogs Sus scrofa L. on the structure of a floodplain vegetation assemblage. Wetlands 19: 535–544.

Baber, D. W., and B. E. Coblentz. 1987. Diet, nutrition, and conception in feral pigs on Santa Catalina Island. Journal of Wildlife Management 51:306–317.

Belden, R., and M. Pelton. 1976. Wallows of the European wild hog in the mountains of east Tennessee. Journal of Tennessee Academy of Science 51:91–93.

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.

Bolds, S. A., B. G. Lockaby, L. Kalin, S. S. Ditchkoff, M. D. Smith, and K. C. VerCauteren. 2022. Wild pig removal reduces pathogenic bacteria in low-order streams. Biological Invasions:1–11.

Boughton, E. H. and R. K. Boughton. 2014. Modification by an invasive ecosystem engineer shifts a wet prairie to a monotypic stand. Biological Invasions 16: 2105–2114.

Bratton, S. P. 1975. The effects of the European wild boar, *Sus scrofa*, on gray beech forest in the Great Smoky Mountains. Ecology 56: 1356–1366.

Campbell, T. A., and D. B. Long. 2009. Feral swine damage and damage management in forested ecosystems. Forest Ecology and Management 257:2319–2326.

Choquenot, D., and W.A. Ruscoe. 2003. Landscape complementation and food limitation of large herbivores: Habitat-related constraints on the foraging efficiency of wild pigs. Journal of Animal Ecology 72:14-26

Clontz, L. M., K. M. Pepin, K. C. VerCauteren, and J. C. Beasley. 2021. Scientific Reports 11:1–14.

Cole, R. J., C. M. Litton, M. J. Koontz, and R. K. Loh. 2012. Vegetation recovery 16 years after feral hog removal from a wet Hawaiian forest. Biotropica 44:463–471.

Davis, A. J., B. Leland, M. Bodenchuk, K. C. VerCauteren, and K. Pepin. 2018. Costs and effectiveness of damage management of an overabundant species (*Sus scrofa*) using aerial gunning. Wildlife Research 45:696–705.

Dickson, J. G. 2001. Pages 191-208 *in* J. G. Dickson, editor. Wildlife of Southern Forests: Habitat and Management. Hancock House Publishers, Blaine, Washington, USA.

Eckert, K. D., D. A. Keiter, and J. C. Beasley. 2019. Animal visitation to wild pig (*Sus scrofa*) wallows and implications for disease transmission. Journal of Wildlife Diseases 55:488–493.

Elkins, D., S. C. Sweat, B. R. Kuhajda, A. L. George, K. S. Hill, and S. J. Wenger. 2019. Illuminating hotspots of imperiled aquatic biodiversity in the southeastern US. Global Ecology and Conservation 19: e00654. https://doi.org/10.1016/j.gecco.2019.e00654.

Fern, M. P., J. B. Armstrong, R. J. Barlow, and J. S. Kush. 2020. Ecological factors influencing wild pig damage to planted pine and hardwood seedlings. Human-Wildlife Interactions 14: 228–238.

Gaskamp, J. A., K. L. Gee, T. A. Campbell, N. J. Silvy, and S. L. Webb. 2018. Damage caused to rangelands by wild pig rooting activity is mitigated with intensive trapping. Cogent Environmental Science 4:1–9.

Gaston, W., J. B. Armstrong, W. Arjo, and H. L. Stribling. 2008. Home range and habitat use of feral hogs (Sus scrofa) on Lowndes County WMA, Alabama. National Conference on Feral Hogs: 1–17.

Gray, S. M., G. J. Roloff, R. A. Montgomery, J. C. Beasley, and K. M. Pepin. 2020. Wild pig spatial ecology and behavior. Pages 33-56 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

Hanberry, B. B. 2021. Addressing regional relationships between white-tailed deer densities and land classes. Ecology and Evolution 11:13570–13578.

Kay, S. L., J. W. Fischer, A. J. Monaghan, J. C. Beasley, R. Boughton, T. A. Campbell, S. M. Cooper, S. S. Ditchkoff, S. B. Hartley, J. C. Kilgo, S. M. Wisley, A. C. Wyckoff, K. C. VerCauteren, and K. M. Pepin. 2017. Quantifying drivers of wild pig movement across multiple spatial and temporal scales. Movement Ecology 5:1–15.

Keiter, D. A., and J. C. Beasley. 2017. Hog heaven? Challenges of managing introduced wild pigs in natural areas. Natural Areas Journal 37:6–16.

Lewis, A. A. 2021. Pigs by the Sounder: wild pigs, whole sounder removal, and their effects on deer and turkey. Thesis, Auburn University, Auburn, Alabama, USA.

Masters, R. E., K. Robertson, W. E. Palmer, J. Cox, K. McGorty, L. Green, and C. Ambrose. 2007. Red hills forest stewardship guide. Tall Timbers Research Station and Land Conservancy Miscellaneous Publication, 12, Tallahassee, Florida, USA.

Mayer, J. J., and I. L. Brisbin Jr., editors. 2009. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, SRNL-RP-2009-00869, Aiken, South Carolina, USA.

Mayer, J. J, J. C. Beasley, R. K. Boughton, and S. S. Ditchkoff. 2020. Wild pigs in southeastern North America. Pages 369–402 *in* K. C. VerCauteren, J. C. Beasley, J. J. Mayer, S. S. Ditchkoff, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: Ecology, impacts, and management. CRC Press, Boca Raton, Florida, USA.

McKee, S., A. Anderson, K. Carlisle, and S. A. Shwiff. 2020. Economic estimates of invasive wild pig damage to crops in 12 US states. Crop Protection 132:1–12.

Mengak, M. T. 2016. Landowner opinions regarding wild pigs in Georgia, USA. Proceedings of the Vertebrate Pest Conference 27:162–169.

Mungall, E. C. 2001. Pages 736–764 *in* S. Demarais and P. R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA.

Neu, C. W., R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data. The Journal of Wildlife Management 38:541–545.

Noss, R. F., W. J. Platt, B. A. Sorrie, A. S. Weakley, D. B. Means, J. Costanza, and R. K. Peet. 2015. How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. Biodiversity Viewpoint 21:236–244.

Palacio, S., C. G. Bueno, J. Azorin, M. Maestro, and D. Gomez-Garcia. 2013. Wild-boar disturbance increases nutrient and C stores of geophytes in subalpine grasslands. American Journal of Botany 100: 1790–1799.

Sash, K. J. 2007. Snake ecology of the red hills region of south Georgia and north Florida. Thesis, University of Georgia, Athens, Georgia, USA.

Seward, N. W., K. C. VerCauteren, G. W. Witmer, and R. M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep and Goat Research Journal 19: 34–40.

Singer, F. J., W. T. Swank, and E. E. C. Clebsch. 1982. Some ecosystem responses to European wild boar rooting in a deciduous forest. Research/Resource Management Report No. 54. U.S. Department of the Interior, National Park Service, SERO, Atlanta, GA, USA.

Snow, N. P., M. A. Jarzyna, and K. C. VerCauteren. 2017. Interpreting and predicting the spread of invasive wild pigs. Journal of Applied Ecology 54:2022–2032.

Stegeman, L. C. 1938. The European wild boar in the Cherokee National Forest, Tennessee. Journal of Mammalogy 19:279–290.

Stevens, R.L., 1996. The Feral Hog in Oklahoma. Samuel Roberts Noble Foundation, Ardmore, OK, USA.

Tanger, S. M., K. Guidry, H. Nui, C. Richard, and M. Abreu. 2015. Dollar estimates of feral hog damage to agriculture in Louisiana. Research Information Sheet 113, Agricultural Economics and Agribusiness, Louisiana State University, Baton Rouge, LA, USA.

Walters C. M., and D. C. Osborne. 2021. Occurrence patterns of wild turkeys altered by wild pigs. Wildlife Society Bulletin 46:1–15.

Whitehouse, D. B. 1999. Impacts of feral hogs on corporate timberlands in the southeastern United States. Pages 108–110 *in* Proceedings of the 1999 Feral Swine Symposium, Ft. Worth, Texas, USA.

Williams, B. L., R. W. Holtfreter. S. S. Ditchkoff, and J. B. Grand. 2011. Trap style influences wild pig behavior and trapping success. Journal of Wildlife Management 75:432–436.

West, B. C., A. L. Cooper, and J. B. Armstrong. 2009. Managing wild pigs: A technical guide. Human-Wildlife Interactions Monograph 1:1–55.

Yarrow, G. K., and J. C. Kroll. 1989. Coexistence of white-tailed deer and feral hogs: management implications. Southeast Deer Study Group 12:13–14.

Table 3.1. Wild pig habitat utilization during January 2021-June 2022 in the Red Hills region of North Florida and South Georgia, USA based on a total of 3,563 camera images.

Habitat	Total cameras	Proportion of total cameras	Number of pig images	Expected number of pig images	Proportion observed in each habitat	95 % confidence interval on proportion of observed
Agriculture	4	0.026	272	94.384	0.076	$0.068 \leq p_1 \leq 0.086$
Wetland	4	0.026	16	94.384	0.004	$0.003 \leq p_2 \leq 0.007$
Planted Pine	23	0.152	157	542.709	0.044	$0.038 \leq p_3 \leq 0.051$
Upland Hardwood	38	0.252	817	896.649	0.229	$0.216 \leq p_4 \leq 0.244$
Upland Pine	82	0.543	2301	1934.874	0.646	$0.630 \leq p_5 \leq 0.662$
Total	151		3563	3563		

Table 3.2. White-tailed deer habitat utilization during January 2021-June2022 in the Red Hills region of North Florida and South Georgia, USA based on 37,201 camera images.

Habitat	Total cameras	Proportion of total cameras	Number of deer images	Expected number of deer images	Proportion observed in each habitat	95% confidence interval on proportion of observed
Agriculture	4	0.026	836	985.457	0.022	$0.021 \leq p_1 \leq 0.024$
Wetland	4	0.026	1281	985.457	0.034	$0.033 \leq p_2 \leq 0.036$
Planted Pine	23	0.152	5253	5666.377	0.141	$0.138 \leq p_3 \leq 0.145$
Upland Hardwood	38	0.252	10131	9361.841	0.272	$0.268 \leq p_4 \leq 0.277$
Upland Pine	82	0.543	19700	20201.868	0.530	$0.525 \leq p_5 \leq 0.535$
Total	151		37201	37201		

Table 3.3. Eastern wild turkey habitat utilization during January 2021-June 2022 in the Red Hills region of North Florida and South Georgia, USA based on a total of 4, 917 camera images.

Habitat	Total cameras	Proportion of total cameras	Number of turkeys images	Expected number of turkey images	Proportion observed in each habitat	Confidence interval on proportion of observed
Agriculture	4	0.026	14	130.252	0.003	$0.002 \leq p_1 \leq 0.005$
Wetland	4	0.026	76	130.252	0.015	$0.012 \leq p_2 \leq 0.019$
Planted Pine	23	0.152	592	748.947	0.120	$0.111 \leq p_3 \leq 0.130$
Upland Hardwood	38	0.252	1806	1237.391	0.367	$0.354 \leq p_4 \leq 0.381$
Upland Pine	82	0.543	2429	2670.159	0.494	$0.480 \leq p_5 \leq 0.508$
Total	151		4917	4917		

Figure 3.1. An example of our sampling scheme at Tall Timbers Research Station in Tallahassee, Florida, USA. Cameras are located at the center of the cross section with transects radiating in each cardinal direction.

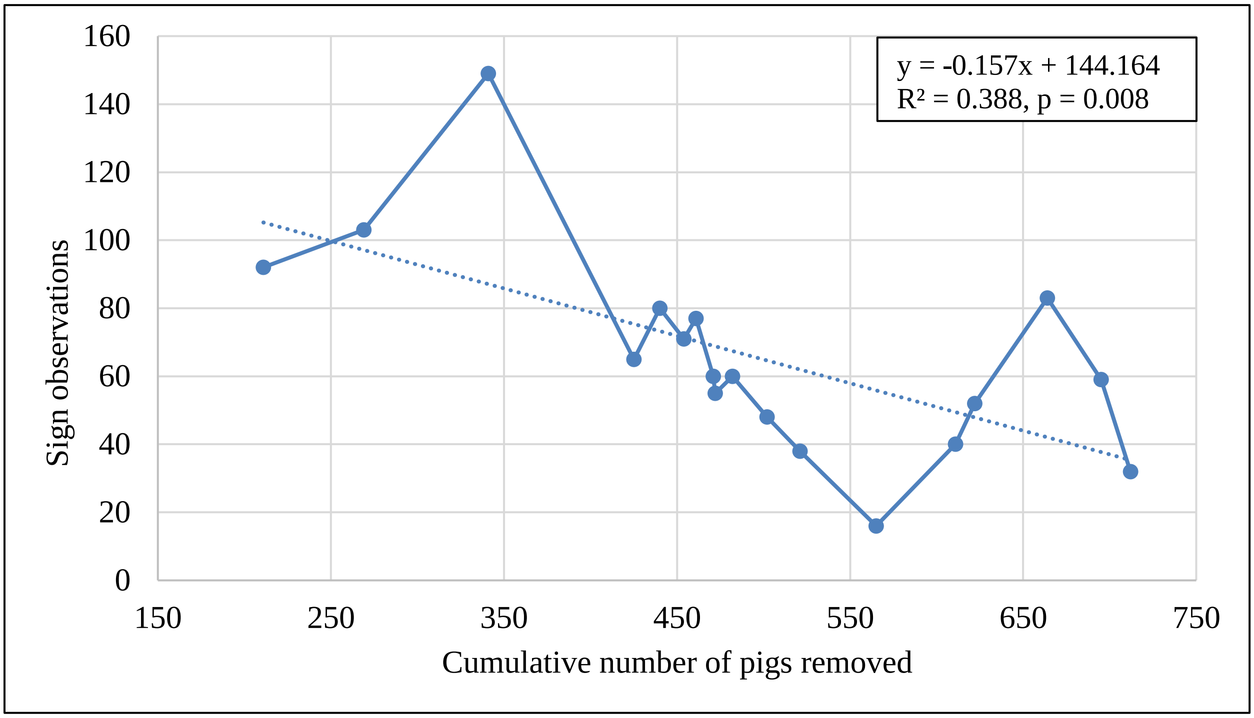


Figure 3.2 Monthly wild pig sign observations (tracks and scat) from line transect surveys plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022.

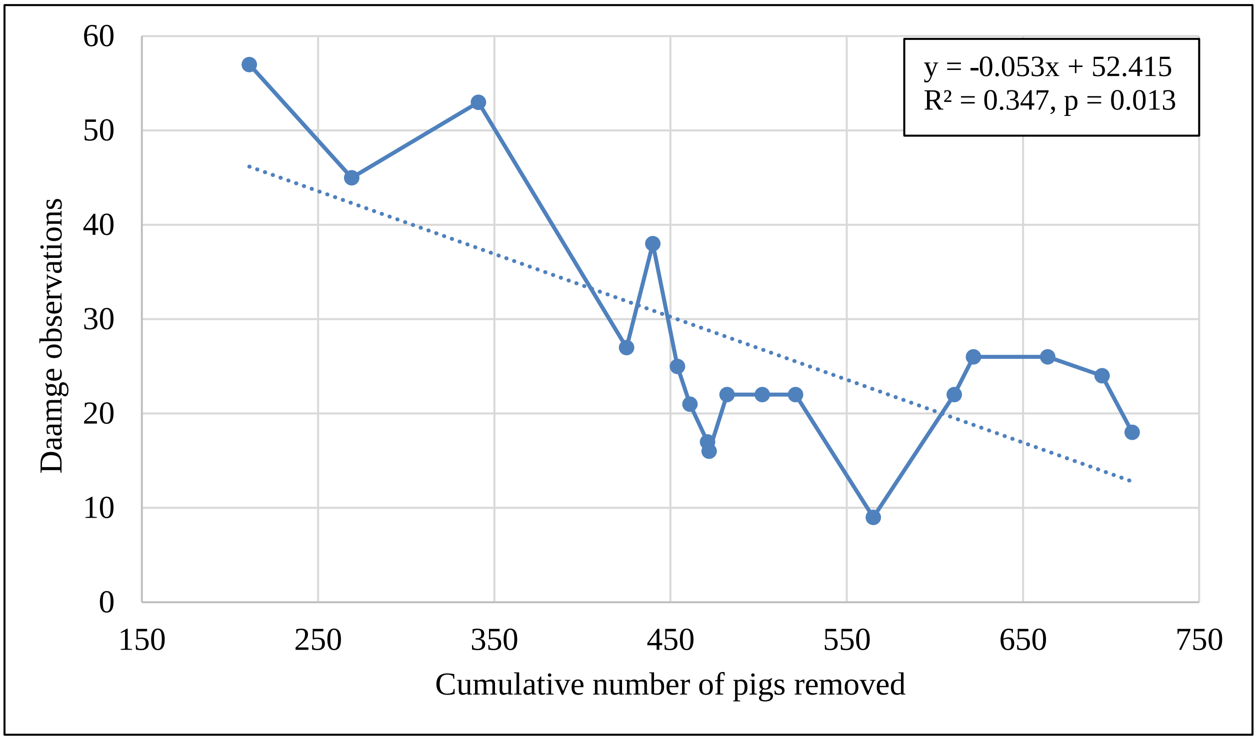


Figure 3.3. Monthly wild pig damage observations (rubs, wallows, and rooting) from line transect surveys plotted against cumulative number of pigs removed (solid line) from our study sites in North Florida and South Georgia, USA, during January 2021-June 2022.

CHAPTER FOUR

CONCLUSION

Knowing how to monitor an invasive species can help researchers and managers learn how and where they can best utilize their time and resources. Wild pigs (*Sus scrofa*) are an invasive mammal that can negatively impact native species like eastern wild turkeys (*Meleagris gallopavo)* and white-tailed deer (*Odocoileus virginianus*) and damage natural and agricultural resources. Depending on the forage and soil type, pigs can root up to a meter beneath the soil surface in search of food (Mayer and Brisbin 2009). If left unmanaged, wild pig populations can spread and severely damage landscapes over time. Our study focused on evaluating and refining wild pig management and control methods. During October 2020 - July 2022, in conjunction with removal efforts provided by USDA APHIS Wildlife Services, we deployed a trail camera and line transect survey across nine private properties to monitor the effects of wild pig reduction in the Red Hills region of northern Florida and southwest Georgia.

Using image data from 151 cameras, we explored how pigs impacted white-tailed deer and eastern wild turkeys because of their importance as game species in our study area. Previous studies have documented negative behavior between pigs, deer and turkeys (Taylor and Hellgren 1997, Elston and Hewitt 2010, Keever 2014). In their native and introduced ranges, pigs are omnivorous generalists with plant matter making up 85-90% of their diets (Rabolli 1983, Schely and Roper 2003, Sweeney et al. 2003, Ballari and Barrios-Garica 2014). This includes seasonally available hard and soft mast, which tend to be consumed in large quantities (Graves 1984, Elston and Hewitt 2010, Barrios-Garcia and Ballari 2012). Dietary overlaps between pigs, deer, and turkeys can lead to competition and interspecific aggression, especially during years of low-mast production (Wood and Barrett 1979, Grether et al. 2017, McDonough et al. 2022). Some studies have documented this behavior, along with pigs excluding white-tailed deer from pulse food resources, like bait piles and acorns (Taylor and Hellgren 1997, Elston and Hewitt 2010, Keever 2014).

We collected over 45,000 images of pigs, deer, and turkeys. We divided the images into three categories: before removal, during removal, and after removal. Wildlife Services removed pigs from all but one of our study sites for varying lengths of time. We referred to this site as our control site. Using an activity pattern analysis, we found deer and turkey activity patterns shifting before, during, and after pig removal occurred across all study sites. On the control site, we found turkeys shifting their regular activity to completely avoid pigs. We also found deer to be less active in the morning on the control site compared to the evening. Using a linear regression analysis, we found pig removal by Wildlife Services to significantly reduce the number of pig images collected per month and the number of individual pigs counted per month. Pig removal did not have an impact on the mean number of pigs per image. We did not observe pig removal impacting the monthly number of deer images, individual deer counted per month, or mean number of monthly deer observations. Eastern wild turkeys were also unaffected by pig removal efforts. There was no impact on the monthly number of turkey images, individual turkeys counted per month, or mean number of monthly turkey observations.

Wild pigs can easily damage various types of landscapes and habitats (Bevins et al. 2014). Pigs modify habitats by rooting, or upturning topsoil and leaf litter, to find food. This behavior may cause the most damage (Dickson 2001). Studies have shown rooting to alter soil chemistry and structure, accelerate erosion, and delay plant succession (Bratton 1975, Mungall 2001, Singer et al. 1982, Seward et al. 2004). Multiple studies and surveys have found corn, soybeans, hay, cotton, and peanuts to be some of the most impacted by wild pigs, with results varying by state (Tanger et al. 2015, Anderson et al. 2016, Mengak 2016). While rooting can heavily impact various crops and natural lands, it may also act as the best indicator for wild pig presence (Mayer and Brisbin 2009).

Using line transect survey data, we quantified the amount of wild pig sign and damage in different habitat types while pigs were being removed. Transects were surveyed by a single observer who walked the transects during monthly camera checks to identify and record any indication of pig presence. The observer scanned for tracks, rooting, wallows, rubs, or scat. We used linear regression analysis and modeled the relationship between pig removal and sign and damage observations. With our camera locations and image data, we used a chi-square analysis to find the proportion of each camera in each habitat category, the expected number of animal images within each habitat category, and the proportion of images observed in each habitat category. We collected 936 observations. There were 690 total records of sign and 490 of damage. The linear regression found pig removal having a significant impact on wild pig sign and wild pig damage observations. Individually, pig removal reduced observations of pig tracks, pig scat, and pig wallows. There was a reduction in pig rubs, but it was not significant. This suggests that pig removal was successful in reducing damage (rooting, rubs, wallows) across our study sites. The chi-square analysis found wild pigs, white-tailed deer, and eastern wild turkeys not using the available habitat types. We found a higher proportion of pig images in agricultural areas. This indicates that pigs used agricultural habitats more than what was available. This was not unusual, as many studies have found wild pigs utilizing agricultural fields on a detrimental level (Mungall 2001, Seward et al. 2004, Snow et al. 2017, McKee et al. 2020). We found pigs avoiding wetlands, contrary to other studies that found pigs frequently selecting for this habitat type (Baber and Colblentz 1987, Choquenot and Ruscoe 2003, Keiter and Beasley 2017). White-tailed deer preferred wetlands, upland hardwoods, and upland pine. These results are like Hanberry (2021) who found an increase in deer density within deciduous mixed forests and woody wetlands when observing the relationship between regional deer densities and land classes. Hanberry (2021) also found deer densities decreasing with agricultural developments, which aligns with our finding of deer slightly underusing agricultural areas. We saw similar results with wild turkeys. Turkeys avoided agricultural areas in comparison to pigs and deer. However, they preferred upland hardwoods, an area where less pig images were observed. Previous literature has found deer and turkeys adjusting their space use in response to pig presence (Yarrow and Kroll 1989, Seward et al. 2004, Lewis 2021, Walters and Osbourne 2021).

Our combined results suggest that intensive wild pig removal can benefit native wildlife by reducing competition and displacement, reduce damage to natural resources, and overall improve habitat quality of our study area. We suggest that landowners and managers who depend on crop production and game hunting as a source of income to consistently monitor for wild pigs and their sign/damage year-round. Our data provides information on where pigs utilize their time and space given what habitat is available. Our methods could be used to identify vulnerable areas where pigs may be present and where a combination of whole-sounder removal via corral-style trapping and necessary night shooting could be applied.

Literature Cited

Anderson, A., C. Slootmaker, E. Harper, J. Holderieath, and S. A. Shwiff. 2016. Economic estimates of feral swine damage and control in 11 states. Crop Protection 89:89–94.

Baber, D. W., and B. E. Coblentz. 1987. Diet, nutrition, and conception in feral pigs on Santa Catalina Island. Journal of Wildlife Management 51:306–317.

Ballari, S. A., and M. N. Barrios-Garcia. 2014. A review of wild boar Sus scrofa diet and factors affecting food selection in native and introduced ranges. Mammal Review 44:124–134.

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.

Bratton, S. P. 1975. The effects of the European wild boar, *Sus scrofa*, on gray beech forest in the Great Smoky Mountains. Ecology 56: 1356–1366.

Choquenot, D., and W.A. Ruscoe. 2003. Landscape complementation and food limitation of large herbivores: Habitat-related constraints on the foraging efficiency of wild pigs. Journal of Animal Ecology 72:14-26

Dickson, J. G. 2001. Pages 191-208 *in* J. G. Dickson, editor. Wildlife of Southern Forests: Habitat and Management. Hancock House Publishers, Blaine, Washington, USA.

Elston, J. J., and D. G. Hewitt. 2010. Intake of mast by wildlife in Texas and the potential for competition with wild boars. The Southwestern Naturalist 55:57–66.

Graves, H. B. 1984. Behavior and ecology of wild and feral swine (Sus scrofa). Journal of Animal Science 58:482–492.

Grether, G. F., K. S. Pieman, J. A. Tobias, and B. W. Robinson. 2017. Causes and consequences of behavioral interference between species. Trends in Ecology and Evolution 32:760–772.

Hanberry, B. B. 2021. Addressing regional relationships between white-tailed deer densities and land classes. Ecology and Evolution 11:13570–13578.

Keever, A. C. 2014. Use of N-mixture models for estimating white-tailed deer populations and impacts of predator removal and interspecific competition. Thesis, Auburn University, Auburn, Alabama, USA.

Keiter, D. A., and J. C. Beasley. 2017. Hog heaven? Challenges of managing introduced wild pigs in natural areas. Natural Areas Journal 37:6–16.

Lewis, A. A. 2021. Pigs by the Sounder: Wild pigs, whole sounder removal, and their effects on deer and turkey. Thesis, Auburn University, Auburn, Alabama, USA.

Mayer, J. J., and I. L. Brisbin Jr., editors. 2009. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, SRNL-RP-2009-00869, Aiken, South Carolina, USA.

McDonough, M. T., S. S. Ditchkoff, M. D. Smith, and K. C. VerCauteren. 2022. A review of the impacts of invasive wild pigs on native vertebrates. Mammalian Biology 102:279–290.

McKee, S., A. Anderson, K. Carlisle, and S. A. Shwiff. 2020. Economic estimates of invasive wild pig damage to crops in 12 US states. Crop Protection 132:1–12.

Mengak, M. T. 2016. Landowner opinions regarding wild pigs in Georgia, USA. Proceedings of the Vertebrate Pest Conference 27: 162–169.

Mungall, E. C. 2001. Pages 736–764 *in* S. Demarais and P. R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA.

Rabolli, C.V. 1983. Nutritional evaluation of the feral hog diet on Hobcaw Barony. Thesis, Clemson University, Clemson, South Carolina, USA.

Schley, L, and T. J. Roper. 2003. Diet of wild boar Sus scrofa in Western Europe, with particular reference to consumption of agricultural crops. Mammal Review 33:43–56.

Seward, N. W., K. C. VerCauteren, G. W. Witmer, and R. M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep and Goat Research Journal 19: 34–40.

Singer, F. J., W. T. Swank, and E. E. C. Clebsch. 1982. Some ecosystem responses to European wild boar rooting in a deciduous forest. Research/Resource Management Report No. 54. U.S. Department of the Interior, National Park Service, SERO, Atlanta, GA, USA.

Snow, N. P., M. A. Jarzyna, and K. C. VerCauteren. 2017. Interpreting and predicting the spread of invasive wild pigs. Journal of Applied Ecology 54:2022–2032.

Sweeney, J. R., J. M. Sweeney, and S. W. Sweeney. 2003. Feral hog. Pages 1164–1179 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America. Johns Hopkins University Press, Baltimore, Maryland, USA.

Tanger, S. M., K. Guidry, H. Nui, C. Richard, and M. Abreu. 2015. Dollar estimates of feral hog damage to agriculture in Louisiana. Research Information Sheet 113, Agricultural Economics and Agribusiness, Louisiana State University, Baton Rouge, LA, USA.

Taylor, R. B., and E. C. Hellgren. 1997. Diet of feral hogs in western south Texas plans. The Southwestern Naturalist 42: 33–39.

Walters C. M., and D. C. Osborne. 2021. Occurrence patterns of wild turkeys altered by wild pigs. Wildlife Society Bulletin 46:1–15.

Wood, G. W., and R. H. Barrett. 1979. Status of wild pigs in the United States. Wildlife Society Bulletin 36:237–246.

Yarrow, G. K., and J. C. Kroll. 1989. Coexistence of white-tailed deer and feral hogs: management implications. Southeast Deer Study Group 12:13–14.