Federal Collaboration through Feral Swine Eradication: A Success Story for Enhanced Biodiversity

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ABSTRACT: Feral swine are a threat to native species and their habitats as well as human health and safety. Feral swine destroy crucial habitat for migratory birds, reptiles, and other animals, especially endangered ground nesting species and protected snakes that are predated on or trampled by feral swine. Feral swine wallowing and rooting behaviors destroy native vegetation and lead to the spread of invasive plant species and soil erosion, which reduces water quality. They also compete with native species for resources such as food and space, leading to a loss of biodiversity. Havasu National Wildlife Refuge (Havasu NWR or refuge) was established in 1941 as a refuge and breeding ground for migratory birds and other wildlife. It encompasses 37,515 acres along the Colorado River, with 47% designated as wilderness. Feral swine escaped from nearby farms and were possibly released for hunting stock in the early 1900s and have since become invasive as their range expanded into Havasu NWR. The U.S. Department of Agriculture's Animal and Plant Health Inspection Service, Wildlife Services, partnered with the U.S. Fish and Wildlife Service to eradicate feral swine from the refuge to combat their negative impacts on critical wetland habitat, wildlife, and human safety. The eradication program uses almost every method available for feral swine removal. After almost a decade of progress it is estimated that the refuge is down to less than five animals. The program has brought together two federal departments to create a wildlife conservation success story.

KEY WORDS: Arizona, endangered species, eradication, feral pigs, Havasu National Wildlife Refuge, history, *Sus scrofa*, wildlife conservation

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INTRODUCTION

The negative impacts of invasive feral swine (*Sus scrofa*) have been well- documented throughout Arizona and around the world. Feral swine include Eurasian wild boars, pot-bellied pigs, escaped and domestic swine as well as hybrids of these species. Other common names include wild pigs, feral pigs, wild boars, or wild hogs, but regardless of the term applied, these animals are destructive, harmful, and invasive species.

To meet the species protection and enhancement goals for the Havasu National Wildlife Refuge (NWR), refuge staff and U.S. Department of Agriculture, Animal and Plant Health Inspection Service-Wildlife Services (USDA-APHIS-WS) cooperatively strive to maintain feral swine at zero population levels in collaboration with the USDA-APHIS-WS National Feral Swine Damage Management Program. This program was developed as a national response to reduce, and where possible, eliminate, the risks and damages inflicted by feral swine to agriculture, natural resources, property, and human health.

HISTORICAL INTRODUCTION OF FERAL SWINE IN ARIZONA

The first swine to the New World were brought by Christopher Columbus on his second voyage in 1493, when he disembarked eight swine in Cuba (Bennett 1970). Hernán Cortés, conqueror of the Aztec empire, relied on supplies of swine when he set out from Cuba in 1519 to Mexico (Zadik 2005). The three animals that were essential to the Spanish soldiers during the conquest of the Americas: the horse (*Equus caballus*), the dog (*Canis lupus familiaris*), and the domestic swine. They form what Morales Padrón called, "la trilogía animal de la conquista" (Padron 1974). Once the conquest was completed and he was in control of Mexico, Cortés sent for additional livestock, including domestic swine, to be brought from Santo Domingo, Jamaica, and Cuba (Padron 1952). Following the conquest of Mexico, Francisco Vázquez de Coronado started in 1541 from the town of Compostela on an expedition that took him up eastern Arizona to Bernalillo in New Mexico and northeast nearly to what is now Wichita in Kansas (Bennett 1970).

The key to Spain's ability to conquer a multitude of individuals was its success in feeding its army. Domestic swine provided a highly productive, reliable, and mobile food sources for the conquistadors. Domestic wine adapted both to the tropical humidity as well as the mountains and dry land. Through varying North American terrain, the swine continued keeping up with the soldiers and finding novel food sources as they went (Zadik 2005). Swine were lost along the way by their Spanish or Native American caretakers or escaped from their holding areas (Zadik 2005).

Following the Spanish conquistadors, the next influx of animals going feral were domestic swine that came with the establishment of Spanish missions in the southwest United States and northwest Mexico. Father Eusebio Francisco Kino lead the establishment of 20 Spanish missions throughout northwest Mexico and the southwest United States. To ensure the missions were successful, Father Kino provided each mission with a variety of livestock including domestic swine. Establishing missions weren't without inherent risks as Native Americas often attacked the mission including stealing or running off their livestock (Olsen 1974). Archaeologists identified swine bones representing large individuals in excavations at the site of the mission. Large individuals of the European swine were also noted from another Colonial Spanish site at Awatovi Mission near Canyon, Arizona, which is in a more desert environment than present at San Xavier (Olsen 1974). Swine remains were part of the assemblage of zooarchaeological remains from San Miguel de Guevavi (Gillespie 1992), established by Father Kino in 1691. Several missions were abandoned on the Spanish frontiers due to continued hostilities. The Western Archeological and Conservation Center confirmed that swine were part of the livestock at the missions in 1991. The group identified multiple bone fragments found during the archaeological excavation including bones from swine (Pavao-Zuckerman and LaMotta 2007). Additional zooarchaeological remains were identified in research from the Tucson Presidio and indicated that the Spanish military diet included swine when they moved the garrison from Tubac to Tucson (Diehl and Waters 2004). The environmental tolerances of domesticated animal species such as swine likely explain their regional representation at early historical period sites prior to selective breeding for tolerant stocks. Reitz (1992) demonstrated that the adoption of domesticated animal species in colonial settings was dependent on a variety of ecological variables including temperature, humidity, primary production, predation, and the presence of ruminant diseases in wild ungulates. Swine and chickens are considered relatively low maintenance domesticates as they are highly adaptable to a multitude of environments and feed. These animals predominate at sites in the tropical and subtropical environments of the Caribbean and the Southeast (e.g., Reitz 1992, 1993).

Since the late 1880s to present, a population of feral swine has been reported to exist along the Colorado River bordering Arizona and California below the city of Needles, California south towards the Mexican border. In the 1890s, feral swine were estimated to number in the thousands of animals and the population originated from free-range domestic stock (The New York Times 1894). By 1887, promotors were recommending grazing of swine on alfalfa fields in Arizona as an enticement to move to Arizona for the good weather and ease of implementing agriculture (Sokol 1993). The relative increase of livestock in the number of horses, mules, asses, swine, and goats from 1890 to 1900 approximates that for sheep as sheep increased 276.4%. (Merriam 1901) allowing for the possibly of escapees to enhance feral swine populations.

Populations of feral swine in Arizona were possibly impacted by hog cholera. By 1917, in Arizona, swine producing centers were found in irrigated and dry farming districts which included the Colorado River where hog cholera was widely spread throughout the state and impacted swine raising including along the Colorado River (Williams 1920}. Hog cholera affected swine differently in Arizona than it did in more humid climates, as disease was a chronic form and not as active as elsewhere in the United States. Only a few of the animals in a herd would become infected at one time, but of these infected animals almost always died (Williams 1920).

Around World War II, the University of Arizona promoted locally raised swine for a home pork supply and to supplement income (Rigden 1941, Stanley et al. 1942). They recommended that whenever possible, a farmer should plan his operations to fit in with his pasture wherein the most economical gains could be made with alfalfa pasture. (Rigden 1941). Stanley et al. (1942) recommended permanent pasture fences should have 26-inch woven wire with two barbed wires on top with the woven wire using heavy 11-gauge stay wires, top and bottom wire 9 gauge, and other horizontal wires at least 12-gauge and should be set 2 to 3 inches from the ground. Posts should be set a rod apart and if wooden, measure at least 3 inches at the top diameter. Well- braced corners are essential. A steel or wooden gate gives most satisfactory use. Stanley et al. (1942) also recommended the use of temporary fences do not need so many posts. The netting wire is essential but can be lighter in weight than that used for permanent fences. On moist ground electric fences give good results. Such fences are useful to hold animals on small areas or pastures for short, intensive grazing periods. Electric fence wires should be on borders as alfalfa or weeds will ground them out if they grow high enough to touch the wire. The fencing promoted in the 1940s allowed for the escape of feral swine to supplement free-ranging populations.

The authors are not aware of any formal population estimate being made along the Colorado River. Beginning with the thousands of feral swine reported by The New York Times (1894) in the late 1800s, Mayer and Brisbin (1991) attributed the establishment of the Mohave County, Arizona, population to a release of domestic swine from a nearby ranch before 1900. McKnight (1964) estimated the population had decreased to several hundred individuals statewide in the 1950s (McKnight 1964). Mayer (2009) estimated the population in Arizona including the counties of Coconino, La Paz, Mohave, Navajo, Pima and Yavapai to be between 500 to 1,000 individuals using a rough bounded estimate in 2009. By 2014, the statewide estimate was further decreased to be between a minimum of 200 feral swine with a mean 400 and a maximum of 600 using a bounding estimate (Mayer 2014).

STUDY AREA

Havasu NWR was established by the Federal Property and Administrative Service Act of 1949 (40 U.S.C. 471-535), as amended; Fish and Wildlife Coordination Act of 1934 (16 U.S.C. 661-666c) as amended; Fish and Wildlife Act of 1956 (16 U.S.C. 742a-742j Stat. 1119) as amended; the Act of May 19, 1948, Public Law 80-537 (16 U.S.C. 667b-667d; 62 Stat. 240) as amended; and The National Wildlife Refuge System (NWRS) Administration Act of 1966 (16 U.S.C. 668dd-668ee). Specifically, Havasu NWR was established by Executive Order 8647 on January 22, 1941, as a refuge and breeding ground for migratory birds and other wildlife.

The refuge actively participates in land management and restoration activities that are designed to improve habitats for federally endangered southwestern willow flycatchers (*Empidonax traillii extimus*), federally threatened yellow-billed cuckoos (*Coccyzus americanus*), federally endangered Yuma Ridgway's rails (*Rallas obsoletus yumenensis*), waterfowl, other migratory bird populations, as well as other native wildlife. In addition to providing sanctuary and breeding habitat for migratory and resident birds and other wildlife, the refuge also provides wildlife-oriented recreational activities for the public. Wildlife observation, photography, hunting, fishing, environmental education and interpretive programs are available. Havasu NWR serves an estimated 3,000,000 visitors annually who enjoy the area for recreation and wildlife values. Feral swine detract from these experiences by altering the wildlife habitat and threatening the health and safety of visitors.

In order to meet the species protection and enhancement goals for the Havasu NWR, refuge staff and U.S. Department of Agriculture, Animal and Plant Health Inspection Service-Wildlife Services (USDA-APHIS-WS) will strive to maintain feral swine at zero population levels in collaboration with the Integrated Feral Swine Damage Management Program. This program was developed as a national response to reduce, and where possible, eliminate, the risks and damages inflicted by feral swine to agriculture, natural resources, property, and human health. Havasu NWR encompasses 37,515 acres adjacent to the Lower Colorado River, spanning from Mohave Valley, Arizona, to Lake Havasu City, Arizona. Occupying both Mohave County in Arizona and San Bernardino County in California, Havasu NWR protects 300 shoreline miles, including the approximately 17-mile Topock Gorge, one of the last remaining natural stretches of the Lower Colorado River. Topock Marsh, an area approximately 4,000 acres located north of Interstate 40 (I-40), occupies a majority of the northern portion of the refuge and consists of a large freshwater body surrounded by emergent wetland species. Most of the land south of the Interstate 40 bridge surrounding Topock Gorge was designated Wilderness in 1990 and 1994 by the states of Arizona and California, respectively. Approximately 47% (17,600 acres) of the Refuge is designated as a Wilderness Area. Predominant riparian community vegetation throughout the Refuge consists of dense stands of salt cedar (*Tamarix* spp.) with mixed Goodding's willow (*Salix gooddingii*), coyote willow (*Salix exigua*), and Fremont cottonwood (*Populus fremontii*). The predominant under story consists of arroweed (*Pluchea sericea*) and cattails (Typha spp.) in wetter and emergent wetland areas. Upland areas consist of mesquite (*Prosopis* spp.) and creosote bush (*Larrea tridentata*) desert scrub communities.

MANAGEMENT ACTIVITIES

The first recorded attempt at controlling feral swine on Havasu NWR was with an experimental feral swine hunting season in 1975 (USFWS 1975). The refuge was open to feral swine hunting in March 1975 within the western part of the Topock Marsh Unit. Hunting was approved on a permit basis via a random drawing with only 25 hunters allowed to hunt at a time, due to dense vegetation and hunter safety concerns. Due to a poor-quality hunt and high administrative costs, the hunt was not reinstated after that year. During the hunt, 42 feral swine were taken by 175 hunters (USFWS 1975). The second recorded removal of feral swine was during 1983 when 13 feral swine were removed to be monitored for hog cholera and vesicular stomatitis virus (Table 1) (Stallknecht et al. 1986, Nettles et al. 1989). Throughout the years, individuals would sneak onto the refuge to illegally remove feral swine (Joe Bennett, pers. commun., August 23, 2017). The total number of illegal removals is unknown.

Early conversations in 2001, between the U.S. Fish and Wildlife Service and Wildlife Services discussed the opportunity to remove feral swine from the refuge. At the time, neither agency had the funding needed to attempt removal. The first opportunity to begin removals was due to the creation of the USDA-APHIS-WS, National Wildlife Research Center's National Wildlife Disease Program (NWDP). The NWDP was established in 2003 to develop a nationally coordinated wildlife disease surveillance and emergency response system. Since its inception, the NWDP has developed collaborations with hundreds of national, including the staff at Havasu NWR, and international partners. The partnerships have resulted in surveillance and management of over 100 pathogens, toxins, and disease syndromes affecting wildlife, domestic animals, and humans. Several of these pathogens, including avian influenza, plague, tularemia, bluetongue, and 10 pathogens carried by feral swine, were monitored on a national or regional level and maintained in a national archive of select wildlife disease samples (Pedersen et al. 2012).

In the beginning, Wildlife Services was limited to feral swine management activities between breeding seasons for endangered birds and waterfowl hunting seasons. The program would operate on the refuge twice a year for two weeks with a goal of removing 25 swine each period with the samples to be used for disease testing or archived for future research projects (Table 1). Tools used during the early collections were snares and firearms (Figures 1 & 2). The removal of feral swine for diagnostic sampling was not enough to make an impact on population on the refuge. Activities on the refuge are done through a permit from Havasu NWR.

The National Feral Swine Damage Management Program was initiated in fiscal year 2014 (FY14) as a way to implement control activities to reduce feral swine damage across the United States, including Arizona, and afflicted territories (USDA NFSDMP 2019). The overarching goal of the USDA NFSDMP is to reduce damage to agricultural

Table 1. Published studies on disease using samples collected from feral swine taken on Havasu National Wildlife Refuge.

Date of sampling	Disease of concern	Feral swine sampled on the refuge	Number of positive feral swine	% positive	Reference
1983	Hog cholera	13	0	0.0	Nettles et al. 1989
1983	Vesicular stomatitis virus	13	0	0.0	Stallknecht et al. 1986
2006-2010	*Neospora caninum*	35	11	31.4	Cerqueira-Cézara et al. 2016
2006-2010	*Trichinella spp.*	17	0	0.0	Hill et al. 2014
2006-2010	*Toxoplasma gondii*	17	1	5.9	Hill et al. 2014
2007-2011	Leptospira	25	5	20.0	Pedersen et al. 2014
2007-2008	Classical swine fever	65	0	0	Swafford et al. 2009
2009-2010	Swine brucellosis	68	0	0.0	Pedersen et al. 2012
2012-2014	*Escherichia coli* (STEC)	34	0	0.0	Jay-Russell et al. 2014
2012-2014	*Escherichia coli* (non-STEC)	34	3	8.8	Jay-Russell et al. 2014
2012-2014	*Salmonella*	34	7	20.6	Jay-Russell et al. 2014
2013-2015	Porcine reproductive and respiratory syndrome virus	44	0	0.0	Pedersen et al. 2018
2014-2020	*Trichinella spp.*	112[a]	0	0.0	Cleveland et al. 2024
2014-2020	*Toxoplasma gondii*	75	9	12.0	Cleveland et al. 2024

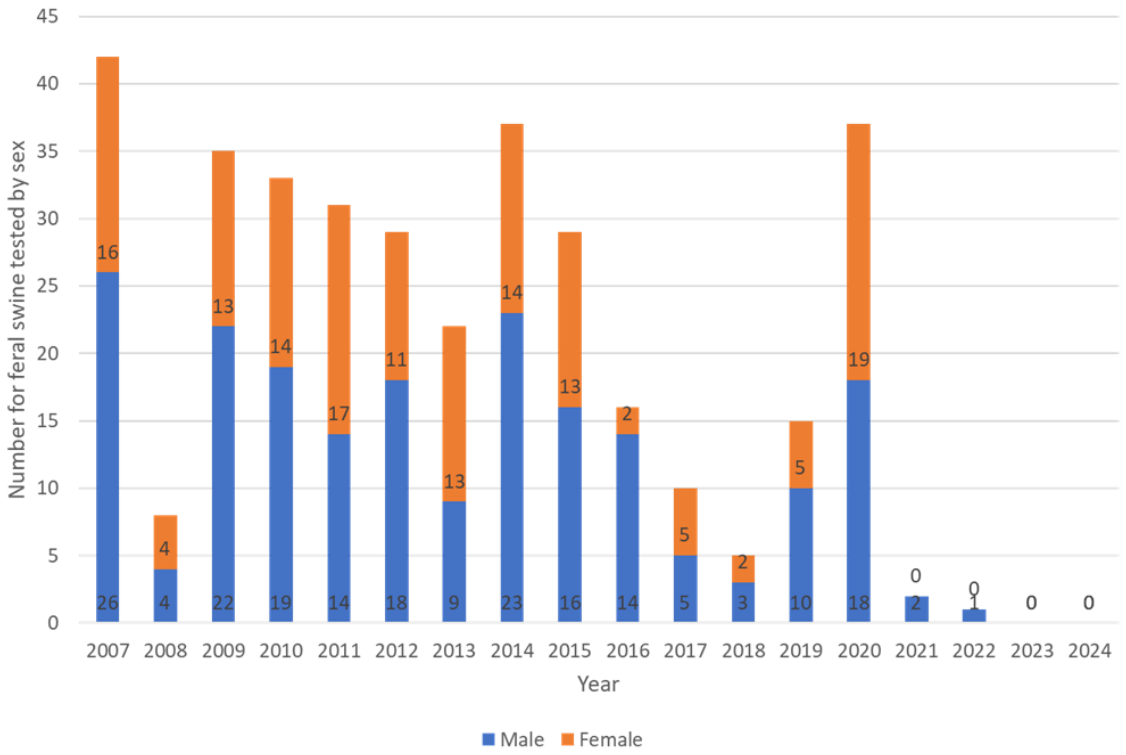

Figure 1. Number and sex of feral swine taken by year and used within disease surveillance studies from Havasu National Wildlife Refuge.

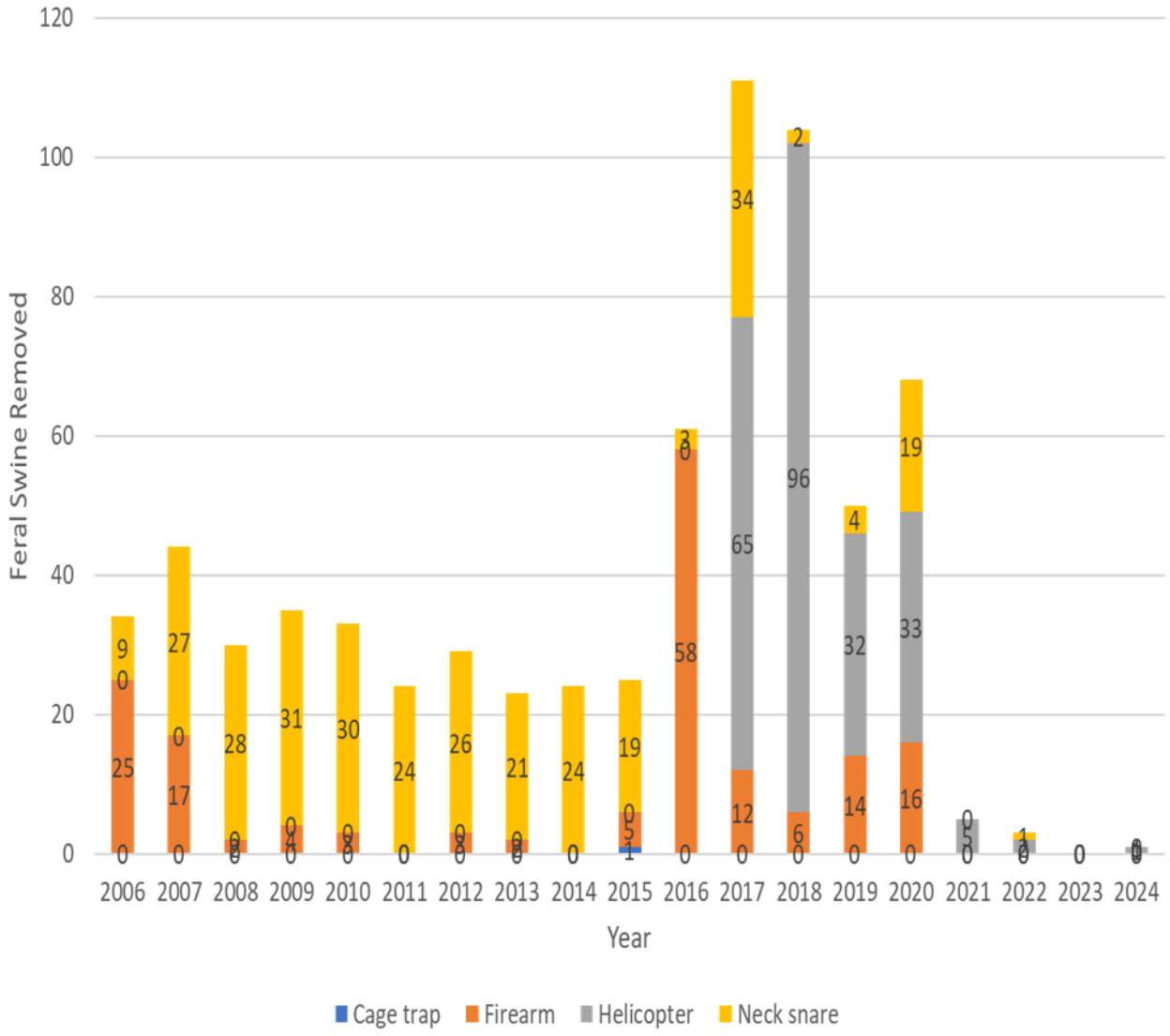

Figure 2. Number of feral swine taken by method and year from Havasu National Wildlife Refuge.

and natural resources, property, animal health, and human health and safety by reducing feral swine populations in the United States. The program is delivered through a nationally coordinated APHIS effort, led by Wildlife Services, and includes Veterinary Services and International Services in key program activities. Each state was classified by level depending on the number of feral swine estimated to be there. This is a tiered system with level 5 being the highest and with the greatest number of feral swine. Arizona was classified as a Level 1 = <1,000 feral swine in state. Funding by the national program allowed for a directed approach for removals on the refuge including the ability to purchase equipment to address feral swine.

In 2015, Zaun and Miller (2015) drafted a Havasu National Wildlife Refuge Feral Swine Management Plan which discussed options for feral swine removals on the refuge. Following the draft plan, the refuge developed an Environmental Assessment to evaluate options for management of feral swine on the refuge in cooperation with Wildlife Services (USFWS 2016). The environmental assessment proposed Alternative B - Proposed Action - (Implementation of the Feral Swine Eradication Plan) which provided for implementation of the Havasu NWR Feral Swine Eradication Plan wherein Wildlife Services and refuge staffs would employ a variety of measures to eliminate the feral swine population on the refuge. A Finding of No Significant Impact (FONSI) was signed by Regional Director Benjamin Tuggle on January 10, 2017 (USFWS 2017). The FONSI selected Alternative B which implemented The Feral Swine Eradication Plan (Zaun and Miller 2015) and assured the refuge and USDA-APHIS-WS utilized the most current and widely accepted methods of eradication procedures.

The creation of National Environmental Policy Act Documents and increased funding by Wildlife Services allowed for a more dedicated program on the refuge to move towards eradication. Increased funding allowed for

Wildlife Services to station personal at the refuge year-round. In addition, the Service has periodically hired personnel to assist in feral swine management. The FONSI allowed aerial operations using a helicopter and were first implemented in February 2017 with the removal of 65 feral swine (Figure 2) (Neskey 2018). Since 2006 and working collaboratively, the program has removed 704 feral swine including 302 by snare, 234 by helicopter, 167 with firearms, and 1 with a cage trap (Figure 1 and 2). Of the 704 animals removed, 701 were removed in Arizona, two were removed by helicopter in California, and one was removed by firearm when it was swimming between the two states. The 704 animals removed is a minimum number of animals since the two agencies began working collaboratively. It does not include animals prior to 2006 as Wildlife Services changed the system of tracking removals after 2005. Nor does it include any animals taken illegally by the public. In 2020, there was a push by the Department of Interior to increase recreational use of refuges. Due to the push, the USFWS made it legal for the public to remove feral swine on Havasu NWR during regulated hunting season. The authors are not aware of any removals of feral swine by the public since the change in regulations.

In the first five years, Arizona used helicopters, traps/snares, and firearms as the primary tools (Figure 2) to remove feral swine with an overall statewide expenditure of $550,600 (USDA NFSDMP 2019). Bodenchuk (2014) evaluated methods to remove feral swine. He found that using helicopters was the most cost-effective way to remove feral swine.

Wildlife Services strives to gain as much information as possible from each animal removed. Efforts are made to handle each animal to collect samples for the genetic archive and for the wildlife disease archive. There have been twelve studies on potential disease issues using samples collected from feral swine on Havasu NWR during our collaborative partnership (Table 1). At a minimum, 523 disease diagnostic tests have been conducted on feral swine off the refuge since 2006 (Table 1). Twelve different diseases have been evaluated, with feral swine from Havasu NWR having positive tests for *Neospora caninum*, *Toxoplasma gondii*, *Leptospira*, *Escherichia coli* (non-STEC), and *Salmonella* (Table 1).

McCann et al. (2018) analyzed genetic samples from feral swine taken from Havasu NWR. The feral swine in Arizona revealed a distinct genetic grouping from the rest of the US, Spain, and Iran. The strong genetic differentiation of feral pigs in Arizona could be explained by geographic isolation or introductions from novel genetic sources (McCann et al. 2018). Further spatial analysis by Smyser et al. (2020) illustrated heterogeneity in feral swine ancestry patterns throughout the invaded range. Associations with the European wild boar cluster were low in Arizona. Similarly, among long-established invasive feral swine populations, deviations from the pervasive pattern of admixed heritage breed-wild boar ancestry were largely restricted to Havasu NWR and Florida (Smyser et al. 2020). Populations from Havasu NWR demonstrated complex ancestries, although patterns of admixture were largely restricted to contributions from reference clusters associated with domestic breeds as opposed to contributions from wild boar (Havasu NWR, n = 99, Q17 =2.82%) (Smyser et al. 2020).

The collaborative program continues to add tools for feral swine management to eliminate the population. Williams et al. (2017) developed techniques to capture eDNA in turbid aquatic systems with varying amounts of target DNA to identify cryptic species. Application of eDNA techniques to the detection of a terrestrial invasive required sampling at intermittent water sources that are used for drinking and cooling; these water bodies may often be stagnant and turbid. The program collects up to 30 samples from the length of the refuge and submits them to WS National Wildlife Research Center for analysis. The information captured with eDNA is added to data from camera traps, and track surveys to assess potential locations of feral swine. The information is used to direct a drone (UAV) to location to assess for feral swine at night using infrared technology. The most optimum time for surveillance is during the winter when the canopy layer is thin and the temperature difference between the ambient temperature and the body temperature of the feral swine is distinct, so that the infrared camera can better detect the feral swine (Kim et al. 2021). To reduce aerial costs, the program uses a combination of eDNA, pictures, and tracks to confirm locations of swine. Confirmations are given to the helicopter crew to reduce the cost and time of using a helicopter to search for feral swine. Adding to our aerial program, we use a fixed-wing Super Cub for aerial overflights. The fixed-wing provides and additional safety layer for oversight and allows the program to track feral swine that split up and move in different directions from the helicopter.

Havasu NWR is extremely choked by cattails with a limited road system. Cattails often grow to 4 m in height. The vegetation provides a good cover for feral swine who burrow and tunnel through the habitat. Two additional methods have been added to look for feral swine in the cattail choked system. Wildlife Services uses a dog team to locate, bay, and hold feral swine for removal by personnel. At times, even, the dogs are hindered by the cattail choked habitat. The Service has added a Marsh Master (Marsh Master, Coast Machinery, Baton Rouge, LA) to its arsenal of tools. The Marsh Master creates trails in the almost impenetrable cattail system while also allowing a shooting platform in case any feral swine are pushed out of the vegetation by the machine. The trails allow for easier access by both dogs and humans while looking for feral swine or feral swine sign. The Service has also implemented cattail management through burning. Since Fiscal Year 2020, the Service has burned 3,899 acres of cattails to improve habitat quality for native species and eliminate habitat for feral swine. The acreage of cattails burned include FY 20, 350 ac, FY 21, 1,323 ac, FY 22, 0 ac, FY 23, 1,052 ac, and FY 24, 588 ac.

CONCLUSION

The collaborative feral swine eradication program has been a model of success between two agencies from two distinct federal departments. Both agencies have a common goal of feral swine eradication to protect America's resources. The program has over 20 years of cooperation

wherein we are close to our goal of feral swine eradication on Havasu National Wildlife Refuge. To better understand the challenges of feral swine eradication on Havasu National Wildlife Refuge, I encourage you to view Feral Swine in America: Episode 4 – Arizona on YouTube, https://www.youtube.com/watch?v=QF7pvWaqqac.

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